thinking about teaching scientifically

Carl Wieman

"you" to refer to generic post-sec physics teacher

Learning task creation homework

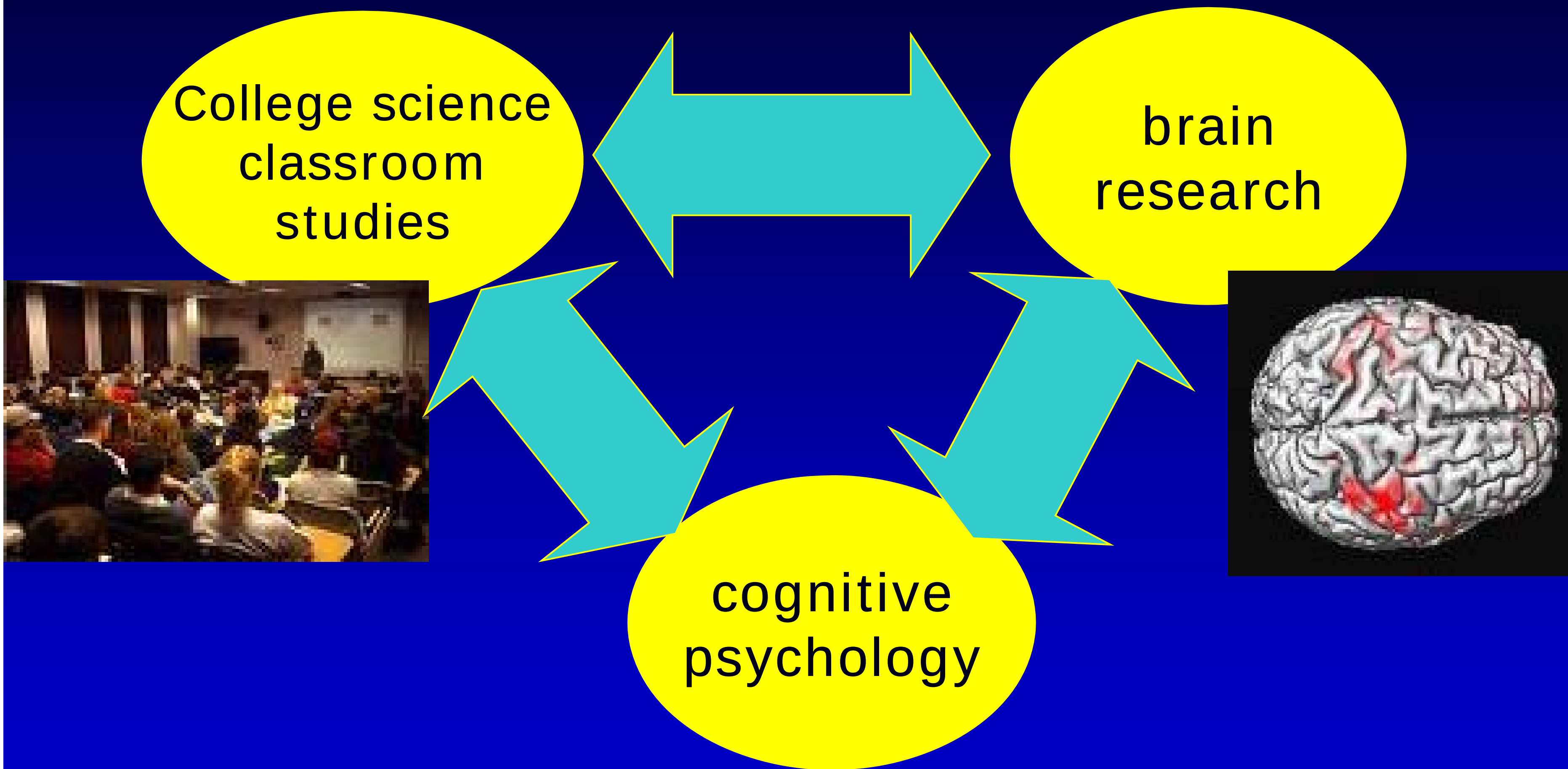
Without giving **ANY specifics of the tas**k, what were general design principles & steps in the design?

Rest of workshop– effective instructional practices

--this talk

- Organizational framework for ideas and info
- Principles to understand why work & essential features

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



educational goal— thinking more like a physicist
“greater physics expertise”

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

tools

Physics Expertise

"Expertise-centered"

good teaching– use and transfer physics expertise

I. What makes up expertise
II. How is it developed
III. How applies in the classroom
IV. Some data
V. Research-based learning task design principles
(starting with attitudes about learning physics)

I. Expertise research*

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

Expert competence =

•factual knowledge

• **Mental organizational framework** ⇒ retrieval and application

or ?

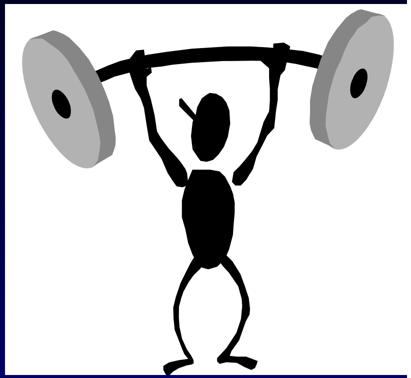
patterns, relationships, scientific concepts, visualizations

•**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*--



Challenging but doable tasks/questions

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

Requires brain "exercise"

Amount of "deliberate practice" far better predictor of level of expertise than any measures of innate talent

Subject expertise of teacher 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

Specifics for physics

General components of physics expertise

Your suggestions?

- concepts and mental models + selection criteria
- recognizing relevant & irrelevant information
- what factors can be neglected, criteria for deciding
- **model** development, testing, and use
- estimation of reasonable values
- specialized representations (types of graphs etc.)
- sets of "automatic skills & procedures"
- self-checking, sense making

Of course only make sense in context of topics

Knowledge important but only as part of broader expertise

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

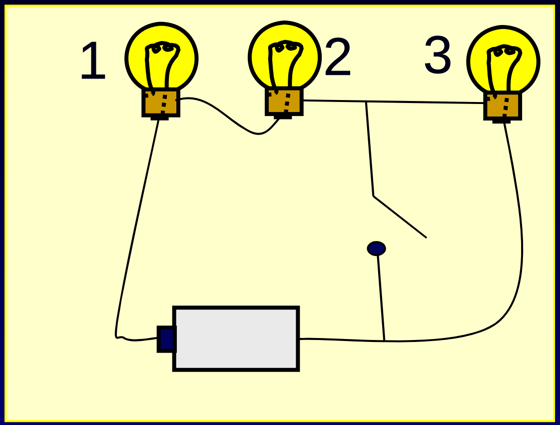
example

Student practicing thinking like physicist with feedback.
Where physics expertise of teacher manifest

Example from teaching about current & voltage using PEER Instruction+

1. Preclass assignment--Read pages on electric current. Learn basic facts and terminology. Short online quiz to check/reward. (expertise not needed-offload)

2. Class starts with task:



When switch is closed, bulb 2 will

a. stay same brightness,
b. get brighter
c. get dimmer,
d. go out.

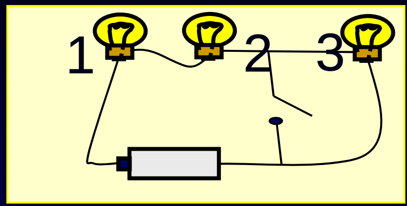
answer & reasoning

Physics expertise in question design:

- Recognize expert conceptual model of current.
- Recognize how physicists would use to make predictions in real world situation.
- Recognize motivational capabilities of the physics ("Lets you understand electricity in house & light bulbs work!")

None, if resistors and voltages & calculating I's & V's

Teaching expertise– Correct level. Addresses common incorrect concept of current.



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 (use *conceptual model*)
(accountability=intense thought, primed for feedback)

4. Discuss with “consensus group”, revote.
Practicing physicist thinking– examining conclusion, finding ways to test, further testing & refining model.
Physics expertise of teacher— evaluating student thinking.
<u>Listening in</u>! What aspects of student thinking like physicist, what not.

5. Whole class discussion led by teacher.
Lay out competing explanations/models
extension of 4, same expertise at work

6. Do experiment (or phet simulation—more explicit representation of physicist conceptual model)

7. Follow up– feedback on which models & which reasoning was correct, **which incorrect and why**
Physics expertise—all the above (& on display)

Could have started class just telling students this.
Expertise invisible to them, information meaningless, but "short-circuits" learning.
= no gain in expertise

8. Large number of student questions. Testing and refining conceptual model. Range of application? Experimental proof? Other applications of electricity? Mechanisms in bulb and wire? Many real world examples.

Extreme demands on physics expertise

How student practicing thinking like a scientist?

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

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

Only possible because of physics expertise in design and implementation of task & in the feedback.

But works educationally *because* that expertise is used to provide "deliberate practice" for students

Same elements in ~ all PER based effective instruction

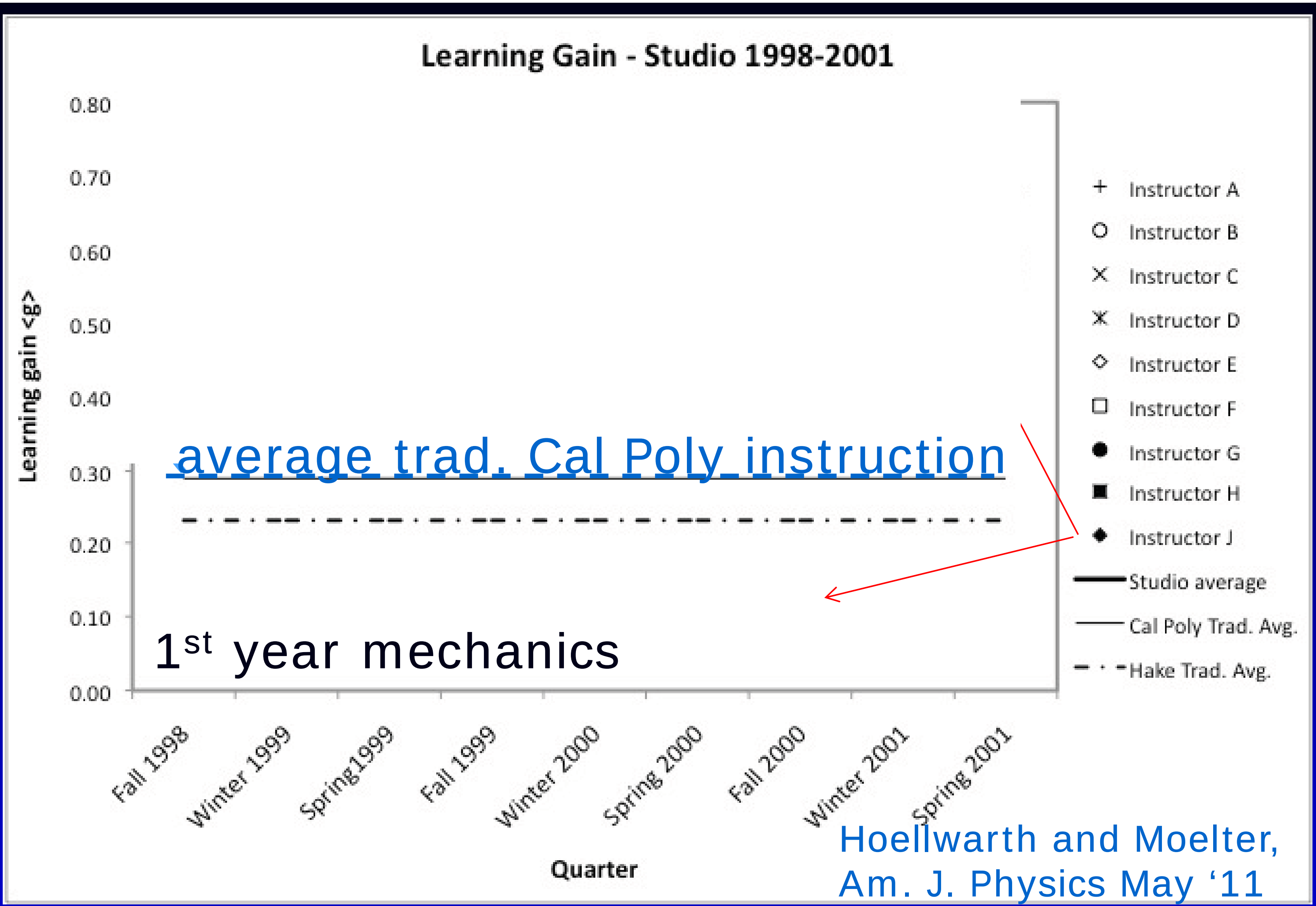
IV. Data– samples from physics courses

2012 NRC Discipline-Based Education Research study (NAS press, free download)

~ 1000 STEM research studies showing methods with consistently better results than traditional lecture.

Conceptual learning—
apply concepts like physicists

“learning gain”?



9 instructors, 8 terms, 40 students/section.
Same prescribed set of student activities.
<u>Mental activities of the students dominate</u>

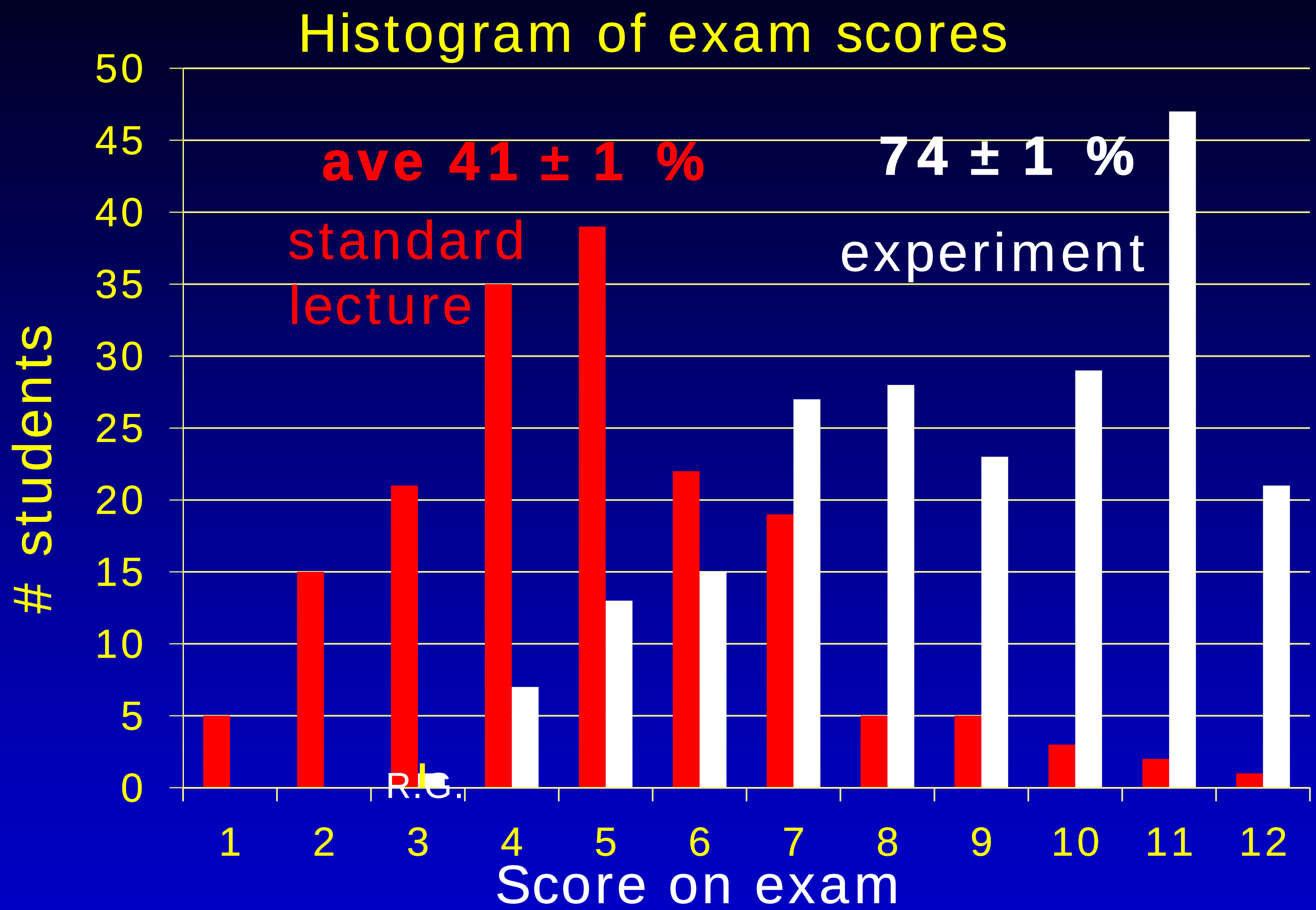
Learning **<u>just</u>** during class
Measured by “normal” test

Two ~identical sections (N=270)
1st year physics for engineers

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

<u>Same</u> learning objectives, **<u>same</u>** class time, <u>same</u> exam (jointly prepared)

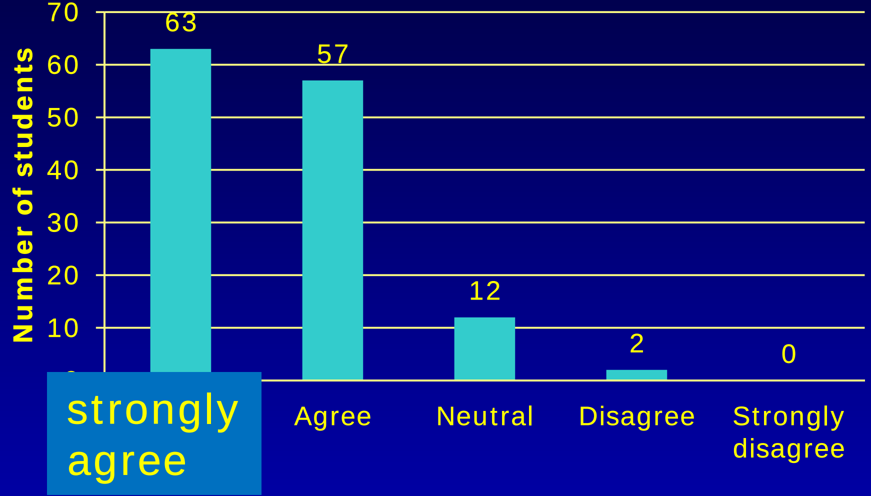
**Deslauriers, Schewlew, Wieman, Sci. Mag. May 13, ‘11*



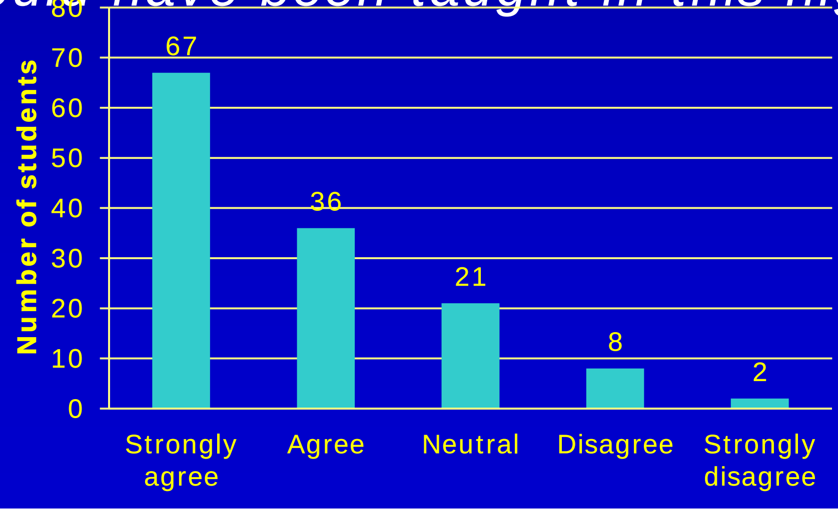
Large improvement for <u>entire</u> student population.
Engagement 85% vs 45%.

Survey of student opinions-- transformed section

"Q1. I really enjoyed the interactive teaching technique during the three lectures on E&M waves."



"Q2 I feel I would have learned more if the whole phys153 course would have been taught in this highly interactive style."



Not unusual for SEI transformed courses

V. 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.

Perceptions about physics & learning it

Novice

Expert

Content: isolated pieces of information to be memorized.

Handed down by an authority. Unrelated to world.

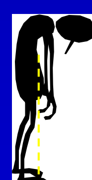
Problem solving: pattern matching to memorized recipes.

Content: coherent structure of concepts.

Describes nature, established by experiment.

Prob. Solving: Systematic concept-based strategies. Widely applicable.

measure student perceptions, 7 min. surveys. Pre-post



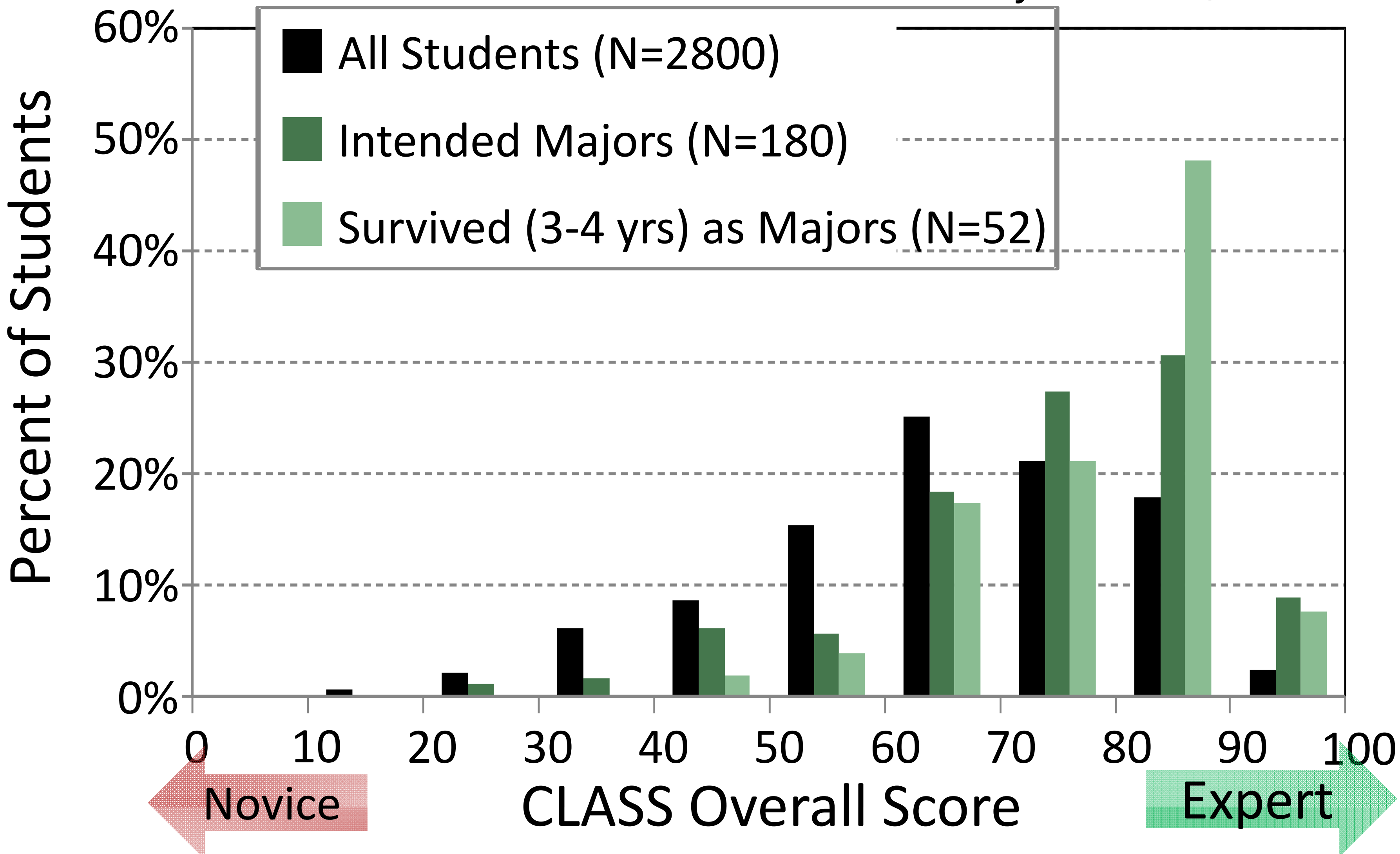
intro physics course ⇒ *more* novice than before

chem. & bio as bad

*adapted from D. Hammer

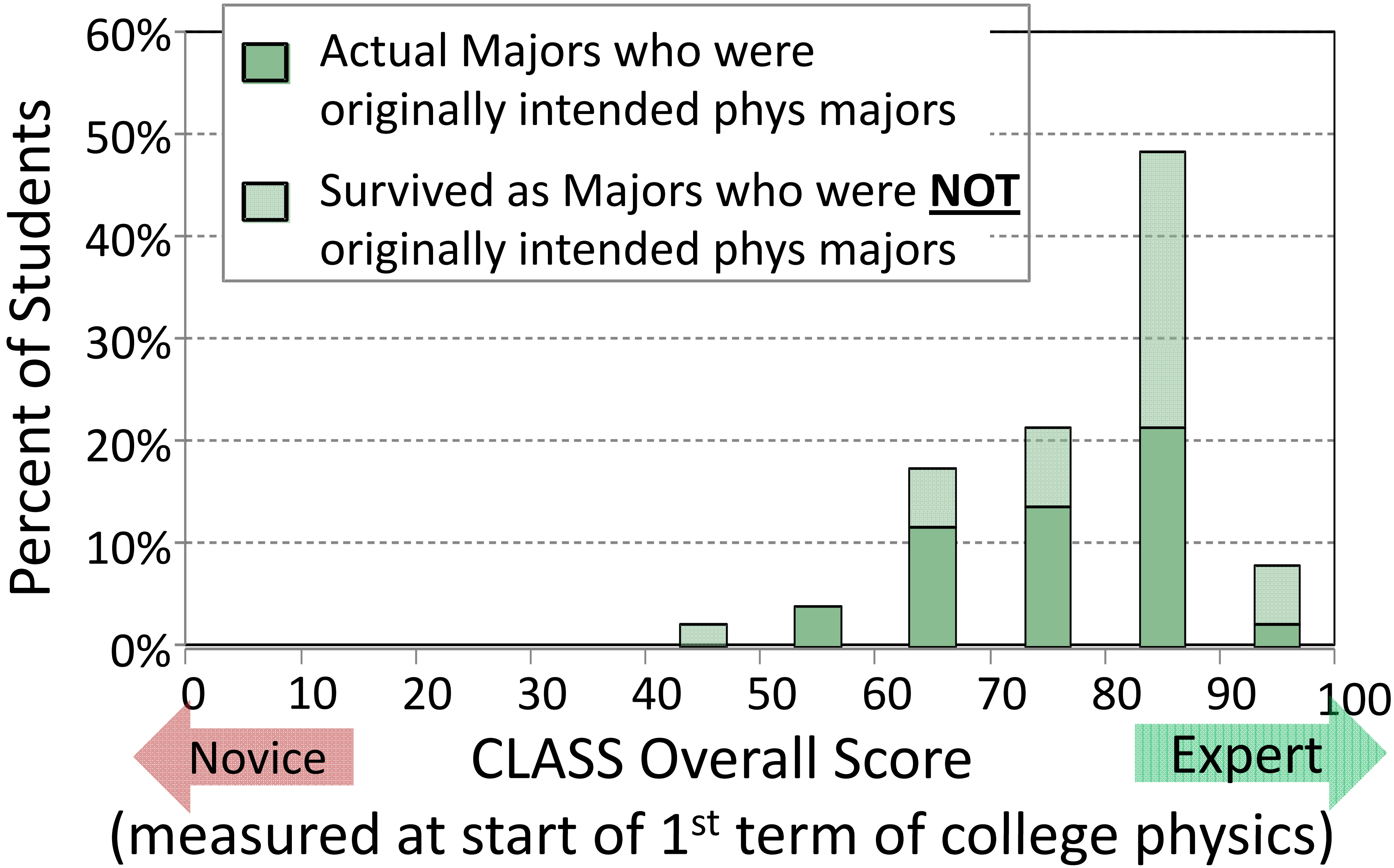
Student Perceptions/Beliefs

Kathy Perkins, M. Gratny



(measured at start of 1st term of college physics)

Student Beliefs



CLASS Perceptions survey results–
Correlates with everything important

7 minute first day survey **better** predictor than first year physics course grades

The problem- failure to recognize differences between expert brain of teacher and brains of students

Recent PER research⇒ changes in instruction that achieve positive impacts on perceptions

- More explicitly focus on process of science, **particularly** model development and use
- Explicit real world connections
- "Real" problems—*"Would anyone care about answer?"*
  (other than a physics teacher)

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.

Conclusion--Expertise and how it is learned--
A framework & guiding principles for thinking about instructional methods. Physics expertise vital.

copies of slides (+30 extras) available

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

NAS Press, "Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering", and "How people learn"

Perceptions/attitudes survey & related research
CLASS.colorado.edu

~ 30 extras below

Importance of addressing misconceptions
(conceptions inappropriately applied)

<u>Misconceptions about learning</u>

1. People develop expertise by having it explained to them.

No. Is not state of knowledge, is condition of brain

Conception misapplied– experts do learn and expand their knowledge by being told.

Already have knowledge framework & motivation.

Novices (students) do not.

Misconception about learning

2. Perceptions of how you learned subject is good guide for teaching, testing, motivating.

Conception misapplied. Is fine model if their brain and experiences similar to yours.
But your expert brain very different from undergrads.
(Actually even very different from you as undergrad, but no independent references so don't realize. Reflections on learning notoriously unreliable.)

a. 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
~ 5 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

Components of effective teaching/learning

apply to all levels, all settings

1. Motivation

2. Connect with and build on prior thinking

3. Apply what is known about memory

   a. short term limitations

   b. achieving long term retention (Bjork)

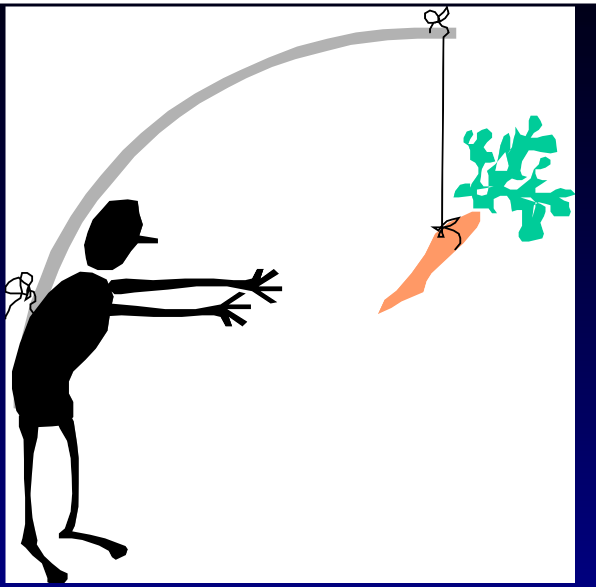
   retrieval and application-- repeated & spaced in time (test early and often, cumulative)

4. Explicit authentic practice of expert thinking. Extended & strenuous

Motivation-- essential

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

Enhancing motivation to learn



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

b. Sense that can master subject and how to master

c. Sense of personal control/choice

Use of Educational Technology

Danger!

Far too often used for its own sake! *(electronic lecture)*
Evidence shows little value.

Opportunity

Valuable tool ***if*** used to supporting principles of effective teaching and learning.

Extend instructor capabilities.
Examples shown.

- Assessment (pre-class reading, online HW, clickers)
- Feedback (more informed and useful using above, enhanced communication tools)
- Novel instructional capabilities (PHET simulations)
- Novel student activities (simulation based problems)

How it is possible to cover as much material?

(if worrying about covering material not developing students expert thinking skills, focusing on wrong thing, but...)

•transfers information gathering outside of class,
•avoids wasting time covering material that students already know

Advanced courses-- can cover more

Intro courses, can cover the same amount.
But typically cut back by ~20%, as faculty understand better what is reasonable to learn.

<u>Implicit assumptions of university science teaching</u>

If you don't tell it to them, they won't learn it.

If you do tell it to them, they will learn it.

The data completely refute.

How to make perceptions significantly more like physicist (very recent)--

- process of science much more explicit (model development, testing, revision)
- real world connections up front & explicit

clickers*--

Not automatically helpful--
give accountability, anonymity, fast response

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

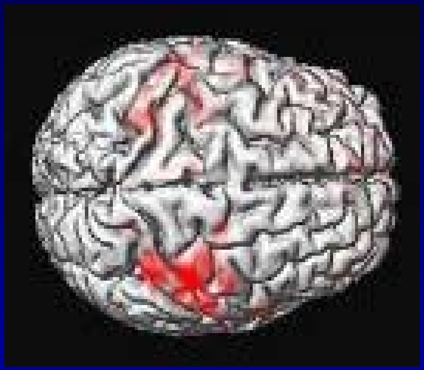
Used/perceived to enhance engagement, communication, and learning $\Rightarrow$ transformative

- 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

Why **so hard** to give up lecturing?

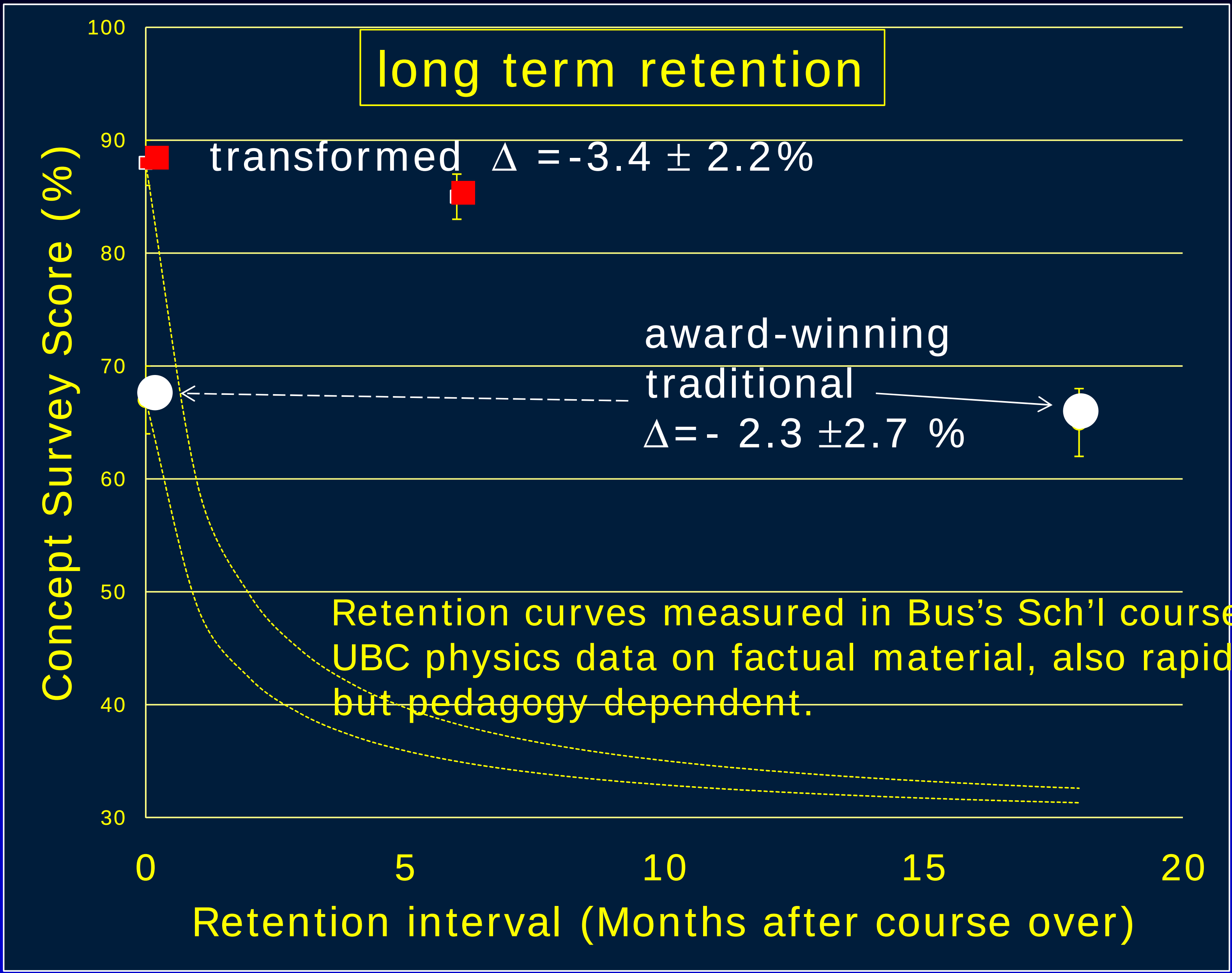
(speculation)



1. tradition
2. Brain has no perspective to detect changes in self. *"Same, just more knowledge"*
3. Incentives not to change— research is closely tracked, educational outcomes and teaching practices not.

Psychology research and our physics ed studies

Learners/experts cannot remember or believe previously held misunderstandings!



(Deslauriers & Wieman, PRST-PER)

Comparison of teaching methods: identical sections (270 each), intro physics. (Deslauriers, Schewlew, submitted for pub)

I

Experienced highly rated instructor-- trad. lecture

wk 1-11

II

Very experienced highly rated instructor--trad. lecture

wk 1-11

very well measured-- identical

Wk 12-- experiment

Two sections the same before experiment.
(different personalities, same teaching method)

	Control Section	Experiment Section
Number of Students enrolled	267	271
Conceptual mastery(wk 10)	47± 1 %	47 ± 1%
Mean CLASS (start of term) (Agreement with physicist)	63±1%	65±1%
Mean Midterm 1 score	59± 1 %	59± 1 %
Mean Midterm 2 score	51± 1 %	53± 1 %
Attendance before	55±3%	57±2%
[redacted]		
Engagement before	45±5 %	45±5 %
[redacted]		

Comparison of teaching methods: identical sections (270 each), intro physics. (Deslauriers, Schewlew, submitted for pub)

I

Experienced highly rated instructor-- trad. lecture

wk 1-11

II

Very experienced highly rated instructor--trad. lecture

wk 1-11

identical on everything diagnostics, midterms, attendance, engagement

Wk 12-- **competition**

elect-mag waves
inexperienced instructor
research based teaching

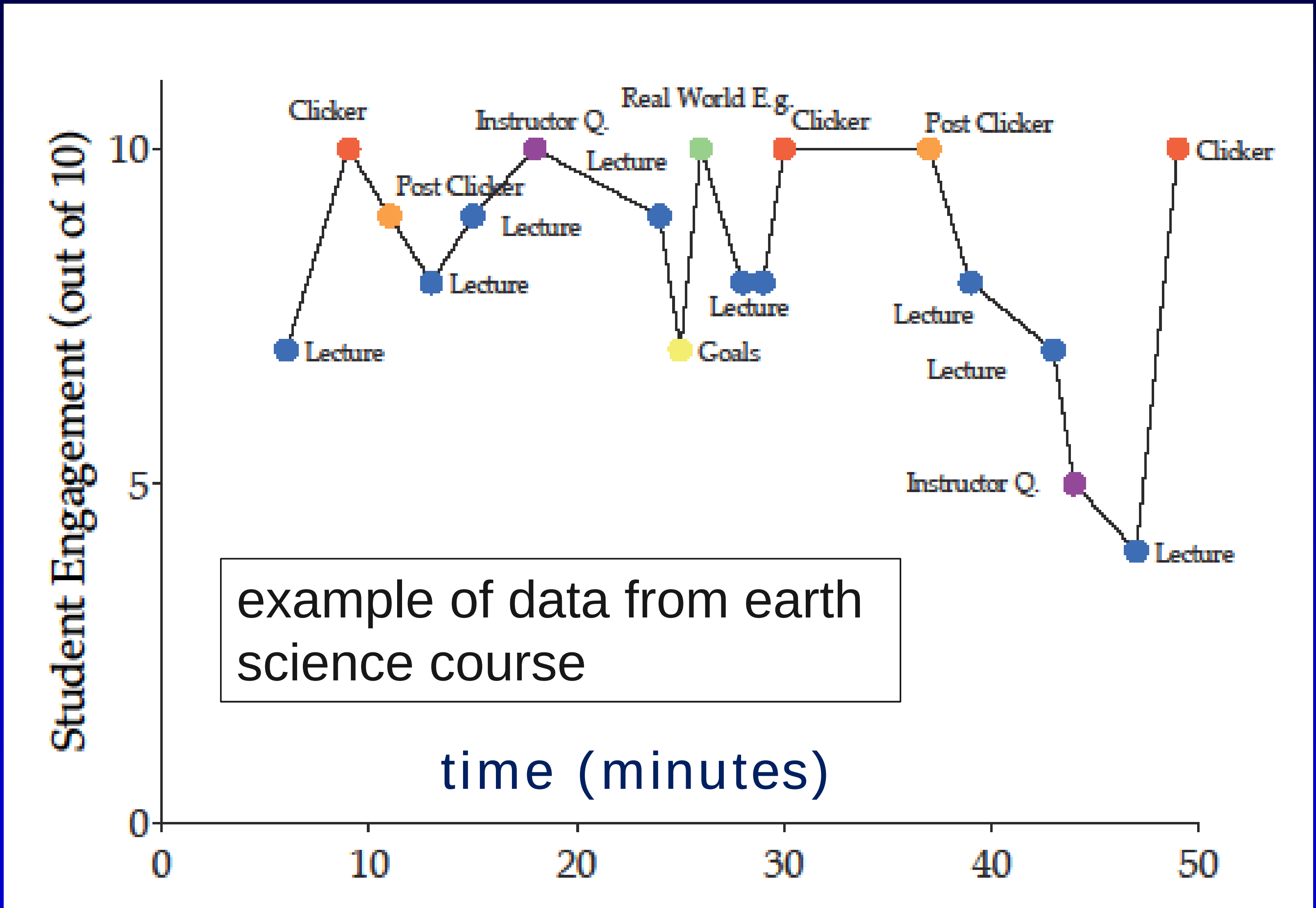
elect-mag waves
regular instructor
intently prepared lecture

wk 13 common exam on EM waves

	control	experiment
2. Attendance	53(3) %	**75(5)%**
3. Engagement	45(5) %	**85(5)%**

<u>Measuring student (*dis*)engagement.</u> *Erin Lane*

Watch random sample group (10-15 students). Check against list of disengagement behaviors each 2 min.



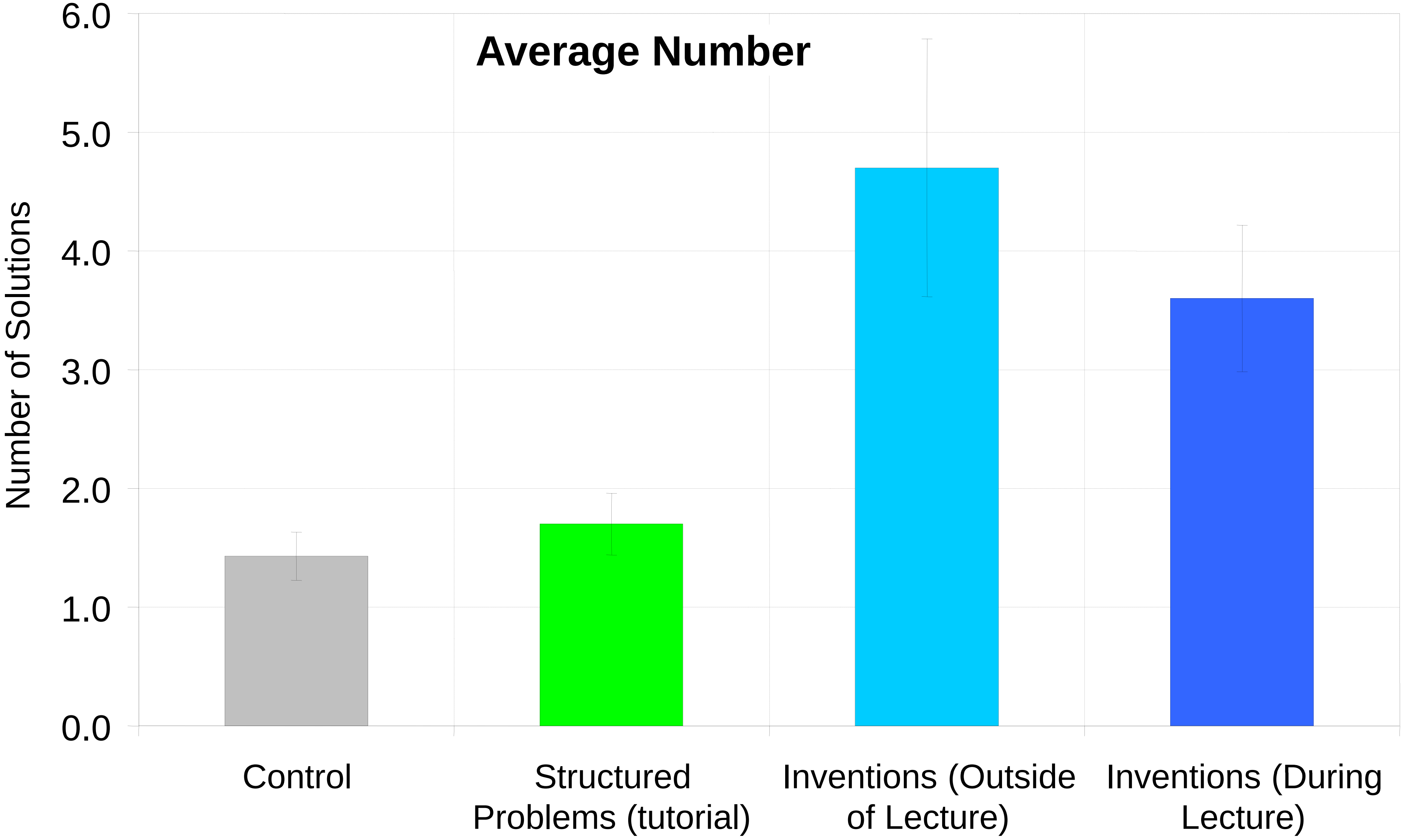
What about learning to think more innovatively?
Learning to solve challenging novel problems

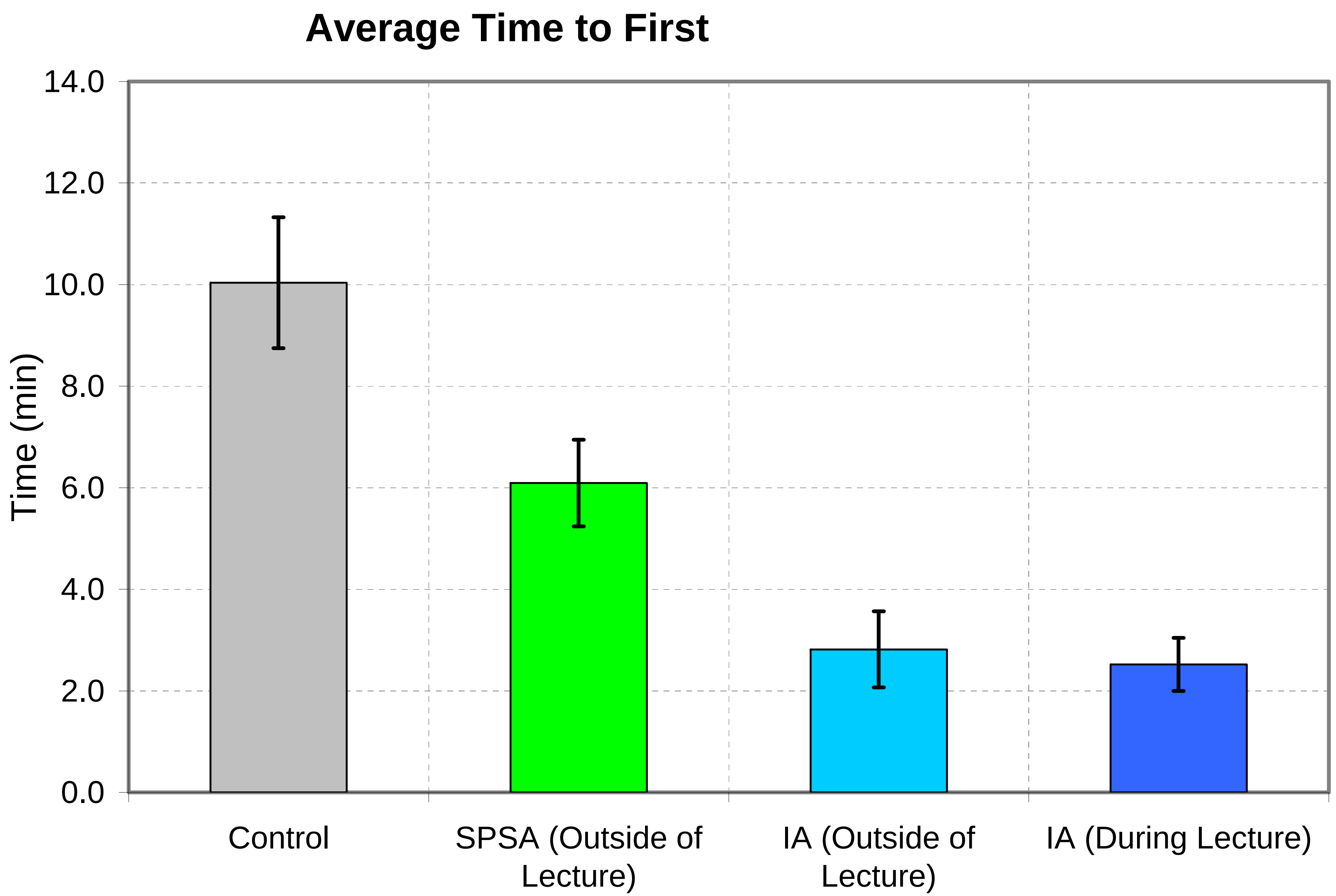
Jared Taylor and George Spiegelman
Cell Biology Education (notable paper of 2011)

"Invention activities"-- practice coming up with mechanisms to solve a complex novel problem. Analogous to mechanism in cell.

2008-9-- randomly chosen groups of 30, 8 hours of invention activities.
This year, run in lecture with 300 students. 8 times per term. (video clip)

Plausible mechanisms for biological process student nev encountered before





Average Time to First
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Time (min)
Control
SPSA (Outside of Lecture)
IA (Outside of Lecture)
IA (During Lecture)

Deslauriers, Lane, Harris, Wieman JCST 2012

Bringing up the bottom of the distribution

"What do I do with the weakest students? Are they just hopeless from the beginning, or is there anything I can do to make a difference?"
many papers showing things that ***do not*** *work*

Here-- Demonstration of how to transform lowest performing students into medium and high.

Intervened with bottom 20-25% of students after midterm 1.

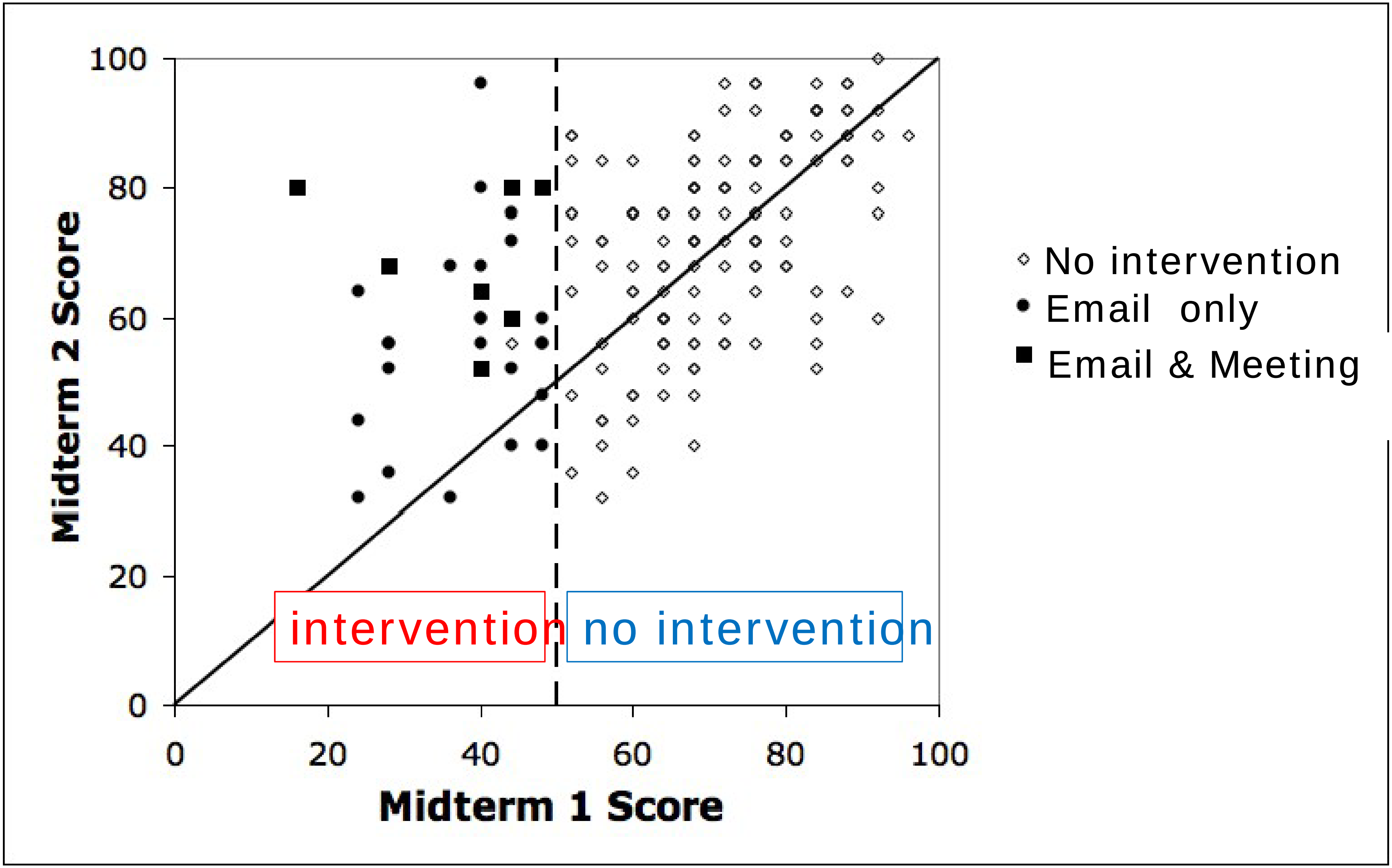
a. very selective physics program 2nd yr course
b. general interest intro climate science course

What did the intervention look like?

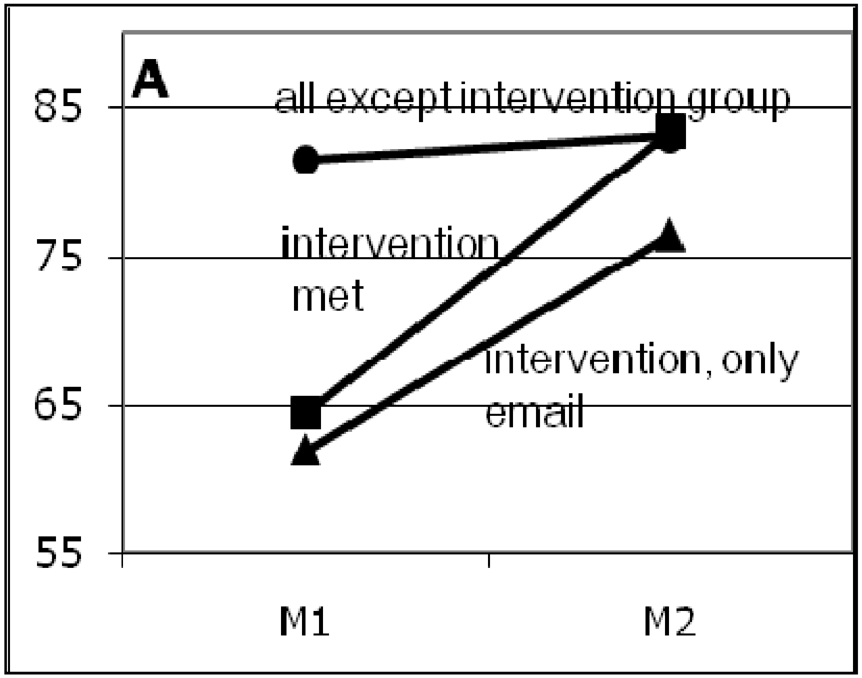
Email after M1-- "Concerned about your performance. 1) Want to meet and discuss";
or 2) 4 specific pieces of advice on studying. **[on syllabus]**

Meetings-- "*How did you study for midterm 1?"*
"mostly just looked over stuff, tried to memorize book & notes"
Give **small number** of **specific** things to do:
1. test yourself as review the homework problems and solutions.
2. test yourself as study the learning goals for the course given with the syllabus.
3. actively (explain to other) the assigned reading for the course.
4. Phys only. Go to weekly (optional) problem solving sessions.

Intro climate Science course (S. Harris and E. Lane)

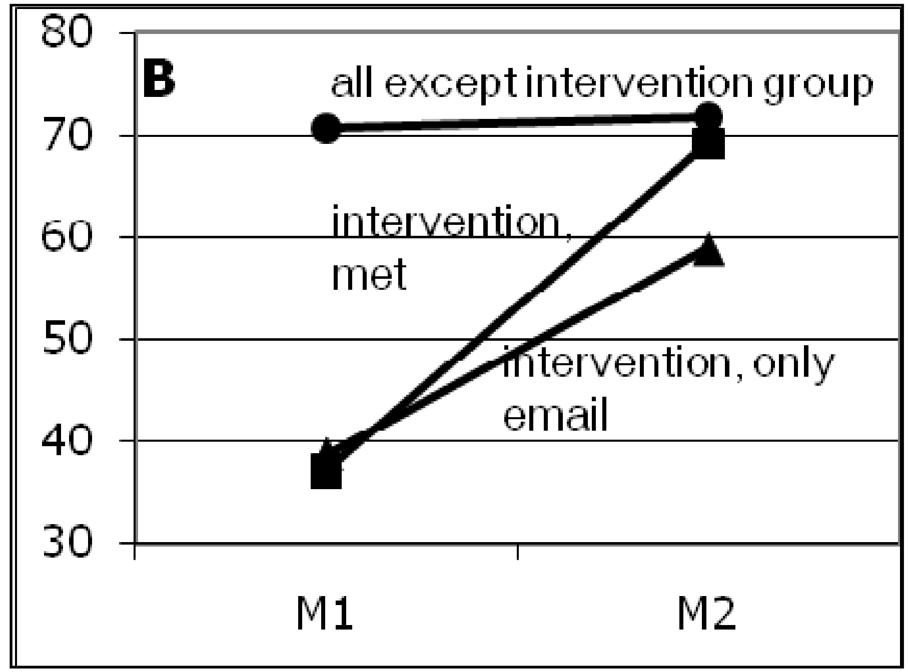


- End of 2nd yr Modern physics course (very selective and demanding, N=67)



bottom 1/4 **averaged +19% improvement on midterm 2 !**

- Intro climate science course. Very broad range of students. (N=185)



Averaged +30% improvement on midterm 2 !

Bunch of survey and interview analysis end of term.

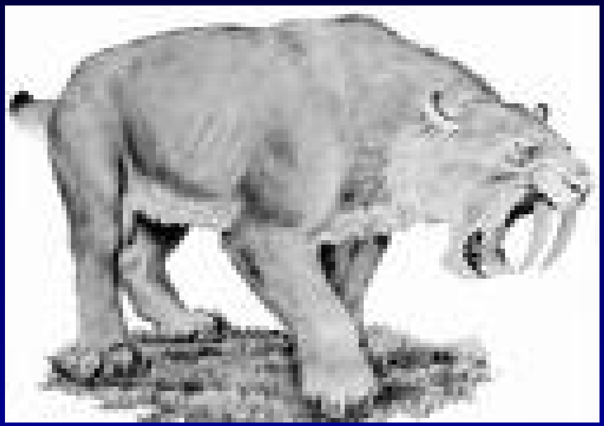
⇒ students changed <u>how</u> they studied

(but did not think this would work in most courses,
⇒doing well on exams more about figuring out instructor than understanding the material)

Instructor can make a dramatic difference in the performance of low performing students with small <u>but appropriately targeted</u> intervention to improve study habits.

(lecture *teaching*) Strengths & Weaknesses

Works well for basic knowledge, prepared brain:



bad, avoid

good, seek

Easy to test. ⇒ Effective feedback on results.
Information needed to survive ⇒ intuition on teaching

But problems with approach if learning:

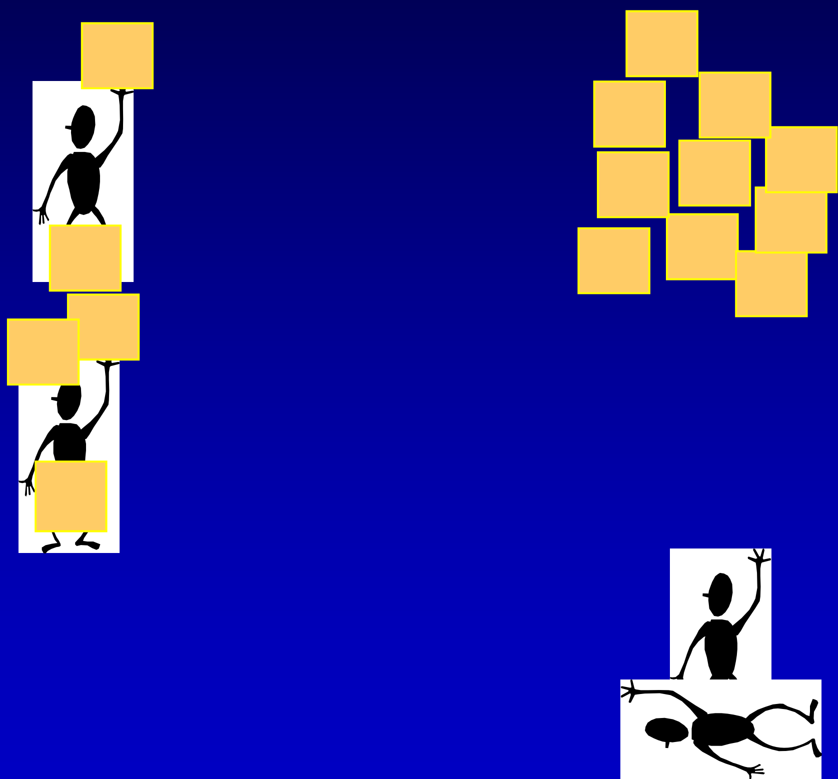
- involves complex analysis or judgment
- organize large amount of information
- ability to learn new information and apply

scientific thinking

Complex learning, unprepared brain-- different.

Reducing unnecessary demands on working memory improves learning.

jargon, use figures, analogies, pre-class reading



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

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

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

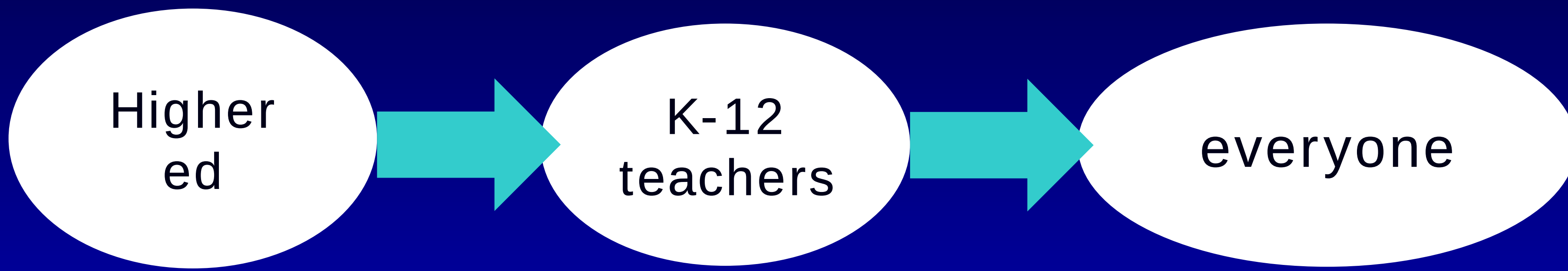
Goal of Univ. of Brit. Col. CW Science Education Initiative *(CWSEI.ubc.ca)* & Univ. of Col. Sci. Ed. Init.

- Departmental level, widespread sustained change at major research universities
  ⇒scientific approach to teaching, all undergrad courses
- Departments selected competitively
- Substantial one-time $$$ and guidance

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

Fixing the system

but…need higher content mastery,
new model for science & teaching



STEM teaching &
teacher preparation

STEM higher Ed
Largely ignored, first step
Lose half intended STEM majors
Prof Societies have important role.

Education Model 1 (I used for many years)

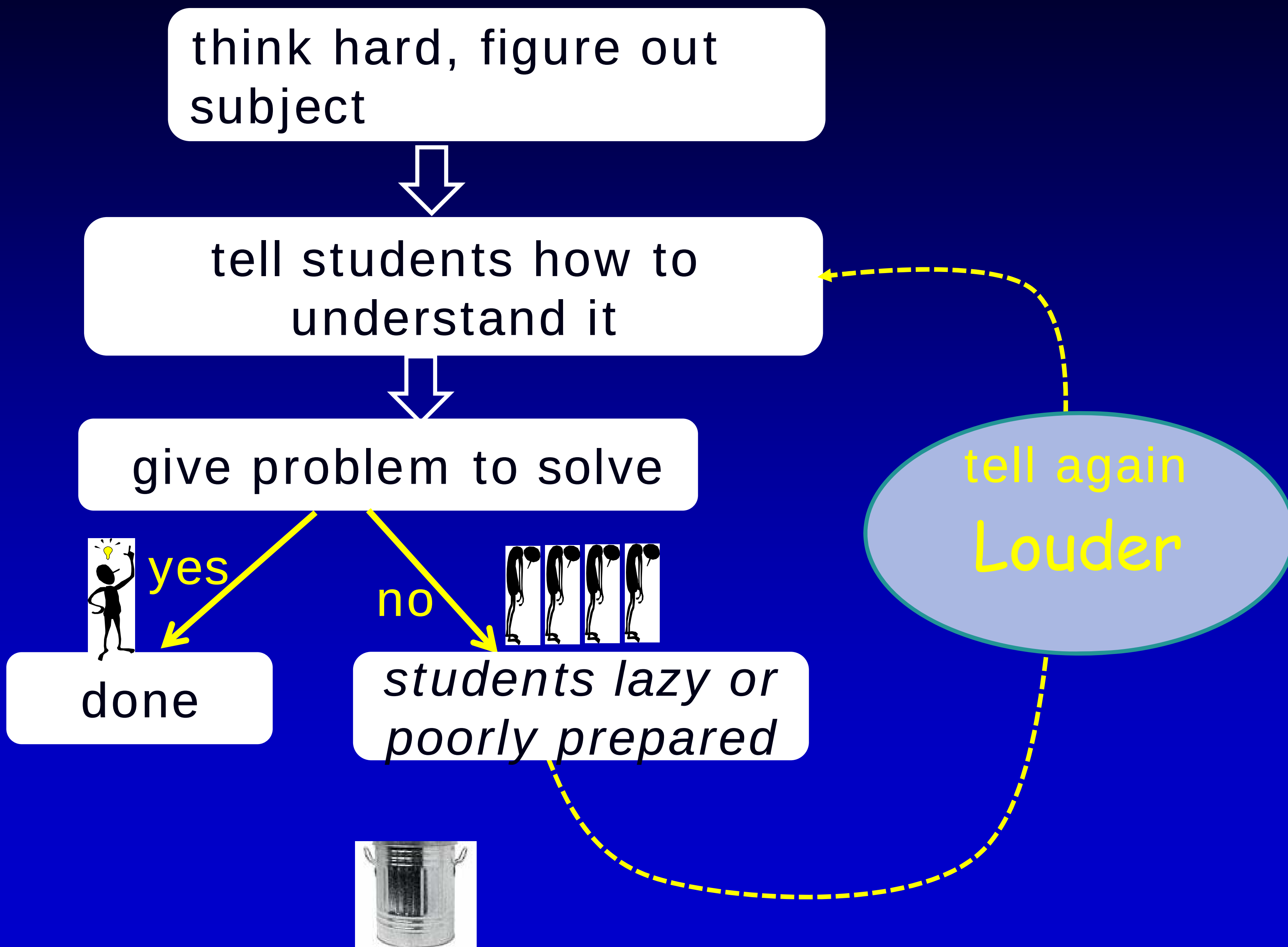
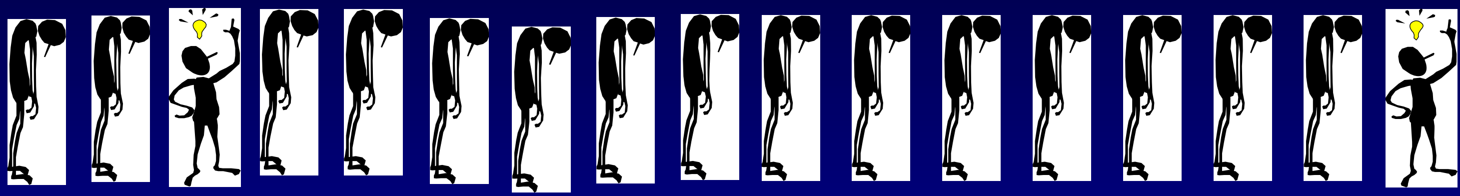
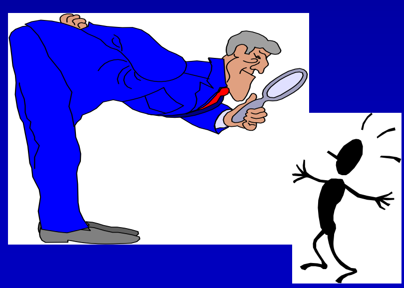


Figure out, tell students



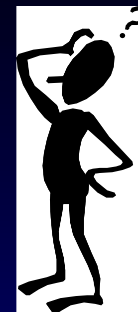
??

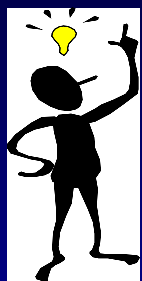
my enlightenment



grad students

17 yrs of success in classes.
Come into lab clueless about physics?





2-4 years later ⇒ expert physicists!

??????

--approach teaching as science.
Research on how people learn, particularly science.
Obtain, use, and test basic principles. ~ 10 years

explained puzzle, different way to think about learning, showed how to greatly improve classes