Using a scientific approach to teach physics

I) Data on effectiveness of traditional physics teaching.
II) Useful results/principles from research on effective learning.
III) Some examples of technology that make it easier to implement these principles.

Science education different, more important purpose than in the past.

Not just for scientists

• Survival of world. *Wise decisions by citizenry on global (technical) issues.*

• Workforce in High-Tech Economy.

Need to make science education effective and relevant for large fraction of population! and diverse!
Essence of an "effective education".

**Transform how think**--

**Think** about and use science like a scientist.
How to teach physics: (I used many years)

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

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

grad students
Approach as science problem.

What do we know about how people learn, particularly science?

Why, after 17 yrs of success in classes, do students come into lab so clueless about physics?

2-4 years later, leave as expert physicists???
II. Some data on effectiveness of traditional approach to physics teaching. lecture, textbook homework problems, exams

(most data from intro university physics)

1. Retention of information from lecture.

2. Conceptual understanding.

3. Beliefs about science.
1. Lecturing and retention

I. Redish - interviewed students as came out of lecture.
   "What was the lecture about?"
   unable to say anything but vaguest generalities

II. Rebello and Zollman - had 18 students answer six questions, then told them to get answers to these 6 questions from following 14 minute lecture. (Commercial video, highly polished)
   Most questions, less than one student able to get answer from listening to lecture.

III. Wieman and Perkins - 15 minutes after nonobvious fact told to students in lecture with illustration, gave simple multiple choice test to see if remembered.
   ~10% get correct (even in phys. dept. colloq.)
2. Conceptual understanding.
Learned in traditional intro physics course?

- Force Concept Inventory—basic concepts of force and motion

Lecturer quality, class size, institution,...doesn't matter!

R. Hake, "...A six-thousand-student survey..." AJP 66, 64–74 (’98).
2. Conceptual understanding (cont).

electricity
Eric Mazur (Paired problems)

Most students can calculate currents and voltages in complex circuit.

BUT, not predict brightness of bulbs when switch closed.

Solving test problems, but **not** like expert!
3. Beliefs about physics and problem solving *(measured)*

**Novice**

Content: isolated pieces of information to be memorized.

Handed down by an authority. Unrelated to world.

Problem solving: pattern matching to memorized arcane recipes.

**Expert**

Content: coherent structure of concepts.

Describes nature, established by experiment.


*nearly all physics courses* \(\Rightarrow\) **more novice**

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

*adapted from D. Hammer*
Science Education Research Conclusions 1:

• Not easy to know what students actually are (and are not) learning.

• Most students "learning" rote memorization of facts and problem solving recipes, not useful understanding.

   most also learning that physics is uninteresting and irrelevant
III. What does research tell us about principles that are important for more effective learning?

Three generally applicable examples
a. cognitive load
b. role of attitudes and beliefs
c. developing expert competence
Results when put into practice

1. Retention of information from lecture
   10% after 15 minutes ⇒ >90% after 2 days

2. Conceptual understanding gain
   25% ⇒ 65%

3. Beliefs about physics and problem solving
   significant drop ⇒ small improvement
examples-- using research on how people learn

a. Cognitive load-- best established, most ignored.

Mr Anderson, May I be excused?
My brain is full.
a. Cognitive load-- every bit more costs.

~7 items short term memory, process 4 ideas at once.

*Typical class, MUCH more than brain can process.*
b. Importance of student beliefs about science and science problem solving

Our new beliefs survey (CLASS.colorado.edu) (similar to MPEX but more general)

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Strongly Agree</th>
</tr>
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<tbody>
<tr>
<td>I think about the physics I experience in everyday life.</td>
<td></td>
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<tr>
<td>After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.</td>
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• <10 minutes, Give online pre- and post- instruction (>10,000 stds)
• Score agree (% favorable) or disagree with expert view
  Lots of data!
  • Beliefs ↔ content learning
  • Beliefs ↔ choice of major/retention
  • Teaching practices → students’ beliefs
b. Teaching practices and beliefs

<table>
<thead>
<tr>
<th>Course Type</th>
<th>Dominant student population</th>
<th>Beliefs (% favorable) Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phys-I (alg)</td>
<td>pre-meds</td>
<td>Pre 60% Post 51%</td>
</tr>
<tr>
<td>Phys-I (calc)</td>
<td>sci. &amp; eng.</td>
<td>Pre 64% Post 58%</td>
</tr>
</tbody>
</table>

Decline in beliefs ~all intro physics courses (also chem.)
Teaching practices and beliefs

Avoid decline if minimal effort to explicitly address beliefs. (Rutgers much more substantial)

Why is this worth learning?
How does it connect to real world?
Why does this make sense?
How connects to things you already know?

Interesting new result- students know expert beliefs and problem solving approaches, but don’t accept as valid. (particularly women)
c. Research on developing expert competence

Expert competence =
· factual knowledge
· **Organizational structure** $\Rightarrow$ effective retrieval and use of facts

or ?

· **Ability to monitor own thinking**
  (“Do I understand this? How can I check?”)

· New ways of thinking--require active mental construction.
· Built on prior thinking.

To develop, needs to be explicit part of learning process.

just pouring in more facts can **hinder** rather than help
How to teach science:
Think very hard about subject, figure out very clearly. Explain it to students, so they understand with same clarity.

- me vs students
  - massively heavier cog. load
  - novice beliefs about why to learn, how to learn.
  - no organizational structure

general principle \(\Rightarrow\) people learn by creating own understanding. Effective teaching: facilitate by guiding that creation.
III. Some technology that can help implement principles.*

a. student personal response systems
b. interactive simulations

* work from Col. sci. ed. research group
III. Some technology that can help.
(when used properly)

• Personal electronic response systems—facilitate active thinking and useful guidance. Relatively cheap.

PERS ("clickers")

"Jane Doe picked B"
15 minutes after telling and showing students how wooden back of violin is what produces sound they hear...

“Sound you hear from a violin is produced …”
a. mostly by strings, b. mostly by wood in back, c. both equally, d. none of above.

students click in responses, then display histogram
clickers-

*Used properly transforms classroom.*

*Dramatically improved engagement, discourse, number (x4) and distribution of questions.*

Not automatically helpful--

Only require students to commit to an answer

*(accountability + peer anonymity + fast feedback)*

Key to educational effectiveness

*use guided by how people learn*

Clicker questions and associated discussion:

• Focus students on processing ideas, “organize and apply”

• Communication and feedback (student-instructor, student-student)

• student consensus-group discussions (& listen in)
Interactive simulations

Physics Education Technology Project (PhET)
Wide range of physics topics and some chem., well tested, free online or download. Run in regular web-browser. Use in lecture, lab, homework. (often better than reality!)

balloon and sweater  laser

supported by: Hewlett Found., Kavli, NSF, Univ. of Col., and A. Nobel
examples:
balloon and sweater
moving man
wave on string

each illustrate a unique pedagogically valuable characteristic of interactive simulations
Research on design and effectiveness of simulations. (Wendy Adams, Kathy Perkins, Noah F., et al)

1. Substantial improvement on concept questions when used in lecture vs real demos or static images.

![Diagram showing standing wave on string with bars for Q1 and Q2 comparing real demo and sim demo percentages.](image)
Students learn to build and understand real circuits better with sim than with real equipment!

*Finkelstein et al. Phy. Rev. PER 1,1*

real world not necessarily best pedagogically, experts and novices see very differently. Need to be very sophisticated to see simplicity.
Summary: Need new, more effective approach to science ed.

Solution: Approach teaching as a science

- Practices and principles based on good data
- Effective use of technology
- Disseminate and copy what works.

Good Refs.:
NAS Press “How people learn”, "How students learn"
Mayer, “Learning and Instruction” (ed. psych. applied)
Wieman and Perkins, Physics Today (Nov. 2005)

CLASS belief survey: CLASS.colorado.edu
phet simulations: phet.colorado.edu