Using insights from science to teach/learn science (and other subjects)

Carl Wieman, UBC & CU

The Vision:

- All effort should be guided by research on learning
- All *students* can be much better educated, allowing them to thrive in our 21st century world.
- *Teaching* can be more effective, as well as more efficient and meaningful for the instructor.

How to achieve this? Three parts to this summary are:

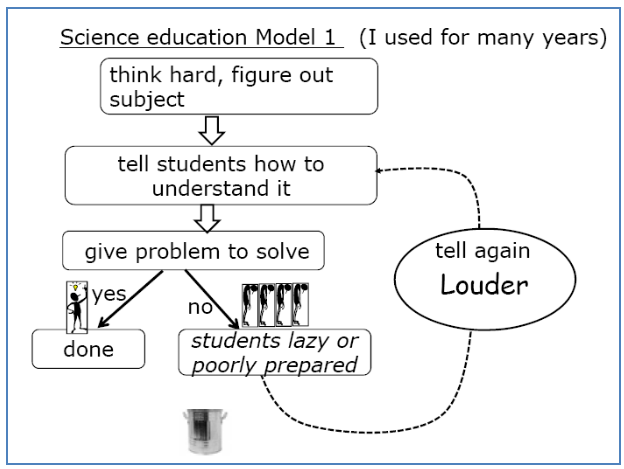
I. Two models for science teaching and learning.
II. Research on science learning, including
  a. Components of scientific expertise
  b. Measuring development of expertise
  c. Effective teaching and learning
III. Practical examples

Part I: Two models for science teaching:

<u>Model 1</u> **(figure out and tell) Strengths & Weaknesses:**

- Works well for basic knowledge, prepared brain:
- Easy to test. ⇒ Effective feedback on results.
- Problem arise if learning ...
  - involves complex analysis or judgment
  - requires organizing large amount of information
  - ability to learn new information and apply
- More complex learning involves the changing brain, not just adding bits of knowledge.
- Model 1 is not adequate for education today.

We need high level expertise & expert learners. How to achieve and measure more complex learning?



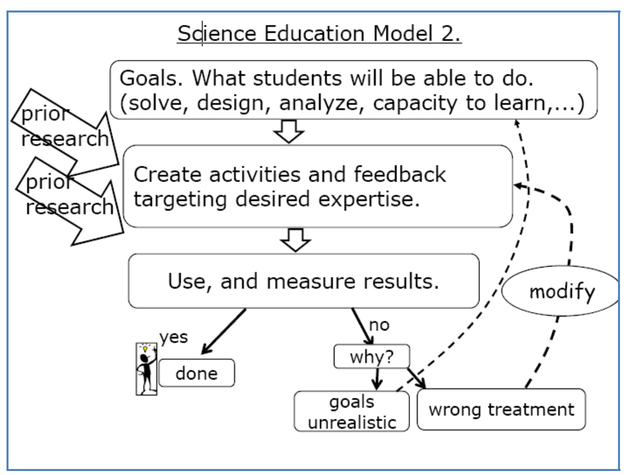
<u>Model 2</u> **is also the model for doing science.**

To describe scientific work, replace three steps with:

- Goals. Questions to be answered. What data will answer them?
- Design and build experiments or observations.
- Run / measure / observe results.

Prior research informs all actions.

Applying this process to teaching also yields new insights on traditional science teaching, and ways to improve.



Part II: What has been learned? New knowledge about developing expertise.

Major advances made in the past 1-2 decades demonstrate a consistent picture about what will successfully achieve learning. Areas of research contributing to this story include:

- Brain research
- Classroom studies
- Cognitive psychology

Some Data (science from classrooms) comparing Model 1 (telling) with Model 2 (scientific teaching):

- How much information from lectures is retained?
  Model 1: 10% after 15 minutes **Model 2**: >90 % after 2 days
- What fraction of concepts are mastered in course?
  Model 1: 15-25% **Model 2**: 50-70% with retention
- What are students' beliefs about science (ie what science is and how to learn it)?
  Model 1: Low (5-10% like scientists) **Model 2**: much more like scientists

The implication is that model 2 has greater capacity for improving future nonscientists and scientists.

Two aspects contribute to making model 2 work:

1. Knowledge about <u>expertise</u>: identifying it's components, how it is developed, and how to measure science expertise (something that traditional exams have been missing!).
2. Understanding about the <u>components</u> of effective teaching and learning.

Expertise

Expert competence is characterized as consisting of

(1) Factual knowledge,
(2) Organizational framework ⇒ effective retrieval and application, and
(3) Ability to monitor one's own thinking and learning (eg: "Do I understand this? How can I check?")

Also ... developing new ways of thinking requires MANY hours of intense practice <u>with guidance and reflection</u>. This is necessary to change the brain.

Experts in science also have unique "belief" systems

Novice	**Expert**
• Content = isolated pieces of memorized info. • Knowledge is handed down by an authority and unrelated to the real world. • Problem solving: pattern matching to memorized recipes.	• Content = coherent structure of concepts. • Knowledge describes nature, and is established by experiment. • Problem Solving: Systematic concept-based strategies. Widely applicable.

Implications of these findings:

Teaching must evolve away **from** delivering content & demonstrations **towards** designing opportunities for students to a) use factual knowledge, b) organize new knowledge / skills / attitudes, and c) practice monitoring their own thinking and learning. **Also**, teaching must include frequent delivery of feedback to students. And of course, demonstrating desired skills, behaviours & attitudes is also a part of teaching.

Components of effective teaching/learning

These apply to all levels and in all settings:

1. Reduce unnecessary demands on working memory
2. Motivation: no desire to learn => no learning.

3. Provide explicit authentic modeling and practice of expert thinking. It must be extended & strenuous (the brain must be *worked* in order to change).
4. Connect with and build on prior thinking. All students have "prior knowledge" of some kind.

Limits on working memory:

These are very well-established but perhaps the most ignored result from cognitive science

1. Working memory capacity is VERY LIMITED! Individuals can remember & process FEWER than seven distinct new items.
2. This is MUCH less than in a typical science lecture.

Processing and retention from lectures is tiny, especially for a novice. Many examples are published, including Wieman and Perkins: test 15 minutes after told a nonobvious fact in lecture: **10% remember.**

Reducing unnecessary demands on working memory improves learning. For example:

- Minimize <u>jargon</u>, use figures, explain with (good!) analogies, avoid digressions, etc.

Motivation:

It is essential! But complex – it depends on previous experiences, academic and personal contexts, etc. A sample of ways to improve motivation include:

1. Make work students do relevant / useful / interesting to the learners ...
2. Incorporate a meaningful context-- connect to what they know and value.
3. Include problems where the value of solution obvious.
4. Provide students with a sense that they can master the subject, and how.
5. Provide a sense of personal control / choice.
6. Poorly motivated students are not "defective". Motivation can be highly modifiable (in both directions!) depending upon what is done in the course.

Explicit practice of expert thinking:

To practicing expert-like thinking, activities should be challenging but doable. Explicitly targeting expert-like thinking means focussing upon ...

- Actively developing concepts and mental models.
- Questions and concepts should be challenging but doable.
- Recognizing and comparing relevant & irrelevant information
- Self-checking, sense making, & reflection. This is rarely actively promoted in courses, perhaps because it is "automatic" for experts, and therefore difficult to recognize as needing support for development.
- Use questions & predictions with simulations / demonstrations / case histories, and follow up with both low-stakes and high-stakes testing.
- Provide effective feedback (i.e. frequent, timely and specific)
- Act as a "cognitive coach", not as a talking text book.

Part III: Practical examples

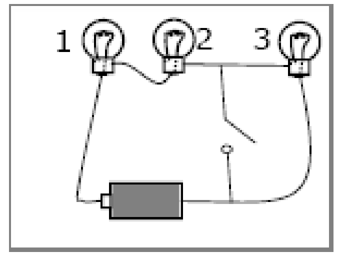
How to actually do it in class?

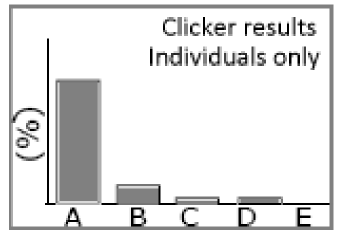
There are many proven practices from research. They will work in classes of a few students or in classes of hundreds. Technical details might vary, but principles will be the same. In large classes, appropriate use of technology will help.

Example: Here is an example from basic physics showing one 3-step approach to facilitating expert thinking in a large class, which includes the all-important effective guidance and feedback:

1. Assignment: Read chapter on electric current. Learn basic facts and terminology. Short quiz in class to check/reward this pre-class homework.
2. Class built around a series of clicker questions which cause students to think about, react to, make decisions about, and discuss. Questions are concept-oriented, not facts-based.
3. The instructor generates the questions, guides their delivery, and interacts when expert intervention is needed. With a little practice, you will get to anticipate where misconceptions or errors will arise, so guidance will become more predictable.

This takes a little practice but is FUN – much more like scientific discourse than one-way talking.





Example question and process:

1. **First the question is posed:** When switch is closed, bulb 2 will
   a. stay same brightness, b. get brighter;
   c. get dimmer, d. go out.
2. Then individuals answer with their clicker (fosters accountability, and primes them to learn).
3. Results show some misconception, therefore - discuss with “consensus group”, and revote. Prof. listens in by wandering around the class.
4. Next, the prof. elicits student reasoning and shows responses.
5. Then in class, the prof. can do the “experiment.”—simulation or live demonstration.
6. A follow up discussion lead by the instructor can review correct and incorrect thinking, extend ideas, and respond to student questions & suggestions (all additional student learning).

Active classrooms are a good start but not enough alone.
Instructors must generate opportunities to work further practice. This means well designed homework requiring expert-like thinking & feedback. It has been shown that long term retention is predicted best by results of homework. Short term results on exams may be improved with quick study (“cramming”) – but these strategies yield poor long term retention.

How to Science Teaching and Learning Fellows (STLFs) factor into the equation:

- Help with re-structuring courses to align with the “vision” (first point of this document).
- Help with developing measurements that provide information about whether “it” is working, both for students and for teachers.
- Making use of precedent – like all science, no one wants to re-invent or re-discover what works.
- When precedent is uncertain – do the data acquisition (develop tests & surveys, do interviews & focus groups, investigate work of colleagues, etc.)

Contributors and references

- Colorado physics & chemistry education research group: W. Adams, K. Perkins, K. Gray, L. Koch, J. Barbera, S. McKagan, N. Finkelstein, S. Pollock, R. Lemaster, S. Reid, C. Malley, M. Dubson... $$ NSF, Hewlett)
- See http://www.ikebarberlearningcentre.ubc.ca/webcasts/Wieman2008.html for a streaming video of the March 2008 version of this seminar.
- R. Hake, ”…A six-thousand-student survey…” AJP 66, 64-74 (‘98).
- David Hammer (Tufts University, MA), several studies and articles related to student versus expert attitudes and believes about science, and implications for teaching.
- The Cambridge Handbook on Expertise and Expert Performance