Science Education for the 21st Century

Using the insights of science to teach/learn science

and most other subjects

Carl Wieman  UBC & CU

Nobel Prize

Data!!

Colorado physics & chem education research group:

The Vision

Students much better educated. Thrive in 21st century world ⇒ host of benefits to society.

Teaching more effective, and more fun, efficient, and meaningful for the instructor.

paraphrase J. Kotter
How to achieve?

I. 2 models for science, ... teaching and learning.

II. Research on science learning
   a. Components of scientific expertise
   b. Measuring development of expertise
   c. Effective teaching and learning

Relevant to:
• becoming better teacher
• becoming better learner
**Science education Model 1** (I used for many years)

think hard, figure out subject

tell students how to understand it

give problem to solve

do you understand? 

- yes: done
- no: tell again.

*students lazy or poorly prepared*

*tell again, Louder*
Model 1 (figure out and tell) Strengths & Weaknesses

Works well for basic knowledge, prepared brain:

- Easy to test. \(\Rightarrow\) Effective feedback on results.
- Problem if learning:
  - involves complex analysis or judgment
  - organize large amount of information
  - ability to learn new information and apply

More complex learning-- changing brain, not just adding bits of knowledge.
Model 1 (*figure out and tell*--*traditional lecture*)

Not adequate for education today. Need high level expertise & expert learners.

- Large fraction of population.
- Scientifically literate public
- Modern economy

**How to achieve and measure more complex learning?**
Science Education Model 2.

Goals. What students will be able to do.
(solve, design, analyze, capacity to learn, ...)

Create activities and feedback targeting desired expertise.

Use, and measure results.

- yes
- done

- no
- wrong treatment
- goals unrealistic
- why?

modify
Is model for *doing* science

Goals. Question to be answered. What data will answer it.

Design and build experiment.

Run and measure results.

- yes
  - done
- no
  - why?
  - goals unrealistic
  - wrong experiment

modify

prior research

prior research
Model 2 --scientific approach to science education

Goals. What students will be able to do. (solve, design, analyze, learn,...)

Create activities and feedback targeting desired expertise.

Run and measure results.

If yes: done
If no: why?
If goals unrealistic: modify
If wrong treatment: modify

⇒New insights on traditional science teaching, how to improve.
Major advances past 1-2 decades
Consistent picture ⇒ Achieving learning

- university classroom studies
- brain research
- cognitive psychology

⇒
**Some Data (science from classrooms):**

<table>
<thead>
<tr>
<th>Model 1 (telling) traditional lecture method</th>
<th>scientific teaching</th>
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<td>improves for future nonscientists and scientists</td>
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Model 2-- scientific approach

What has been learned?

1. Identifying components of expertise, and how expertise developed.

2. How to measure components of science expertise. (and what traditional exams have been missing)

3. Components of effective teaching and learning.
Developing expertise-- transforming brain

Think about and use science like a scientist.

What does that mean? How is it accomplished?
Expert competence research*
historians, scientists, chess players, doctors,…

Expert competence =
• factual knowledge
• **Organizational framework** ⇒ effective retrieval and application

or ?

• Ability to monitor own thinking and learning
  ("Do I understand this? How can I check?")

New ways of thinking-- require **MANY** hours of intense practice with guidance/reflection. Change brain “wiring”

*Cambridge Handbook on Expertise and Expert Performance
Measuring conceptual mastery

- 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 for conceptual learning in other courses.

R. Hake, "...A six-thousand-student survey…” AJP 66, 64-74 (‘98).
• Experts in science also have unique “belief” systems

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<tr>
<th><strong>Novice</strong></th>
<th><strong>Expert</strong></th>
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<td>Content: isolated pieces of information to be memorized.</td>
<td>Content: coherent structure of concepts.</td>
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<td>Handed down by an authority. Unrelated to world.</td>
<td>Describes nature, established by experiment.</td>
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*adapted from D. Hammer*
Measuring student beliefs about science

**Novice**

**Expert**

Survey instruments--
MPEX--1st yr physics, CLASS--physics, chem, bio tests

~40 statements, strongly agree to strongly disagree--

*adapted from D. Hammer*

*Understanding physics basically means being able to recall something you've read or been shown.*

*I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.*

5-10% shift?

intro physics ⇒ *more* novice

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

Intro Chemistry and biology just as bad!

*adapted from D. Hammer*
Model 2-- scientific approach

**What has been learned?**

1. Identifying components of expertise, and how expertise developed.

2. How to measure components of science expertise. *(and what traditional exams have been missing)*

3. **Components of effective teaching and learning.**
Components of effective teaching/learning apply to all levels, all settings

1. Reduce unnecessary demands on working memory

2. Explicit authentic modeling and practice of expert thinking. Extended & strenuous (brain like muscle)

3. Motivation

4. Connect with and build on prior thinking
Mr Anderson, May I be excused? My brain is full.

**Limits on working memory** -- best established, most ignored result from cognitive science

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

**MUCH less than in typical science lecture**

make PPT slides available
⇒ processing and retention from lecture tiny (for novice)

many examples from research:

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

Also true in technical talks!
Reducing unnecessary demands on working memory improves learning.

- jargon, use figures, analogies, avoid digressions
Features of effective activities for learning.

1. Reduce unnecessary demands on working memory

2. Explicit authentic modeling and practice of expert thinking. Extended & strenuous  *(brain like muscle)*

3. Motivation

4. Connect with and build on prior thinking
3. Motivation-- essential
(complex- depends on previous experiences, ...)

a. Relevant/useful/interesting to learner
(meaningful context-- connect to what they know and value)
Problems where value of solution obvious.

b. Sense that can master subject and how to master

c. Sense of personal control/choice
Effective activities for learning.

1. Reduce unnecessary demands on working memory

2. Explicit authentic practice of expert thinking. Extended & strenuous *(brain like muscle)*

3. Motivation

4. Connect with and build on prior thinking
Practicing expert-like thinking--

**Challenging but doable tasks/questions**

Explicit focus on expert-like thinking
- concepts and mental models
- recognizing relevant & irrelevant information
- self-checking, sense making, & reflection

Provide effective feedback (timely and specific)
“cognitive coach”
How to actually do in class?
Hundreds of students???

a) good examples from Mazur and others

b) use technology to help
   printing press, ...

**Example from a class--practicing expert thinking with effective guidance/feedback**

1. Assignment--Read chapter on electric current. Learn basic facts and terminology. Short quiz to check/reward.

2. Class built around series of questions.
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 *(accountability, primed to learn)*

4. Discuss with “consensus group”, revote. *(prof listen in!)*

Do “experiment.”-- simulation.
Follow up instructor discussion--
review correct and incorrect thinking, extend ideas. Respond to student questions & suggestions.
*(covers extensive *new* material)*
How practicing expert thinking--

Challenging but doable question (difficult concept)

Explicit focus on expert-like thinking
  • actively developing concepts and mental models
  • recognizing relevant & irrelevant information
  • self-checking, sense making, & reflection

Getting timely and specific feedback (peers, clicker histogram, instructor)

Highly engaged-- further questions/predictions with sim, testing understanding = “Expert learning”
good start, but not enough time in class!

further practice-- well designed homework
Require expert thinking & feedback,

⇒ long term retention
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Summary:
Scientific model for science education

Much more effective. (and more fun)

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

CLASS belief survey: CLASS.colorado.edu
phet simulations: phet.colorado.edu
cwsei.ubc.ca-- resources, Guide to effective use of clickers
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