From Research to Action – Improving Undergraduate STEM Education

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GAME CHANGERS

SUMMARY
RESEARCH UNIVERSITIES
AND THE FUTURE OF AMERICA
Ten Breakthrough Actions Vital to Our Nation’s Prosperity and Security

Education Data Jam

Science of Learning: Prospects
Report from a workshop at NSF, 28 February-1 March 2013

Datapalooza@ed.gov
Two Revolutions in Learning

- Learning science can inform learning online.
- Research on online learning can inform learning in all environments.
Learning any time, any place
Blurring the Boundaries

- Face-to-face and technology-enhanced learning
- Formal and informal learning
- Research and course-based research
- Academic civic engagement and citizen science
- Across grade bands
Learning and Learning Environments

- Need to understand the cognitive and affective foundations of learning,
- to study the emerging contexts and tools for the learning of concepts and skills, and
- to build the environments that afford new, high impact learning opportunities for tomorrow’s citizens and workforce.
Disruption Afoot

- MOOCs focused an intense spotlight on higher education and learning.
- MOOCs have only begun to scratch the surface of the nexus of brain, cognitive science, and education research.
Research-based Education Principles *

- Learning is highly dependent on prior knowledge.
- Motivation is critical – it determines, directs, and sustains what learners do.
- How learners organize knowledge influences how they learn and apply what they know.
- Goal-directed practice, coupled with targeted feedback, enhances learning quality (vs. the grade).
- Intellectual, social, and emotional climate of the course has significant impact on student perception and outcomes.
- Self-directed learners need to monitor and adjust their learning approaches.

*Adapted from: “How People Learn”, “How Learning Works: Seven Research-Based Principles for Smart Teaching,” and “Discipline-based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering.”
Moving cognitive science “into the wild”

- Developing expertise
  - 10,000 hours/10 years productive practice
  - Too easy or too far a reach, no gain

- Retrieval practice matters
  - Testing effect: Value of frequent quizzes
  - Rereading, reviewing without retrieval don’t help

- Space out practice
  - Value of interleaving

- Elaboration – making your own meaning
  - Extract key ideas and make your own mental model
  - Avoids limits of short term memory capacity

- Catering to “learning styles” is a misconception
Focusing on Undergraduates: Discipline-based Education Research

- Deep disciplinary knowledge
- The nature of human thinking and learning as they relate to a discipline
- Students’ motivation to understand and apply findings of a discipline
- Research methods for investigating human thinking, motivation, and learning

*Adapted from: “Discipline-based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering.”*
Goals of Discipline-based Education Research

- Understand how people learn the concepts, practices, and ways of thinking of science and engineering.
- Understand the nature and development of expertise in a discipline.
- Help to identify and measure appropriate learning objectives and instructional approaches that advance students toward those objectives.
- Contribute to the knowledge base in a way that can guide the translation of DBER findings to classroom practice.
- Identify approaches to make science and engineering education broad and inclusive.
Solid evidence to apply across learning environments

- Students’ conceptual understanding
- Problem solving
- Use of representations
- Effective instructional strategies
In all disciplines, undergraduate students have incorrect ideas and beliefs about fundamental concepts.

Students have particular difficulties with concepts that involve very large or very small temporal or spatial scales.

Several types of instructional strategies have been shown to promote conceptual change.
- Bridging analogies
- Interactive lecture demonstrations
Interactive lecture demonstrations

Misconception: Air has no mass
As novices in a domain, students are challenged by important aspects of the domain that can seem easy or obvious to experts.

- Superficial details
- Working backward
- Expert blindspot
Novices focus on surface detail


Novice: Inclined plane problems

Expert: Conservation of energy problems
Representations matter
Students can be taught more expert-like problem-solving skills and strategies to improve their understanding of representations.

- Socially-mediated learning environments
- Open-ended problems
- Interventions to promote metacognition
- Scaffolding (steps and prompts to guide students)
- Use of multiple representations
Effective instruction includes a range of well-implemented, research-based approaches.

Involving students actively in the learning process can enhance learning more effectively than lecturing.

The use of learning technology in itself does not improve learning outcomes. Rather, how technology is used matters more. (MOOCs aren’t magic.)
Active learning increases student performance in science, engineering, and mathematics

Scott Freeman\textsuperscript{a,1}, Sarah L. Eddy\textsuperscript{a}, Miles McDonough\textsuperscript{a}, Michelle K. Smith\textsuperscript{b}, Nnadozie Okoroafor\textsuperscript{a}, Hannah Jordt\textsuperscript{a}, and Mary Pat Wenderoth\textsuperscript{a}
Research on sequencing learning can inform online courses.

Much discussion of the “flipped classroom”

But we may be flipping it backwards:

- putting lectures online and asking students to view them in advance of class is:
- less likely to advance learning.
- Encountering the problem should proceed “telling”
- Students who confront problems before the explanation appear better at transferring their learning to other contexts

D. L. Schwartz et al., J. Educ. Psychol. 103, 759 (2011)
Embodied Cognition
Susan Fischer, DePaul University

Can physically handling objects and directly experiencing “the physics” improve student understanding?

- Observers score lower on angular momentum and torque problems
- fMRI patterns differ

Building a case for “hands on”
Applications: Blending for Success

- Welding simulators machine records student assessment based on speed, angle, and coordination.

- Remote access to nanotechnology equipment.
  - AFM: Atomic Force Microscopy
  - FESEM: Field Emission Scanning Electron Microscopy
  - Profilometry
  - UV-Vis Spectrophotometry

Penn State NACK Center
Application: Blending for Success

- Automotive Manufacturing Technical Education Collaborative (AMTEC)
  - Partnerships between auto industry rivals, 32 community colleges, and five vocational schools
  - Modular, hybrid online lecture and in-person lab curriculum.

- Additional work needed in more traditional academic arenas
  - Balancing sophisticated feedback from machine learning with face-to-face mentoring.
Fast forwarding the education research agenda

Common Guidelines for Education Research and Development

A Report from the Institute of Education Sciences,
U.S. Department of Education
and the National Science Foundation

August 2013

How do we reimagine research at the speed and scale in the digital world of rapid iteration and A/B experiments?

- Common Guidelines for six types of R&D
  - Foundational
  - Early Stage and Exploratory
  - Design and Development
  - Impact Studies
    - Efficacy
    - Effectiveness
  - Scale-up
Need ways to answer “Why?” questions

Adaptive learning -> Textbook revision

- Heat maps generated from vast amounts of student data
- Addresses the “What?” but not the “Why?”
Research gaps

- Studies of similarities and differences among different groups of students
- Longitudinal studies
- Additional basic research in DBER
- Interdisciplinary studies of cross-cutting concepts and cognitive processes
- Additional research on the translational role of DBER
One motivator for disaggregating data:

Figure 3.18 Postsecondary Destination of High-Scoring Students, by Socioeconomic Status

Carnevale & Strohl (2010)
Needed: more coordinated, comprehensive research studies and sharing of data...

- Utilization of BIG data – with focus on a small number (e.g., ONE)

- Challenges of data collection and archiving – standardized format.

- Privacy concerns – Asilomar Compact, PCAST reports

- Collaborative approaches to analytical tools and research methodologies
  - Applying lessons learned from quasi-experimental and randomized control trial designs.
  - Qualitative approaches, especially in the blended world

- Grow more data scientists with education analytics expertise
What problem are we trying to solve?

- Federal Science, Technology, Engineering, and Mathematics (STEM) Education 5-year Strategic Plan (CoSTEM report, May 2013)

- Enhance STEM experience of undergraduate students.

- Graduate one million additional students with degrees in STEM fields over the next 10 years.
5-year Strategic Plan
Undergraduate Goals

① Identify and broaden implementation of evidence-based instructional practice and innovations to improve undergraduate learning and retention in STEM and develop national architecture to improve empirical understanding of how these changes relate to key student outcomes.

② Improve support of STEM education at 2-year colleges and create bridges between 2- and 4-year postsecondary institutions.

③ Support the development of university-industry partnerships, and partnerships with Federally supported entities, to provide relevant and authentic STEM learning and research experiences for undergraduate students, particularly in their first two years.

④ Address the problem of excessively high failure rates in introductory mathematics courses at the undergraduate level, to open pathways to more advanced STEM courses.
STEM Education

GOAL STATEMENT: Improve Science, Technology, Engineering and Mathematics (STEM) Education by implementing the Federal STEM Education 5-Year Strategic Plan, announced in May 2013, specifically:

- Improve STEM instruction
- Increase and sustain youth and public engagement in STEM
- Enhance STEM experience of undergraduate students
- Better serve groups historically under-represented in STEM fields
- Design graduate education for tomorrow’s STEM workforce
- Build new models for leveraging assets and expertise
- Build and use evidence-based approaches

Themes: EDUCATION, TRAINING, EMPLOYMENT, AND SOCIAL SERVICES
GENERAL SCIENCE, SPACE, AND TECHNOLOGY
Lots of promising practices, but

“The problem in STEM education lies less in not knowing what works and more in getting people to use proven techniques.”

- James Fairweather, Promising Practices commissioned paper for the NRC Board of Science Education (2008)
Barriers to the Implementation:

1. Faculty Time and Motivation
2. Faculty Knowledge
3. Traditions Within Disciplines
4. Content Coverage and Curriculum
5. Assessments of Learning Outcomes
Barriers to the Implementation:

6. Department, Institution, and Colleague Support
7. Institutional Reward Structures
8. Course Scheduling, Staffing, and Classroom Layout
9. Inclusion of Non-tenure Track and Part Time Faculty
10. Student Resistance
I-Corps- L Pilot

- Give the I-Corps-L team an experiential learning opportunity to help determine the readiness of their innovation for sustainable scalability. Sustainable scalability involves a self-supported entity that is sustainable and systematically promotes the adoption of the educational innovation and enables and facilitates its use.

- Enable the team to develop a clear go/no go decision regarding sustainable scalability of the innovation.

- Develop a transition plan and actionable tasks to move the innovation forward to sustainable scalability, if the team decides to do so.
Network Improvement Communities
Tony Bryk – Statway and Quantway

Effects: Time to Complete a College Level Math Course

- **Traditional Sequence**
  - 1 Year: 6%
  - 2 Years: 15%
- **Statway**
  - 1 Year: 51%
  - 2 Years: 51%

Triple the success rate in half the time.
Purpose: “to transform institutions of higher education into supportive environments for STEM faculty members to substantially increase their use of evidence-based teaching and learning practices.”

39 Funded Awards for the July 2013 Review cycle
Involving 3,141 Faculty and approximately 200,000 students
• Theory of Change supported by the literature on institutional and/or faculty change
• Administration involvement to improve chances for effective outcomes
• Baseline data including current use of evidence-based instructional practices
DESCRIPTING & MEASURING UNDERGRADUATE STEM TEACHING PRACTICES

A Report from a National Meeting on the Measurement of Undergraduate Science, Technology, Engineering and Mathematics (STEM) Teaching

17–19 DECEMBER 2013
Using STEM Teaching Practice Data

- Of individuals
  - Improving teaching practice – not evaluative
  - Tenure and promotion decisions
- Documenting practices used institutionally or more broadly
- Research on teaching and learning
Examples of Approaches

“Metrics to Shift Institutional Culture Toward Evidence-Based Instructional Practices” (1256221)

American Association of Universities, Tobin Smith and James Fairweather
“MOOC-Supported Learning Communities for Future STEM Faculty: Multiple Paths to Advance Evidence-based Teaching Across the Nation” (1347605)
Michigan State University, H. Campa, K. Barnicle, D. Bruff, B. Goldberg, & R. Mathieu
“Collaborative Research: Understanding and Reducing Student Resistance as a Barrier to Faculty Change” (1347718)

Univ. of Michigan Ann Arbor, North Carolina A&T State Univ., Western Michigan University, Virginia Polytechnic Institute and State University.

What specific, evidence-based strategies (and in what contexts) can faculty employ to significantly reduce student resistance?”
Looking ahead

- Leveraging synergies in the world of big data, citizen science, academic civic engagement, and cutting edge science
- New R&D approaches to learn while we’re building programs, interventions, tools, resources
- Better understanding of and new ideas for spreading promising practices
- Unpacking the many dimensions of integrating education and research
White House College Opportunity Agenda

January 2014 Summit

Regional workshop to: Improve STEM learning and degree completion for more students.

September 16 – UMBC
September 22 – Univ. Colorado
October 1 – FIU
October 7- Cal State Northridge

December 2014 Summit in DC
Questions?

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