Engineering Education Research: Some History and Examples from the U.S.

Opening Address
Danish Centre for Engineering Education Research and Development
June 8, 2007

Cindy Atman
Director, Center for Engineering Learning and Teaching
Director, Center for the Advancement of Engineering Education
Mitchell T. Bowie and Lella Blanche Bowie Endowed Chair
Professor, Industrial Engineering
University of Washington

This work has been supported by grants from the National Science Foundation RED-9358516, EEC-0639895, REC-012554, ESI-0227558, SBE-0354453, the Boeing Company, and the Ford Motor Company Fund.

Center for Engineering Learning and Teaching
Engineering: Part of the Global Human Endeavor

Doing Engineering (one definition)

“The engineering method is the strategy for causing the best change in a poorly understood situation within the available resources.” (Koen, 2003)

...in Context

Engineering is a central element of the solutions for the global challenges we all face...environment, access to clean water, sustainability...
What does every engineer need to know?

- ethics
- global context
- management skills
- math
- engineering analysis
- problem solving
- leadership
- design
- professionalism
- contemporary issues
- analyze data
- teamwork
- conduct experiments
- life-long learning
- societal context
- science
- communication
- business knowledge
- technical knowledge
- creativity
- engineering tools
Our Challenge as Educators

How do we teach our students...
...everything on the previous slide, plus

• Understanding engineering as a rich, interconnected set of knowledge and skills that can be used to solve complex problems
• Understanding uncertainty and tolerating ambiguity
• Knowing how to identify when they don’t know something
• The ability to learn from failure
• The ability to reflect
• The sense of “peripheral vision” needed to ensure a good design
• ...and much more
A Global Need and Response

A global need
- Research on how engineering students learn
- Research on effective teaching for engineering learning
- Research on effective change strategies for colleges of engineering
- ...and much more

A global response
- Danish Centre on Engineering Education Research and Development
- Recent research activity across the globe, including the U.S.
The Global Engineering Education Community: Piecing Together a Picture of Engineering Education
Today’s Agenda

Engineering Education: A Global Challenge

History of Engineering Education Research in the U.S.
A Focus on Centers
• Campus-based
  - Example center and research: CELT
• National
  - Example center and research: CAEE

Engineering Education: A Global Challenge
Growth of Engineering Education Research in the U.S.

A growing community...

- Professional organizations, committees, centers, departments, funding agencies

...with a voice

- Publication venues
- Influential publications
- Government/industry reports, books, papers
- Community articulating goals
Sample of activity relevant to engineering education research in the U.S.
Sample of the community voice

Sample of presentation, publication venues:
ASEE, FIE, ICEE, MDW, iCEER; JEE, AREE, AEE, IEEE Transactions on Ed., IJEE, EJEE, JSTEM, JWMSE, Design Studies, and more...

1980s
- Green Report
  - Bordogna, Fromm & Ernst
- Cooperative Learning
  - Johnson, Johnson & Smith
- Teaching Engineering
  - Wankat & Oreovicz

1990s
- Innovation Through Integration
  - NSF
- Systemic Reform
  - NSF
- Restructuring Engr. Ed.
  - NSF
- ...Adaptive System
  - NRC
- Longitudinal Study, Part I
  - Felder et al.
- From Analysis to Action
  - NRC

2000s
- Engineer of 2020
  - Heywood
- Educating the Engineer of 2020
  - NAE
- Teaching & Learning Practices...
  - Sheppard et al.
- JEE Special Issue
- EERC research agenda
- ICREE Inaugural Proceedings

2010
- From Analysis to Action
- NSF
### Sample of the funding picture

<table>
<thead>
<tr>
<th>1980s</th>
<th>1990s</th>
<th>2000s</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Science</td>
<td>Engineering Education &amp; Centers division EEC</td>
<td>Engineering Education Scholars EESP</td>
<td></td>
</tr>
<tr>
<td>Foundation NSF</td>
<td>graduate fellowships for women, minorities GEE/IGERT, GRF</td>
<td>Model Institutions for Excellence MIE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Engineering Research Centers ERC</td>
<td>Fund for the Improvement of Postsecondary Education, U.S. Dept. of Education FIPSE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Department Level Reform</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ctrs for Teaching &amp; Learning</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Engr. Ed. Research</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>other funding sources: corporations, foundations</td>
<td></td>
</tr>
</tbody>
</table>
Sample of engineering education research organizations

1980s
national centers

1990s
NSF Engineering Education Coalitions
Leonhard Center, Penn State U.

2000s
CAEE
CIRTL
NCETE
VanTH-ERC
CASEE
39 affiliates in 2007

2010

Engineering Education Centers
12 centers in 2001

NCEER, Northwestern U.

departments/programs in engineering education

Purdue U.
Virginia Tech
Utah State U.
Colorado State U.
Clemson U.
Sample of activity relevant to engineering education research in the U.S.
Today’s Agenda

Engineering Education: A Global Challenge

History of Engineering Education Research in the U.S.

A Focus on Centers

• Campus-based
  - Example center and research: CELT

• National
  - Example center and research: CAEE
A Focus on Centers

Engineering Education Centers (EEC) members, 2001
- CRESMET, Arizona State U.
- CEE, Colorado School of Mines
- CETL, Georgia Tech
- EDC, IUPUI
- CETL, Kettering U.
- Leonhard Center, Penn State U.
- AE3, UIUC
- CELT, U. of Washington
- ELC, U. of Wisconsin-Madison
- U. of Oklahoma (proposed)
- S. Dakota School of Mines & Technology (proposed)
- U. of Texas-Austin (proposed)

Center for the Advancement of Scholarship on Engineering Education (CASEE) affiliates, 2007
- CAEE
- CDR, Stanford U.
- CEE, Colorado School of Mines
- CEEO, Tufts U.
- CELT, U. of Washington
- CETL, Georgia Tech
- CSHE, U. of California-Berkeley
- WST, Georgia Tech
- Commission on Professionals in Science and Technology
- Virginia Tech Dept. of Engineering Education
- Dept. of Mechanical Engineering, U. of Maryland-Baltimore County
- Dept. of Technology & Society, Stony Brook U.
- EERC, Washington State U.
- Learning in Formal and Informal Environments Center, U. of Washington
- Boeing Learning, Training, and Development
- Leonhard Center, Penn State U.
- Materials Engineering Dept., Cal Poly State U.-San Luis Obispo
- Model Institutions for Excellence, U. of Texas-El Paso
- National Center for Engineering and Technology Education
- NCEER, Northwestern U.
- Schaefer School of Engineering, Stevens Institute of Technology
- School of Engineering and Applied Science, U. of Virginia
- Teaching and Learning Laboratory, MIT
- Texas Engineering Experiment Station, Texas A&M U.
- Committee on Academic Prerequisites for Professional Practice, American Society of Civil Engineers
- College of Engineering, Cal Poly State U.-San Luis Obispo
- College of Engineering and Science, Louisiana Tech U.
- College of Engineering, U. of Massachusetts-Amherst
- College of Engineering, U. of Michigan
- College of Engineering, Purdue U.
- Technology Education Program, Dept. of Industrial Technology, Purdue U.
- Dept. of Technology and Society, Stony Brook U.
- Dwight Look College of Engineering, Texas A&M U.
- East Lake High School Robotic Boosters, Inc.
- Faculty Innovation Center, College of Engineering, U. of Texas-Austin
- Laboratory for Innovative Technology and Engineering Education (LITEE), Auburn U.
- Lean Aerospace Initiative Educational Network (LAI EdNet)
- Project Lead The Way
- Rowan University

12 centers EEC in 2001
39 centers CASEE in 2007
# A Focus on Centers: Relative Emphasis

<table>
<thead>
<tr>
<th>centers</th>
<th>campus-based</th>
<th>national</th>
</tr>
</thead>
<tbody>
<tr>
<td>conducting research</td>
<td>*</td>
<td>**</td>
</tr>
<tr>
<td>supporting teaching</td>
<td>**</td>
<td>*</td>
</tr>
</tbody>
</table>
A Focus on Centers: Campus-based Centers

Research on Learning/Teaching
- Center research program
- Support other faculty research

College/Department Support
- Accreditation
- Curriculum development

Faculty Support
- Individual consultations
- Workshops
- Seminars, brown-bags
- Resource bank
- Education technology support

Evaluation/Assessment
- Individual faculty (formative/diagnostic)
- Grants
- Programs

Graduate Student Support
- TA Training
- Graduate courses on learning/teaching
- Workshops

Undergraduate Student Support
- Student organizations
- Student programs
A Focus on Centers:  
Three Example Campus-Based Centers

NCEER, Northwestern Center for Engineering Education Research
  • Recent center in the U.S.
  • est. 2007, Northwestern U.

Leonhard Center for the Enhancement of Engineering Education
  • First center in a College of Engineering in the U.S.
  • est. 1990, Penn State U.

CELT, Center for Engineering Learning & Teaching
  • First center in the U.S. with combined research and effective teaching missions
  • est. 1998, U. of Washington
Campus-Based Centers
Northwestern Center for Engineering Education Research (NCEER)

Research on Learning/Teaching
- Center research program
- Support other faculty research

College/Department Support
- Accreditation
- Curriculum development

Faculty Support
- Individual consultations
- Workshops
- Seminars, brown-bags
- Resource bank
- Education technology support

Evaluation/Assessment
- Individual faculty (formative/diagnostic)
- Grants
- Programs

Graduate Student Support
- TA Training
- Graduate courses on learning/teaching
- Workshops

Undergraduate Student Support
- Student organizations
- Student programs
Campus-Based Centers
Leonhard Center

Research on Learning/Teaching
- Center research program
- Support other faculty research

College/Department Support
- Accreditation
- Curriculum development

Faculty Support
- Individual consultations
- Workshops
- Seminars, brown-bags
- Resource bank
- Education technology support

Evaluation/Assessment
- Individual faculty (formative/diagnostic)
- Grants
- Programs

Graduate Student Support
- TA Training
- Graduate courses on learning/teaching
- Workshops

Undergraduate Student Support
- Student organizations
- Student programs
Campus-Based Centers
Center for Engineering Learning & Teaching (CELT)

Research on Learning/Teaching
- Center research program
- Support other faculty research

College/Department Support
- Accreditation
- Curriculum development

Faculty Support
- Individual consultations
- Workshops
- Seminars, brown-bags
- Resource bank
- Education technology support

Evaluation/Assessment
- Individual faculty (formative/diagnostic)
- Grants
- Programs

Graduate Student Support
- TA Training
- Graduate courses on learning/teaching
- Workshops

Undergraduate Student Support
- Student organizations
- Student programs
Center for Engineering Learning and Teaching

- research findings
- research on engineering student learning
- promoting effective teaching in engineering
- feedback about what works
CELT: First Center in U.S. to Combine Research and Effective Teaching Missions

Research on engineering student learning
Promoting effective teaching
  • Based on current scholarship on learning
  • Individualized services at the faculty, dept., college levels
    - Implementing new teaching methods
    - Documenting student learning
    - Obtaining resources about effective learning, teaching
    - Curriculum development
Doing Engineering Design

- Freshmen
- Seniors
- Experts

Gathering Information

Design Processes

Considering Context

C. Atman, 2007 Jun 08
Research Focus
Problem Scoping in Design

Engineering design happens *in context*

- Local, regional, national, global
- Environmental
- Social, economic, political
- Technical

Assessing student problem-scoping approaches
Verbal Protocol Study

Solved “Midwest Floods problem” thinking aloud

Over the summer, the Midwest experienced massive flooding of the Mississippi River. What factors would you take into account in designing a retaining wall system for the Mississippi?

Took from 20–30 minutes to solve the problem
Third in a series of three short design tasks
Responses transcribed, segmented, and coded
29 freshmen, 44 senior engineering students; mid-1990s

C. Atman, 2007 Jun 08

Coding for Breadth:
A Problem-Scoping Space

Physical location
- Wall
- Water
- Bank
- Surroundings

Frame of reference
- Technical
- Logistical
- Natural
- Social
Seniors: Broader, more extensive problem-scoping

Seniors’ responses (vs. freshmen’s)

- More factors \((p < 0.001)\)
- More coverage of problem def. space \((p < 0.01)\)
Context vs. Detail Nodes

- Social
- Natural
- Logistical
- Technical
- No code
- Wall
- Water
- Bank
- Surroundings
Examples of Detail and Context Factors

- "aesthetic appeal"
- "surrounding habitat"
- "cost of materials"
- "budget"
- "detail"
- "context"

- social
- natural
- logistical
- technical
- no code
Growth in Problem-Scoping

**Segments**

- Freshmen: Context 5, Detail 10
- Seniors: Context 15, Detail 15

**Node Coverage**

- Freshmen: Context 5, Detail 3
- Seniors: Context 7, Detail 2
Insights from research on problem-scoping

• On average...
  - Freshmen and seniors consider contextual issues in approaching engineering design.
  - Seniors show growth in problem-scoping.
• ...but wide variation within each group.

Connecting to the classroom

• Assessment tools
• Curriculum design
• Classroom exercises
Today’s Agenda

- Engineering Education: A Global Challenge
- History of Engineering Education Research in the U.S.
- A Focus on Centers
  - Campus-based
    - Example center and research: CELT
  - National
    - Example center and research: CAEE

Engineering Education: A Global Challenge
## A Focus on Centers

<table>
<thead>
<tr>
<th></th>
<th>campus-based</th>
<th>national</th>
</tr>
</thead>
<tbody>
<tr>
<td>conducting research</td>
<td>*</td>
<td>**</td>
</tr>
<tr>
<td>supporting teaching</td>
<td>**</td>
<td>*</td>
</tr>
</tbody>
</table>
A Focus on Centers: National Centers

Advantages of larger scale

More opportunity to

• approach larger challenges
• gain broader/deeper insights
• collaborate across community
• build community

Example emphases

• Conducting research on learning/teaching
• Building community
• Developing resources
• Developing educational technology
• Implementing change
A Focus on Centers: National Centers

Current NSF-funded Research Centers

• VanTH-ERC, Vanderbilt Northwestern Texas Harvard/MIT Engineering Research Center
• CAEE, Center for the Advancement of Engineering Education
• CIRTL, Center for the Integration of Research, Teaching, and Learning
• NCETE, National Center for Engineering and Technology Education

Research/Implementation/Networking

• NAE CASEE, Center for the Advancement of Scholarship on Engineering Education
Center for the Advancement of Engineering Education (CAEE)

Leadership Team: Adams, Atman, Fleming, Leifer, Miller, Sheppard, Smith, Streveler, Stevens, Turns
Institutions: Colorado School of Mines, Howard University, Stanford University, University of Minnesota, University of Washington

Scholarship on Learning Engineering (Sheppard)
  • Research on the engineering student experience
  • Academic Pathways Study (APS)

Scholarship on Teaching Engineering (Turns)
  • Research on engineering teaching decision making and knowledge acquisition

Institute for Scholarship on Engineering Education (Adams)
  • Building the engineering education research community
  • Year-long Institutes at UW, Stanford, Howard

National Science Foundation, Grant No. ESI-0227558
Academic Pathways Study (APS)
Sheppard (lead), Atman, Fleming, Miller, Smith, Streveler, Stevens

• Large scope, multi-year, longitudinal study of undergraduate engineering students
• Three cohorts of students and one cohort of early career engineers from four very different undergraduate engineering programs
• Descriptive, multi-method study

From a student’s perspective...
APS Research Questions

Skills
- How do students’ skills and knowledge develop and change over time?

Identity
- How do students come to identify themselves as engineers?

Education
- What elements of a student’s education contribute to changes observed in skills and knowledge development?
APS Research Methods

Surveys
Structured interviews
Unstructured interviews, ethnographic observations
Engineering “thinking and doing” tasks
Academic transcript evaluation
Exit interviews
## APS Research Questions by Methodology

<table>
<thead>
<tr>
<th></th>
<th>Surveys</th>
<th>Structured Interviews</th>
<th>Unstructured Interviews</th>
<th>Engineering Doing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skills</td>
<td>✅✅</td>
<td>✅✅</td>
<td>✅</td>
<td>✅✅✅</td>
</tr>
<tr>
<td>Identity</td>
<td>✅</td>
<td>✅✅</td>
<td>✅✅✅</td>
<td>✅</td>
</tr>
<tr>
<td>Education</td>
<td>✅✅✅</td>
<td>✅✅</td>
<td>✅✅</td>
<td>✅</td>
</tr>
</tbody>
</table>
Sample APS Research Results from “Engineering Doing” and Survey Methods

<table>
<thead>
<tr>
<th></th>
<th>Surveys</th>
<th>Structured Interviews</th>
<th>Unstructured Interviews</th>
<th>Engineering Doing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Skills</strong></td>
<td>✔️ ✔️</td>
<td>✔️ ✔️</td>
<td>✔</td>
<td>✔️ ✔️ ✔️</td>
</tr>
<tr>
<td><strong>Identity</strong></td>
<td>✔</td>
<td>✔️ ✔️</td>
<td>✔️ ✔️ ✔️</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td>✔️ ✔️ ✔️</td>
<td>✔️ ✔️</td>
<td>✔️ ✔️ ✔️</td>
<td>✔</td>
</tr>
</tbody>
</table>
Engineering Thinking and Doing Focus

Student conceptions of engineering and design (Engineering ‘Thinking’)
Student performance on engineering design tasks (Engineering ‘Doing’)

Part of CELT’s long-term research program on engineering design processes
Engineering Doing: Freshmen

10-minute, Paper-and-Pencil Engineering Task:

Over the summer the Midwest experienced massive flooding of the Mississippi River. What factors would you take into account in designing a retaining wall system for the Mississippi?

Streamlined method, compared to past study
• Written (not verbal) response
• 10-minute limit
142 students at four partner institutions, 2003

Average Profile of Freshman Responses

APS freshmen (N = 124)

- Social: 0.8, 0.4, 0.2, 0.7
- Natural: 1.8, 1.2, 0.5
- Logistical: 2.9, 0.1, 0.1, 0.1
- Technical: 1.9, 0.6, 0.2

- Wall
- Water
- Bank
- Surroundings
Detail vs. Context Factors by Gender

Factors by category and by gender
(all APS, $N = 51\ F + 92\ M$)
significant difference, $p < 0.02$
Engineering Doing:
An emerging picture from the first year

Comparing datasets

• APS data consistent with past data
• With new sample and streamlined method

Considering context – gender differences

• men: emphasis on details of solution such as material, financial...
• women: emphasis on contextual factors such as social, natural...
Sample APS Research Results from “Engineering Doing” and Survey Methods

<table>
<thead>
<tr>
<th></th>
<th>Surveys</th>
<th>Structured Interviews</th>
<th>Unstructured Interviews</th>
<th>Engineering Doing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skills</td>
<td>✓✓</td>
<td>✓✓</td>
<td>✓</td>
<td>✓✓✓</td>
</tr>
<tr>
<td>Identity</td>
<td>✓</td>
<td>✓✓</td>
<td>✓✓✓</td>
<td>✓</td>
</tr>
<tr>
<td>Education</td>
<td>✓✓✓</td>
<td>✓✓</td>
<td>✓✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Persistence in Engineering (PIE) Survey Focus

To identify correlates of persistence in engineering

- ACADEMIC PERSISTENCE is operationalized as majoring in engineering
- PROFESSIONAL PERSISTENCE is operationalized as expressing an intention to practice engineering for at least 3 years after graduating with a bachelor’s degree.

PIE Survey Findings from the First Three Years

A focus on persisters/non-persisters

- motivation
- confidence
- perceived importance of skills
- disengagement/engagement
No overall difference between persisters and non-persisters in...

• Financial motivation to pursue engineering
• Social relevance as a motivation to pursue engineering
• Perception of the importance of math and science
• Confidence in interpersonal and professional skills
• Reported familiarity with the field of engineering in first and sophomore years
Non-persisters, compared to persisters report…

- On motivation to pursue engineering
  - At the start of their academic career, a greater degree of family influence
  - Lower degree of a mentor’s influence
- Lower confidence in math and science skills
- Lower rating of the importance of interpersonal and professional skills
- More academically disengaged in both engineering and liberal arts courses
Motivation: Family Influence
Persisters/Non-persisters

![Graph showing the motivation levels of persisters and non-persisters over academic years.](image-url)

- **Persisters**
- **Non-persisters**

**Construct 2b: Motivation (Family Influence)**

Administration (academic years)

FR1  FR2  SO1  SO2  JR1  JR2
Confidence in Math and Science Skills
Persisters/Non-persisters

Construct 3a: Confidence in Math and Science Skills

Administration (academic years)
Persistence in Engineering:
An emerging picture from the first three years

Non-persisters report:

• More family influence to be an engineer at the start of their career
• Lower confidence in math and science skills
• More academically disengaged in both engineering and liberal arts courses
Emerging Findings Across the Study: From the student perspective

Large variation across sample at four institutions, e.g.

Reasons for choice of major

• Financial security
• Contribution to society
• Influence of family or mentors

Curriculum and skill development issues

• Heavy workloads, competition, stress
• First two years give little “vision” of engineering (design and teamwork come late)
• Understanding context vs. detail (a “systems” view)
Emerging Findings Across the Study: From the student perspective (cont.)

Commitment to field of engineering

• Varies greatly, affected by personal situation, learning experiences, institutional procedures
• Decision to be an engineer reexamined often

Reasons for leaving

• Lack of confidence in math/science skills
• Fear of losing scholarships
• Perception that engineering is too narrow (no insight into the contributions of engineering to social good)
• Factors affect men and women differently
A Focus on Centers: National Centers

Advantages of larger scale

More opportunity to:

• approach larger challenges
• gain broader/deeper insights
• collaborate across community
• build community
CAEE’s National Presence, January 2003

Legend

- team member or advisor
- institution
CAEE's Growing Presence, May 2006

Legend

- project connection
- travel
- relocation (people) or replication (projects)
- project or program
Today’s Agenda

Engineering Education: A Global Challenge

History of Engineering Education Research in the U.S.

A Focus on Centers

• Campus-based
  - Example center and research: CELT

• National
  - Example center and research: CAEE

Engineering Education: A Global Challenge
A Global Conversation
To Meet a Global Challenge:
Piecing Together a Picture of Engineering Education
Continuing the Conversation

Today…

• Research questions?
• Research communities?
• Change strategies?
• Other topics?
• Coffee or tea?

After today…

• atman@engr.washington.edu
• CELT: http://depts.washington.edu/celtweb/
• CAEE: http://www.engr.washington.edu/caee/
References (1 of 3)


References (2 of 3)


References (3 of 3)


Relevant Websites

- Accreditation Board for Engineering and Technology, Inc. (ABET)
  http://www.abet.org/
- American Society for Engineering Education (ASEE)
  http://www.asee.org/
- American Society for Engineering Education, Educational Research and Methods Division (ASEE ERM)
  http://fie.engr.pitt.edu/erm/
- Center for the Advancement of Scholarship on Engineering Education (CASEE)
  http://www.nae.edu/NAE/caseecomnew.nsf?OpenDatabase
- Center for the Advancement of Engineering Education (CAEE)
  http://www.engr.washington.edu/caee/
- Center for Engineering Learning & Teaching (CELT)
  http://depts.washington.edu/celtweb/
- Center for Integration of Research, Teaching, and Learning (CIRTL)
  http://cirtl.wceruw.org/
- Colorado State University, Engineering Education Program
  http://www.engr.colostate.edu/es/engineeringed
- Leonhard Center for Enhancement of Engineering Education
  http://www.engr.psu.edu/LeonhardCenter/eec/lc/
- National Academy of Engineering (NAE)
  http://www.nae.edu/
- National Center for Engineering and Technology Education (NCETE)
  http://www.ncete.org/
- National Science Foundation (NSF)
  http://www.nsf.gov/
- Purdue University, Department of Engineering Education
  https://engineering.purdue.edu/ENE/
- Utah State University, Department of Engineering and Technology Education
  http://www.engineering.usu.edu/ete/
- Vanderbilt-Northwestern-Texas- Harvard/MIT Engineering Research Center (VanTH-ERC)
  http://www.vanth.org/
- Virginia Tech, Department of Engineering Education
  http://www.enge.vt.edu/
Acknowledgements

I would like to thank many people for their input and review of these slides, including Jim Borgford-Parnell, Debbie Chachra, Ö zgür Eris, Rich Felder, Norman Fortenberry, Patricia Gomez, Sue Kemnitzer, Deborah Kilgore, Tom Litzinger, Tina Loucks-Jaret, Dennis Lund, Ann McKenna, Bayta Maring, Liz Moore, Barbara Olds, Sheri Sheppard, Karl Smith, Jennifer Turns. I would particularly like to thank Ken Yasuhara for his insights on the content, and production and artwork on these slides.

This work has been supported by grants from the National Science Foundation RED-9358516, EEC-0639895, REC-012554, ESI-0227558, SBE-0354453, the Boeing Company, and the Ford Motor Company Fund.