Rene Magritte, c. 1956

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

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

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Director, Center for the Advancement of Engineering Education
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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.

CELT *Center for Engineering Learning and Teaching*

RESEARCH · LEARNING · TEACHING · DIVERSITY · COMMUNITY
CAEE
CENTER FOR THE ADVANCEMENT OF ENGINEERING EDUCATION

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

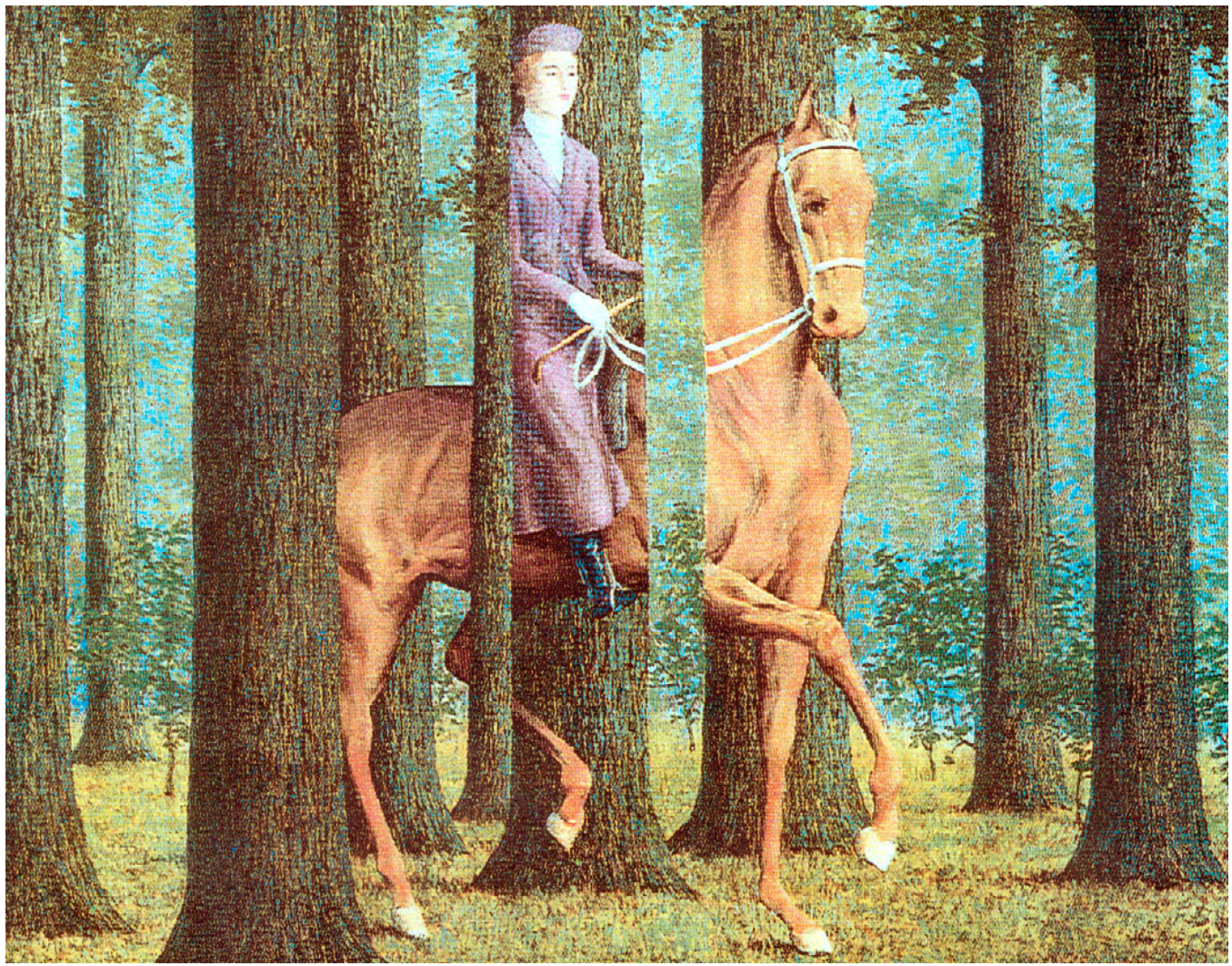
A global need

- 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

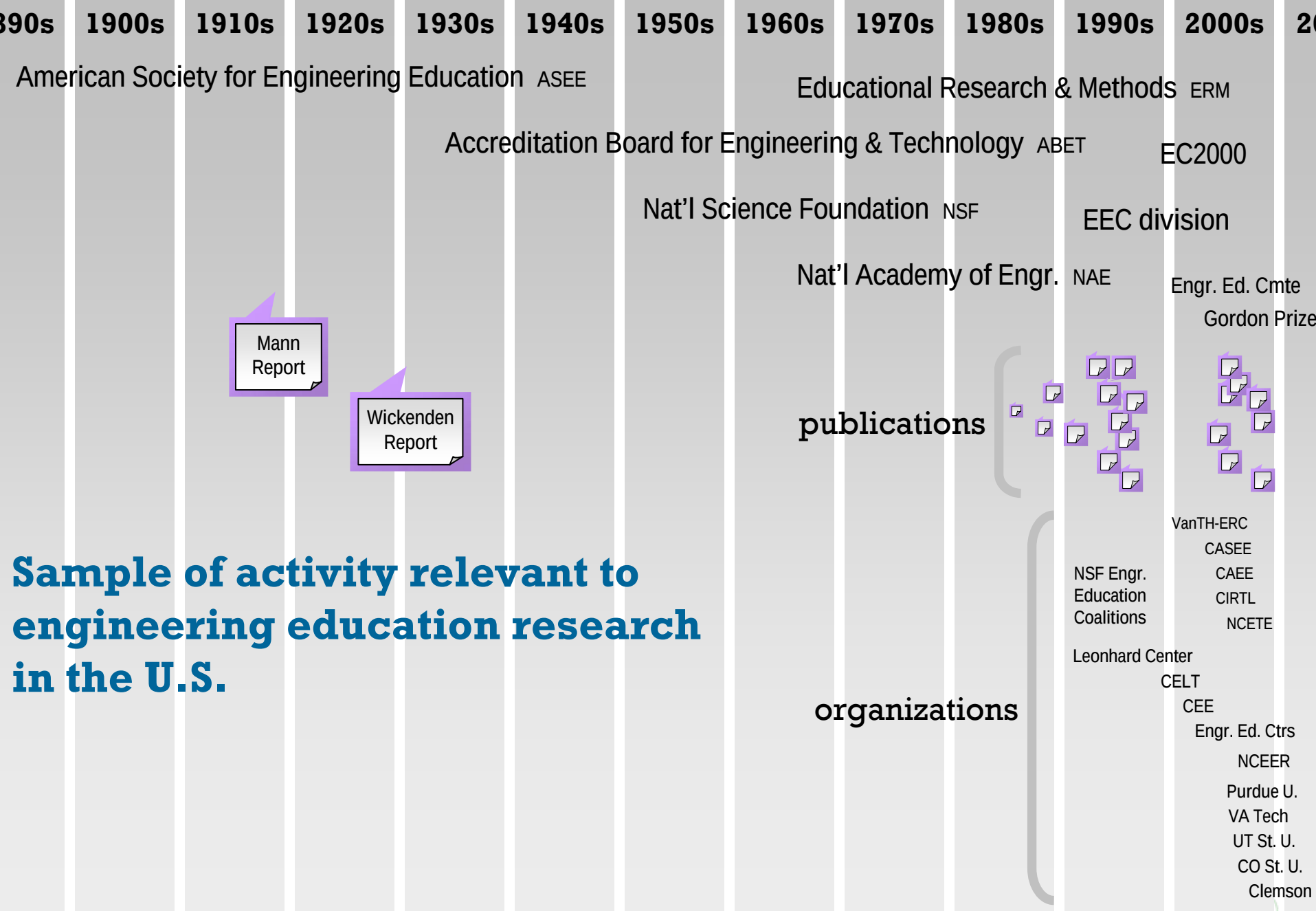
Growth of Engineering Education Research in the U.S.

A growing community...

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

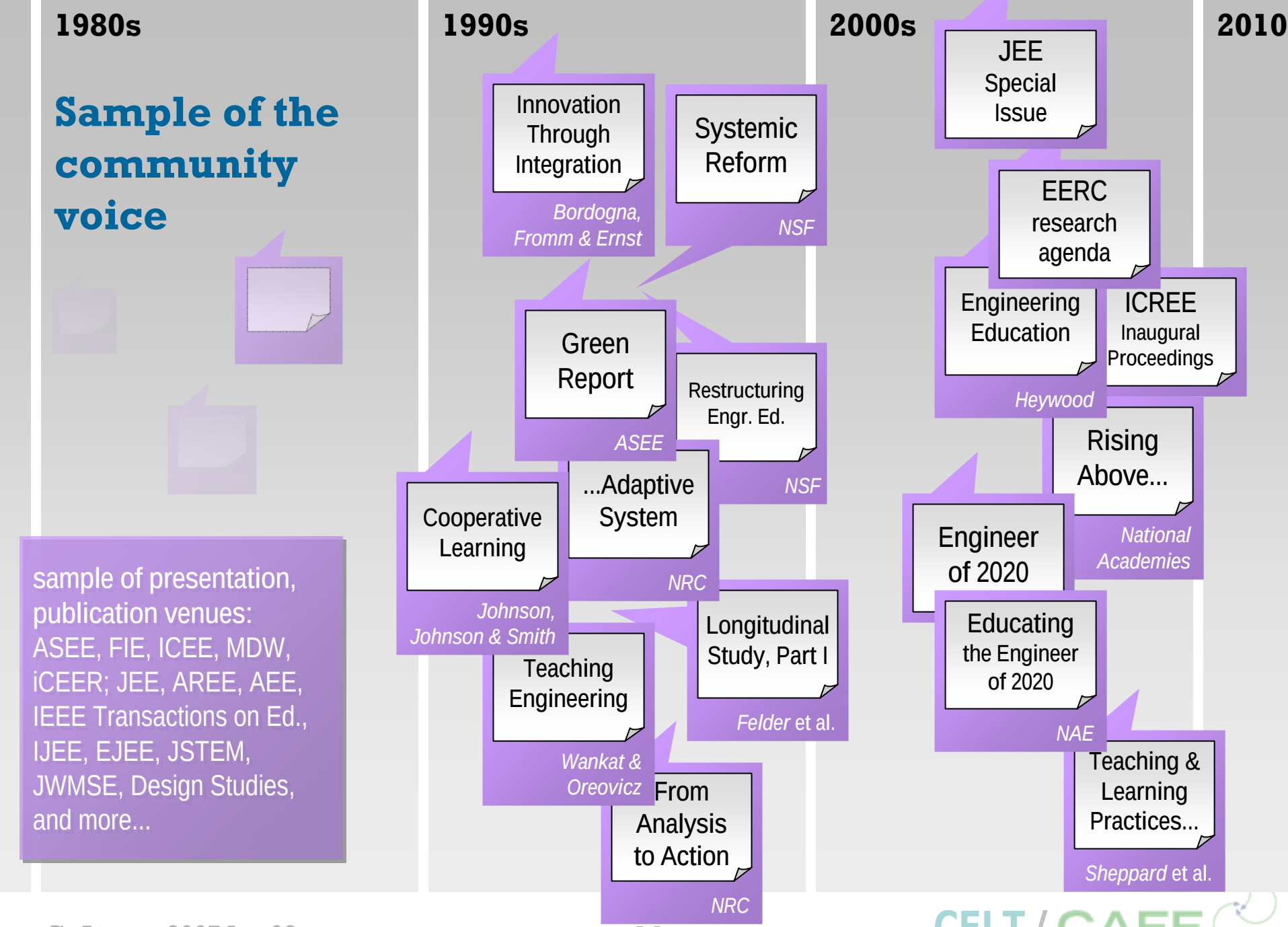
...with a voice

- 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 **1990s** **2000s** **2010**

Engineering Research Centers ERC

Engineering Education & Centers division EEC

graduate fellowships for women, minorities GEE/IGERT, GRF

GK–12 graduate teaching fellowships

Model Institutions for Excellence MIE

Engineering Education Scholars EESP

Department Level Reform

Ctrs for Teaching & Learning

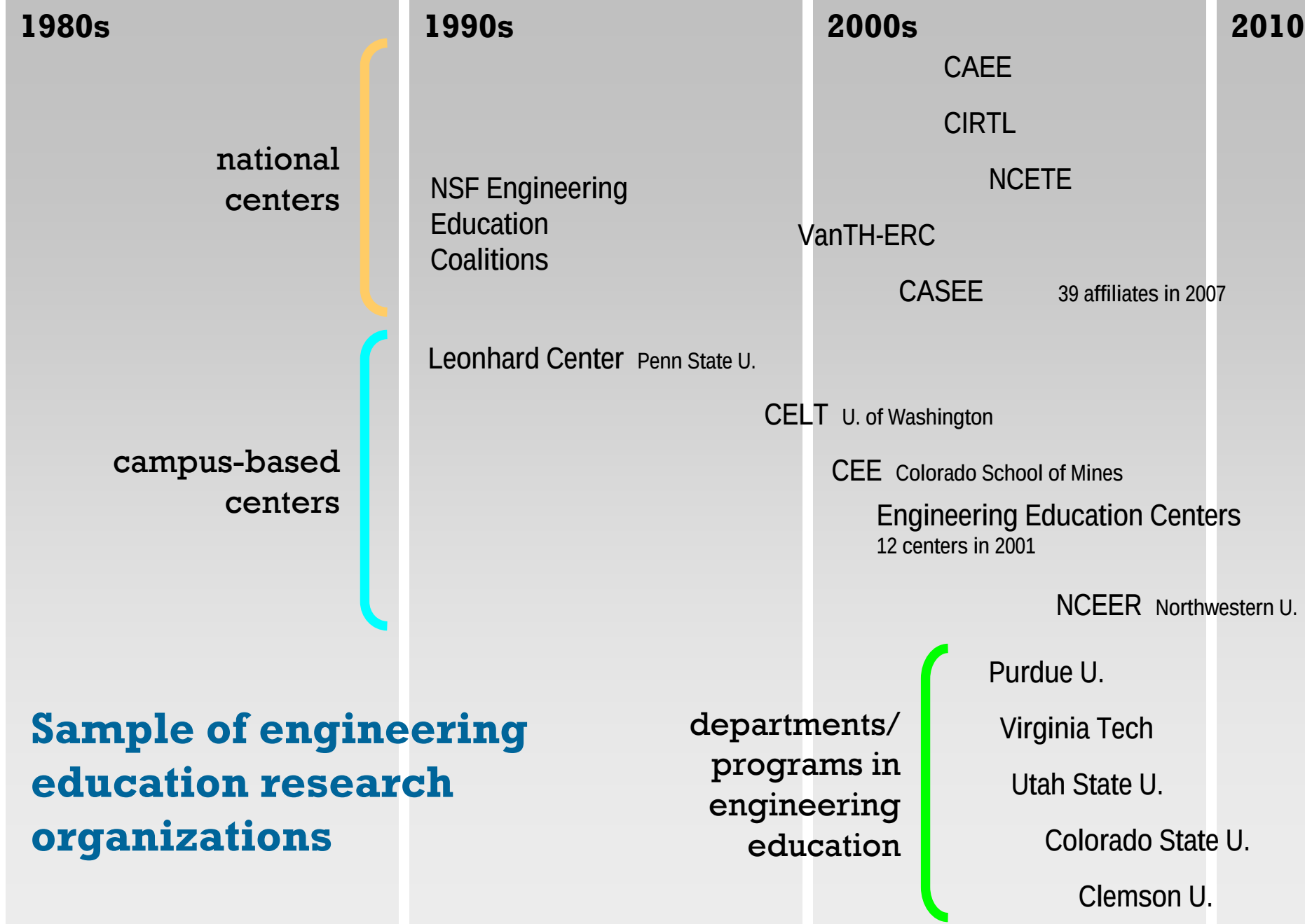
Engr. Ed. Research

National Science Foundation NSF

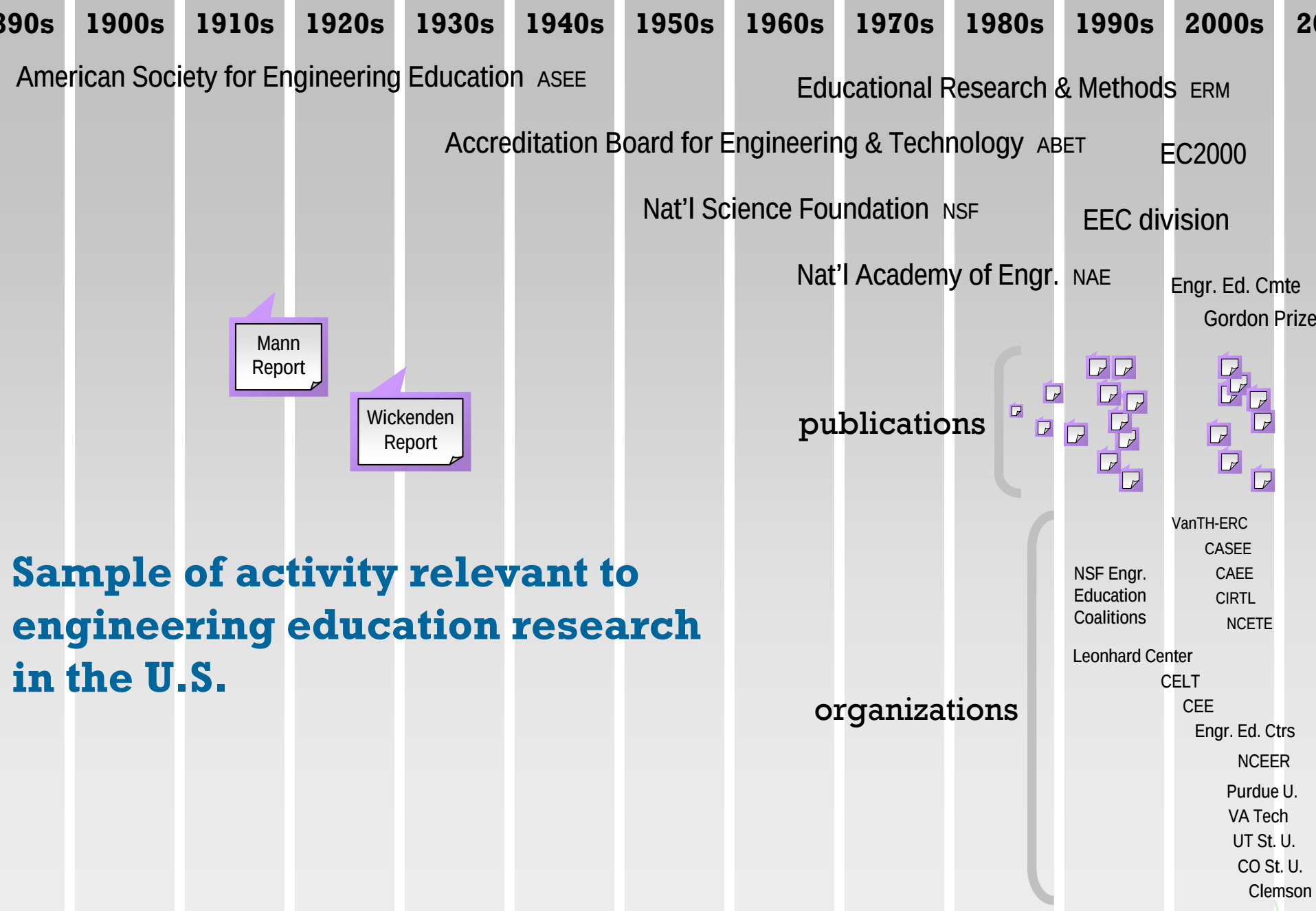
Fund for the Improvement of Postsecondary Education, U.S. Dept. of Education FIPSE

Sample of the funding picture

other funding sources:
corporations, foundations



Sample of engineering education research organizations


1890s
1900s
1910s
1920s
1930s
1940s
1950s
1960s
1970s
1980s
1990s
2000s
American Society for Engineering Education ASEE
Educational Research & Methods ERM
Accreditation Board for Engineering & Technology ABET
EC2000
Nat'l Science Foundation NSF
EEC division
Nat'l Academy of Engr. NAE
Engr. Ed. Cmte
Gordon Prize
Mann Report
Wickenden Report
publications
Sample of activity relevant to engineering education research in the U.S.
VanTH-ERC
CASEE
CAEE
CIRTL
NCETE
NSF Engr. Education Coalitions
Leonhard Center
CELT
CEE
Engr. Ed. Ctrs
NCEER
Purdue U.
VA Tech
UT St. U.
CO St. U.
Clemson
organizations

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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)

12 → 39

centers EEC in 2001

centers CASEE in 2007

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

A Focus on Centers: Relative Emphasis

	centers	
	campus-based	national
conducting research	*	**
supporting teaching	**	*

A Focus on Centers:
Campus-based Centers

	centers	
	campus-based	national
conducting research	*	**
supporting teaching	**	*

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

	centers	
	campus-based	national
conducting research	*	**
supporting teaching	**	*

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)

	centers	
	campus-based	national
conducting research	*	**
supporting teaching	**	*

Research on Learning/Teaching
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Undergraduate Student Support
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- Student programs

Campus-Based Centers
Leonhard Center

	centers	
	campus-based	national
conducting research	*	**
supporting teaching	**	*

Research on Learning/Teaching
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Campus-Based Centers
Center for Engineering Learning & Teaching (CELT)

	centers	
	campus-based	national
conducting research	*	**
supporting teaching	**	*

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

College/Department Support
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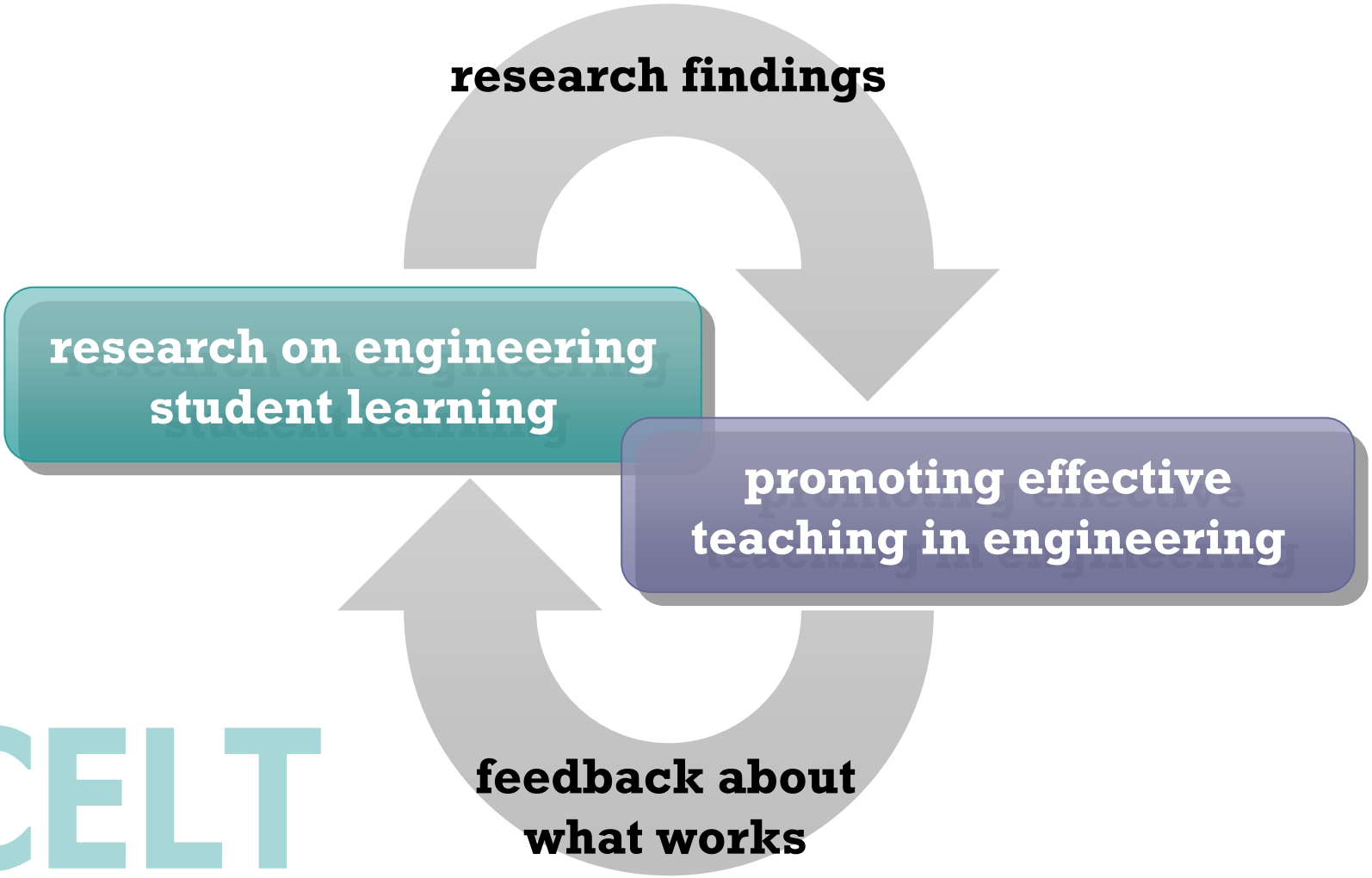
Center for Engineering Learning and Teaching



CELT: First Center in U.S. to Combine Research and Effective Teaching Missions

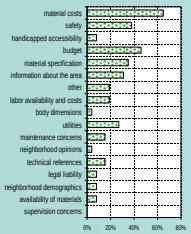
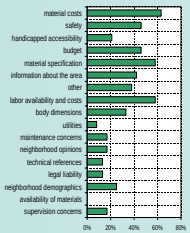
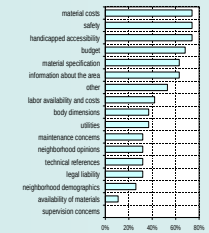
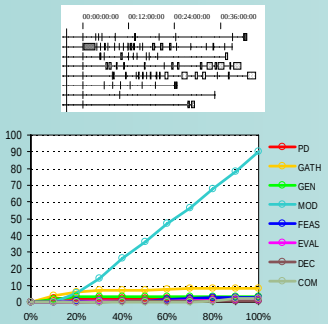
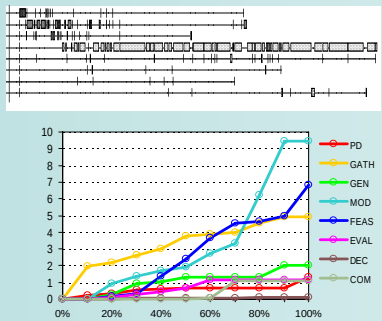
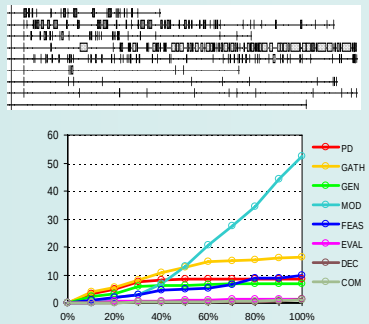
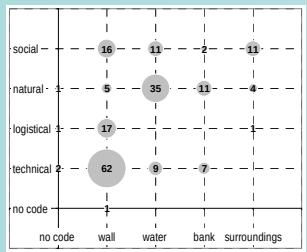
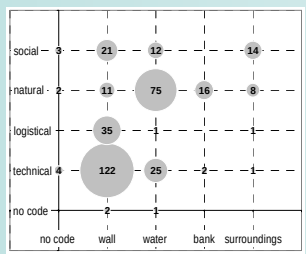
Research on engineering student learning

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

DESIGN PROCESS SKILLS

	… Freshmen …	… Seniors …	… Experts …
Gathering Information			
Design Processes			
Considering Context			

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

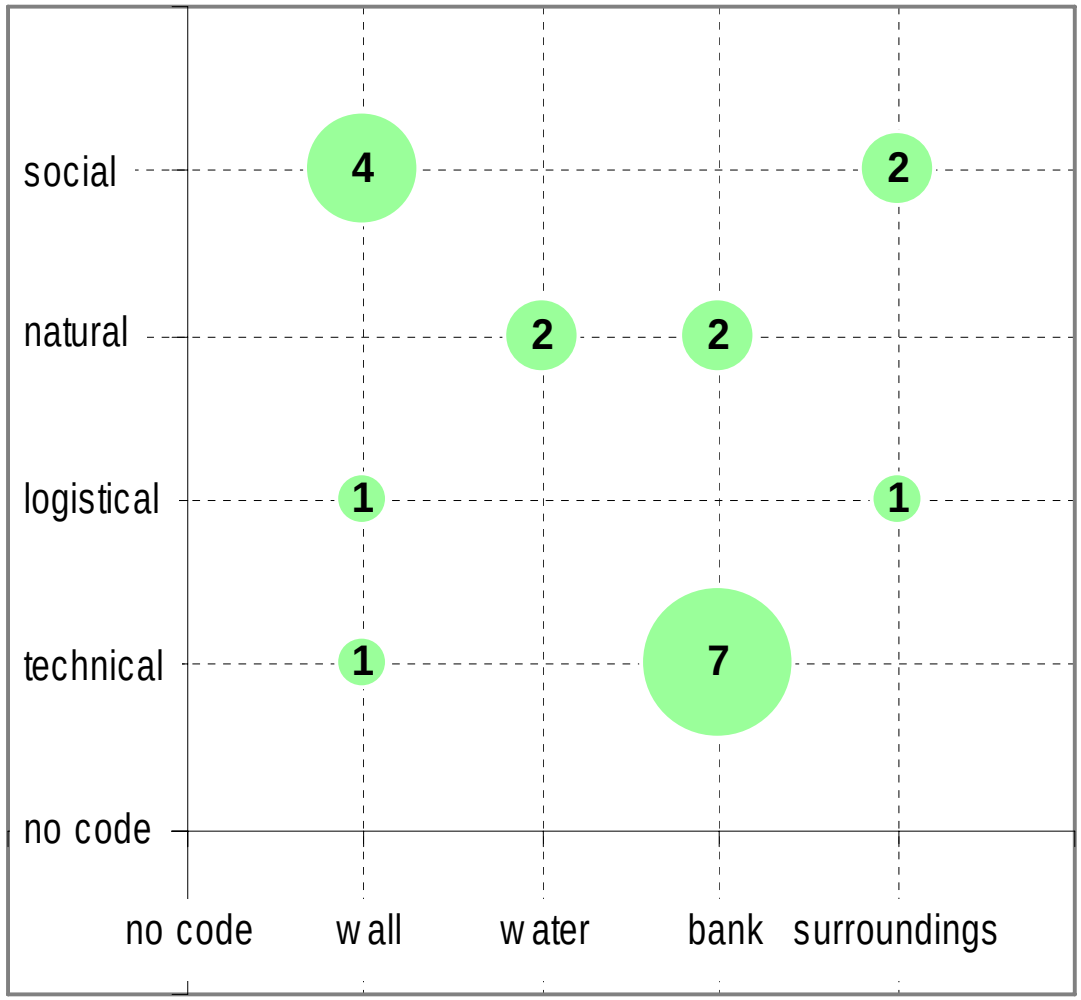
29 freshmen, 44 senior engineering students; mid-1990s

Atman, C.J. *et al.* (2007). Breadth in problem scoping: A comparison of freshman and senior engineering students. Mudd Design Workshop VI.

Coding for Breadth:
A Problem-Scoping Space

Physical location
- Wall
- Water
- Bank
- Surroundings

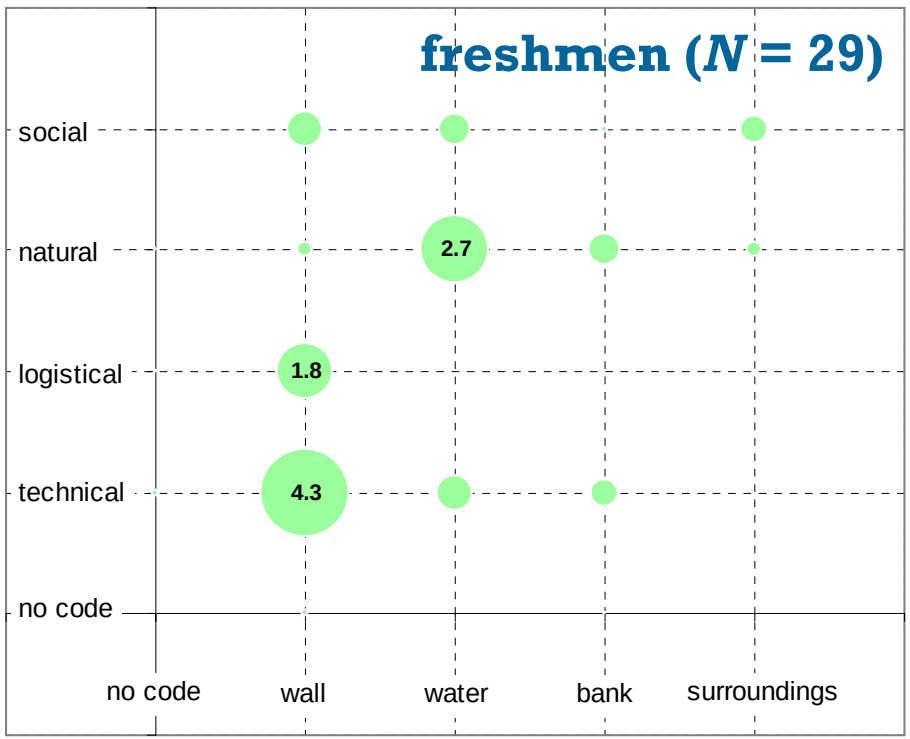
Frame of reference
- Technical
- Logistical
- Natural
- Social

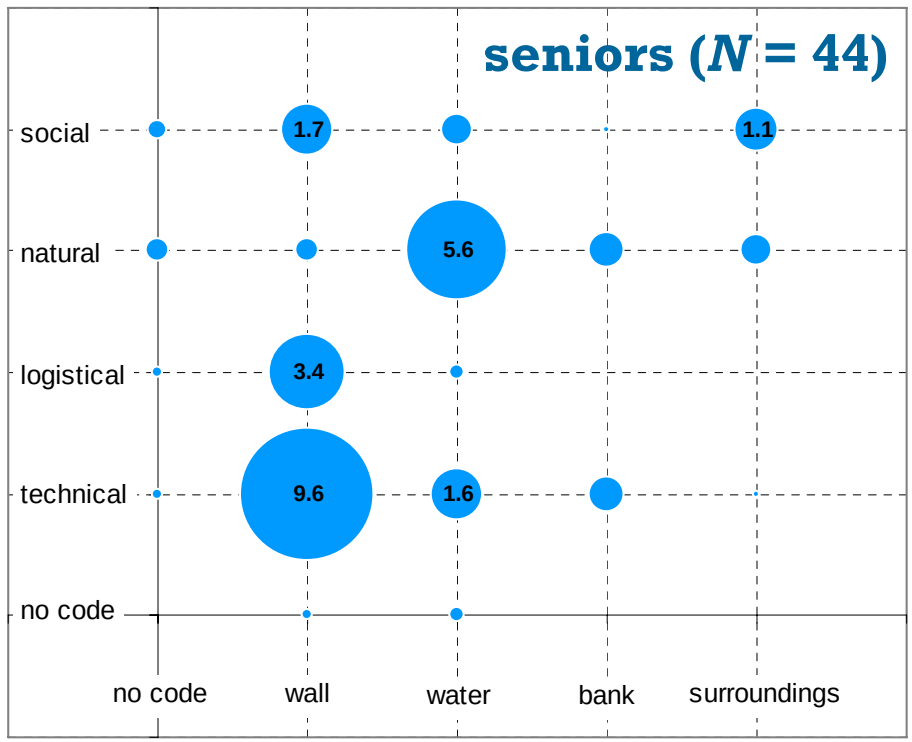


Seniors: Broader, more extensive problem-scoping

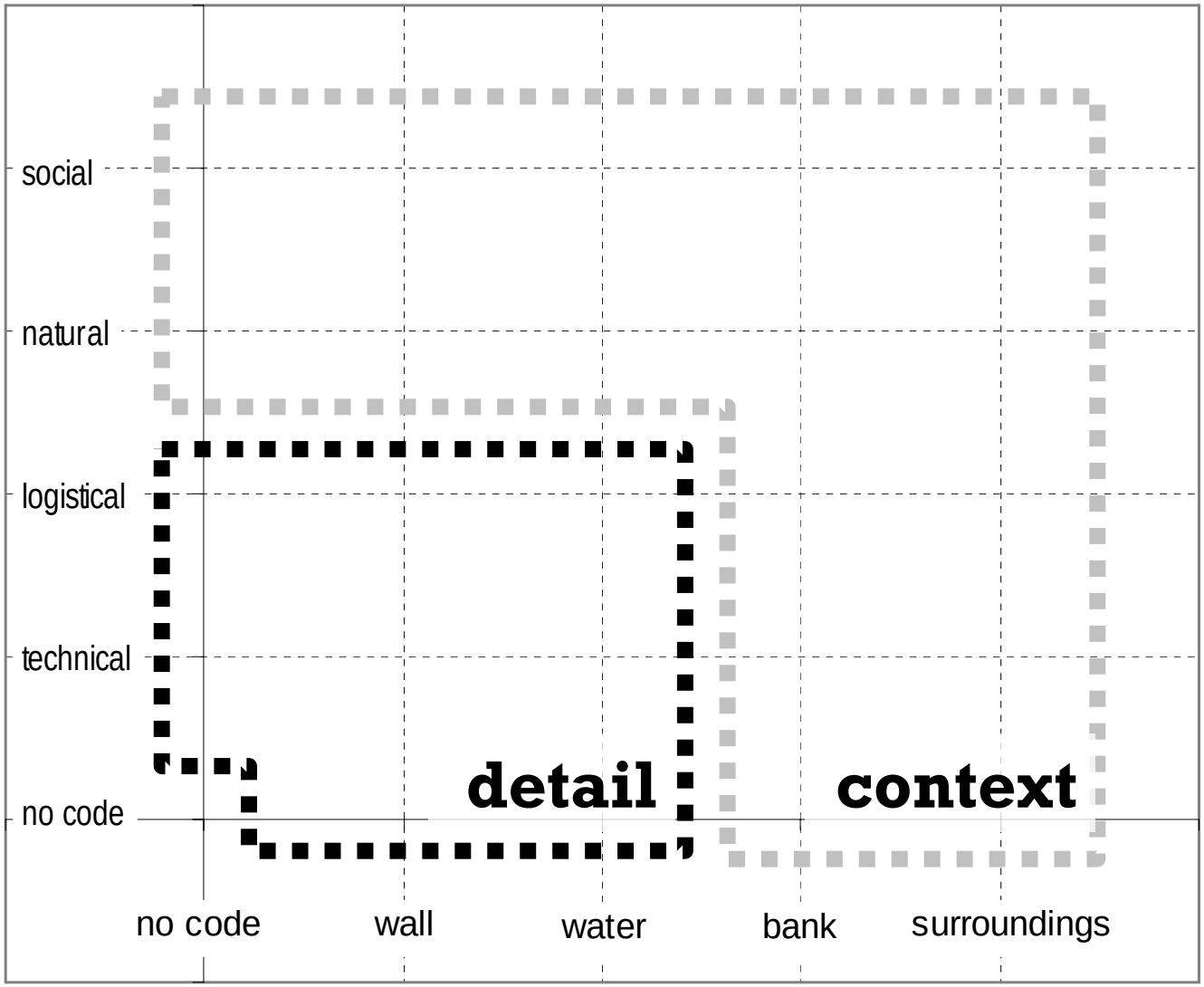
Seniors' responses (vs. freshmen's)

- More factors ($p < 0.001$)
- More coverage of problem def. space ($p < 0.01$)

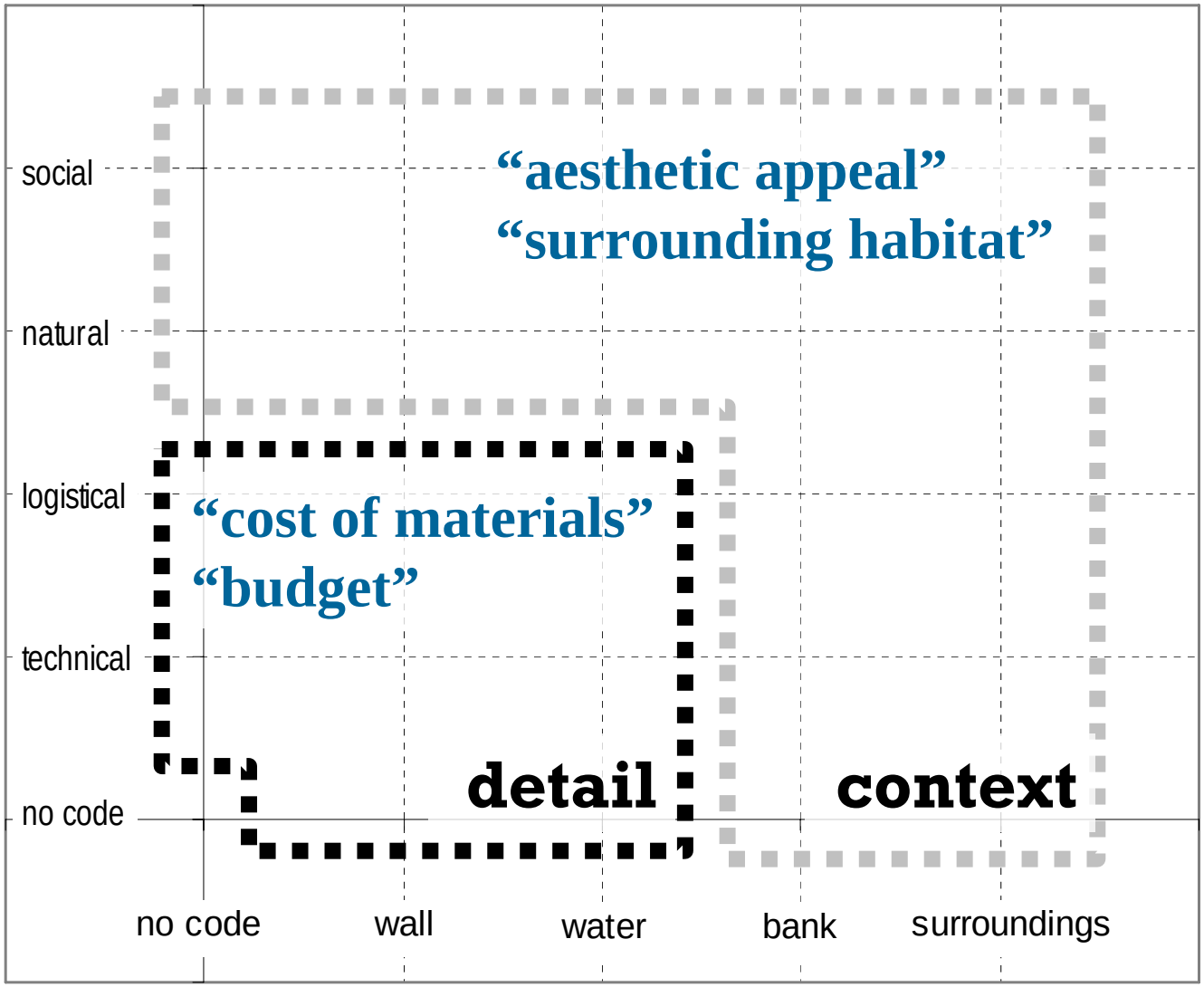




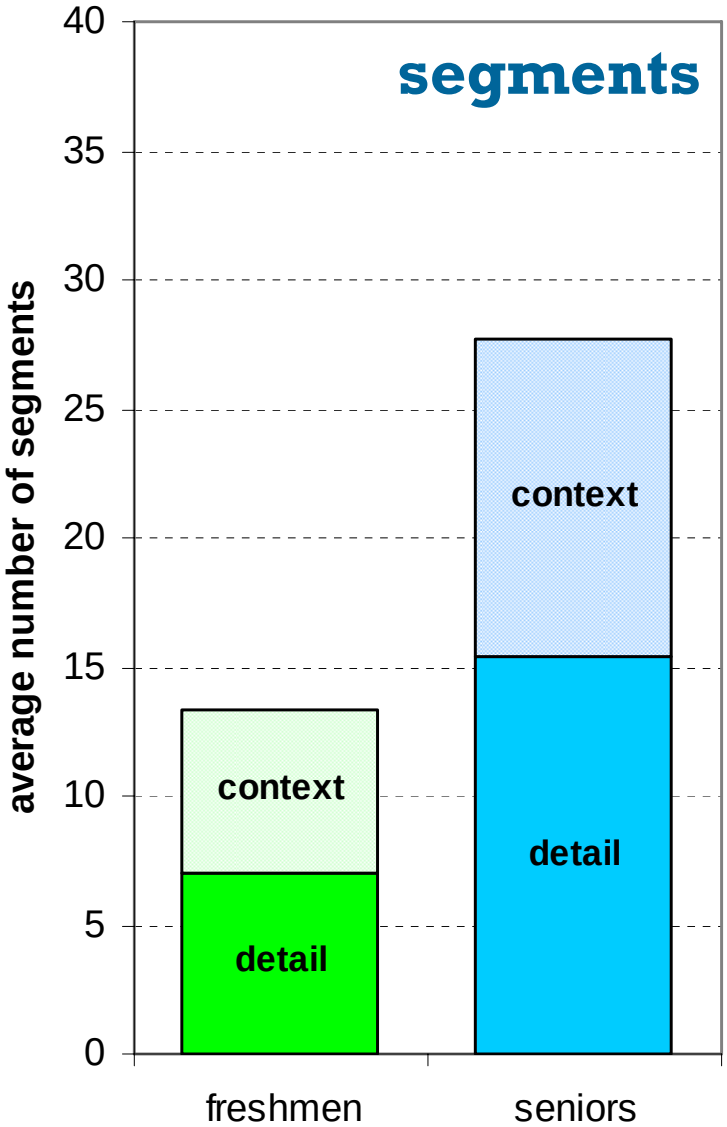
Context vs. Detail Nodes

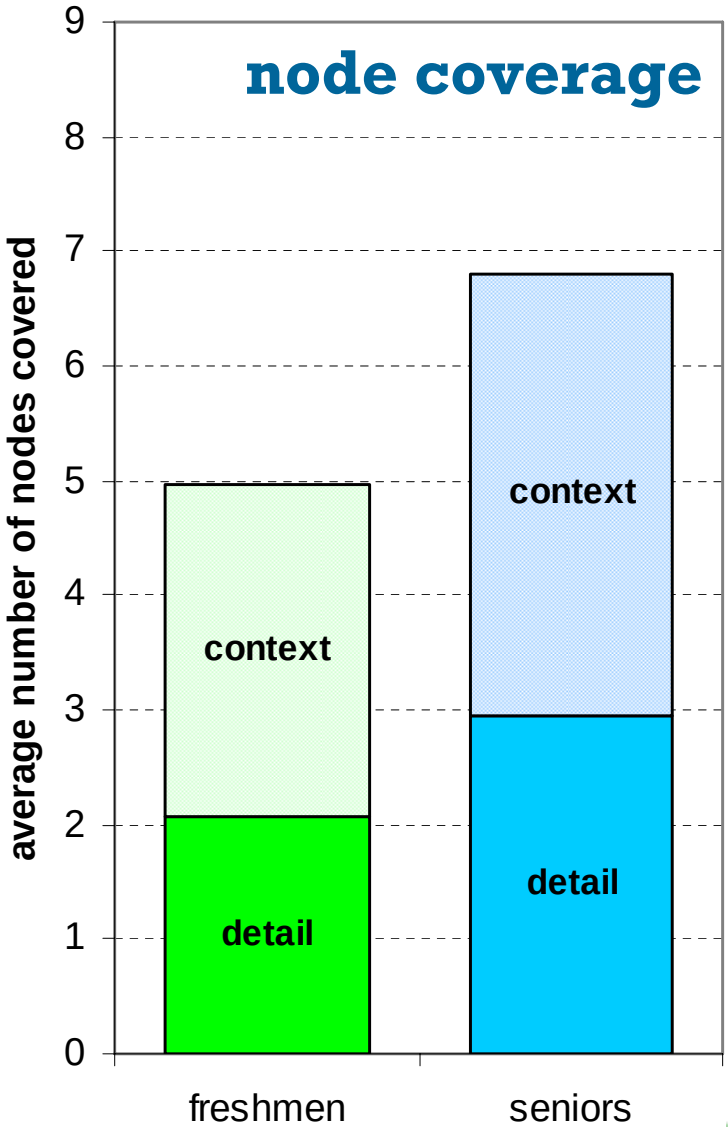


Examples of Detail and Context Factors



Growth in Problem-Scoping





Campus-Based Centers
Connecting Research and Practice

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

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A Focus on Centers

	centers	
	campus-based	national
conducting research	*	**
supporting teaching	**	*

A Focus on Centers: National Centers

	centers	
	campus-based	national
conducting research	*	**
supporting teaching	**	*

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

	centers	
	campus-based	national
conducting research	*	**
supporting teaching	**	*

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

CAEE

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

	Surveys	Structured Interviews	Unstructured Interviews	Engineering Doing
Skills	✓✓	✓✓	✓	✓✓✓
Identity	✓	✓✓	✓✓✓	✓
Education	✓✓✓	✓✓	✓✓	✓

Sample APS Research Results from "Engineering Doing" and Survey Methods

	Surveys	Structured Interviews	Unstructured Interviews	Engineering Doing
Skills	✓✓	✓✓	✓	✓✓✓
Identity	✓	✓✓	✓✓✓	✓
Education	✓✓✓	✓✓	✓✓	✓

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?

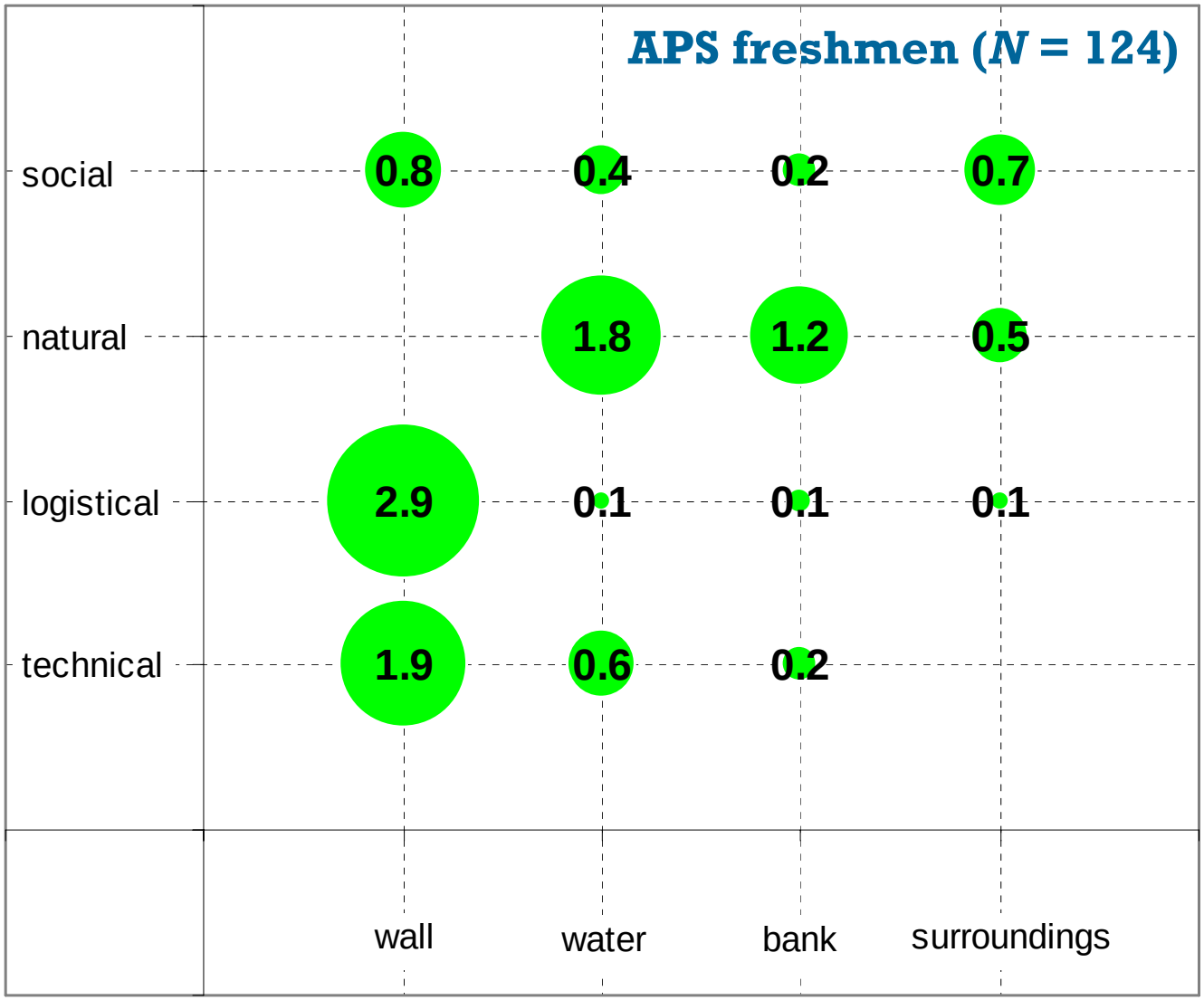
Streamlined method, compared to past study

- Written (not verbal) response
- 10-minute limit

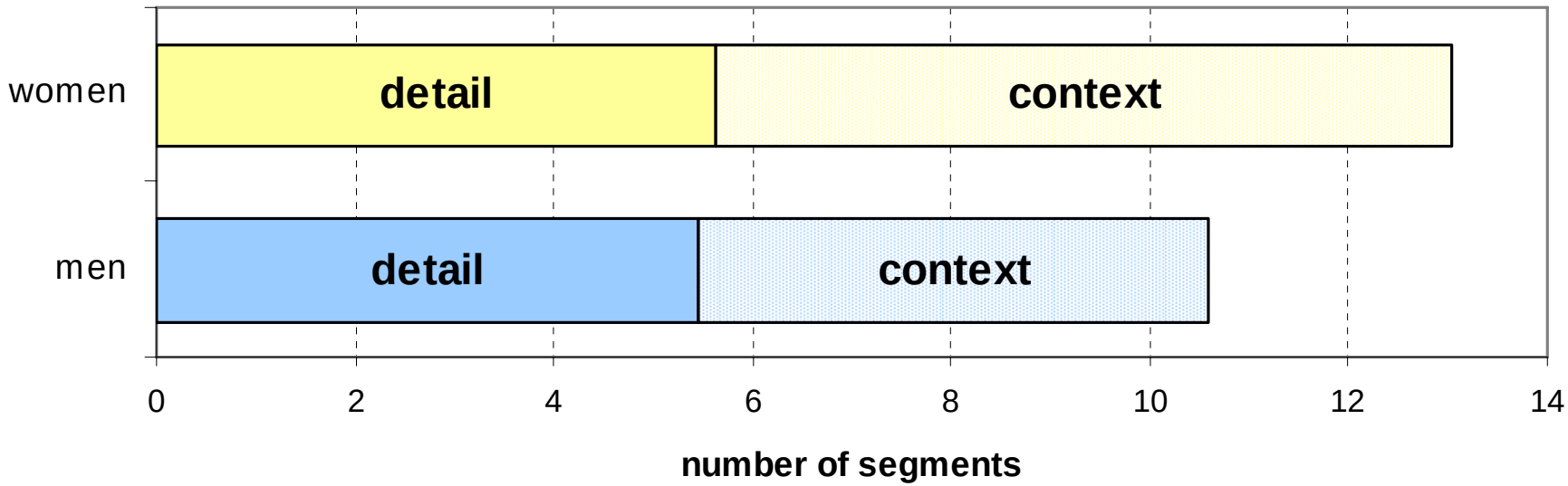
142 students at four partner institutions, 2003

Kilgore, D. *et al.* (to appear). Considering context: A study of first-year engineering students. *Journal of Engineering Education*.

Average Profile of Freshman Responses



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

	Surveys	Structured Interviews	Unstructured Interviews	Engineering Doing
Skills	✓✓	✓✓	✓	✓✓✓
Identity	✓	✓✓	✓✓✓	✓
Education	✓✓✓	✓✓	✓✓	✓

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.

Eris, Ö., *et al.* (2007). A preliminary analysis of correlates of engineering persistence: Results from a longitudinal study. Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition.

PIE Survey Findings from the First Three Years

A focus on persisters/non-persisters

- motivation
- confidence
- perceived importance of skills
- disengagement/engagement

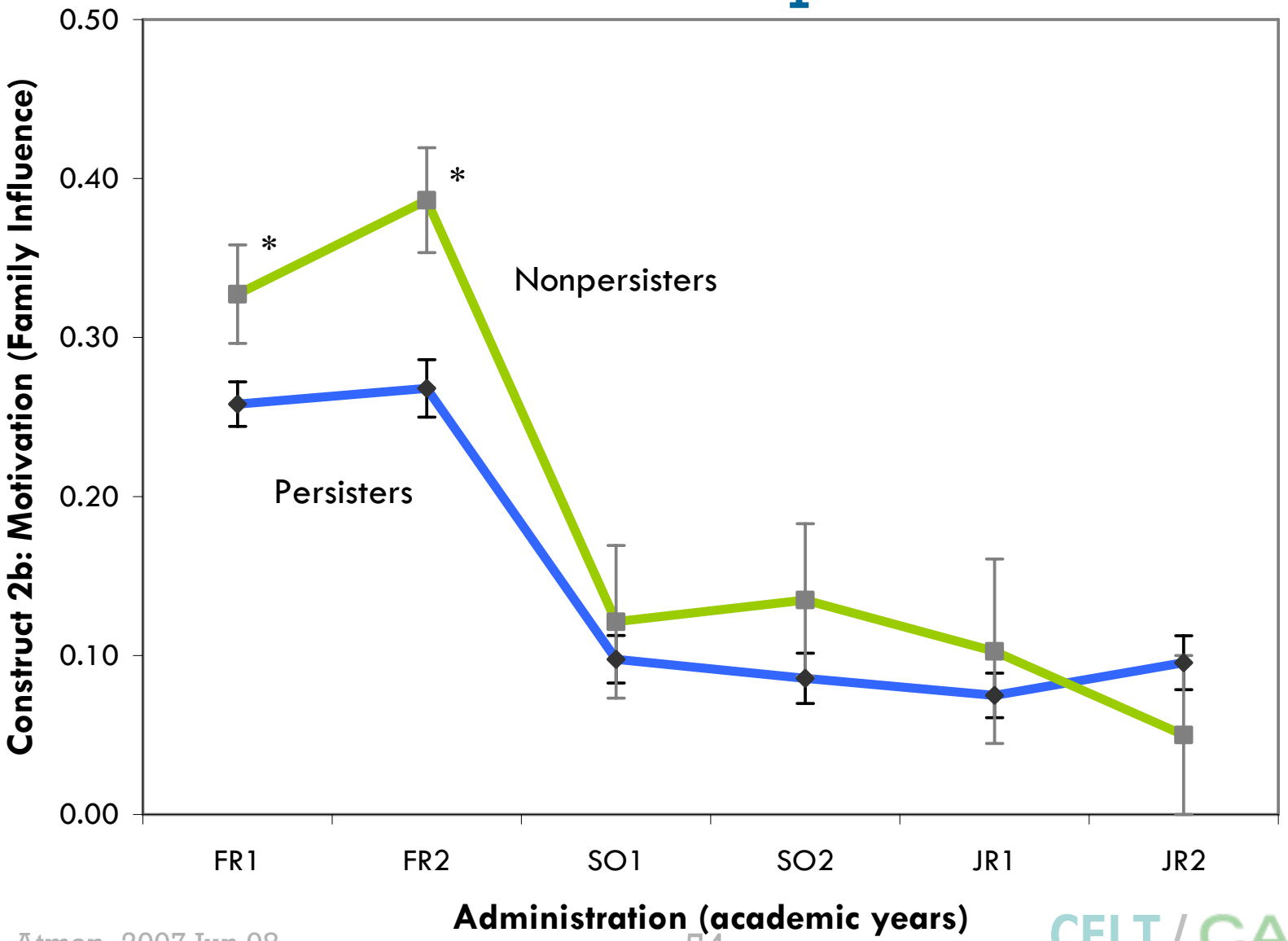
No overall difference between persisters and non-persisters in…

- 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

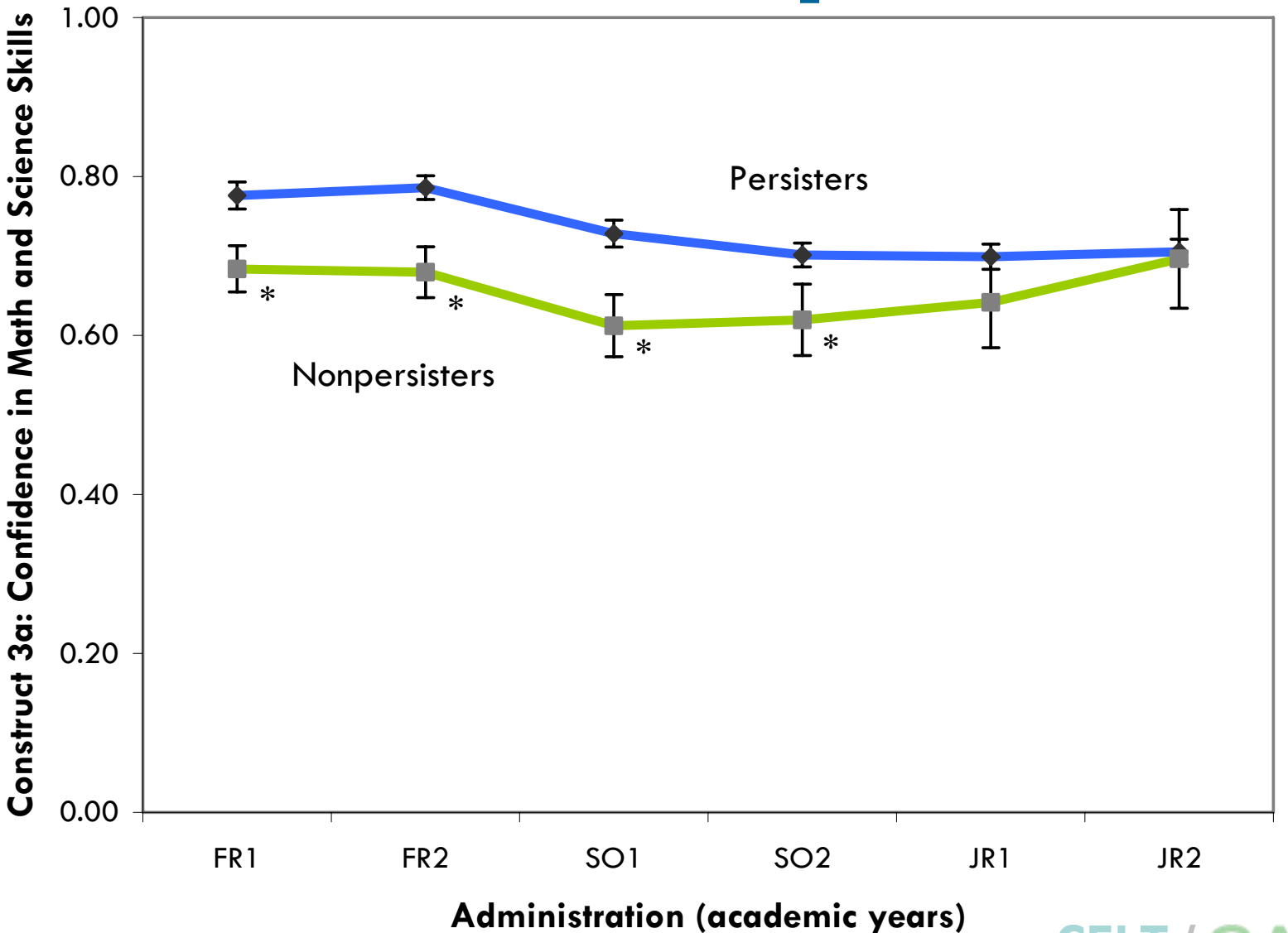
Non-persisters, compared to persisters report…

- 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



Confidence in Math and Science Skills
Persisters/Non-persisters



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

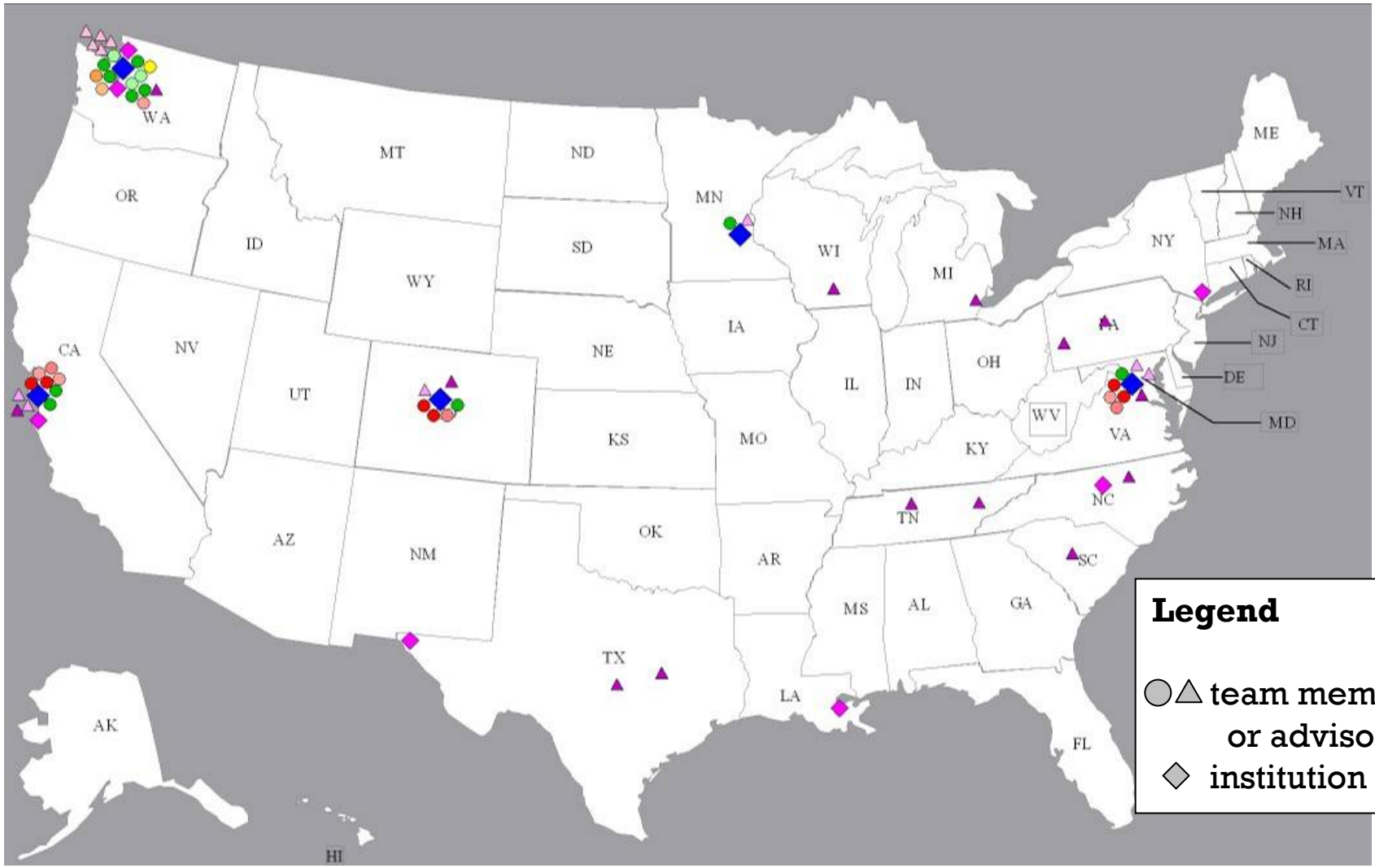
	centers	
	campus-based	national
conducting research	*	**
supporting teaching	**	*

Advantages of larger scale

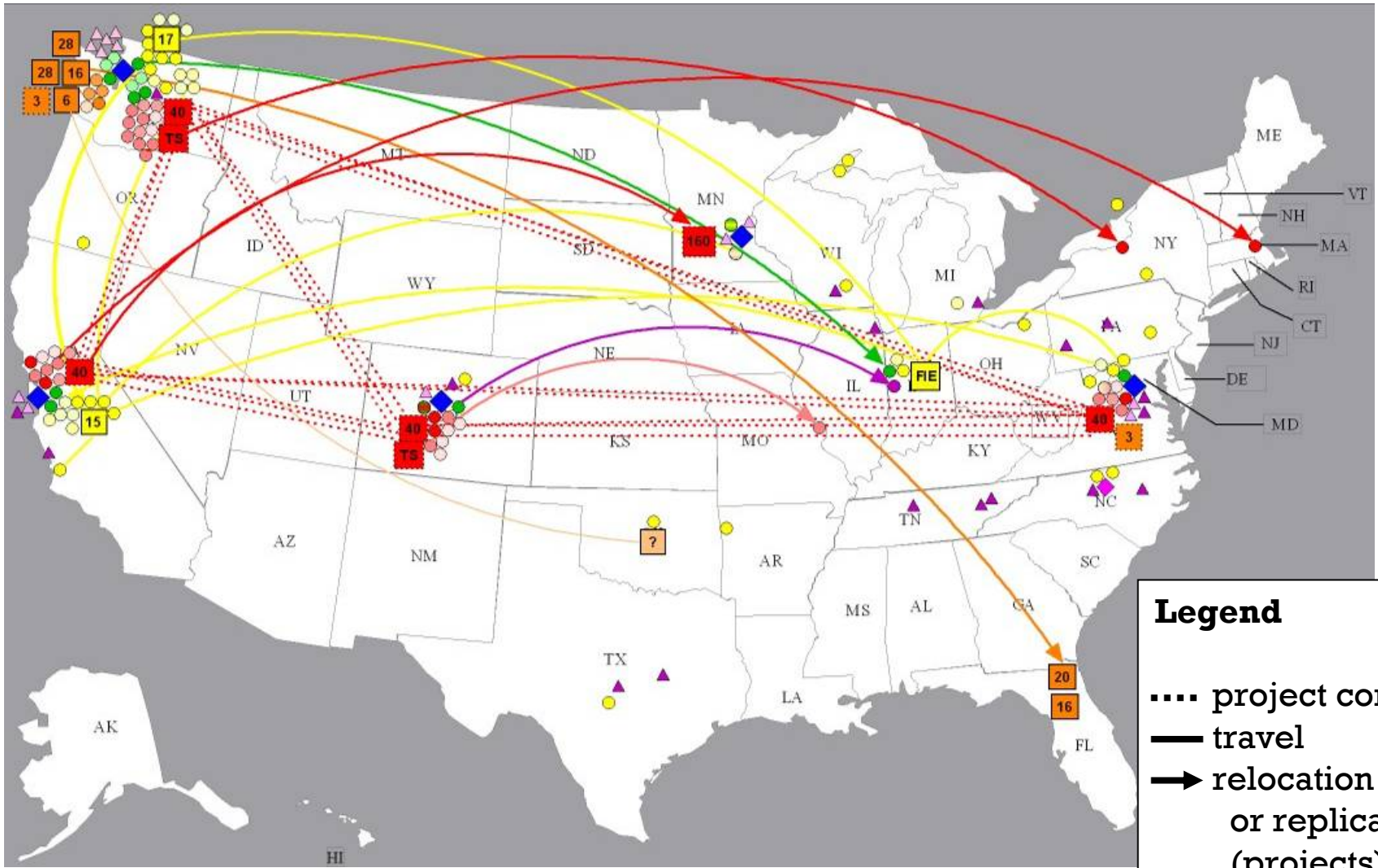
More opportunity to:

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

CAEE's National Presence, January 2003



CAEE's Growing Presence, May 2006



Legend

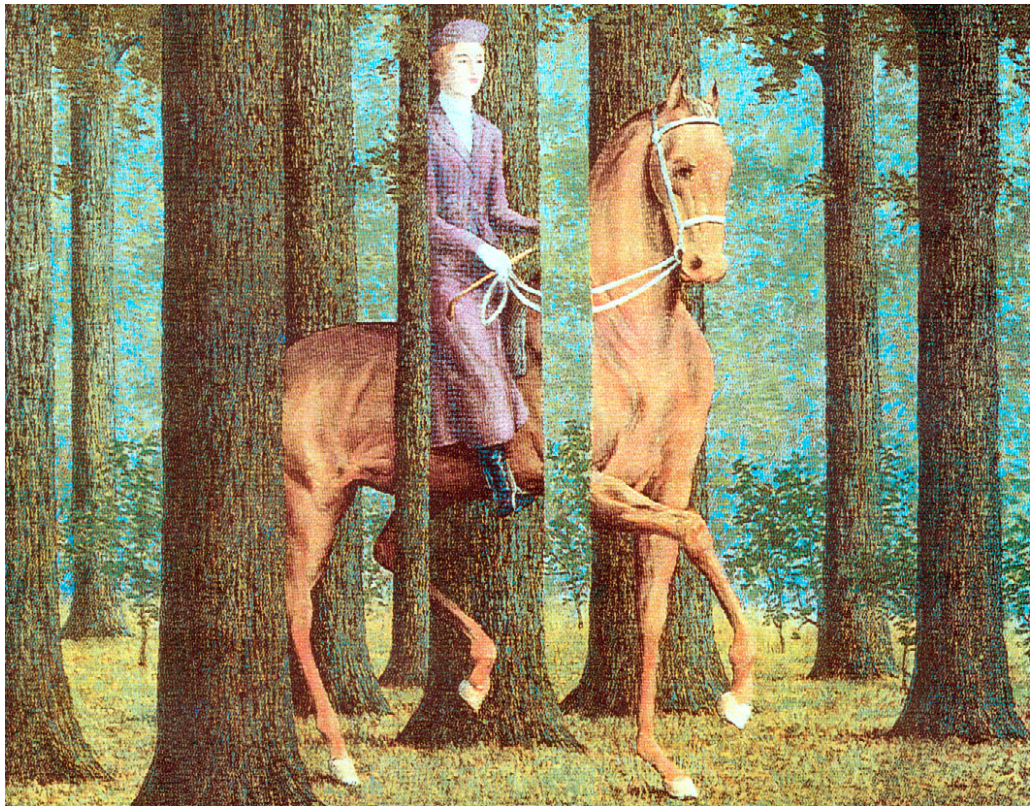
- project connection
- travel
- relocation (people) or replication (projects)
- project or program

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/

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