A scientific approach to learning (and teaching) physics

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Today- how you can learn to think like an expert physicist as quickly and effectively as possible
(and how to best teach to others)

25 years ago— *"Why can my grad students do so well in many years of physics courses, but come into my lab and cannot do physics? But then, they rapidly learn?"*

copies of slides to be provided

Beyond opinions—is a science of the teaching and learning of science.

Doing controlled experiments.
Measuring learning results.

DATA and fundamental principles

Started in physics, now similar research & results from all undergrad sciences and engineering
(me ~ 25 yrs, ~ 100 papers)

Experiment #1: 3 equivalent groups of students.

1) go to lecture, take notes, learn as much as possible (AMAP)
2) go to lecture, don’t take notes, learn AMAP
3) stay home, study instructors notes 1 hour, learn AMAP (*good instructor notes*)

then all get same test on the material covered in lecture.

Predict learning: most to least (write down choice, then raise hand to vote)

a. 1,2,3 b. 3,2,1 c. 2,1,3 d. 2,3,1, e. 3,1,2

Experiment:

1) go to lecture, take notes, learn as much as possible (AMAP)
2) go to lecture, don't take notes, learn AMAP
3) stay home, study instructors notes 1 hour, learn AMAP

correct answer. b. 3,2,1. Learn least going to lecture and taking notes.

Students never choose b., but when hear correct answer, easily figure out why. "Brainwashed"

2>1. Taking notes just added distraction, "cognitive load", compared to focusing on understanding in class.

3>2. Reading over notes, better pace, organization, more processing *(when decent notes!)*

Experiment #2: Learning from lecture*

Two nearly identical 250 student sections intro physics—
same learning objectives, same class time, same test (given right after 3 lectures).

Experienced highly rated traditional lecturer (*good teacher by current standards*)
versus
Postdoc in physics, trained in scientific teaching

How will results for the two sections compare?

Science Mag. May 13, '11, Deslauriers, Schelew, Wieman

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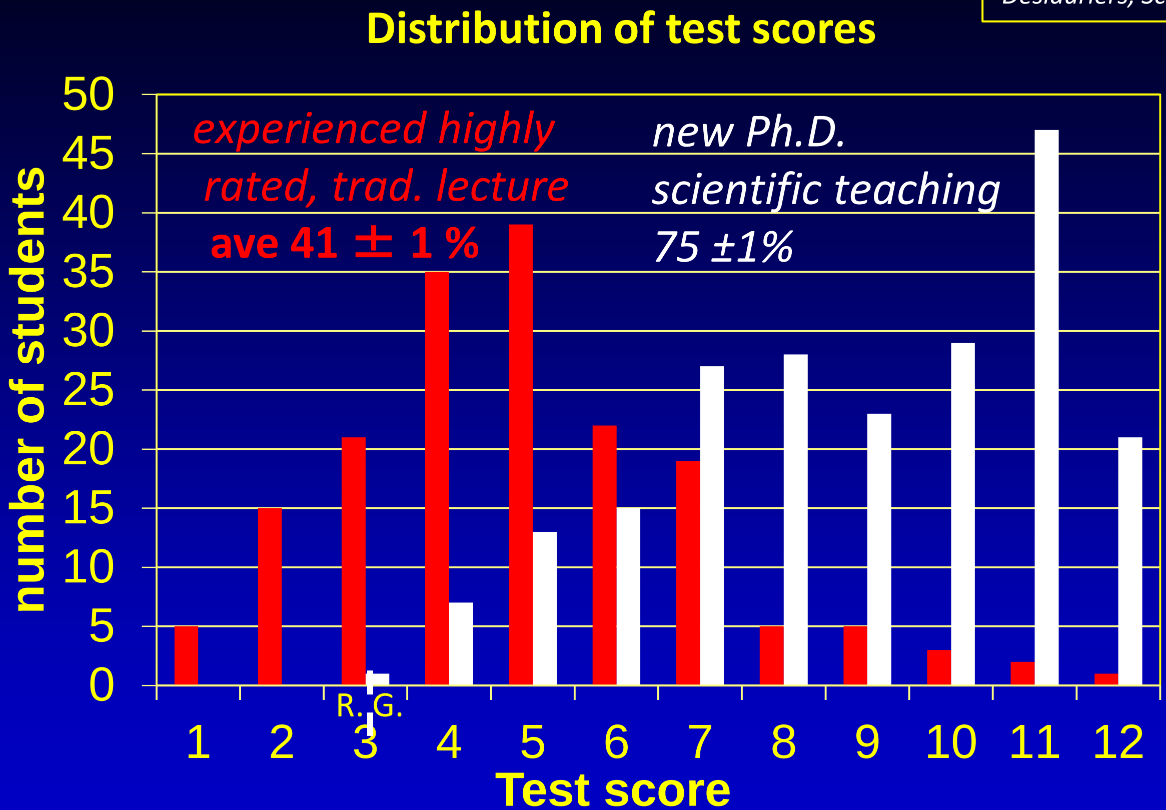


Entire distribution shifted up (34%).
Learning from traditional, "good" lecture 41-25 = tiny **16% !!**

"But traditional lectures can't be as bad as you claim. Look at all these Nobel Prize winners who were taught by traditional lectures and how well they turned out!"

Bloodletting was the medical treatment of choice for ~ 2000 years, based on exactly the same logic.

Need proper comparison group. (science)

Those N.P. winners would likely have been much ***more*** *successful if they had better teaching!*

caveat- expert/prepared mind can learn from lecture

- thousands of studies on learning
- ~ 1000 published comparing lecture method with other ways of teaching university science

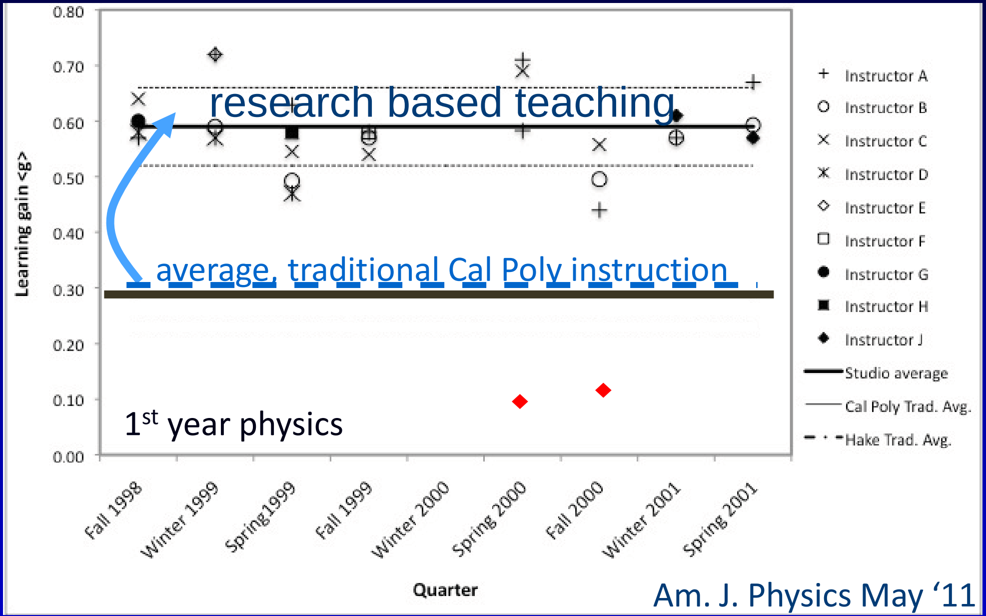
show consistent differences in learning

examples:

Learning to apply concepts of force and motion in new contexts

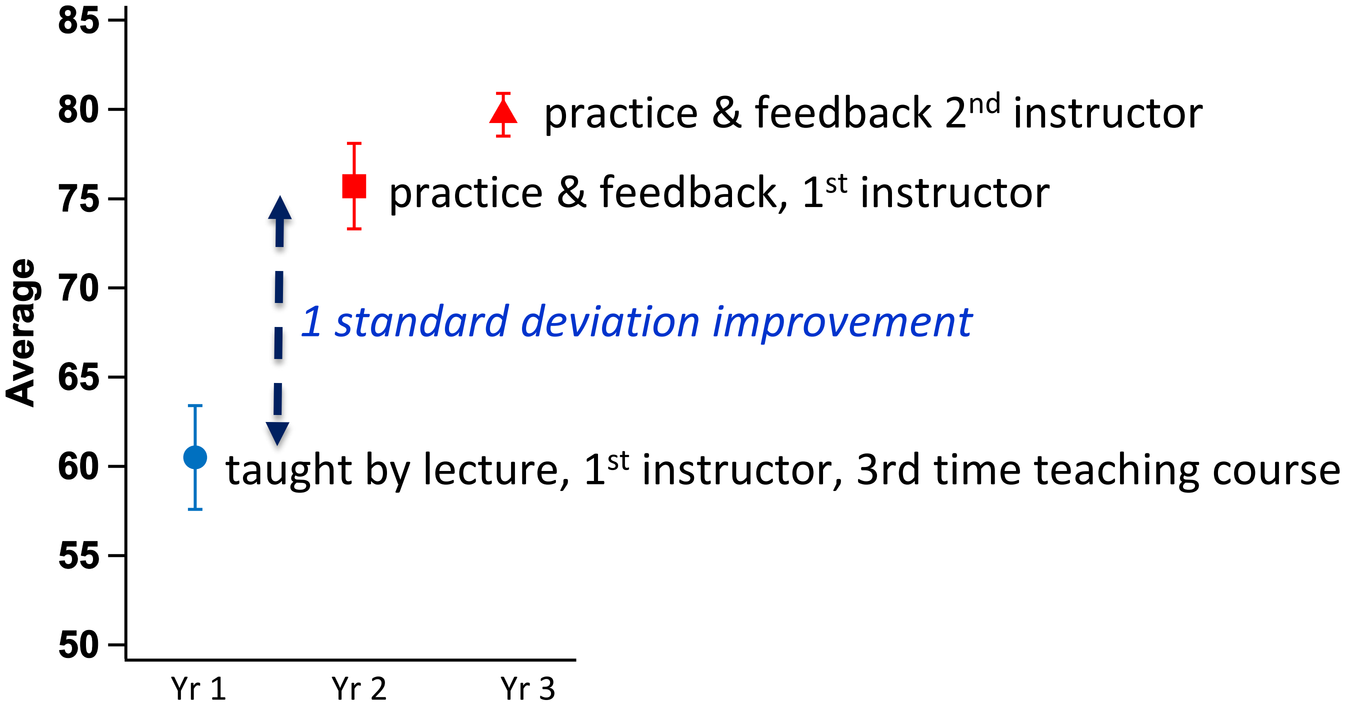
9 instructors, 8 terms, 40 students/section.

Same instructors, **changed** teaching methods ⇨ **changed** learning!



4^{th} year physics – modern optics

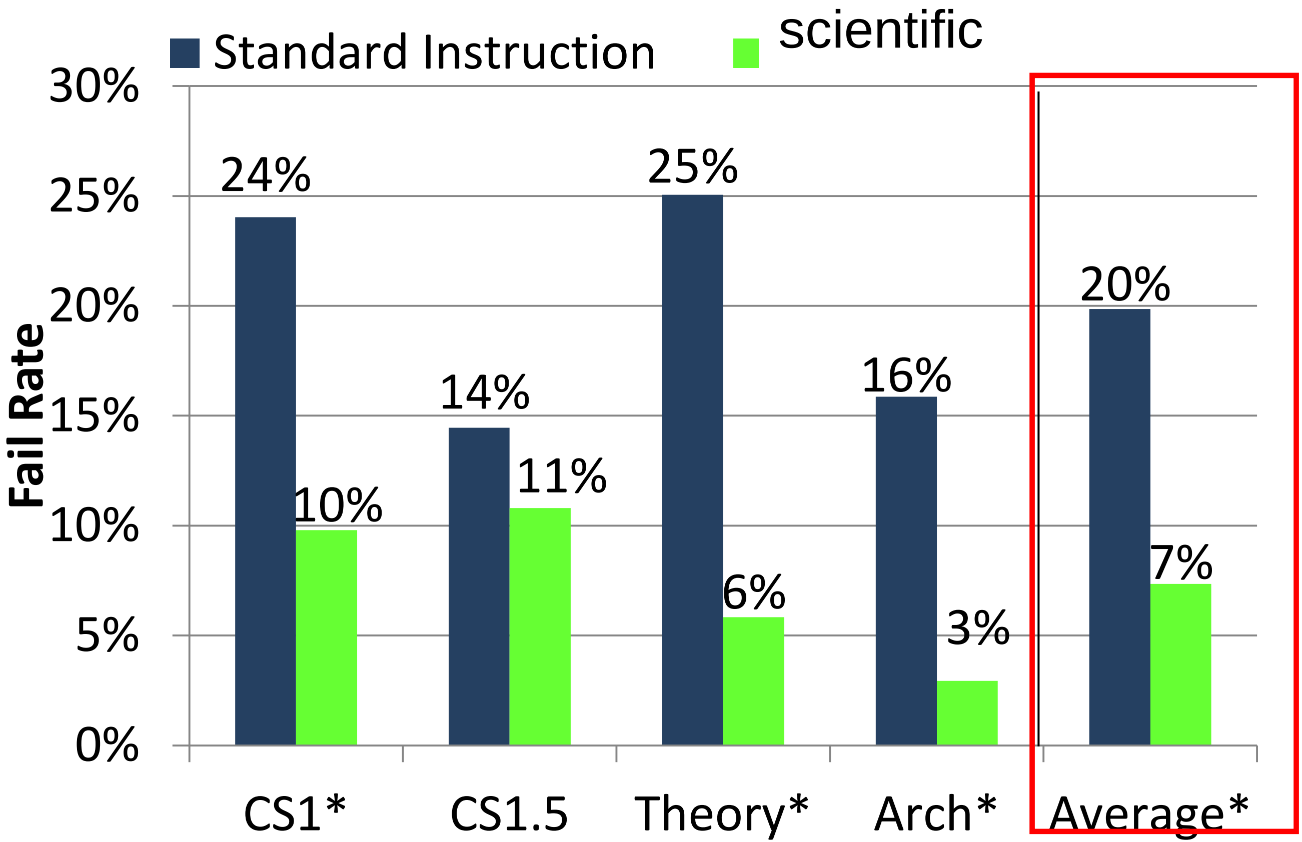
scores on ~identical final exam problems



Jones, Madison, Wieman, Transforming a fourth year modern optics course using a deliberate practice framework, Phys Rev ST – Phys Ed Res, V. 11(2), 020108-1-16 (2015)

U. Cal. San Diego, Computer Science

Failure & drop rates– *Beth Simon et al., 2012*



Same instructors, changed teaching methods ⇨ 1/3 DFW

⇒ principles and methods you can use to learn how to think like expert physicist

Rest of talk

I. Nature of expert thinking and how it is learned.

II. How applies to physics

III. How you can use in your own learning

I. Expertise research* *(thinking like expert)*

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

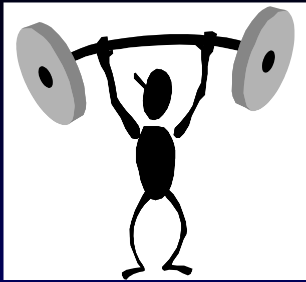
New ways of thinking-- everyone requires MANY hours of intense practice to develop.

Brain changed

*Cambridge Handbook on Expertise and Expert Performance

II. Learning expertise*--

Challenging but doable tasks/questions. Practicing all the elements of expert physics thinking with feedback.



Requires brain "exercise"

Some components of S & E expertise

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

Knowledge important but only as integrated part with how and when to use.

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

Research on Learning

Components of effective teaching/learning

1. Motivation
   - relevant/useful/interesting to learner
   - sense that can master subject
2. Connect with prior thinking
3. Apply what is known about memory
   - short term limitations
   - achieving long term retention
4. Explicit authentic practice of expert thinking
5. Timely & specific feedback on thinking

Practicing physicist thinking processes.
What you can do on your own.

& To teach effectively, what to have your students do.
(plus providing feedback)

NOT!! Reading over text and lecture notes many times. Passively listening to lecture.
Too easy, no benefit.

Practicing & improving your physics thinking

1) Study intensively & focused– full attention, or not at all.
2) Figure out in own mind how the topics are connected and related, and how fits with what you already know.
3) Formulate criteria for when new concept does & doesn't apply
4) Always look for ways to refine & check your thinking. (analogies, other situations, other students, Profs.)
5) Try/imagine explaining to someone else ("*grade 10 sibling*")
6) Explicitly plan out solution before start—breakdown into parts
7) Think of alternative ways to solve problem, alternative simplifying approximations.
8) If have something wrong, DON'T JUST GET CORRECT ANSWER. FIND OUT WHAT IS WRONG IN YOUR THINKING AND HOW TO FIX NEXT TIME.
9) test yourself repeatedly—retrieve & apply (use or lose)
10) sleep (consolidates learning)

Increase your learning from homework

Expertise practiced with typical HW (& exam) problems.

- Provide all information needed, and only that information, to solve the problem
- Say what to neglect
- Not ask for argument for 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.)~~

Increase your learning from homework

Rewrite the standard homework problems.

***Find realistic context**

- Provide all information needed, and only that information, to solve the problem ***How decide what information needed?**
- Say what to neglect ***What if not make those assumptions?**
- Not ask for argument for ***Why answer reasonable ?**
- Only call for use of one representation ***Use multiple rep's.**
- *Possible* to solve quickly and easily by plugging into equation/procedure ***What concepts apply or not. Why?**

- 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.)

This talk, too much stuff, too fast to process.

copies of slides will be available

Afternoon session–

- discuss how to implement
- coming up with examples
- getting feedback

(actually learn something)

A scientific approach to teaching & learning physics

Good References to learn more:

S. Ambrose et. al. “How Learning works”

Colvin, “Talent is over-rated”

Summary of field and a number of good references –Pts I & II in “Microbe” magazine by Wieman and Gilbert (see at cwsei.ubc.ca website under research)

Science education initiative website cwsei.ubc.ca– lots of resources, references, videos

Things students should do to improve your **teaching**

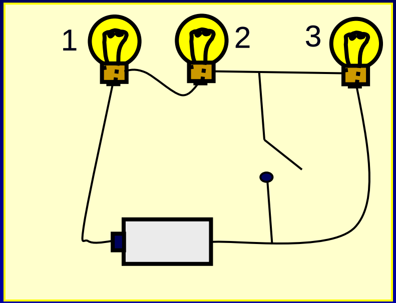
Don't passively accept tedious ineffective traditional lectures *(pedagogical blood-letting) Point out to your teachers all the evidence and high level calls for change from important organizations. Get groups of students together to lobby Deans, Department Chairs, Instructors for better methods.*

National Academy of Sciences
American Assoc. of Universities
& many others calling for change in how science being taught based on research.
PNAS metaanalysis- improved learning, reduced failure rates. Consistent across all STEM & all levels

If do not walk out of every class thinking "here is what I learned today, this was useful" demand better- the data backs you up

What is happening in these classes?

Students are solving tasks



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

"Answer individually with clicker, then discuss with students around you. Come up with reasons for right answer and why the others are wrong. Revote with clicker."

Instructor is circulating, listening in, coaching, then leads follow-up discussion/feedback. Many additional questions.