A scientific approach to STEM education

Carl Wieman
Associate Director for Science
White House OSTP

I. NSTC Committee on STEM education update
II. Research on STEM education

*based on the research of many people, some my group
(most talk examples from physics, but results general)
**A Scientific Approach To STEM Education**

The National Science and Technology Council Committee on STEM Education
(created Jan. 2011, by America Competes reauthorization)

Co-Chairs  Carl Wieman OSTP  
            Subra Suresh NSF
Committee on STEM Education
(2010 America Competes Legislation)
Formed March 4, 2011

Federal STEM Inventory Task Force
Finish—late Summer
Detailed characterization of all federal STEM activities.

Federal STEM Ed Strategic Plan Task Force
Finish—~January 2012
Develop a 5-year STEM Ed strategic plan.
### NSTC STEM Inventory compared to ACC

<table>
<thead>
<tr>
<th>Topic</th>
<th>Previous Inventory by Academic Competitiveness Council</th>
<th>Current Inventory by Committee on STEM Ed (anticipated late summer ‘11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definitions of units</td>
<td>Collected information on “programs”. Different at each agency.</td>
<td>Common unit of analysis within and across all agencies.</td>
</tr>
<tr>
<td>Definition of STEM Education</td>
<td>Each agency defined STEM education differently.</td>
<td>Detailed consistent definition that captures only those efforts whose primary goals are STEM Ed.</td>
</tr>
<tr>
<td>Program Details</td>
<td>Only general information on goals, budget, range of objectives, and target audience.</td>
<td>More detailed information (objectives, services provided, products, who served, type of evaluations, $$ $$, ...)</td>
</tr>
<tr>
<td>Total number</td>
<td>110</td>
<td>250-300</td>
</tr>
<tr>
<td>Total funding</td>
<td>ACC $3.6 billion</td>
<td>NSTC $ less (guess)</td>
</tr>
</tbody>
</table>
Why need better science & eng education?

• Scientifically literate public

• Modern defense & economy built on S & T

Need **all** students to think about and use STEM more like scientists and engineers.
II. Science Education as a science

My Physics graduate students--
Why excellence in physics courses≠ competence in physics research?
Two years in lab transforms?

approached as science problem,
look at research (past and future)

15 years later...
Major advances past 1-2 decades
Consistent picture $\Rightarrow$ Achieving learning

College science classroom studies

brain research

cognitive psychology
Research on learning complex tasks (e.g. expertise in math, science, ...)

old view, current teaching

knowledge soaks in, variable

new view brain plastic

transform via suitable “exercise”

Ask not “What do I want to explain or show?”, but “What mental processes do I want to stimulate?”
Expert competence research*

historians, scientists, chess players, doctors,...

Expert competence =
• factual knowledge
• Mental organizational framework ⇒ 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. Change brain “wiring”.
Brain develops with “exercise”

*Cambridge Handbook on Expertise and Expert Performance
Practicing expert-like thinking--

**Challenging but doable tasks/questions**

Intense explicit focus on expert-like thinking
- concepts, mental models, and analogies
- means to test when and how apply
- recognizing relevant & irrelevant information
- self-checking, reflection, and correction

Teacher--effective feedback & guidance, motivates

knowledge, but embedded in context and process

Brief sampling of data on the results—college science classrooms.
1. Measuring conceptual mastery

- basic concepts of force and motion
- “Force concept inventory” carefully developed test.

Ask 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!
Many similar examples.

R. Hake, ”…A six-thousand-student survey…” AJP 66, 64-74 (‘98).
2. Multiple instructors facilitating same established set of student activities. Mental activities of the student dominates!
3. Good traditional teacher vs. research based practices*

• 2 identical groups of 270 regular students
• Same topics and learning objectives
• Same time (1 week), same test

Very experienced, highly rated Prof--lecture

vs.

Inexperienced instructor trained in research-based teaching

*L. Deslauriers, E. Schelew, and C. Wieman
Clear improvement for **entire** student population
<table>
<thead>
<tr>
<th></th>
<th>control</th>
<th>experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Attendance</td>
<td>53(3) %</td>
<td>75(5)%</td>
</tr>
<tr>
<td>2. Engagement</td>
<td>45(5) %</td>
<td>85(5)%</td>
</tr>
</tbody>
</table>
4. Intro biology Univ. of Wash.– similar research-based instruction

• All students improve
• Underrepresented students improve more (+1/3 letter grade)

Science Magazine June 3, 2011 (Haak et al)
How does research-based teaching look in practice
Example from teaching about current & voltage--

1. Preclass assignment--Read pages on electric current. Learn basic facts and terminology. Short online quiz to check/reward (and retain).

2. Class built around series of questions & tasks, minimal pre-prepared lecture.
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)

Jane Smith chose a.

4. Discuss with “consensus group”, revote. (prof listen in!)
6. Variety of other small group tasks. (5-10 min)
   “Explain why the light in a dorm room dims when an electric heater is plugged in. Include a diagram showing possible way(s) room may be wired.”
   “Write down on piece of paper with your name.”

Instructor talking often, but reactive-- responding to (many!) student questions. Guide thinking.

Requires much more subject expertise.
Research check list for an effective educational activity
apply to all levels, all settings

- Connects with prior thinking?
- Motivates to want to learn?
- Not overload working memory?
  Facilitates long term retention?
- Ensures practicing desired expert thinking?
- Effective feedback provided?
- Measures the learning that matters?
Summary:
Scientific approach to teaching $\Rightarrow$ dramatic improvements in learning & success for all students.

Good Refs.:
NAS Press “How people learn”
Colvin, “Talent is over-rated”
Wieman, Change Magazine-Oct. 07
at [www.carnegiefoundation.org/change/](http://www.carnegiefoundation.org/change/)
cwsei.ubc.ca-- resources, references, effective clicker use booklet and videos

interactive simulations-- free at phet.colorado.edu
**Perceptions about science**

<table>
<thead>
<tr>
<th>Novice</th>
<th>Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content:</strong> isolated pieces of information to be memorized.</td>
<td><strong>Content:</strong> coherent structure of concepts.</td>
</tr>
<tr>
<td>Handed down by an authority.</td>
<td>Describes nature, established by experiment.</td>
</tr>
<tr>
<td>Problem solving: pattern matching to memorized recipes.</td>
<td>Widely applicable.</td>
</tr>
</tbody>
</table>

*adapted from D. Hammer*
Motivation-- essential (complex- depends on previous experiences, ...)

Enhancing motivation to learn

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

b. Sense that can master subject and how to master

c. Sense of personal control/choice
Look at experts solving problem in their discipline—

Some Generic Components in STEM
• concepts and mental models
• testing these and recognizing when apply
• distinguishing relevant & irrelevant information
• established criteria for checking suitability of solution method or final answer

(knowledge, but linked with process and context)

Student Perceptions/Beliefs

Kathy Perkins, M. Gratny
PERC Proc. 2010

Percent of Students

CLASS Overall Score
(measured at start of 1st term of college physics)

All Students (N=2800)

Intended Majors (N=180)

Actual Majors (N=52) 3-4 yrs later

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

0 10 20 30 40 50 60 70 80 90 100

elementary ed

Novice

Expert
Student Beliefs

- Actual Majors who were originally intended phys majors
- Actual Majors who were **NOT** originally intended phys majors

Percent of Students

CLASS Overall Score
(measured at start of 1st term of college physics)

Novice

Expert
Course Grade in Phys I or Phys II
*(day 1 beliefs more important than 1st yr grades)*

<table>
<thead>
<tr>
<th>Grade in 1st term of college physics</th>
<th>Percent of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFW</td>
<td>10%</td>
</tr>
<tr>
<td>C</td>
<td>25%</td>
</tr>
<tr>
<td>B</td>
<td>45%</td>
</tr>
<tr>
<td>A</td>
<td>20%</td>
</tr>
</tbody>
</table>

- All Students (2.7/4)
- Intended Majors (2.7/4)
- Actual Majors (3.0/4)
Mr Anderson, May I be excused?
My brain is full.

Working memory capacity
VERY LIMITED!
(remember & process
~ 5 distinct new items)

MUCH less than in
typical lecture

slides to be provided

a. Limits on working memory--best established, most ignored result from cognitive science
Two sections the same before experiment. (different personalities, same teaching method)

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

<table>
<thead>
<tr>
<th></th>
<th>control</th>
<th>experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Attendance</td>
<td>53(3) %</td>
<td>75(5)%</td>
</tr>
<tr>
<td>2. Engagement</td>
<td>45(5) %</td>
<td>85(5)%</td>
</tr>
</tbody>
</table>
Survey of student opinions--transformed section

“Q1. I really enjoyed the interactive teaching technique during the three lectures on E&M waves.”

Not unusual for SEI transformed courses

“Q2. I feel I would have learned more if the whole phys153 course would have been taught in this highly interactive style.”