Board on Science Education

Science Education
• All levels
• All settings
• All issues
Status of science education as a research field

Requires knowing science and education research (cognitive science, ed. psychology)

Growing level and quality of activity in all sciences, physics leading.
*(new Phys. Rev. journal in physics education research, Science now publishing science ed. research)*

Over last ~ 10-20 years.
Much better understanding of how people learn, how people learn science,

What characteristics needed to “think like scientist”, how to better measure and teach.
Why, after 17 yrs of success in classes, do grad students come into lab so clueless about physics?  

but 2-4 years later, are expert physicists???

Approach as science problem.

What do we know about how people learn, particularly science?  
⇒ above results actually makes sense, indicates how to improve teaching.
II. Some data on effectiveness of traditional approach to science teaching. lecture, textbook homework problems, exams

(most data from intro university physics, all consistent with other subjects, other levels.)

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 from traditional intro physics course?

- Force Concept Inventory—basic concepts of force and motion

Learn <30% of concepts did not already know. 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** thinking 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 ⇒ more novice*

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

*adapted from D. Hammer*
Seymour and Hewitt multi-institution ethnographic study--
Reasons for large rate of students switching out of physical sciences?

Not primarily ability or preparation, instead

1. “learning” that subjects inherently uninteresting.
2. style/quality of teaching

Same causes for women and minorities, but bigger effect.

survey data from my group shows similar results
Science Education Research Conclusions:

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

*Three generally applicable examples of research*

* a. cognitive load
  
* b. role of attitudes and beliefs
  
* c. developing expert competence*
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 addressing student beliefs about science and science problem solving

my group studies-- new survey instrument.

Lots of data!

- Beliefs $\leftrightarrow$ content learning
- Beliefs $\leftrightarrow$ choice of major/retention
- Teaching practices $\Rightarrow$ students’ beliefs

Normally decline (less like expert) after undergrad physics (or chem.) class.

BUT, can avoid decline if explicitly address beliefs.

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

Long term effects?
c. Research on developing expert competence

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

- 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.
general principle

⇒ people can memorize what told, but actual learning of science (*thinking like scientist*) is construction process. Built on foundation of previous thinking.

Effective teaching: encouraging and guiding that construction.
Variety of new methods and technology uses based on this. Ways to go, but data shows substantial progress

- Force Concept Inventory—basic concepts of force and motion

![Graph showing fraction of unknown basic concepts learned with Traditional Lecture in red and research-based methods in green.](image-url)
Board on Science Education

Science Education
• All levels
• All settings
• All issues

Similarities to BPA studies-- need to sort through good and bad research (ratio maybe different)

Challenges:
• $$$ (most ed $$ K-12, not look to NRC)
• Expertise- NAS in science, also need bunch of other stuff: education, policy, …
• Finding areas of importance where enough good research to say useful things, and people willing to pay for study.
Summary of BOSE projects
I. Completed (inherited)
II. In progress (some inherited, some new)
III. Under development (fully BOSE)
IV. Potential collaborations with BPA

**Completed Projects (inherited from Comm. on Sci. Ed. k-12)**

<table>
<thead>
<tr>
<th>Project</th>
<th>Sponsor</th>
<th>Type of Activity</th>
<th>Project Duration</th>
<th>Organizing Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COMPLETED PROJECTS</strong></td>
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<tr>
<td>1 High School Science Laboratories: Role and Vision</td>
<td>National Science Foundation</td>
<td>Consensus Study</td>
<td>2/04-6/06</td>
<td>Review of the evidence for effects of high school labs on learning science ideas; future laboratory experience</td>
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<tr>
<td>2 STEM workforce preparation</td>
<td></td>
<td>1 day workshop</td>
<td>01/04-03/05</td>
<td>Collaboration with COSEPUP (8835-017)</td>
</tr>
<tr>
<td>3 Informal Science, Planning Activity</td>
<td>National Science Foundation</td>
<td>1 day meeting</td>
<td>10/04-11/05</td>
<td>Review the state of research on learning across informal science environments</td>
</tr>
<tr>
<td></td>
<td>Current Projects</td>
<td>Sponsor</td>
<td>Type of Activity</td>
<td>Project Duration</td>
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<tr>
<td>1</td>
<td>Learning Science, K-8</td>
<td>NSF, National Institute of Child Health and Human Development, Merck</td>
<td>Consensus Study</td>
<td>6/04-5/07 6/05-5/06</td>
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<tr>
<td>2</td>
<td>Learning Science, K-8 Practitioner Volume</td>
<td>Merck Institute for Science Education</td>
<td>Volume for Science Practitioners built around learning science, K-8 formal study</td>
<td>11/04-6/07</td>
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<td>3</td>
<td>Information Technology Fluency</td>
<td>National Science Foundation</td>
<td>Workshop</td>
<td>12/04-11/06</td>
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<td>4</td>
<td>MRSEC -- BPA Collaboration</td>
<td>National Science Foundation</td>
<td>Consensus Study, BOSE to work on evaluation of education components</td>
<td>begin 6/1/05</td>
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<tr>
<td>5</td>
<td>Informal Science learning</td>
<td>National Science Foundation</td>
<td>Consensus Study</td>
<td>10/05-3/08</td>
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<tr>
<td>6</td>
<td>Int. Interacademy Panel meeting: evaluation of inquiry-based science</td>
<td>International Interacademy Panel</td>
<td>Planning meeting</td>
<td>2/1/06 – 6/31/06</td>
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<tr>
<td>7</td>
<td>Mapping the Research Agenda in Sci. Ed.</td>
<td>NSTA</td>
<td>Advice giving and Hosting</td>
<td>1/15-06/06</td>
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<tr>
<td>8</td>
<td>NASA Education Programs (NEW)</td>
<td>NASA</td>
<td>Consensus Study; Collaboration w/SSB, ASEB</td>
<td>16 months</td>
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<td></td>
<td>UNDER develop.</td>
<td>Sponsor</td>
<td>Type of Activity</td>
<td>Organizing Focus</td>
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<tr>
<td>2</td>
<td>Infancy and Early Childhood &amp; The Learning of Science</td>
<td>National Inst of Child Health and Human Dev., NSF, Bristol-M. Squibb</td>
<td>A series of Planning Meetings and Public Workshop</td>
<td>State and place of cognitive development rsch in context of developmental outcomes related to learning science; alson influence of cognitive rsch on school science</td>
</tr>
<tr>
<td>3</td>
<td>The Big Ideas in Science , Education Project</td>
<td>U.S. Dept of Ed. NSF, NIH</td>
<td>Design Activity</td>
<td>Open up a strand of the standards (heredity and genetics) to determine major constructs &quot;big ideas,&quot; appropriate rsch on learning their ideas,</td>
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<tr>
<td>4</td>
<td>Discipline Based Education Research</td>
<td>National Science Foundation</td>
<td>Possible Consensus Study</td>
<td>State of research on instruction in undergraduate science</td>
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<tr>
<td>5</td>
<td>Science Education across Muslim Countries</td>
<td>U.S. Department of State, NSF</td>
<td>Series of Planning Meetings and a Public Workshop to explore topic</td>
<td>Understanding the interaction between culture and learning science in Muslim countries</td>
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<tr>
<td>6</td>
<td>Methods and Measures for Research on Instruction in Science and Mathematics</td>
<td>Department of Education, NSF, Spencer</td>
<td>Public Workshop and/or Planning Meetings</td>
<td>Linking learning to instruction ; measures of instruction</td>
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<tr>
<td>7</td>
<td>The Role of MCAT, undergrad science ed., and medical education</td>
<td>R. W. Johnson, Macy, Kellog Foundations</td>
<td>Collaboration with the Institute on Medicine resulting in consensus study</td>
<td>The MCAT exam as a factor in science instruction at the undergraduate level as well as in aspects of medical education</td>
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<tr>
<td>8</td>
<td>Diversity/Gender</td>
<td></td>
<td></td>
<td>Recruitment and retention during the years 1-2 undergraduate education.</td>
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<tr>
<td>9</td>
<td>Distributed Expertise (Science Specialist)</td>
<td>Exxon Mobil</td>
<td>Planning meeting to give direction.</td>
<td>Knowledge basis for science specialist role</td>
</tr>
<tr>
<td>10</td>
<td>Informal Science Practitioner Volume</td>
<td>Burroughs Wellcome Fund, NSF, Instr Lib. Sci</td>
<td>Volume for Informal Science Practitioners</td>
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</tr>
<tr>
<td>11</td>
<td>High School Lab Safety</td>
<td>Chemical Safety &amp; Hazard Inv. n Board</td>
<td>Consensus Study; Collab. w/BCST</td>
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</tbody>
</table>
BOSE membership

Carl Wieman, Chair, physics, Univ of Colorado, (NAS Member)
Alice Agogino, Dept of Mech. Engineering, Univ of Cal. Berkeley, CA (NAE Member)
Philip Bell, Cognitive Studies in Education, Univ of Washington,
John Bransford, Dept of Education and Psychology, Univ of Washington,
David Conley, Center for Educational Policy Research, Univ of Oregon,
Okhee Lee, Dept of Teaching and Learning, Univ of Miami
Sharon Long, Biology, & Dean Humanities and Sci., Stanford Univ, (NAS Member)
Brett Moulding, Utah Office of Education,
Mary “Margo” Murphy, teacher Georges Valley High School, Rockport, ME
Carlo Parravano, Merck Institute for Science Education,
Helen Quinn, SLAC, Stanford University (NAS Member)
Susan Singer, Dept of Biology, Carleton College,
James Spillane, Institute for Policy Research, Northwestern University,
William B. Wood, Dept of MCD Biology, Univ of Colorado (NAS Member)
Issues where potential collaboration with BPA

1. Evaluating NSF “criteria 2”.
   MRSEC warm-up.
   NASA ???
   What research can tell us about what works, what doesn’t, how to evaluate rigorously.

2. Diversity in sciences.
   What can do to improve situation.
   (psychology, sociology, science, education)

3. Improving numbers and quality of STEM workforce.
   (including physicists & k-12 science teachers)
III. Bunch on new technology that can help implement principles for effective learning. (Monitor thinking and provide targeted feedback to guide development.)

Personal response systems
Interactive simulations
Intelligent homework/tutoring systems
...