Using the tools of science to teach science

I) Why should we care about science education?

II) What does research tell us about teaching and how people learn?

III) Some technology that can help improve learning (if used correctly!)

IV) Institutional change (brief) -- Science Education Initiatives Univ. of Brit. Columbia, and U. Col.
Changing purpose of science education
historically-- training next generation of scientists (< 1%)

- Scientifically-literate populace--wise decisions

- Workforce in modern economy.

Need science education effective and relevant for large fraction of population!

Effective education
Transform how think--

Think about and use science like a scientist.
Hypothesis--
possibl e, if approach teaching of science like science--

• Practices based on good data & standards of evidence
• Guided by fundamental research
• Disseminate results in scholarly manner, & copy what works
• Utilize modern technology

Supporting the hypothesis.....

What does research tell us about effective science teaching? (my enlightenment)

How to teach science: (I used)

1. Think very hard about subject, get it figured out very clearly.

2. Explain it to students, so they will understand with same clarity.

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

2-4 years later ⇒ expert physicists!

Research on how people learn, particularly science.
- above actually makes sense.
⇒ opportunity--how to improve learning.

Major advances past 1-2 decades
Consistent picture ⇒ Achieving learning
II. Research on teaching & learning

A. Research on traditional science teaching.

B. Cognitive psychology research-- explains results & provides principles for how to improve.

C. Research on effective teaching practices --implementing the principles

A. Research on traditional science teaching
-lectures, textbook homework problems, exams

1. Transfer/retention of information from lecture.
2. Conceptual understanding.
3. Beliefs about physics and chemistry.

Consistent data from all sciences & levels, but most from introductory physics.
Data 1. Retention of information from lecture

I. Redish- students interviewed as came out of lecture. "What was the lecture about?" only vaguest generalities

II. Wieman and Perkins - test 15 minutes after told nonobvious fact in lecture. 10% remember

many other studies-- similar results

Cog. Pysch. says is just what one expects!
a. Cognitive load-- best established, most ignored.

Working memory capacity VERY LIMITED! (remember max 7± 2 items, process 4 ideas)

MUCH less than in typical science lecture

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

PPT slides will be available
Data 2. Conceptual understanding in traditional course.

- Force Concept Inventory - basic concepts of force and motion 1st semester physics

Ask at start and end of semester -
What % learned? (100’s of courses)

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

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

Data 3. Beliefs about physics/chem and problem solving

<table>
<thead>
<tr>
<th>Novice</th>
<th>Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content: isolated pieces of information to be memorized.</td>
<td>Content: coherent structure of concepts.</td>
</tr>
<tr>
<td>Handed down by an authority. Unrelated to world.</td>
<td>Describes nature, established by experiment.</td>
</tr>
</tbody>
</table>

% shift?

intro physics & chem courses ⇒ more novice

ref.s Redish et al, CU work--Adams, Perkins, MD, NF, SP, CW

*adapted from D. Hammer
II. Research on teaching & learning

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**Expert competence**

- factual knowledge
- **Organizational structure** → effective retrieval and use of facts

*Cambridge Handbook on Expertise and Expert Performance*
recent research--Brain development much like muscle

Requires strenuous extended use to develop
(classroom, cog. pysch., & brain imaging)

Not stronger or smarter!
Both require strenuous effort
17 yrs of success in classes. Come into lab clueless about physics?

2-4 years later ⇒ expert physicists!

??????

Makes sense!

Traditional science course poor at developing expert-like thinking.

Principle ⇒ people learn by developing own understanding. Effective teaching = facilitate development, by engaging, then monitoring & guiding thinking. Continually happening in research lab!

⇒ guidance for improving classroom instruction

II. Research on teaching & learning

A. Research on traditional science teaching.

B. Cognitive psychology research-- explains results & provides principles for how to improve.

C. Research on effective teaching practices --implementing the principles
What does research say is the most effective pedagogical approach?*

⇒ **expert** individual tutor

Large impact on all students

**Average** for class with expert individual tutors
>98% of students in class with standard instruction

* Bloom et al *Educational Researcher*, Vol. 13, pg. 4

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**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*
What expert tutors do matches research from very different contexts

- Cog. psychologists -- activities/motivation required for expert mastery
- Educational pysch. -- how people learn, activities most effective for learning.
- Science education -- effective classroom practices

E.g. A. Ericsson et. al., Cambridge Handbook on Expertise...
Bransford et al, How People Learn, NAS Press
Redish, Teaching Physics, Handlesman, Scientific Teaching
K. Perkins, S. Pollock, et al, PR ST-PER, ...
Engaging, monitoring, & guiding thinking.

5-300 students at a time?!

Technology that can help, (when used properly)
examples:
   a. Interactive lecture (students discussing & answering questions) supported by personal response system--“clickers”

   b. interactive simulations (too physics specific)

a. concept questions & “Clickers”--

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

"Jane Doe picked B"
**clickers**--

Not automatically helpful--

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

Used/perceived to enhance engagement, communication, and learning ⇒ transformative

• challenging questions
• student-student discussion ("peer instruction") & responses
• 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-- [http://www.cwsei.ubc.ca/](http://www.cwsei.ubc.ca/)

**Highly Interactive simulations**-- novel technology

Highly effective when based on/incorporates research on learning.
Perfect Classroom not enough!

Build further with extended “effortful practice” focusing on developing expert-thinking and skills. (Required to develop long term memory)

(\textit{homework} - authentic problems, useful feedback)

\begin{itemize}
\item Retention of information from lecture
  \begin{itemize}
  \item 10\% after 15 minutes $\Rightarrow$ >90 \% after 2 days
  \end{itemize}
\item Conceptual understanding gain
  \begin{itemize}
  \item 25\% $\Rightarrow$ 50-70\%
  \end{itemize}
\item Beliefs about physics and problem solving, interest
  \begin{itemize}
  \item 5-10\% drop $\Rightarrow$ small improvement \textit{(just starting)}
  \end{itemize}
\end{itemize}
IV. Institutional change --
“from bloodletting to antibiotics”

Widespread improvement in science education
Requirement--change educational culture in major
research university science departments

CW Science Education Initiative and U. Col. SEI
- Departmental level-- internally driven.
- scientific approach to teaching, all undergrad
courses = goals, measures, tested best practices
- Departments selected competitively
- Focused $$$ and guidance

All materials, assessment tools, etc available on web
Visitors program

Summary:
Need new, more effective approach to science ed.

Tremendous opportunity for improvement
⇒ Approach teaching like we do science

and teaching is more fun!

Good Refs.:
NAS Press “How people learn”
Handelsman, et al. “Scientific Teaching”
Wieman, (~ this talk) Change Magazine-Oct. 07
at http://www.carnegiefoundation.org/change/

CLASS belief survey: CLASS.colorado.edu
phet simulations: phet.colorado.edu
IV. Institutionalizing improved research-based teaching practices. *(From bloodletting to antibiotics)*

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

**Implications for instruction**

Student beliefs about science and science problem solving important!

- Beliefs ↔ content learning
- Beliefs -- powerful filter → choice of major & retention
- **Teaching practices → students’ beliefs**  
  typical significant decline (phys and chem)  
  (and less interest)

Avoid decline if **explicitly** address beliefs.

**Why is this worth learning?**  
**How does it connect to real world?**  
**How connects to things student knows/makes sense?**
Who from Calc-based Phys I, majors in physics?  

- Calc-based Phys I (Fa05-Fa06): 1306 students
- “Intend to major in physics”: 85 students
- Actually majoring in physics 1.5-3 yrs later: 18 students

Powerful selection according to initial CLASS beliefs!

K. Perkins

Implication for instruction--Reducing unnecessary cognitive load improves learning.

jargon   use figures, connect topics, ...

V. Institutional change -- what is the CWSEI?

Widespread improvement in science education
Requirement--change educational culture in major research university science departments

Carl Wieman Science Education Initiative
• Departmental level, widespread sustained change ⇒ scientific approach to teaching, all undergrad courses
• 5 departments, selected competitively
• Focused $$$ and guidance
• Partner with Univ. Colorado SEI

All materials, assessment tools, etc available on web Visitors program
**effective clicker use**

Class designed around series of questions and follow-up--Students actively engaged in figuring out.

Student-student discussion (consensus groups) & enhanced student-instructor communication

⇒ rapid + targeted = effective feedback.

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**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!
V. Issues in structural change (my assertions)

Necessary requirement--become part of culture in major research university science departments

set the science education norms
⇒ produce the college teachers, who teach the k-12 teachers.

Challenges in changing science department cultures--
• no coupling between support/incentives and student learning.
• very few authentic assessments of student learning
• investment required for development of assessment tools, pedagogically effective materials, supporting technology, training
• no $$$ (not considered important)

b. Interactive simulations

Physics Education Technology Project (PhET)
>60 simulations
Wide range of physics (& chem) topics. Activities database.
Run in regular web-browser, online or download site.

supported by: Hewlett Found., NSF, Univ. of Col., and A. Nobel
examples:
balloon and sweater
circuit construction kit

data on effectiveness- many different settings and types of use

Simulation testing ⇒ educational research microcosm. Consistently observe:

• Students think/perceive differently from experts (not just uninformed--brains different)
• Understanding created/discovered. (Attention necessary, not sufficient)
  Actively figuring out + with timely feedback and encouragement ⇒ mastery.