Taking a scientific approach to Science education*

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and most other subjects

*based on the research of many people, some from my science ed research group
How I used to teach.
Figure out subject, then tell students

my enlightenment
(~ 25 years ago)

grad students
17 yrs of success in courses
Come into lab clueless about physics?

2-4 years later ⇒ expert physicists!

Research on how people learn, particularly physics
- explained puzzle
- different way to think about learning
- how to improve the teaching of courses
- got me started doing science ed research
Approach teaching and learning in same way as physics.

Controlled experiments and data. *Works uniquely well for university science classes.*
example of what is achievable with scientific approach

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

Experienced highly rated traditional lecturer versus

New physics Ph.D. trained in scientific principles and methods of effective teaching
Histogram of test scores

**ave 41 ± 1 %**

Experienced highly rated, trad. lect. using principles of effective teaching

**74 ± 1 %**

Highly rated teacher, same populations, same class time, same test.

What is going on?
Major advances past 1-2 decades ⇒ Guiding principles for achieving learning

- University classroom studies
- Brain research
- Cognitive psychology

Today
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
I. Exactly what is “thinking like a scientist (or other expert)?” (making decisions like…– ed goal) Not all become scientists!

II. How is it learned?

III. Examples from university classroom research
   Skip many details about how to implement - questions & references.

IV. Achieving widespread adoption of research-based methods?
I. Research on expert thinking*

historians, scientists, chess players, doctors,…

Expert thinking/competence =
• factual knowledge
• Mental organizational framework ⇒ retrieval and application
  or ?
  patterns, relationships, hierarchy of importance, 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 expertise with feedback and reflection.

Some elements 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
- 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
Effective teacher—
• Designing suitable practice tasks
• Providing timely guiding feedback
• Motivating
(“cognitive coach”)

All require **high level content mastery**
The justification of research universities
III. How to apply in classroom?
practicing expert thinking with feedback

Easier in smaller classes.
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
b. get dimmer,
d. go out.

3. Individual answer with clicker
(accounability=intense thought, primed for learning)

4. Discuss with “consensus group”, revote.

Instructor listening in! What aspects of student thinking
like physicist, what not?

Jane Smith chose a.
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
(applying, testing conceptual models, critiquing reasoning...)

**Feedback that guides thinking**—other students, informed instructor, demo

Continue practice in homework and exams
3. Evidence from the Classroom

~ 1000 research studies from undergrad science and engineering
  • consistently show greater learning
  • lower failure rates
  • benefits all, but at-risk most

a few examples—
  • learning from course
  • failure and drop rates
  • learning in classroom

Massive meta-analysis
all sciences & eng. similar.
PNAS Freeman, et. al. 2014

various class sizes and subjects
Apply concepts of force & motion like physicist to make predictions in real-world context?

average trad. Cal Poly instruction

1st year mechanics

Hoellwarth and Moelter, Am. J. Physics May '11
U. Cal. San Diego, Computer Science
Failure & drop rates— *Beth Simon et al., 2012*

same 4 instructors, better methods = 1/3 fail rate
Learning in the 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-- new physics Ph. D. trained in principles & methods of research-based teaching.

They agreed on:
• Same learning objectives
• Same class time (3 hours, 1 week)
• Same exam (jointly prepared)- start of next class

mix of conceptual and quantitative problems

*Deslauriers, Schelew, Wieman, Sci. Mag.  May 13, ’11
Experimental class design

1. Targeted pre-class readings

2. Questions to solve, respond with clickers or on worksheets, discuss with neighbors. Instructor circulates, listens.

3. Discussion by instructor follows, not precedes. (but still talking ~50% of time)
Clear improvement for entire student population. Engagement 85% vs 45%.
Class Design

- Student pre-class preparation.
- In-class, students work in small groups on worksheets.
- Instructor facilitates. Whole class feedback ~ every 10 minutes.
- Continues/builds on in homework.

(see Jones, Madison, Wieman ref. for details)
Final Exam Scores

nearly identical ("isomorphic") problems
(highly quantitative and involving transfer)

1 standard deviation improvement

### Stanford Active Learning Physics courses (all new in 2015-16)

#### 2nd-4th year physics courses, 6 Profs

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Professor</th>
<th>Term</th>
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<tr>
<td>PHYS 70</td>
<td>Modern Physics</td>
<td>Wieman</td>
<td>Aut 2015</td>
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<tr>
<td>PHYS 120</td>
<td>E&amp;M I</td>
<td>Church</td>
<td>Win 2016</td>
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<td>E&amp;M II</td>
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<td>PHYS 130</td>
<td>Quantum I</td>
<td>Burchat</td>
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<tr>
<td>PHYS 131</td>
<td>Quantum II</td>
<td>Hartnoll</td>
<td>Spr 2016</td>
</tr>
<tr>
<td>PHYS 110</td>
<td>Adv Mechanics</td>
<td>Hartnoll</td>
<td>Aut 2015</td>
</tr>
<tr>
<td>PHYS 170</td>
<td>Stat Mech</td>
<td>Schleier-Smith</td>
<td>Aut 2015</td>
</tr>
</tbody>
</table>
Stanford Outcomes

- Attendance went from 50-60% to ~95% for all.
- Covered as much or more content
- Student anonymous comments:
  
  90% positive (mostly VERY positive, “All physics courses should be taught this way!”)
  only 4% negative

- All the instructors (tenure-track Profs) greatly preferred to lecturing.
  
  Typical response across ~ 200 faculty at UBC & Col. New way of teaching much more rewarding, would never go back.
IV. Widespread adoption of effective research-based teaching methods?

**A better way to evaluate undergraduate science teaching**
Change Magazine, Jan-Feb. 2015
Carl Wieman

☞ *Measure what practices are being used.*
   *Extent of use of those shown to improve learning.*

“The Teaching Practices Inventory: A New Tool for Characterizing College and University Teaching in Mathematics and Science”
Carl Wieman* and Sarah Gilbert

*(and engineering & social sciences)*

*Try yourself. ~ 10 minutes to complete.*
http://www.cwsei.ubc.ca/resources/TeachingPracticesInventory.htm
A scientific approach to teaching

Improve student learning & faculty enjoyment of teaching
A scientific approach to teaching
Improve student learning & faculty enjoyment of teaching

Good References:  slides will be available
S. Ambrose et. al. “How Learning works”
D. Schwartz et. al. “The ABCs of how we learn”
Colvin, “Talent is over-rated”
“Reaching Students” NAS Press (free pdf download)

cwsei.ubc.ca-- resources (implementing best teaching methods), references, effective clicker use booklet and videos
~ 30 extras below
Expertise practiced and assessed 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.)
Typical variations of extent of use of teaching practices that improve learning across science departments before and after Dept that made effort to improve teaching
Lesson from these Stanford courses—

**Not hard for typical instructor to switch to active learning and get good results**

- read some references & background material (like research!)
- fine to do incrementally, start with pieces
No Prepared Lecture

**Actions**

**Preparation**
- **Students:** Complete targeted reading
- **Instructors:** Formulate/review activities

**Introduction (2-3 min)**
- **Students:** Listen/ask questions on reading
- **Instructors:** Introduce goals of the day

**Activity (10-15 min)**
- **Students:** Group work on activities
- **Instructors:** Circulate in class, answer questions & assess students

**Feedback (5-10 min)**
- **Students:** Listen/ask questions, provide solutions & reasoning when called on
- **Instructors:** Facilitate class discussion, provide feedback to class
Lecture Notes Converted to Activities

3) Consider this optical setup

3a) Explain what this second expression means:
3b) What is the meaning of the terms \( U_n \) and \( U_{n+1} \)?
3c) What is \( U_0 \) in terms of \( r_1, r_2, r_1, \) and \( U_{\text{laser}} \)?
3d) What is \( r \) in terms of \( r_1 \) and \( r_2 \)?
3e) Suppose there was a loss inducing optical element inside the cavity with a field transmission coefficient of \( t_{\text{loss}} \). What would \( r \) be in terms of \( t_{\text{loss}}, r_1, \) and \( r_2 \) ? What if \( t_{\text{loss}} \) were complex?
3e) What is the effect of changing the index of refraction of the material between the mirrors? Is this equivalent to changing the distance between the mirrors? Why or why not?
3f) What is the effect of changing the wavelength of the input laser field? Is this equivalent to changing the distance between the mirrors? Why or why not?
3g) Evaluate the infinite sum for the field and derive an expression for the intensity.

Often added bonus activity to keep advanced students engaged
Pre-class Reading

Purpose: Prepare students for in-class activities; move learning of less complex material out of classroom
Spend class time on more challenging material, with Prof giving guidance & feedback

Can get >80% of students to do pre-reading if:
• Online or quick in-class quizzes for marks (tangible reward)
• Must be targeted and specific: students have limited time
• DO NOT repeat material in class!

Why **so hard** to stop lecturing?

1. Habit
2. Experts can learn from a lecture
   - Have knowledge framework & background, see why valuable
3. Learn so much *by giving* a lecture
Also, incentive system against improving teaching

Evaluation of teaching poor (only student evaluations)
Not correlated with learning or use of good methods.

“A better way to evaluate undergraduate science teaching”
Change Magazine, Jan-Feb. 2015, Carl Wieman

Widespread adoption of effective research-based methods?
⇒ Measure what methods are being used!

What every university should do...
Necessary (and probably sufficient) 1st step—have good way to evaluate teaching quality

Requirements:
• measures what leads to most learning
• equally valid/fair for use in all courses
• actionable—how to improve, & measures when do
• is practical to use routinely

student course evaluations fail on all but #4

Better way—thoroughly characterize all the practices and decisions used in teaching a course. Determine extent of use of research-based methods (ones shown to improve learning).

better proxy for what matters

“A better way to evaluate undergraduate science teaching”
Change Magazine, Jan-Feb. 2015, Carl Wieman
Math classes— similar design

Other types of questions---

• What is next (or missing) step(s) in proof?
• What is justification for (or fallacy in) this step?
• Which type of proof is likely to be best, and why?
• Is there a shorter/simpler/better solution? Criteria?

Small change, big effect!

“Concepts first, jargon second improves understanding”
L. Macdonnell, M. Baker, C. Wieman, *Biochemistry and Molecular biology Education (in press)*
2 simple immediately applicable findings from research on learning. Apply in every course.

1. expertise and homework design

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

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

**MUCH less than in typical lecture**

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

*slides to be provided*
Reducing demands on working memory in class

- Targeted pre-class reading with short online quiz
- Eliminate non-essentential jargon and information
- Explicitly connect
- Make lecture organization explicit.
Perceptions about science

**Novice**

Content: isolated pieces of information to be memorized.

Handed down by an authority. Unrelated to world.

Problem solving: following memorized recipes.

**Expert**

Content: coherent structure of concepts.

Describes nature, established by experiment.


measure student perceptions, 7 min. survey. Pre-post intro physics course ⇒ more novice than before chem. & bio as bad

*adapted from D. Hammer*
Perceptions survey results—Highly relevant to scientific literacy/liberal ed. Correlate with everything important

Who will end up physics major 4 years later?

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

recent research ⇒ changes in instruction that achieve positive impacts on perceptions
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
Student Beliefs

- Actual Majors who were originally intended phys majors
- Survived as Majors who were NOT originally intended phys majors

Percent of Students

CLASS Overall Score (measured at start of 1st term of college physics)
Emphasis on motivating students
Providing engaging activities and talking in class
Failing half as many
“Student-centered” instruction

 Aren’t you just coddling the students?

Like coddling basketball players by having them run up and down court, instead of sitting listening?

Serious learning is inherently hard work
Solving hard problems, justifying answers—much harder, much more effort than just listening.

But also more rewarding (if understand value & what accomplished)---motivation
A few final thoughts—

1. Lots of data for college level, does it apply to K-12?

_There is some data and it matches. Harder to get good data, but cognitive psych says principles are the same._

2. Isn’t this just “hands-on”/experiential/inquiry learning?

_No. Is practicing thinking like scientist with feedback. Hands-on may involve those same cognitive processes, but often does not._
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)
New paradigm on learning complex tasks (e.g. science, math, & engineering)

old view, current teaching

knowledge soaks in, variable

new view

transform via suitable “exercise”
Perfection in class is not enough!

Not enough hours

- Activities that prepare them to learn from class (targeted pre-class readings and quizzes)

- Activities to learn much more after class
good homework—-
  - builds on class
  - explicit practice of all aspects of expertise
  - requires reasonable time
  - reasonable feedback
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 background)

Enhancing motivation to learn

a. Relevant/useful/interesting to learner (meaningful context -- connect to what they know and value)
   requires expertise in subject

b. Sense that can master subject and how to master, recognize they are improving/accomplishing

c. Sense of personal control/choice
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-- often cover more

Intro courses, can cover the same amount. But typically cut back by ~20%, as faculty understand better what is reasonable to learn.
Benefits to interrupting lecture with challenging conceptual question with student-student discussion

Not that important whether or not they can answer it, just have to engage.

Reduces WM demands– consolidates and organizes. Simple immediate feedback (“what was mitosis?”)

Practice expert thinking. Primes them to learn.

Instructor listen in on discussion. Can understand and guide much better.
Measuring conceptual mastery

- Force Concept Inventory - basic concepts of force and motion

*Apply like physicist in simple real world applications?*

**Test at start and end of the semester--**

**What % learned?** (100’s of courses/yr)

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

R. Hake, "...A six-thousand-student survey…” AJP 66, 64-74 ('98).
Highly Interactive educational simulations--
phet.colorado.edu  >100 simulations
FREE, Run through regular browser. Download
Build-in & test that develop expert-like thinking and learning (& fun)
balloons and sweater  
laser
clickers*--

Not automatically helpful--

give accountability, anonymity, fast response

Used/perceived as expensive attendance and testing device ⇒ little benefit, student resentment.

Used/perceived to enhance engagement, communication, and learning ⇒ 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
What is the role of the teacher?

“Cognitive coach”

• Designs tasks that practice the specific components, of “expert thinking”.
• 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

Implies what is needed to teach well: expertise, understanding how develops in people, common difficulties, effective tasks and feedback, effective motivation.
Retention curves measured in Bus’s Sch’l course. UBC physics data on factual material, also rapid but pedagogy dependent. (in prog.)
Comparison of teaching methods: identical sections (270 each), intro physics. (Deslauriers, Schewle, submitted for pub)

I

Experienced highly rated instructor--trad. lecture

wk 1-11

very well measured--identical

Wk 12-- experiment

II

Very experienced highly rated instructor--trad. lecture

wk 1-11
Two sections the same before experiment. (different personalities, same teaching method)

<table>
<thead>
<tr>
<th></th>
<th>Control Section</th>
<th>Experiment Section</th>
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<tbody>
<tr>
<td>Number of Students enrolled</td>
<td>267</td>
<td>271</td>
</tr>
<tr>
<td>Conceptual mastery (wk 10)</td>
<td>$47 \pm 1%$</td>
<td>$47 \pm 1%$</td>
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<tr>
<td>Mean CLASS (start of term)</td>
<td>$63 \pm 1%$</td>
<td>$65 \pm 1%$</td>
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<tr>
<td>Mean CLASS (Agreement with physicist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Midterm 1 score</td>
<td>$59 \pm 1%$</td>
<td>$59 \pm 1%$</td>
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<tr>
<td>Mean Midterm 2 score</td>
<td>$51 \pm 1%$</td>
<td>$53 \pm 1%$</td>
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<tr>
<td>Attendance before</td>
<td>$55 \pm 3%$</td>
<td>$57 \pm 2%$</td>
</tr>
<tr>
<td>Engagement before</td>
<td>$45 \pm 5%$</td>
<td>$45 \pm 5%$</td>
</tr>
</tbody>
</table>
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

**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**
<table>
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<th>control</th>
<th>experiment</th>
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<tbody>
<tr>
<td>2. Attendance</td>
<td>53(3) %</td>
<td>75(5)%</td>
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<tr>
<td>3. Engagement</td>
<td>45(5) %</td>
<td>85(5)%</td>
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Measuring student (dis)engagement. Erin Lane
Watch random sample group (10-15 students). Check against list of disengagement behaviors each 2 min.

example of data from earth science course

time (minutes)
Design principles for classroom instruction
1. Move simple information transfer out of class. Save class time for active thinking and feedback.

2. “Cognitive task analysis” -- how does expert think about problems?
3. Class time filled with problems and questions that call for explicit expert thinking, address novice difficulties, challenging but doable, and are motivating.
4. Frequent specific feedback to guide thinking.
What about learning to think more innovatively? Learning to solve challenging novel problems

Jared Taylor and George Spiegelman

“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 novelty encountered before

**Average Number**

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of Solutions</th>
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</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>Structured Problems (tutorial)</td>
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</tr>
<tr>
<td>Inventions (Outside of Lecture)</td>
<td></td>
</tr>
<tr>
<td>Inventions (During Lecture)</td>
<td></td>
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</table>
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)

- No intervention
- Email only
- Email & Meeting

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**Scatter Plot**

- Midterm 1 Score vs. Midterm 2 Score
- Data points categorized by intervention type:
  - No intervention
  - Email only
  - Email & Meeting

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**Legend**

- ◆ No intervention
- ● Email only
- ■ Email & Meeting
• 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 **how** 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
but **appropriately targeted** 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

Complex learning-- 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. ⇒ 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 Performance
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.

Higher ed → K-12 teachers → everyone
Many new efforts to improve undergrad stem education (partial list)

1. College and Univ association initiatives (AAU, APLU) + many individual universities

2. Science professional societies

3. Philanthropic Foundations

4. New reports — PCAST, NRC (~april)


6. Government — NSF, Ed $$, and more

7. ...