“It could well be that faculty members of the twenty-first century college or university will find it necessary to set aside their roles as teachers and instead become designers of learning experiences, processes, and environments.”

James Duderstadt, 1999
Nuclear Engineering Professor; Former Dean, Provost and President of the University of Michigan
Global Calls for Reform

K-12 Engineering

Research-based Transformation
Discipline-Based Education Research (DBER)

Understanding and Improving Learning in Undergraduate Science and Engineering

http://www.nap.edu/catalog.php?record_id=13362
Study Charge

- Synthesize empirical research on undergraduate teaching and learning in physics, chemistry, engineering, biology, the geosciences, and astronomy.

- Examine the extent to which this research currently influences undergraduate science instruction.

- Describe the intellectual and material resources that are required to further develop DBER.
Committee on the Status, Contributions, and Future Directions of Discipline-Based Education Research

- SUSAN SINGER (Chair), Carleton College
- ROBERT BEICHER, North Carolina State University
- STACEY LOWERY BRETTZ, Miami University
- MELANIE COOPER, Clemson University
- SEAN DECATUR, Oberlin College
- JAMES FAIRWEATHER, Michigan State University
- KENNETH HELLER, University of Minnesota
- KIM KASTENS, Columbia University
- MICHAEL MARTINEZ, University of California, Irvine
- DAVID MOGK, Montana State University
- LAURA R. NOVICK, Vanderbilt University
- MARCY OSGOOD, University of New Mexico
- TIMOTHY F. SLATER, University of Wyoming
- KARL A. SMITH, University of Minnesota and Purdue University
- WILLIAM B. WOOD, University of Colorado
Discipline-Based Education Research (DBER) Report Update

Follow the Evidence

Discipline-based education research disputes myths about learning and yields results that might otherwise be ignored by educators.

Many students have increased understanding of fundamental concepts, particularly in mathematics and science, by large or small changes in their courses. Understanding how education can challenge students\' misconceptions is at the core of long-term efforts to develop effective instructional techniques. One possibility approach is to "framing"—to introduce new ideas and strategies to students in a way that builds on their existing knowledge and understanding.

Students are challenged by key aspects of engineering and science that can seem obvious or obvious to experts.

Guest Editorial

Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering

Sean Stiger and Karl A. Smith

Carleton College, St. Paul University and University of Minnesota

Engineering education research (EE) has been in the fast lane since 2004 with an exponential rise in the number of PhDs awarded and the establishment of new programs, even in well-established departments. The National Research Council's Discipline-Based Education Research (DBER) report (National Research Council, 2012) captures the state-of-the-art advances in our understanding of engineering and science student learning and highlights opportunities for collaboration with other science-based education research programs. The DBER report is the central analysis of evidence in undergraduate education research and can be used to understand how students learn in large or small classes and how their experiences influence their perceptions of the engineering major. This report provides evidence that engineering and science students learn in a variety of ways, including through active learning strategies, such as the faculty-student interaction, the student's role in the classroom, and the student's role in the laboratory. The report also recognizes the role of the engineering and science community in supporting student learning and provides recommendations for future research and practice.

ASEE Prism Summer 2013

National Research Council

Journal of Engineering Education
Editorial – October, 2013

Practitioner Guide - In Preparation
Reflection and Dialogue

• Individually reflect on Designing Courses for High-Quality Learning. Think/Write for about 1 minute
  – Promising Approaches & Innovations
  – Ideas for encouraging adoption by colleagues

• Discuss with your neighbor for about 2 minutes
  – How to propagate and scale education innovations
Understanding Misunderstanding

A Private Universe – www.learner.org

Also see Minds of Our Own (Annenberg/CPB Math and Science Collection – www.learner.org)

1. Can we believe our eyes?
2. Lessons from thin air
3. Under construction

http://www.youtube.com/watch?v=Ng5qzH39nyg
Seminar Layout

• Welcome & Overview
• Engineering Method
• How People Learn and Course Design Foundations
• Pedagogies of Engagement (PoE)
  – Cooperative Learning
• Design and Implementation (Tuesday Workshop)
Seminar/Workshop Objectives

• Participants will be able to:
  – Articulate an engineering approach to course design
  – Summarize research on *How People Learn* (HPL)
  – Describe key features of the *Understanding by Design* (UbD) process – Content (outcomes) – Assessment – Pedagogy
  – Explain key features of and rationale for Pedagogies of Engagement – Cooperative Learning
  – Identify connections between cooperative learning and desired outcomes of courses and programs

• Participants will begin applying key elements to the design on a course, class session or learning module
Design Foundations

Science of Instruction (UbD)

<table>
<thead>
<tr>
<th>Good Theory/ Poor Practice</th>
<th>Good Theory &amp; Good Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
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</table>

Science of Learning (HPL)

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</tr>
</thead>
<tbody>
<tr>
<td>No</td>
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</tbody>
</table>

The engineering method is design under constraints – Wm. Wulf, Former President, National Academy of Engineering

The engineering method (design) is the use of state-of-the-art heuristics to create the best change in an uncertain situation within the available resources – Billy Koen, Mechanical Engineering Professor, UT-Austin, author *Discussion of the Method*, 2003, 2011
Understanding by Design (UbD) Process vs. Engineering Design Process

**Understanding by Design**
- Identify the desired results
- Determine acceptable evidence
- Plan learning experiences

**Engineering Design**
- Determine requirements specifications
- Develop or use established metrics to measure against outcomes
- Plan and develop process, system, etc. to implement

**Think about it...**
Why is it important to understand the parallels between these two processes?
Engineering Education: Advancing the Practice
Karl Smith

Research
• Process Metallurgy 1969-1992
• Learning ~1974
• Design ~1995
• Engineering Education Research & Innovation ~ 2000
  • STEM Education ~ 2010
  • STEM Innovation – NSF I-Corps-L ~ 2013

Innovation – Cooperative Learning
• Need identified ~1974
• Introduced ~1976
• FIE conference 1981
• JEE paper 1981
• Research book 1991
• Practice handbook 1991…2006
  • Change paper 1998
  • Teamwork and project management 2000…2014
• JEE paper 2005
• Ed Psy Review paper 2007

Process Metallurgy

• Dissolution Kinetics – liquid-solid interface
• Iron Ore Desliming – solid-solid interface
• Metal-oxide reduction roasting – gas-solid interface
Dissolution Kinetics

• Theory – Governing Equation for Mass Transport

\[(\nabla c \bullet v) = D \nabla^2 c\]

\[v_y \frac{dc}{dy} = D \frac{d^2 c}{dy^2}\]

• Research – rotating disk

• Practice – leaching of silver bearing metallic copper & printed circuit-board waste
First Teaching Experience

• Practice – Third-year course in metallurgical reactions – thermodynamics and kinetics
Engineering Education

- Practice – Third-year course in metallurgical reactions – thermodynamics and kinetics
- Research – ?
- Theory – ?
Pedago-pathologies

Amnesia

Fantasia

Inertia

Lee Shulman – MSU Med School – PBL Approach (late 60s – early 70s), President Emeritus of the Carnegie Foundation for the Advancement of College Teaching

What do we do about these pathologies?

- **Activity** – Engage learners in meaningful and purposeful activities
- **Reflection** – Provide opportunities
- **Collaboration** – Design interaction
- **Passion** – Connect with things learners care about

University of Minnesota College of Education
Social, Psychological and Philosophical Foundations of Education

• Statistics, Measurement, Research Methodology
• Assessment and Evaluation
• Learning and Cognitive Psychology
• Knowledge Acquisition, Artificial Intelligence, Expert Systems
• Development Theories
• Motivation Theories
• Social psychology of learning – student – student interaction
Cooperative Learning

- Research – Randomized Design Field Experiments
- Practice – Formal Teams/Professor’s Role
Cooperative Learning Introduced to Engineering – 1981

## Cooperative Learning Adopted

The American College Teacher: National Norms for 2007-2008

<table>
<thead>
<tr>
<th>Methods Used in “All” or “Most”</th>
<th>All – 2005</th>
<th>All – 2008</th>
<th>Assistant - 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative Learning</td>
<td>48</td>
<td>59</td>
<td>66</td>
</tr>
<tr>
<td>Group Projects</td>
<td>33</td>
<td>36</td>
<td>61</td>
</tr>
<tr>
<td>Grading on a curve</td>
<td>19</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>Term/research papers</td>
<td>35</td>
<td>44</td>
<td>47</td>
</tr>
</tbody>
</table>

http://www.heri.ucla.edu/index.php
Undergraduate Teaching Faculty, 2011*

<table>
<thead>
<tr>
<th>Methods Used in “All” or “Most”</th>
<th>STEM women</th>
<th>STEM men</th>
<th>All other women</th>
<th>All other men</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative learning</td>
<td>60%</td>
<td>41%</td>
<td>72%</td>
<td>53%</td>
</tr>
<tr>
<td>Group projects</td>
<td>36%</td>
<td>27%</td>
<td>38%</td>
<td>29%</td>
</tr>
<tr>
<td>Grading on a curve</td>
<td>17%</td>
<td>31%</td>
<td>10%</td>
<td>16%</td>
</tr>
<tr>
<td>Student inquiry</td>
<td>43%</td>
<td>33%</td>
<td>54%</td>
<td>47%</td>
</tr>
<tr>
<td>Extensive lecturing</td>
<td>50%</td>
<td>70%</td>
<td>29%</td>
<td>44%</td>
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</table>

*Undergraduate Teaching Faculty. National Norms for the 2010-2011 HERI Faculty Survey, [www.heri.ucla.edu/index.php](http://www.heri.ucla.edu/index.php)
Cooperative Learning
• Positive Interdependence
• Individual and Group Accountability
• Face-to-Face Promotive Interaction
• Teamwork Skills
• Group Processing

[*First edition 1991]
Cooperative Learning Research Support

- Over 300 Experimental Studies
- First study conducted in 1924
- High Generalizability
- Multiple Outcomes

**Outcomes**

1. Achievement and retention
2. Critical thinking and higher-level reasoning
3. Differentiated views of others
4. Accurate understanding of others' perspectives
5. Liking for classmates and teacher
6. Liking for subject areas
7. Teamwork skills

---

*Journal of Engineering Education* January 2005

*Educational Psychology Review* March 2007
Student Engagement Research Evidence

• Perhaps the strongest conclusion that can be made is the least surprising. Simply put, the greater the student’s involvement or engagement in academic work or in the academic experience of college, the greater his or her level of knowledge acquisition and general cognitive development ...(Pascarella and Terenzini, 2005).

• Active and collaborative instruction coupled with various means to encourage student engagement invariably lead to better student learning outcomes irrespective of academic discipline (Kuh et al., 2005, 2007).

Cooperative Learning is instruction that involves people working in teams to accomplish a common goal, under conditions that involve both positive interdependence (all members must cooperate to complete the task) and individual and group accountability (each member is accountable for the complete final outcome).

Key Concepts

• Positive Interdependence
• Individual and Group Accountability
• Face-to-Face Promotive Interaction
• Teamwork Skills
• Group Processing

Design Foundations

Science of Instruction (UbD)

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Science of Learning (HPL)

Part I – Introduction
1 Learning: From Speculation to Science 3

Part II – Learners and Learning
2 How Experts Differ from Novices 31
3 Learning and Transfer 51
4 How Children Learn 79
5 Mind and Brain 114

Part III – Teachers and Teaching
6 The Design of Learning Environments 131
7 Effective Teaching: Examples in History, Mathematics, and Science 155
8 Teacher Learning 190
9 Technology to Support Learning 206

Part IV – Future Directions for the Science of Learning
10 Conclusions 233
11 Next Steps for Research 248

http://www.nap.edu/openbook.php?record_id=6160
How People Learn (HPL)

Expertise Implies (Ch. 2):
- a set of cognitive and metacognitive skills
- an organized body of knowledge that is deep and contextualized
- an ability to notice patterns of information in a new situation
- flexibility in retrieving and applying that knowledge to a new problem

Understanding by Design (UbD)

http://books.google.com/books?id=N2EfKlyUN4QC&printsec=frontcover&source=gbs_v2_summary_r&cad=0#v=onepage&q=&f=false
Understanding by Design Process

What should learners know, understand and be able to do?

How will we know if the learners have achieved the desired results? What will be accepted as evidence of learner’s understanding and proficiency?

What activities will equip learners with the needed knowledge and skills? What materials and resources will be useful?

Learning Activities Aligned

Identify the Desired Results

Determine Acceptable Evidence

Plan Learning Experience
Understanding by Design (UbD) Process vs. Engineering Design Process

Understanding by Design

Identify the desired results
Determine acceptable evidence
Plan learning experiences

Engineering Design

Determine requirements specifications
Develop or use established metrics to measure against outcomes
Plan and develop process, system, etc. to implement

Think about it...
Why is it important to understand the parallels between these two processes?
HOW PEOPLE LEARN

UNDERSTAND BIG IDEAS
Things to Consider:

• Are the topics **enduring and transferable** big ideas having value beyond the classroom?

• Are the topics big ideas and **core processes** at the heart of the discipline?

• Are the topics **abstract, counterintuitive, often misunderstood, or easily misunderstood** ideas requiring uncoverage?

• Are the topics big ideas **embedded in facts, skills and activities**?

Bransford, Vye and Bateman – Creating High Quality Learning Environments
1. Students prior knowledge can help or hinder learning
2. How student organize knowledge influences how they learn and apply what they know
3. Students’ motivation determines, directs, and sustains what they do to learn
4. To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned
5. Goal-directed practice coupled with targeted feedback enhances the quality of students’ learning
6. Students’ current level of development interacts with the social, emotional, and intellectual climate of the course to impact learning
7. To become self-directed learners, students must learn to monitor and adjust their approach to learning
Active Learning: Cooperation in the College Classroom

- Informal Cooperative Learning Groups
- Formal Cooperative Learning Groups
- Cooperative Base Groups

Notes: Cooperative Learning Handout (CL College-912.doc)
www.ce.umn.edu/~smith/docs/CL%20College-912.doc
Active Learning: Cooperation in the College Classroom

• Informal Cooperative Learning Groups

• Formal Cooperative Learning Groups

• Cooperative Base Groups
How would you like to teach (or learn) in a classroom like this one at MIT?

The purpose of this website is to share designs for state-of-the-art learning studios, teaching methods, and instructional materials that are based on more than a decade of discipline-based education research.

For a quick introduction, visit our Frequently Asked Questions page, or take a look at this 5 minute video or view some of these short video clips created by adopters:

Minnesota, McGill, Iowa, Virginia Tech, Old Dominion, Northern Michigan, Oklahoma, Windward High School

As a visitor to the site, you can view classroom designs and find contact information for scores of colleges and a growing number of high schools that are offering highly interactive, collaborative, guided-inquiry-based instruction.

Registered site members have access to many more details and classroom materials being developed and tested by faculty from around the world.

Visitors may click here to go to pages describing the work of many of the institutions adopting SCALE-UP.

Registered site members, click here to log in. (There is additional detailed information available only to those who have registered.)
The ribbon cutting for the new STSS Building featured, from left to right: student veteran Chris Hgberek, U of M President Robert Bruininks, Regent Linda Cohen, building architect and UI alumn Bill Pedersen, College of Biological Sciences associate dean Robin Wright, Provost Tom Sullivan and Minnesota Student Association President Sarah Shotz.

The 115,000-square-foot STSS, which replaces the demolished Science Classroom Building, will be home not only to new, state-of-the-art "active learning" classrooms but also to numerous student services offices, including One Stop Student Services, veterans services and career services.

"This really is the future of education at our Twin Cities campus," said university President Robert Bruininks. "We're grateful to the people of Minnesota for making this investment in their University."

The building, which was funded in large part by state bonding funds, has five stories and offers a wide view of the West Bank and downtown Minneapolis over the Mississippi River. It has 10 active learning classrooms, which provide for technology-driven and collaborative interaction among students and faculty. There are also five multipurpose classrooms and two larger lecture halls.

"Active learning classrooms are the classrooms of the future and have proven results in improving educational achievement for students," said university Provost Thomas Sullivan.

"There is a critical need for more degrees in science, technology, engineering and mathematics fields to meet expected job growth. This new facility supports our efforts to educate the scientists and engineers who make the discoveries of tomorrow."

In addition, the STSS is designed to meet or exceed the requirements of Minnesota's stringent 63 sustainable design code and seeks LEED Gold Certification. Sustainable...
Inside an Active Learning Classroom

- STSS in University of Minnesota

http://vimeo.com/andyub/activeclassroom

“I love this space! It makes me feel appreciated as a student, and I feel intellectually invigorated when I work and learn in it.”
The Motivation to Learn Begins with a Problem

In a problem-based learning (PBL) model, students engage complex, challenging problems and collaboratively work toward their resolution. PBL is about students connecting disciplinary knowledge to real-world problems—the motivation to solve a problem becomes the motivation to learn.

Recipient of a Hesburgh Certificate of Excellence

The Theodore M. Hesburgh Award was created to acknowledge and reward successful, innovative faculty development programs that enhance undergraduate teaching. ITUE is a recipient of the Hesburgh Certificate of Excellence for its work in implementing problem-based learning in the classroom.
PoE Video Examples

- Early examples (80s & early 90s)
  - Smith
  - Derek Bok Center - Harvard
  - STEMTEC
- Mid 90s
  - Felder - NCSU
  - U Wisconsin – Chem Concepts
  - Jones - Purdue
- Recent
  - Mazur – Peer Instruction
  - University of Minnesota – Active Learning (SCALE-UP)
Session Summary
(Minute Paper)

Reflect on the session:

1. Most interesting, valuable, useful thing you learned.
2. Things that helped you learn.
3. Question, comments, suggestions.

4. Pace: Too slow 1 . . . . 5 Too fast
5. Relevance: Little 1 . . . 5 Lots
6. Instructional Format: Ugh 1 . . . 5 Ah
OSU – Seminar (4-28-14)

Q4 – Pace: Too slow 1 . . . 5 Too fast (3.0)
Q5 – Relevance: Little 1 . . . 5 Lots (3.9)
Q6 – Format: Ugh 1 . . . 5 Ah (3.7)