Research Areas and Topics in Engineering Education

Karl A. Smith
Purdue University/University of Minnesota
ksmith@umn.edu
www.ce.umn.edu/~smith

Universiti Teknologi Malaysia

November 28, 2007

Research Areas and Topics in Engineering Education

- Research Questions
  - Internal Quandaries
  - External Pressures
    - ABET/NSF/NAE/Carnegie Foundation
    - Demographics
      - Interest in Engineering
      - Current Workforce
    - Globalization
      - Outsourcing of Engineering
      - Engineering Capabilities
- Engineering Education as a Field of Research
  - Features of Scholarly and Professional Work
  - Characteristics of Disciplines – Kuhn & Fensham
- Building Engineering Education Research Capabilities – Current Activities – NSF/NAE

First Teaching Experience

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

Engineering Education

- Practice – Dismal failure!
- Research – ?
- Theory – ?
Cooperative Learning

- Research – Empirical Support - Randomized Design Field Experiments
- Practice – Formal Teams/Professor’s Role

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

Small-Group Learning: Meta-analysis

Small-group (predominantly cooperative) learning in postsecondary science, mathematics, engineering, and technology (SMET). 383 reports from 1980 or later, 39 of which met the rigorous inclusion criteria for meta-analysis.

The main effect of small-group learning on achievement, persistence, and attitudes among undergraduates in SMET was significant and positive. Mean effect sizes for achievement, persistence, and attitudes were 0.51, 0.46, and 0.55, respectively.

Pedagogies of Engagement: Classroom-Based Practices
http://www.asee.org/about/publications/jee/upload/2005jee_sample.htm

Strategies for Energizing Large Classes: From Small Groups to Learning Communities:
Jean MacGregor, James Cooper, Karl Smith, Pamela Robinson
New Directions for Teaching and Learning, No. 81, 2000. Jossey-Bass
Engineering Education Research and Practice – Your Story

- Individually reflect on your interest in engineering education
- Identify critical incidents or marker events that influenced your interest
- Turn to the person next to you, introduce yourselves and talk about your stories

Continuum of Engineering Education Research Practice

- Teach as Taught
- Excellent Teacher
- Scholarly Teacher
- Scholarship of Teaching and Learning (SoTL)
- Engineering Education Research

Scholarly Teaching and the Scholarship of Teaching and Learning*

- Scholarly teaching: The instructor
  (a) is aware of modern pedagogical developments and incorporates them in his/her teaching where appropriate
  (b) reflects on, assesses, and attempts to improve his/her teaching (classroom research)
- Scholarship of teaching and learning: Research, publication, possibly grants on work related to education

Why do SoTL?

- Fosters significant, long-lasting learning for all students
- Enhances practice and profession of teaching
- Brings faculty’s work as teachers into the scholarly realm.

*Shulman & Hutchings

CASTL project purposes http://www.ahebulletin.com

Types of Questions

- Instructional Knowledge—components of instructional design
- Pedagogical Knowledge—student learning & how to facilitate it
- Curricular Knowledge—goals, purposes & rationales for courses or programs

3 types of reflection within each form of knowledge

- Content—What should I do…
- Process—How did I do…
- Premise—Why does it matter…
Examples for process reflection:

How did I (we) do at:

- Course design, methods & assessing effectively? (instructional)
- Facilitating student knowledge? Was I successful? (pedagogical)
- Arriving at goals & rationale for courses? (curricular)

Engineering Education Research

Colleges and universities should endorse research in engineering education as a valued and rewarded activity for engineering faculty and should develop new standards for faculty qualifications.

Expertise Implies:

- 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

Expertise Implies:


Acquisition of Expertise


- Cognition: Learn from instruction or observation what knowledge and actions are appropriate
- Associative: Practice (with feedback) allowing smooth and accurate performance
- Automaticity: "Compilation" or performance and associative sequences so that they can be done without large amounts of cognitive resources

“The secret of expertise is that there is no secret. It takes at least 10 years of concentrated effort to develop expertise.” Herbert Simon

Classic Studies in Expertise Research

- Fitts and Posner (1967) - model with three phases and for acquiring acceptable (not expert) performance
- Simon and Chase (1973) - theory of expertise acquisition where time spent leads to acquisition of patterns, chunks, and increasingly-complex knowledge structures
- Ericsson and Smith (1991) - expert performance must be studied with individuals who can reliably and repeatedly demonstrate superior performance
- Ericsson, Krampe, & Tesche-Romer (1993) - expert levels of performance are acquired gradually over time through use of deliberate practice and are mediated by mental representations developed during the deliberate practice period

Stages of Skill Acquisition

<table>
<thead>
<tr>
<th>Skill Level</th>
<th>Components</th>
<th>Perspective</th>
<th>Decision</th>
<th>Commitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Novice</td>
<td>Context-free</td>
<td>None</td>
<td>Analytical</td>
<td>Detached</td>
</tr>
<tr>
<td>2. Advanced</td>
<td>Context-free</td>
<td>None</td>
<td>Analytical</td>
<td>Detached</td>
</tr>
<tr>
<td>3. Competent</td>
<td>Context-free</td>
<td>Chosen</td>
<td>Analytical</td>
<td>Detached</td>
</tr>
<tr>
<td>4. Proficient</td>
<td>Context-free</td>
<td>Experienced</td>
<td>Analytical</td>
<td>Involved understanding and deciding</td>
</tr>
<tr>
<td>5. Expert</td>
<td>Context-free</td>
<td>Experienced</td>
<td>Intuitive</td>
<td>Involved</td>
</tr>
</tbody>
</table>

(Bransford & Brown, 1986. Mind over machine: The power of human intuition and expertise in the era of the computer, p. 88)
Paradox of Expertise

- The very knowledge we wish to teach others (as well as the knowledge we wish to represent in computer programs) often turns out to be the knowledge we are least able to talk about.

Research Areas and Topics in Engineering Education

- Research Questions
  - Internal Quandaries
  - External Pressures
    - ABET/NSF/NAE/Carnegie Foundation
    - Demographics
      - Interest in Engineering
      - Current Workforce
    - Globalization
      - Outsourcing of Engineering
      - Engineering Capabilities
- Engineering Education as a Field of Research
  - Features of Scholarly and Professional Work
  - Characteristics of Disciplines – Kuhn & Fensham
- Building Engineering Education Research Capabilities – Current Activities – NSF/NAE

Scholarship Reconsidered: Priorities of the Professoriate Ernest L. Boyer

- The Scholarship of Discovery, research that increases the storehouse of new knowledge within the disciplines;
- The Scholarship of Integration, including efforts by faculty to explore the connectedness of knowledge within and across disciplines, and thereby bring new insights to original research;
- The Scholarship of Application, which leads faculty to explore how knowledge can be applied to consequential problems in service to the community and society;
- The Scholarship of Teaching, which views teaching not as a routine task, but as perhaps the highest form of scholarly enterprise, involving the constant interplay of teaching and learning.

The Basic Features of Scholarly and Professional Work

1. Requires a high level of discipline-related expertise;
2. Is conducted in a scholarly manner with clear goals, adequate preparation, and appropriate methodology;
3. Has significance beyond the setting in which the research is conducted;
4. Is innovative;
5. Can be replicated or elaborated on;
6. Is appropriately and effectively documented, including a thorough description of the research process and detailed summaries of the outcomes and their significance;
7. Is judged to be meritorious and significant by a rigorous peer review process.

Adapted from: Diamond and Adam (1993) and Diamond (2002).
Engineering Education as a Field of Research

CRITERIA FOR A FIELD

1. Structural Criteria
   1. Academic recognition
   2. Research journals
   3. Professional associations
   4. Research conferences
   5. Research centers
   6. Research training

2. Intra-Research Criteria
   1. Scientific knowledge
   2. Asking questions
   3. Conceptual and theoretical development
   4. Research methodologies
   5. Progression
   6. Model publications
   7. Seminal publications

3. Outcome Criteria
   1. Implications for practice

Four components of a “disciplinary matrix”
1. shared theories
2. models
3. values (accurate and quantitative predictions)
4. exemplars (concrete problem-solutions).

Research Areas and Topics in Engineering Education

- Research Questions
  - Internal Quandaries
  - External Pressures
    - ABET/NSF/NAE/Carnegie Foundation
    - Demographics
      - Interest in Engineering
      - Current Workforce
    - Globalization
      - Outsourcing of Engineering
      - Engineering Capabilities
- Engineering Education as a Field of Research
  - Features of Scholarly and Professional Work
  - Characteristics of Disciplines – Kuhn & Fensham
- Building Engineering Education Research Capabilities – Current Activities – NSF/NAE

SEESP Background

- National Science Foundation initiated at
  - Georgia Tech
  - University of Wisconsin – Madison
  - Carnegie Mellon University
  - Stanford University
  - Syracuse University
- UW Madison – SEESP continued by CIC Graduate School and Engineering Deans
  - UW Madison – 1996 -1999
  - UUC – 2000
  - Penn State – 2004, 2005
  - Vanderbilt University – 2008

Building Engineering Education Research Capabilities:

- NSF Initiated Science and Engineering Education Scholars Program (SEESP)
- NSF – Centers for Learning and Teaching (CLT)
  - Center for the Advancement of Engineering Education (CAEE)
  - Center for the Integration of Research, Teaching, and Learning (CIRTL)
  - National Center for Engineering and Technology Education (NCETE)
- NAE: Center for the Advancement of Scholarship on Engineering Education (CASEE)
  - AREE: Annals of Research on Engineering Education
- NSF-CCLI-ND: Rigorous Research in Engineering Education (RREE)

Defining an Identity

Peter J. Fensham

Journal of Engineering Education: Guest Editorials

SEESP Program Objectives:

• Strengthen preparation as teachers of undergraduate students and, thereby, strengthen skills for the competitive job market in higher education;
• Understand undergraduate students and especially appreciate diversity in terms of cultural background, age, gender, interests, and learning styles;
• Improve teaching methods and examine the learning process;
• Embrace future responsibilities for leadership in higher education; and
• Develop confidence in becoming "change agents" at local institutions to create effective learning environments for students and faculty.

Participant Response

• Quote:
  “I truly believe that the week last summer in Minnesota was the most valuable time I have spent as a new faculty member, particularly in the area of teaching. The knowledge gained from the program would have probably taken me several years to learn through experience, the hard way! Incorporating several teaching and learning ideas from the workshop (active learning, quick feedback, incorporating exercises and small group work in a lecture setting, "minute quizzes") has drastically improved my abilities and interest in teaching and learning. As a result, student evaluations of my teaching have gone from dismal (winter semester before SEESP) to great (past fall semester after SEESP).”

Key - Changing the People:
Engineering Education Scholars Workshops*

Vision
To cultivate a new generation of engineering faculty dedicated to the lifelong pursuit of integration and excellence in teaching and research

* The term “education scholar” conveys the notion that the scholarship of knowledge transfer is intertwined with and equal in importance to that of knowledge creation.

CAEE Vision for Engineering Education

CAEE Team

University of Washington
Colorado School of Mines
Howard University
Stanford University
University of Minnesota

CAEE Affiliate Organizations
City College of New York (CCNY), Edmonds Community College, Highline Community College (HCC), National Action Council for Minorities in Engineering (NACME), North Carolina A&T (NCA&T), San Jose State University (SJSU), University of Texas, El Paso (UTEP), Women in Engineering Programs & Advocates Network (WEPAN) and Xavier University

CAEE - Elements for Success

• Scholarship on Learning Engineering
  Learn about the engineering student experience
• Scholarship on Engineering Teaching
  Help faculty improve student learning
• Institute for Scholarship on Engineering Education
  Cultivate future leaders in engineering education

Marshall Lih, 2002
NCETE Overview

- National Center for Engineering and Technology Education (NCETE) is an NSF-funded Center for Learning and Teaching
  - Funded on September 15, 2004
  - One of 18 CLT’s in the country
  - NCETE is the only CLT focused on engineering and technology education
  - NCETE is the only CLT with 9 partner institutions
  - $10M over 5 years with a required 18-month reverse site visit

NCETE Overview

CLT Goals:

- Renew and diversify the cadre of leaders in STEM education, particularly in higher education, who educate STEM teachers and professionals in leadership positions at state and district levels and other education organizations.
- Enhance the content knowledge and pedagogical skills of current and future elementary and secondary teachers, and
- Support research into STEM education issues of national import.

NCETE Overview

- Team engineering faculty with technology educators
- NCETE’s ultimate goal is to infuse engineering design and problem solving into technology education in grades 9-12
- Team engineering faculty with technology educators

NCETE Overview

- Build a community of researchers and leaders to conduct research in emerging engineering and technology education areas
- Recruitment and retention of doctoral students
- Develop and teach shared core courses
- Prepare technology education teachers at the BS and MS level who can teach engineering design and problem solving into the 9-12 grade curricula, current and future
- Professional development experiences
- Refocus the pre-service experience
- Create a body of research that improves our understanding of learning and teaching engineering and technology subjects
- RFP process

Center for the Integration of Research, Teaching, and Learning (CIRTL)

NSF Center for Learning and Teaching

University of Wisconsin - Madison
Michigan State University
Pennsylvania State University
...develop a national STEM faculty ...

FACULTY
Community College
Liberal Arts
HBCU
Masters University
Comprehensive Univ.
Research University

UNDERGRADS
Community College
Liberal Arts
HBCU
Masters University
Comprehensive Univ.
Research University

100 RUs => 80% Ph.D's

CIRTL Mission
To promote a national STEM faculty committed to implementing and advancing effective teaching practices for diverse student audiences as part of their professional careers.

Teaching-as-Research
“The nation must develop STEM faculties who themselves continuously inquire into their students’ learning.”

• Engagement in teaching as engagement in STEM research
  • Hypothesize, experiment, observe, analyze, improve
  • Aligns with skills and inclinations of graduates-through-faculty, and fosters engagement in teaching reform
  • Leads to self-sustained improvement of STEM education

Learning Communities
“Rich, enduring, integrative environments for change in learning and teaching … learning communities are life-changing.”

• Provide community with shared values of learning, teaching, and professional development
• Blend diverse participants and levels of participation.
• Develop strong relationships that are a foundation for institutional and national change.

Diversity
“Many STEM faculty are not aware of the diversity of their students and thus do not design their teaching practice to respond to them.”

• STEM faculty are teaching ever more diverse student populations.
• Mounting research shows the pivotal role of classroom experiences on student learning and persistence.
• Thread teaching and learning with diverse student audiences through every facet of the learning community.
NAE and Education—Wm. A. Wulf’s 4-legged stool

1999, established the Committee on Engineering Education
- Stream of reports, workshops, etc. of intrinsic value
- Implicit, repeated message that NAE values engineering education
2000, reinterpreted NAE membership criteria to better recognize contributions to engineering
2001, initiated the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education
- $500,000 on par with Draper (engineering and society) and Russ (bioengineering) Prizes
October 2002, inaugurated an operational center for scholarship on engineering education

CASEE Mission

Enable engineering education to meet, in a significantly better way, the needs of employers, educators, students, and society at large.

CASEE Objectives

Working collaboratively with key stakeholders, CASEE
- Encourages rigorous research on all elements of the engineering education system, and
- Seeks broad dissemination, adoption, and use of research findings.

Research Thrust Areas

1. Define the bodies-of-knowledge required for engineering practice and use of engineering study for other careers.
2. Develop strategies that value diversity in the formulation and solution of engineering problems.
3. Develop cost-effective and time-efficient strategies and technologies for
   - Improving student learning, and
   - Enhancing the instructional effectiveness of current and future faculty.
4. Develop assessments of student learning and instructional effectiveness.

Annals of Research on Engineering Education (AREE)

- Link journals related to engineering education
- Increase progress toward shared consensus on quality research
- Increase awareness and use of engineering education research
- Increase discussion of research and its implications
- Resources – community recommended
  - Annotated bibliography
  - Acronyms explained
  - Conferences, Professional Societies, etc.
- Articles – education research
  - Structured summaries
  - Reflective essays
  - Reader comments

Conducting Rigorous Research in Engineering Education: Creating a Community of Practice (RREE)

NSF-CCLI-ND
American Society for Engineering Education
Karl Smith & Ruth Streveler
University of Minnesota & Colorado School of Mines

www.areeonline.org
Rigorous Research Workshop

- Initial Event for year-long project
- Presenters and evaluators representing
  - American Society for Engineering Education (ASEE)
  - American Educational Research Association (AERA)
  - Professional and Organizational Development Network in Higher Education (POD)
- Faculty funded by two NSF projects:
  - Conducting Rigorous Research in Engineering Education (NSF DUE-0341127)
  - Strengthening HBCU Engineering Education Research Capacity (NSF HRDF-041194)
  - Council of HBCU Engineering Deans
  - Center for the Advancement of Scholarship in Engineering Education (CASEE)
  - National Academy of Engineering (NAE)

Key Aspects of Engineering Education Research

- Rigor
- Complexity – order emerges from a large number of distributed efforts, through a process of coevolution (Hagel & Seely Brown, 2005)
- Methodology – Bricolage – using the tools available to complete a task

Guiding Principles for Scientific Research in Education

1. Question: pose significant question that can be investigated empirically
2. Theory: link research to relevant theory
3. Methods: use methods that permit direct investigation of the question
4. Reasoning: provide coherent, explicit chain of reasoning
5. Replicate and generalize across studies
6. Disclose research to encourage professional scrutiny and critique

Research Inspired By:

<table>
<thead>
<tr>
<th>Understanding (Basic)</th>
<th>Use (Applied)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Pure basic research (Bohr)</td>
</tr>
<tr>
<td>No</td>
<td>Pure applied research (Edison)</td>
</tr>
</tbody>
</table>

National Research Council, 2002

Engaged Scholarship

1. Design the project to addresses a big question or problem that is grounded in reality.
2. Design the research project to be a collaborative learning community.
3. Design the study for an extended duration of time.
4. Employ multiple models and methods to study the problem.
5. Re-examine assumptions about scholarship and roles of researchers.

“Knowledge For Theory and Practice” by Andrew H. Van de Ven and Paul E. Johnson. Carlson School of Management, University of Minnesota. Forthcoming in Academy of Management Review, Last revised January 24, 2005

Evidence-Based Management


