Fundamentals of Engineering Education Research

Rigorous Research in Engineering Education Initiative
(NSF DUE 0817461)
https://stemedhub.org/groups/cleerhub

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A Workshop on Building Capability and Communities in Engineering Education Research

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Rigorous Research in Engineering Education Initiative

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Overview
What are we going to do?

- Welcome and introductions
- Topics of the workshop
  - Background and context
  - Features of engineering education research
  - Research questions and methodologies
  - Print and online resources
  - Global communities and their networks
- Format of the workshop
  - Interactive and team-based work

Who’s here?

- Your workshop leaders
  - Introduce yourself to those near you
Engineering Education Research and/or Innovation STORY

- When and how did you become interested in engineering education research and/or innovation?
- Was there a critical incident or memorable event associated with your initial interest?

Background and Context
Workshop frame of reference

- **Workshop is about**
  - Identifying faculty interested in engineering education research
  - Deepening understanding of engineering education research
  - Building engineering education research capabilities

- **Workshop is NOT about**
  - Pedagogical practice, i.e., “how to teach”
  - Convincing you that good teaching is important
  - Writing engineering education research grant proposals or papers
  - Advocating all faculty be engineering education researchers

Levels of inquiry in engineering education

- **Level 0** Teacher
  - Teach as taught

- **Level 1** Effective Teacher
  - Teach using accepted teaching theories and practices

- **Level 2** Scholarly Teacher
  - Assesses performance and makes improvements

- **Level 3** Scholar of Teaching and Learning
  - Engages in educational experimentation, shares results

- **Level 4** Engineering Education Researcher
  - Conducts educational research, publishes archival papers

Workshop Intentions / Participant Learning Outcomes

1. Describe key features of engineering education research
2. Explain emergence of engineering education research as a discipline
3. Describe recent reports and their relevance for and relationship with engineering education research
4. Summarize growth of engineering education research
5. Speculate on the future of engineering education research

Some history about this workshop

• Rigorous Research in Engineering Education (RREE1)
  – One-week summer workshop, year-long research project
  – Funded by National Science Foundation (NSF), 2004-2006
  – About 150 engineering faculty participated

• Goals
  – Identify engineering faculty interested in conducting engineering education research
  – Develop faculty knowledge and skills for conducting engineering education research (especially in theory and research methodology)
  – Cultivate the development of a Community of Practice of faculty conducting engineering education research
RREE Approach

Theory
(study grounded in theory/conceptual framework)

Research that makes a difference . . . in theory and practice

Research (appropriate design and methodology)

Practice (implications for teaching)

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Research can be 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>

Expanding and sustaining research capacity in engineering and technology education: Building on successful programs for faculty and graduate students

Collaborative partners: Purdue (lead), Alverno College, Colorado School of Mines, Howard University, Madison Area Technical College, National Academy of Engineering
Follow-up proposal (RREE2)

- Includes a series of 5 short courses*
  - Fundamentals of Engineering Education Research
  - Selecting Conceptual Frameworks
  - Understanding Qualitative Research
  - Designing Your Research Study
  - Collaborating with Learning and Social Scientists

*Recorded and posted on https://stemedhub.org/groups/cleerhub

Today’s objectives

- Identify principal features of engineering education research
- Frame and situate research questions and methodologies
- Gain familiarity with several print and online resources
- Become aware of global communities and their networks
Objective 1

Identify principal features of engineering education research

What does high-quality research in your discipline look like?

- What are the **qualities, characteristics, or standards** for **high-quality** research in your discipline?
- Think of it this way: "**Research in my field is high-quality when....**"

👉 Individually, list the qualities, characteristics or standards in your discipline

👉 Compare your lists, and as a group, develop a list of high-quality research qualities, characteristics or standards
What does high-quality research in your discipline look like?

- (Workshop list)
- (Workshop list)

What does education research in your discipline look like?

- What are the qualities, characteristics, or standards for high-quality education research in your discipline?

  Individually, list:

  1) Which qualities, characteristics, or standards identified in the previous list DO NOT apply?

  2) What qualities, characteristics, or standards can you envision that are DIFFERENT for education research?

  As a group, combine your lists.
Guiding principles for scientific research in education

1. Pose significant questions that can be investigated empirically
2. Link research to relevant theory
3. Use methods that permit direct investigation of the question
4. Provide coherent, explicit chain of reasoning
5. Replicate and generalize across studies
6. Disclose research to encourage professional scrutiny and critique

• How do our lists compare with the NRC six?
• Is a global list possible? Do cultural contexts matter?

Source: Scientific Research in Education, National Research Council, 2002

1. Significant questions that can be investigated empirically

• Who would care about your results?

• What data will you need to gather to answer your question?
2. Link research to relevant theory

- Learning theories
  - Cognition
  - Novice – expert differences
  - Instructional psychology
  - Psychometrics
- Motivational theories
- Moral and ethical development
- Social context of education

3. Methods for direct investigation (examples)

Quantitative methods
- Tests
- Surveys & questionnaires (defined response)
- Faculty or peer ratings

Qualitative methods
- Focus groups
- Interviews
- Observations
4. Reasoning

What makes a convincing argument

- Builds on what others have done before (literature)
- Theoretical foundation – make sense of results within existing frameworks of learning and teaching
- Methodology is explicit and appropriate
  - Instruments are reliable and valid
- Strength of observed relationships
- Elimination of alternative explanations
  - Study design
  - Confounding variables

5. Replicate and generalize – use the results

Setting the results in a larger context

- MUST know the literature
- Strict replication is rare in educational research
  - Transferable with extension - to new topic, setting, learners, etc.
6. Disclose

- Scholarly journals
- Conference presentations

- Peer-review is the core issue
  - One of the few quality controls we have

The research process and reasoning

Practical Problem

and helps

Research Answer

leads to

Research Problem

motivates

Research Question

informs

Research Process

Claim

Reason

Evidence

Warrant

Acknowledgment and Response

Research Reasoning
Objective 2
Frame and situate research questions and methodologies

Most common frameworks in educational research

- Theories of learning
- Theories of motivation
- Theories of development
- Theories of contextual effects

Multiple theoretical frameworks

Which comes first: **framework** or **observation**?
Can go in either direction

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Multiple theoretical frameworks

Going from framework to research question to research study

**Framework**
Self-determination framework says - students’ motivation for a task is affected by the degree of control they have over it.

**Therefore**
If we manipulate the degree of student control, we should see variations in motivation levels.

**Design**
Different groups are given different degrees of control over the topic and process of their project and their motivation for the project is measured at various times throughout the semester.
Multiple theoretical frameworks

Going from observation to framework to research question to research study and back to observation

Observation
Some students in a class participate more than others.

Possible Frameworks
• Learning theory: Prior knowledge differences
• Motivation theory: Goal orientations, task value, self-efficacy
• Contextual variables: Course contingencies; classroom climate

Design possibilities
• Measure and regress level of participation on potential variables.
• Manipulate course contingencies or course practices.

Research Methodologies

Quantitative methods (Positivist/postpositivist)
• Tests
• Surveys & questionnaires (defined response)
• Faculty or peer ratings

Qualitative methods (Interpretivist)
• Focus groups
• Interviews
• Observations
Silently reflect on your experience with engineering education research

Jot down
- What has been the most exciting opportunity for you in this area?
- What has been the most difficult challenge you have faced?

Share with the person next to you
Objective 3
Gain familiarity with several print and online resources

Books, journals, online resources

• The Craft of Research
• Scientific Research in Education
• Journal of Engineering Education (JEE)
• Science Citation Index
• Some other journals
Global Calls for Reform

K-12 Engineering

Research-based Transformation

http://tinyurl.com/engedu
Discipline-Based Education Research (DBER)

- Discipline-based education research (DBER) is a small but growing field of inquiry.
- Conducting DBER and using DBER findings are distinct but interdependent pursuits.
- DBER is inherently interdisciplinary.
- Individual fields of DBER have made notable inroads in terms of establishing their fields but still face challenges in doing so.
- Blending a scientific/engineering discipline with education research poses unique professional challenges for DBER scholars.
- There are many pathways to becoming a discipline-based education researcher.

Discipline-Based Education Research Timeline

DBER Departments and Graduate Programs

- Engr. Sci. Reform
- Curricula Reform
- EC2000
- EER
- Geoscience
- Biology ER
- Curricula Reform
- Chemistry ER
- Curricula Reform
- Physics ER
- Medical ER

DBER is located in the relevant disciplinary school, e.g. medicine, physics.
Discipline-Based Education Research (DBER)

Understanding and Improving Learning in Undergraduate Science and Engineering

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

Undergraduate Science and Engineering Education: Goals

- Provide all students with foundational knowledge and skills
- Motivate some students to complete degrees in science or engineering
- Support students who wish to pursue careers in science or engineering
Undergraduate Science and Engineering Education: Challenges and Opportunities

• Retaining students in courses and majors
• Increasing diversity
• Improving the quality of instruction

What is Discipline-Based Education Research?

• Emerging from various parent disciplines
• Investigates teaching and learning in a given discipline
• Informed by and complementary to general research on human learning and cognition
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
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• MELANIE COOPER, Clemson University
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Structure of the Report

- Section I. Status of Discipline-Based Education Research
- Section II. Contributions of Discipline-Based Education Research
- Section III. Future Directions for Discipline-Based Education Research

Section I. Status of Discipline-Based Education Research
Status of DBER: Goals

- 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.

Status of DBER: Types of Knowledge Required To Conduct DBER

- 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
Status of DBER: Conclusions

• DBER is a collection of related research fields rather than a single, unified field. (Conclusion 1)

• High-quality DBER combines expert knowledge of:
  – a science or engineering discipline,
  – learning and teaching in that discipline, and
  – the science of learning and teaching more generally.
  (Conclusion 4)

Section II. Contributions of Discipline-Based Education Research
Contributions of DBER: Conceptual Understanding and Conceptual Change

- In all disciplines, undergraduate students have incorrect ideas and beliefs about fundamental concepts. (Conclusion 6)

- Students have particular difficulties with concepts that involve very large or very small temporal or spatial scales. (Conclusion 6)

- Several types of instructional strategies have been shown to promote conceptual change.

Contributions of DBER: Problem Solving and the Use of Representations

- As novices in a domain, students are challenged by important aspects of the domain that can seem easy or obvious to experts. (Conclusion 7)

- Students can be taught more expert-like problem-solving skills and strategies to improve their understanding of representations.
Contributions of DBER: Research on Effective Instruction

- Effective instruction includes a range of well-implemented, research-based approaches. (Conclusion 8)

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

Section III. Future Directions for Discipline-Based Education Research
Future Directions for DBER: Translating DBER into Practice

• Available evidence suggests that DBER and related research have not yet prompted widespread changes in teaching practice among science and engineering faculty. (Conclusion 12)

• Efforts to translate DBER and related research into practice are more likely to succeed if they:
  – are consistent with research on motivating adult learners,
  – include a deliberate focus on changing faculty conceptions about teaching and learning,
  – recognize the cultural and organizational norms of the department and institution, and
  – work to address those norms that pose barriers to change in teaching practice. (Conclusion 13)

Future Directions for DBER: Recommendations for Translating DBER Into Practice

• **RECOMMENDATION:** With support from institutions, disciplinary departments, and professional societies, faculty should adopt evidence-based teaching practices.

• **RECOMMENDATION:** Institutions, disciplinary departments, and professional societies should work together to prepare current and future faculty to apply the findings of DBER and related research, and then include teaching effectiveness in evaluation processes and reward systems throughout faculty members’ careers. (Paraphrased)
Future Directions for DBER: Advancing DBER through Collaborations

- Collaborations among the fields of DBER, and among DBER scholars and scholars from related disciplines, although relatively limited, have enhanced the quality of DBER. (Conclusion 15)

Future Directions for DBER: Research Infrastructure

- Advancing DBER requires a robust infrastructure for research. (Conclusion 16)

- **RECOMMENDATION**: Science and engineering departments, professional societies, journal editors, funding agencies, and institutional leaders should:
  - clarify expectations for DBER faculty positions,
  - emphasize high-quality DBER work,
  - provide mentoring for new DBER scholars, and
  - support venues for DBER scholars to share their research findings.
Future Directions for DBER: Some Key Elements of a Research Agenda

- 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

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  - Fifteen reviewers
  - Report Review Monitor (Susan Hanson, Clark University) and Coordinator (Adam Gamoran, University of Wisconsin-Madison)
- Commissioned paper authors
- NRC staff (Natalie Nielsen, Heidi Schweingruber, Margaret Hilton)
Seven Recommendations for Innovation with Impact

Who

2. Expand collaborations.

What

3. Expand efforts to make engineering more engaging, relevant, and welcoming.

How

4. Increase, leverage, and diversify resources for engineering teaching, learning, and innovation.
5. Raise awareness of proven practices and of scholarship in engineering education.
Seven Recommendations for Innovation with Impact *(continued)*

Creating a Better Culture
To measure progress in implementing policies, practices, and infrastructure in support of scholarly and systematic innovation in engineering education:

6. Conduct periodic self-assessments in our individual institutions.


https://www.asee.org/member-resources/reports/Innovation-with-Impact

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1. a shift from hands-on and practical emphasis to engineering science and analytical emphasis;
2. a shift to outcomes-based education and accreditation;
3. a shift to emphasizing engineering design;
4. a shift to applying education, learning, and socialbehavioral sciences research;
5. a shift to integrating information, computational, and communications technology in education.

http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&tp=&amnumber=6185632
Objective 4

Become aware of global communities and their networks

An emerging global community

- Groups, centers, departments
- Engineering education societies
- Forums for dissemination

What follows is a sample — it is NOT an exhaustive list!
Engineering Education Centers — Australia: UICEE, UNESCO International Centre for Engineering Education; Denmark: UCPBLEE, UNESCO Chair in Problem Based Learning in Engineering Education; Hong Kong: E2I, Engineering Education Innovation Center; Hong Kong University of Science and Technology; Pakistan: Center for Engineering Education Research, NUST, National University for Science and Technology; South Africa: CREE, Centre for Research in Engineering Education, U of Cape Town; Sweden: Engineering Education Research Group, Linköping U; UK: ESC, Engineering Subject Centre, Higher Education Academy; USA: CELT, Center for Engineering Learning and Teaching, U of Washington; CRLT North, Center for Research on Learning and Teaching, U of Michigan; Faculty Innovation Center, U of Texas-Austin; Engineering Learning Center, U of Wisconsin-Madison; CASEE, Center for the Advancement of Scholarship in Engineering Education, National Academy of Engineering; EEIC, Engineering Education Innovation Center, Ohio State University; CEER, Center for Engineering Education Research, Michigan State University, EECs, Engineering Education Centers in Korea.

Engineering Education Degree-granting Departments — USA: School of Engineering Education, Purdue U; Department of Engineering Education, Virginia Tech; Department of Engineering and Science Education, Clemson U; Department of Engineering and Technology Education, Utah State U; Malaysia: Engineering Education PhD program, Universiti Teknologi Malaysia; India: National Institute for Technical Teacher Training and Research; Mexico: Universidad de las Americas, Puebla.


Forums for dissemination...

Conferences with engineering education research presentations:
- ASEE — Annual Conference, American Society for Engineering Education, see www.asee.org
- ASEE — Annual Conference, Australasian Association for Engineering Education, see www.asee.com.au
- GCEE — Global Colloquium on Engineering Education, sponsored by ASEE and local partners where the meeting is held, see www.asee.org
- SEFI — Annual Conference, Société Européenne pour la Formation des Ingénieurs, see www.sefi.be
- REES — Research on Engineering Education Symposium, rees2009.pbwiki.com/
- SASEE – South African Society for Engineering Education.

1. Find and follow your dream.
2. Find and build community.
3. Do your homework. Become familiar with engineering education research.
4. Remember what it is like to be a student—be open to learning and the associated rewards and challenges.
5. Find balance. You will feel like you have multiple identities.
6. Be an architect of your own career.
7. Wear your researcher “lenses” at all times.
8. Use research as an opportunity for reflective practice.

What Are Your Plans?

• Silently reflect on your interests and plans for applying and/or supporting engineering education research, or becoming an engineering education researcher.

• Jot down
  – What do you plan to do next?
  – What are your longer range plans?

• Share with the person next to you

Workshop Resources

• Fundamentals of Engineering Education Research
  • Slides [Texas State-San Marcos-EER-Workshop-Smith-Oct-6-2017-v2.pdf]
  • Collaboratory for Engineering Education Research (CLEERhub) Research Monographs - https://stemhub.org/groups/cleerhub
    • A Guidebook On Conceptual Frameworks For Research In Engineering Education
  • National Academy Press Reports
    • Scientific Research in Education
    • Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering
    • Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering
  • Other Reports
    • ASEE - Innovation with Impact: Creating a Culture for Scholarly and Systematic Innovation in Engineering Education
    • IEEE - Five Major Shifts in 100 Years of Engineering Education
Thank you!

An e-copy of this presentation will be posted to:
http://personal.cege.umn.edu/~smith/links.html

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