Educating the well-rounded engineer

Insights from the Academic Pathways Study

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Frontiers in Education 2009

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Academic Pathways Study

- **APS lead:** Sheri Sheppard
- **APS team:** Cynthia Atman, Lorraine Fleming, Ronald Miller, Karl Smith, Reed Stevens, Ruth Streveler
- **CAEE Leadership team:** Robin Adams, Cynthia Atman, Sheri Sheppard, Lorraine Fleming, Larry Leifer, Ronald Miller, Barbara Olds, Karl Smith, Reed Stevens, Ruth Streveler, Jennifer Turns

CAEE-related sessions at FIE

- **How Do Engineering Educators Take Student Difference Into Account?**
  Yesterday, 4:30–6:00 pm (M4E); B. Sattler, J. Turns, K. Gygi
- **Research Findings on Engineering Student Learning and Engineering Teaching**
  Today, 10:00–11:30 am, El Mirador East (T2A); D. Chachra *et al.*
- **Developing Engineering Student's Philosophical Inquiry Skills**
  Today, 3:30–5:00 pm, El Mirador West (T4B); R. Korte & K. Smith
- **Outside the Classroom: Gender Differences in Extracurricular Activities of Engineering Students**
  Tomorrow, 8:00–9:45 am, La Condesa West (W1D); D. Chachra, H. L. Chen, D. Kilgore, S. D. Sheppard
- **We are Teaching Engineering Students What They Need to Know, Aren't We?**
  Tomorrow, 8:00–9:45 am, La Espada (W1E); H. Matusovich, R. Streveler, R. Miller

Selected APS findings: Successful engineering students

- Learning skills and language of engineering, *e.g.*, teamwork, communication
- Becoming more confident with design
- Developing identity as engineers
- Better understanding what engineers do, *e.g.*, through co-ops, internships
- Good persistence rates, but little in-migration

Selected APS findings:
Challenges

- Heavy workload, competitive culture
- Disconnect between early math/science courses and "real engineering"
- Difficult transition from individual work on "textbook" problems to teaming on open-ended problems
- Gendered experiences, confidence

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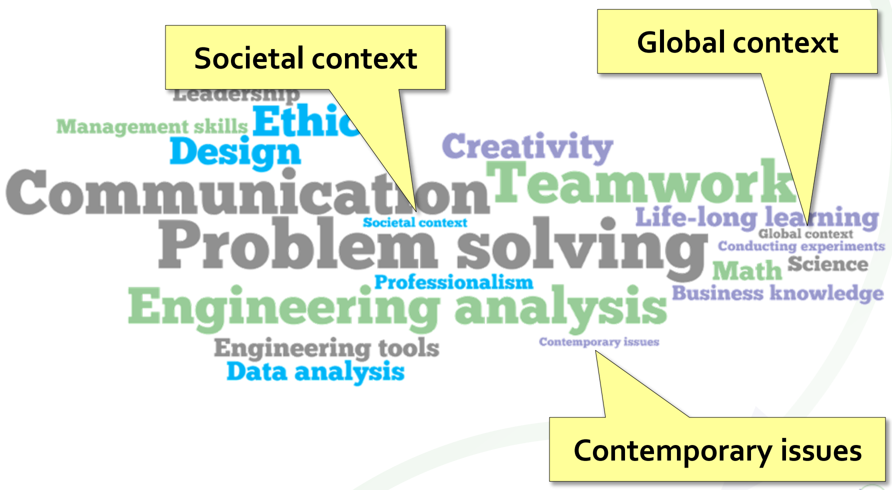
Which three are the most important?

Contemporary issues	**Life-long learning**
Societal context	**Data analysis**
Global context	**Math**
Conducting experiments	**Creativity**
Professionalism	**Design**
Management skills	**Ethics**
Science	**Engineering analysis**
Business knowledge	**Teamwork**
Leadership	**Communication**
Engineering tools	**Problem solving**

Importance (seniors)



Preparedness
(seniors, self-report)

Global context

Contemporary issues

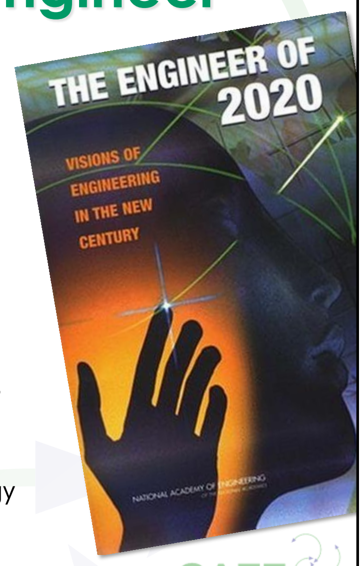
Societal context

The well-rounded engineer

- Understanding engineering as discipline and profession
- Life-long learning

  "...the engineer of 2020 will learn continuously throughout his or her career, not just about engineering but also about history, politics, business, and so forth."
- Consideration of broader context

  "Successful engineers in 2020 will, as they always have, recognize the broader contexts that are intertwined in technology and its application in society."

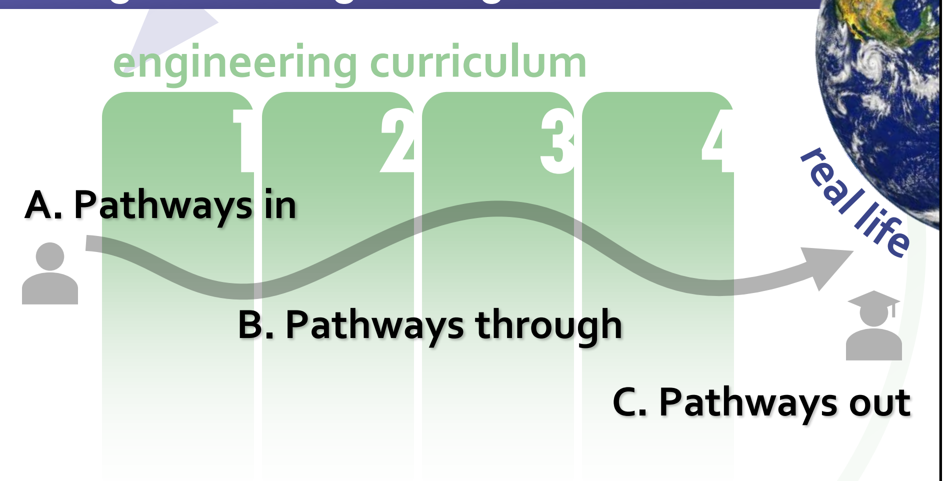


Research methods & samples

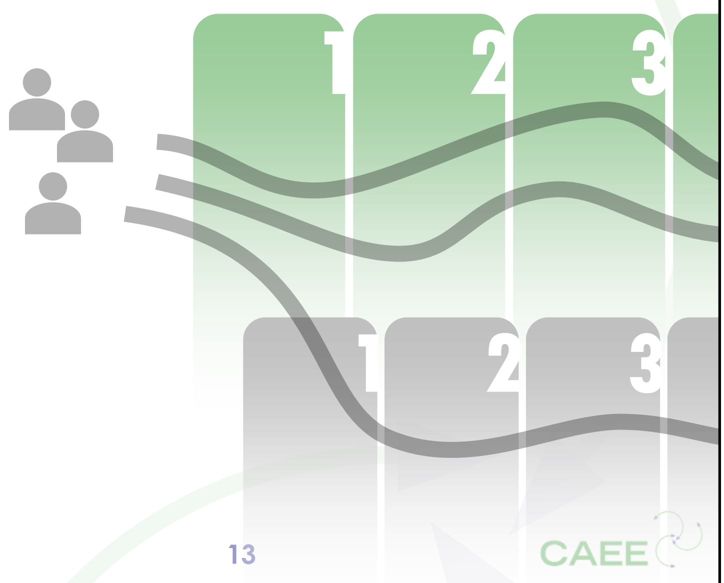
- **N NSSE national sample (2002, 2006–2007)**
  - National Survey of Student Engagement
  - *N* = 11,819; matched pairs (first-year and senior) from 247 institutions
- **L Longitudinal cohort (2003–2007)**
  - Surveys, structured interviews, ethnographic interviews and observations, engineering design tasks
  - *N* ≈ 160,* from four campuses
- **B Broad national sample (Spring 2008)**
  - APPLES2 survey
  - *N* = 4,266,* cross-sectional sample from 21 engineering colleges
- **W Workplace cohort (2007)**
  - Interviews
  - N = 17, early-career engineers at a U.S.-based, global manufacturer

*Oversampled for underrepresented groups

Undergraduate engineering education



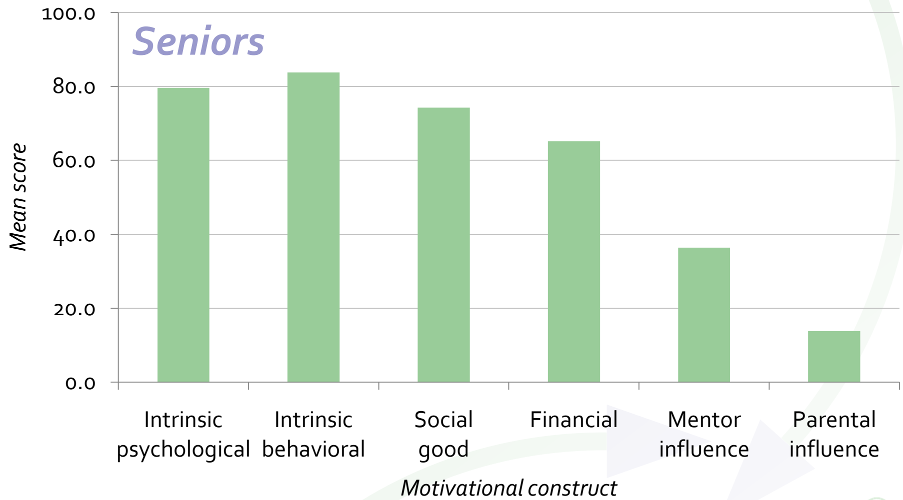
A. Pathways in



Outline

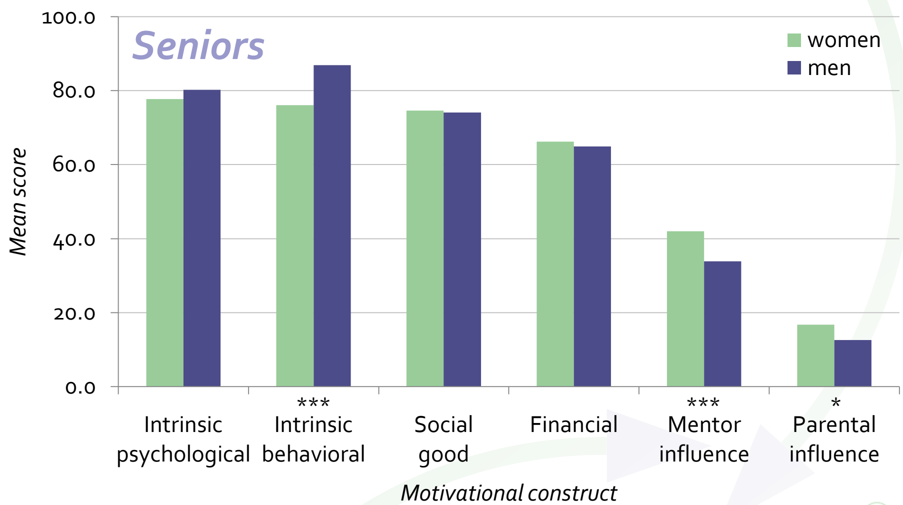
- A. Pathways in
  - Student motivation
- B. Pathways through
  - 1. What we offer
  - 2. What students learn
- C. Pathways out
  - Career choices
  - Early-career engineers

Motivation to study engineering



N = 1,130

Motivation to study engineering



*$p < 0.05$, ***$p < 0.001$; $N = 326$ women + 795 men

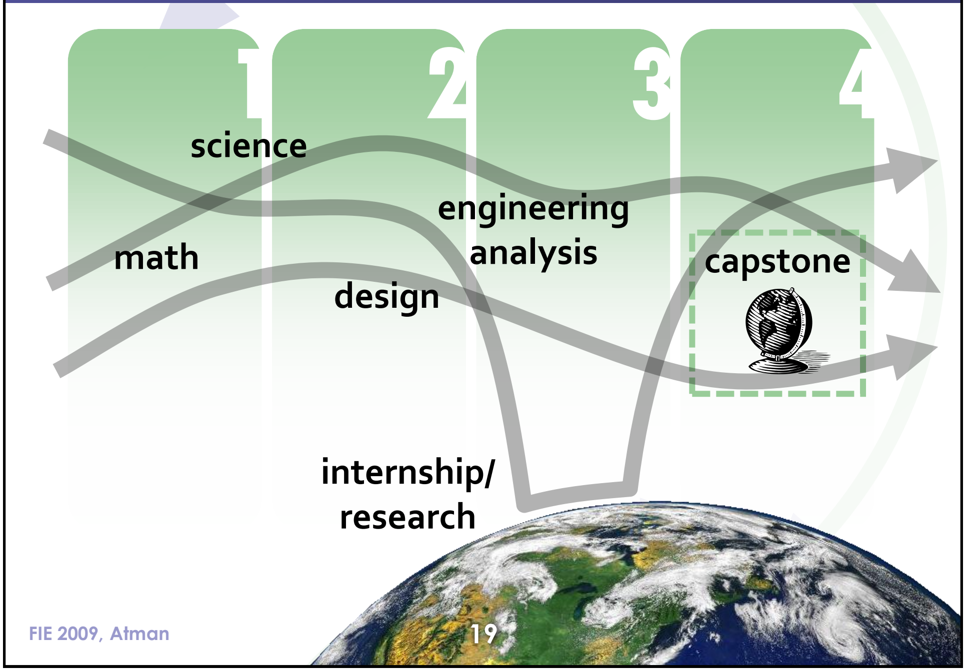
RECAP:
Student motivation

- Engineering majors are motivated in part by the opportunity to be well-rounded.
  - Social good
  - Potentially part of intrinsic psychological, behavioral

DISCUSSION:
Pathways in

Do these findings match your experiences on your campus?

B. Pathways through



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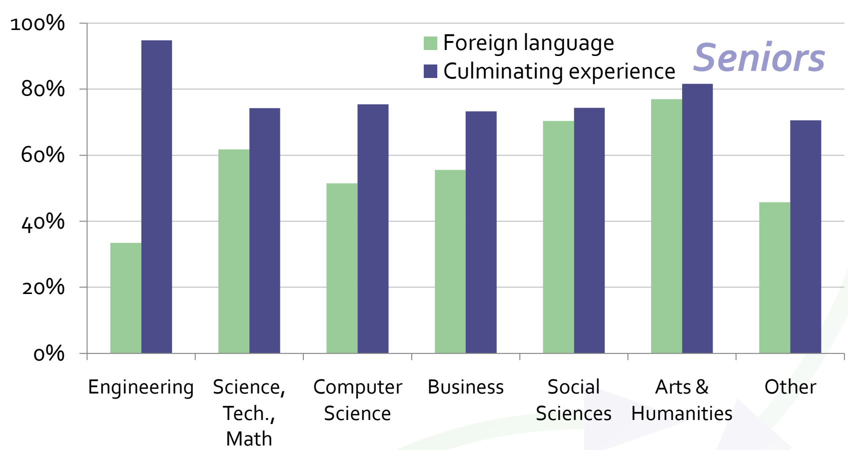
Engineering *vs.* other majors:
Educational experiences (seniors)

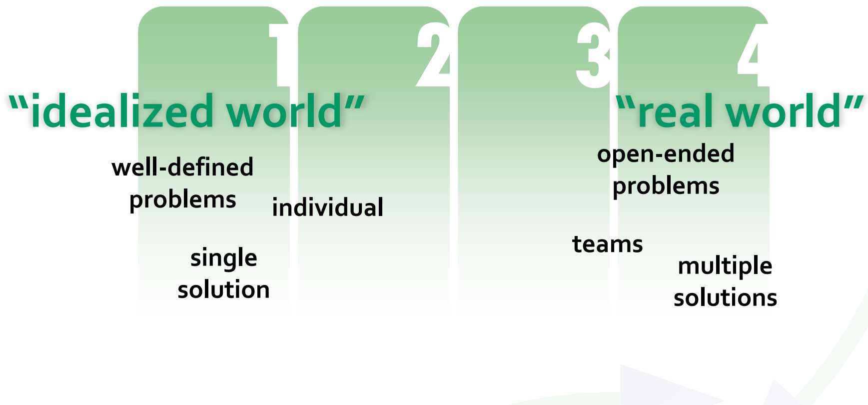
HIGH		LOW	
Culminating senior experience	95%	Study abroad	22%
Practicum/co-op/ internship/field experience	86%	Indep. study/self-designed major	23%
		Foreign language coursework	34%

(% engineering seniors)

Engineering *vs.* other majors:
Educational experiences



What counts as engineering?



RECAP:
What we offer

- Compared with other majors, we offer more opportunities for practice, but place less emphasis on opportunities for a well-rounded education.
- The structure of our curriculum often begins with “idealized world” that doesn’t necessarily require well-roundedness, and doesn’t get to “real world” which requires well-roundedness until the later years.

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N

Engineering *vs.* other majors: Engagement and outcomes scales

HIGH		LOW	
FY higher order thinking practices	71	FY gains, gen ed	62
FY gains, practical competence	73	Sr gains, personal & social developm't	49
Sr gains, practical competence	82	Sr integrative learning practices	55
		Sr reflective learning practices	54

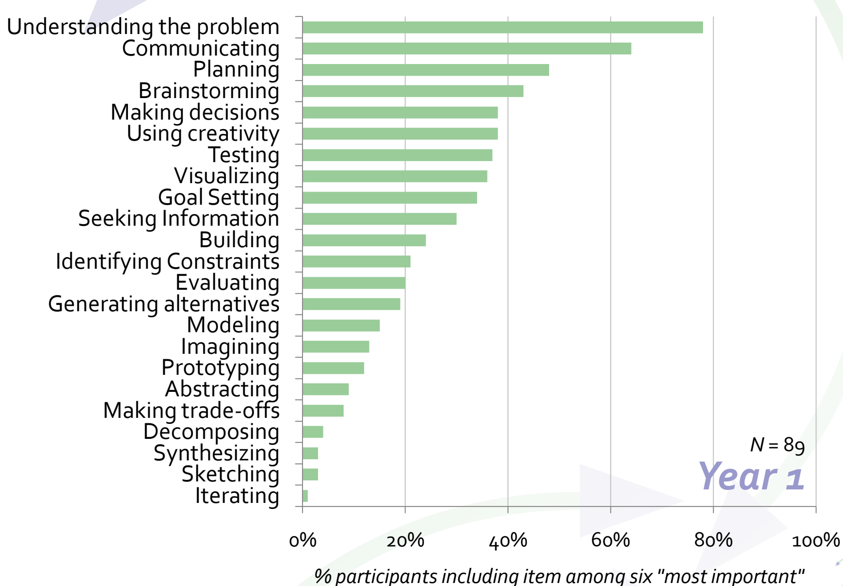
(0–100 scale)

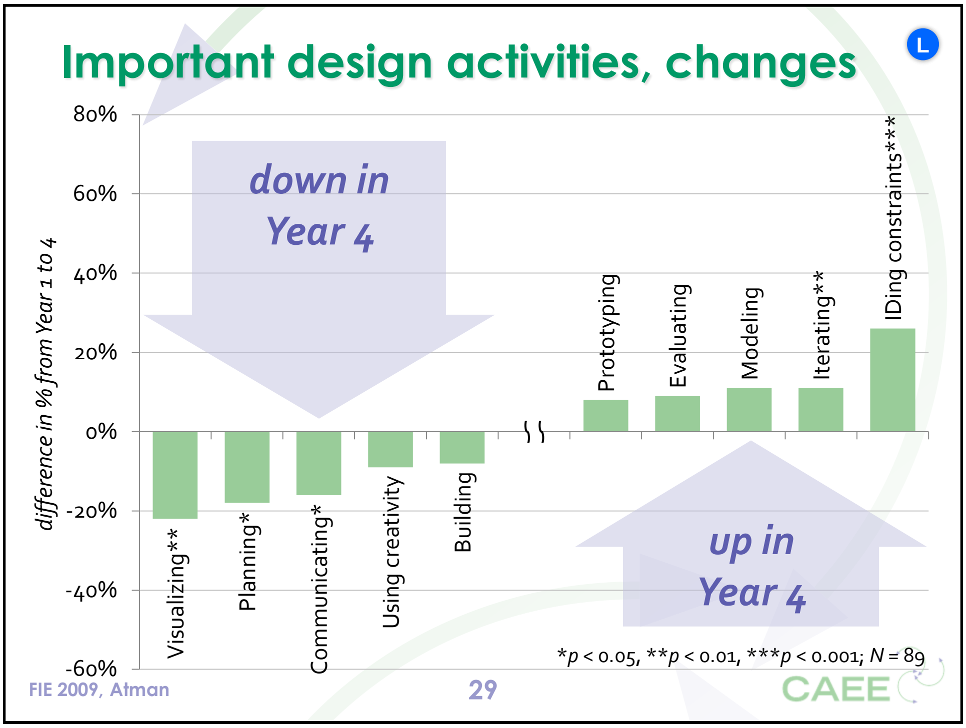
Important design activities

"Of the twenty-three design activities below, please put a check mark next to the SIX MOST IMPORTANT:

- ❑ Abstracting
- ❑ Brainstorming
- ❑ Building
- ❑ Communicating
- ❑ Decomposing
- ❑ Evaluating
- ❑ Generating alternatives
- ❑ Goal setting
- ❑ Identifying constraints
- ❑ Imagining
- ❑ Iterating
- ❑ Making trade-offs
- ❑ Modeling
- ❑ Planning
- ❑ Prototyping
- ❑ Seeking information
- ❑ Sketching
- ❑ Synthesizing
- ❑ Testing
- ❑ Understanding the problem
- ❑ Using creativity
- ❑ Visualizing

Important design activities




Important design activities, changes
L
80%
60%
40%
20%
0%
-20%
-40%
-60%
difference in % from Year 1 to 4
down in Year 4
up in Year 4
Visualizing**
Planning*
Communicating*
Using creativity
Building
Prototyping
Evaluating
Modeling
Iterating**
IDing constraints***
*p < 0.05, **p < 0.01, ***p < 0.001; N = 89
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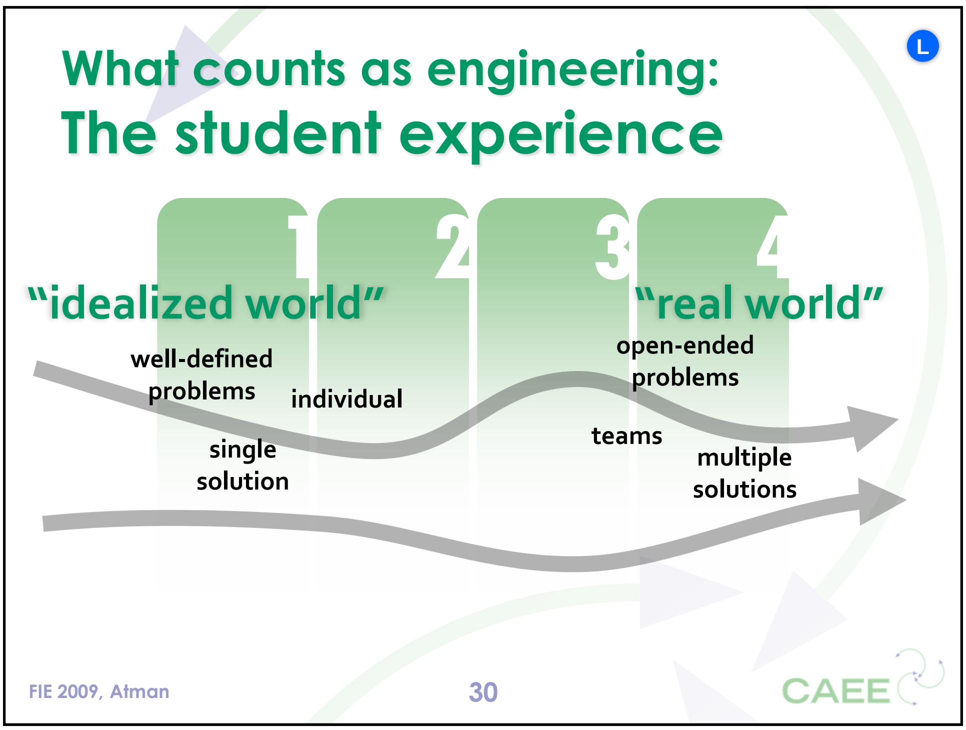
What counts as engineering:
The student experience
L
1
2
3
4
"idealized world"
"real world"
well-defined problems
individual
single solution
open-ended problems
teams
multiple solutions
FIE 2009, Atman
30
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Alternating design tasks

1. Midwest floods
2. Street crossing
3. Midwest floods
4. Street crossing

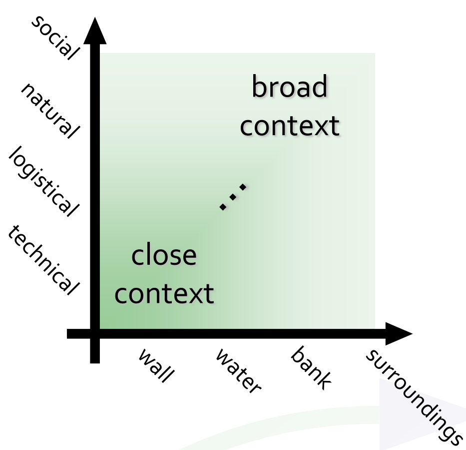
Midwest floods design task

10-minute, paper-and-pencil design 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?"

Year 3 floods task responses

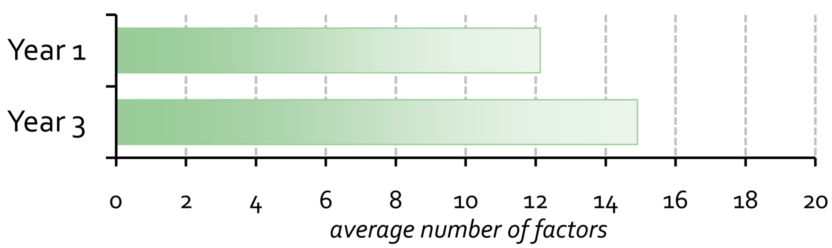
Floods coding scheme



Close/broad contextual factors

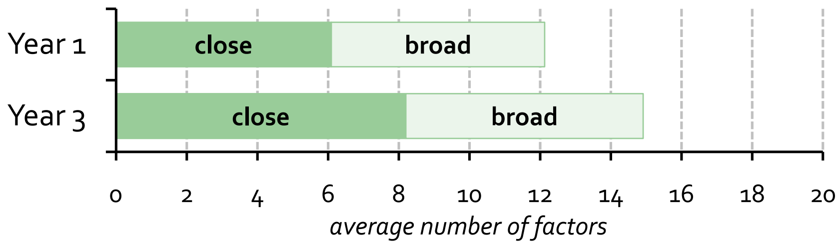
- **Broad context** factors: social, natural, riverbank, surroundings, *etc.*
  - "aesthetic appeal – is it going to draw local complaint?"
  - "the surrounding habitat – make sure little or no damage is done to the environment"
  - "would wall impact use of the river by industry?"
- **Close context** factors: technical, wall, logistical, water, *etc.*
  - "cost of materials"
  - "check the budget available for the operation"
  - "how to contain the river water that has flooded out"

More factors in Year 3



N = 69 (longitudinal sample)
p < 0.001 (total factors)

More close context in Year 3

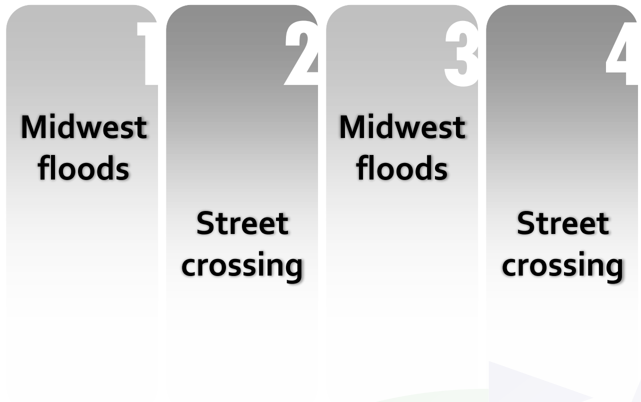


N = 69 (longitudinal sample)
p < 0.001 (total factors and close context factors)

Gender differences

- Important design activities
  - Women were less likely to select *Building*, more likely to select *Seeking information* and *Goal setting*.
- Midwest floods
  - Women cited more factors than men.
  - Specifically, women cited more *broad context* factors than men.

Alternating design tasks



RECAP:

What we offer, what students learn

- Just as they are given more opportunities to practice than other majors…

  …students report greater gains in practical competence.

- Just as opportunities to become well-rounded are not emphasized…

  …students report fewer gains in areas related to well-roundedness (*e.g.*, life-long learning skills, personal development).

RECAP:
What we offer, what students learn

- Reflecting the trajectory of their curriculum, from "idealized world" to "real world," from well-defined problems to more open-ended design…

  …students develop in their use of the language of engineering and design

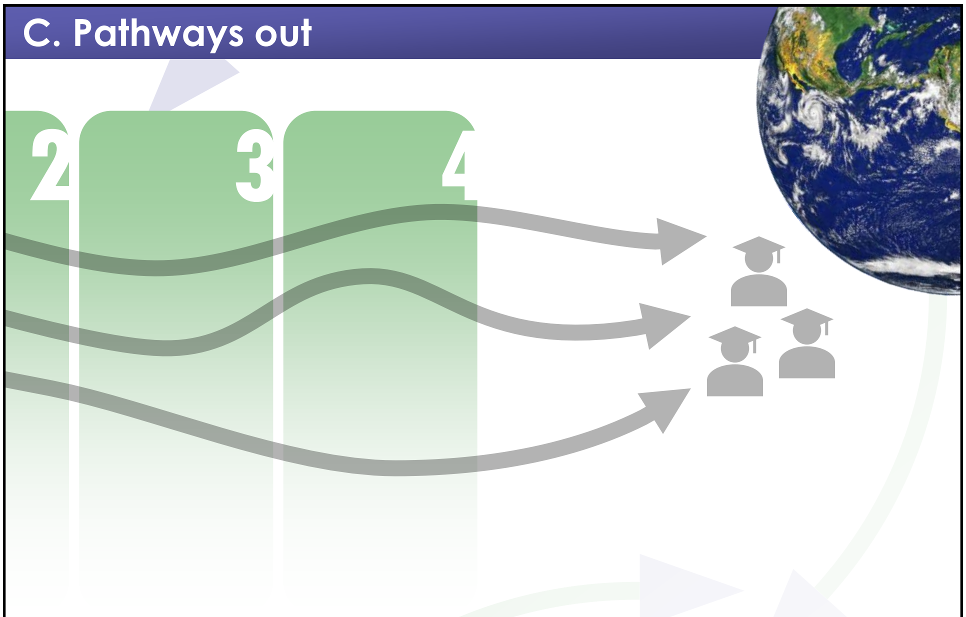
- Reflecting the emphasis on practical competence relative to well-roundedness…

  …students may not exhibit adequate attention to context when engaged in design.

DISCUSSION:
Pathways through

Do these findings match your experiences on your campus?

C. Pathways out



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  - **Early-career engineers**

Career choices

- Students who complete a major in engineering are not necessarily committed to careers in engineering or even STEM.
- Commitment to engineering career after graduation varies with institution.
- Student career decisions strongly swayed by specific, significant experience, *e.g.*, internship, faculty interaction, mentor advice.

Early career engineers

- Perception of not doing a lot of "real engineering"

  "I don't feel like I've had to actually do engineering"
- Problems highly uncertain, ambiguous, complex

  "In the real world, it's a lot more difficult to model things…There's a lot more variables involved…"
- More practical, hands-on work

  "There's no mathematical formula you could use, like you would in school…"

RECAP:
Pathways out

- Graduates don't always choose engineering careers
- When they do, they don't always feel well-rounded enough

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1 2 3 4

Supporting student pathways

L

Student voices:
Significant learning opportunities

- Relevant and meaningful (applicable, experiential, real-world, hands-on)
- Challenge, conflict, dilemma, frustration, and/or obstacles
- Promotes self-directed learning
- Student ownership of the experience
- Facilitates a broader vision, shows how the pieces fit together

B

Senior-year setbacks

Compared with first-years, seniors...

- ...are less involved in engineering courses.
- ...interact more frequently with instructors.
- ...are less satisfied with instructors.
- ...are less satisfied with their college experiences.

The well-rounded engineer

- Understanding engineering as discipline and profession
- Life-long learning

  "...the engineer of 2020 will learn continuously throughout his or her career, not just about engineering but also about history, politics, business, and so forth."

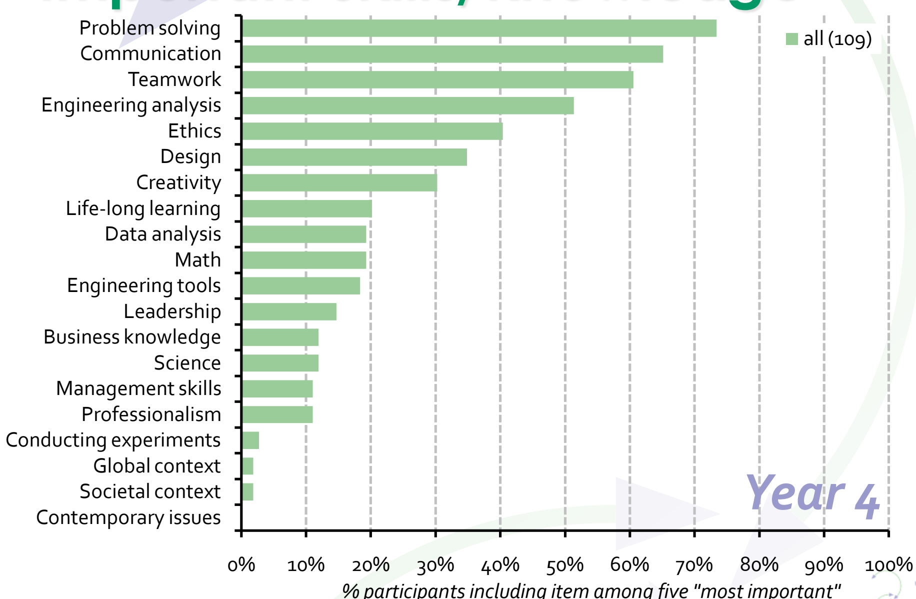
- Consideration of broader context

  "Successful engineers in 2020 will, as they always have, recognize the broader contexts that are intertwined in technology and its application in society."

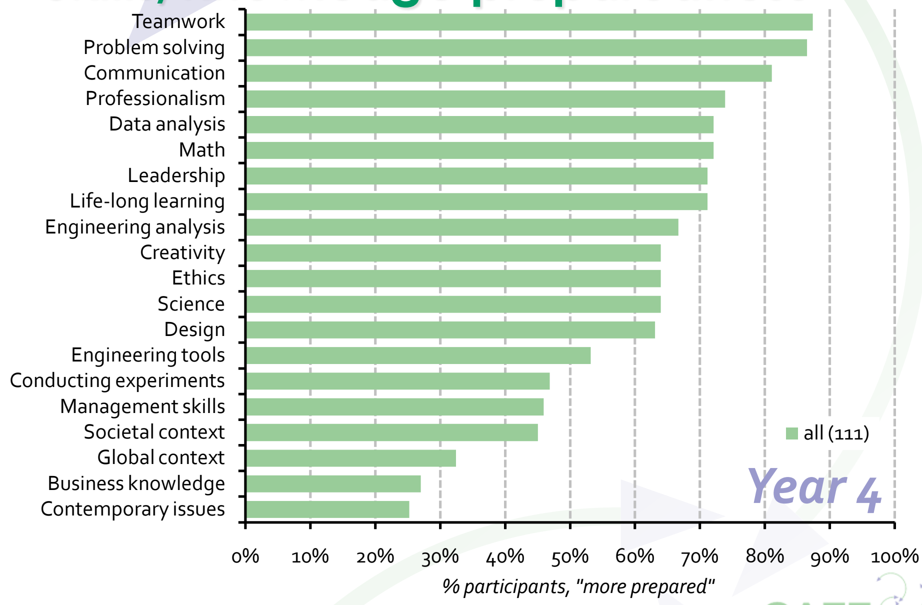
Recalling the large list of learning outcomes

- Contemporary issues
- Societal context
- Global context
- Conducting experiments
- Professionalism
- Management skills
- Science
- Business knowledge
- Leadership
- Engineering tools
- Life-long learning
- Data analysis
- Math
- Creativity
- Design
- Ethics
- Engineering analysis
- Teamwork
- Communication
- Problem solving

Important skills/knowledge



Skills/knowledge preparedness



Campuses responding

- Bringing understanding of real engineering to the early years…
  - Enabling *informed* choices (major, career)
  - Enabling students who care about social good and broader goals to see that they fit
- Empowering students to *own* their learning, become life-long learners
- Helping students develop "interdisciplinary respect"

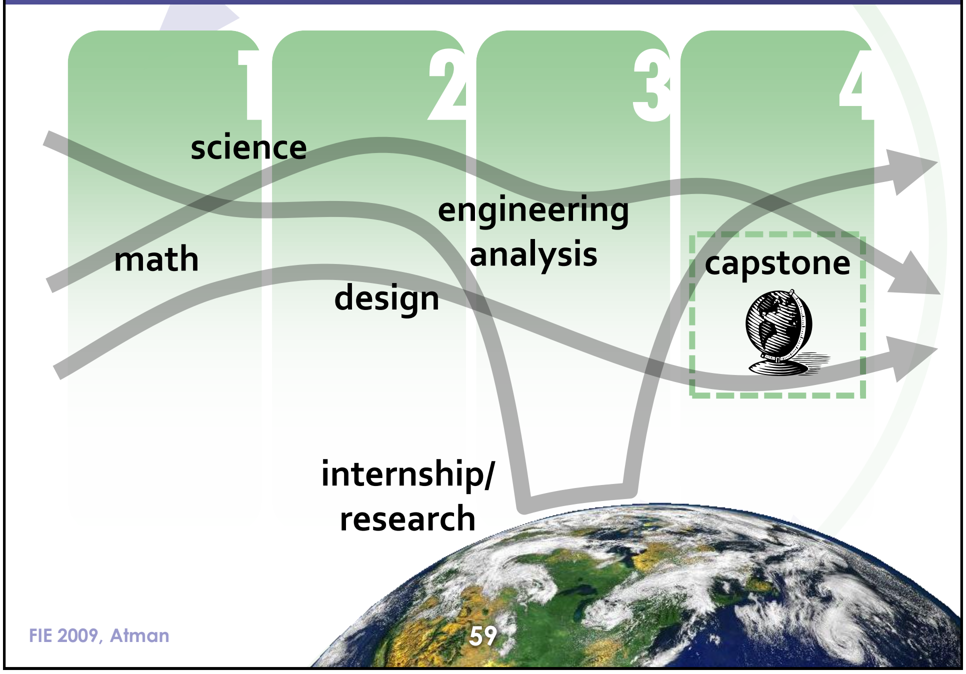
Campuses responding

- Helping faculty and administrators recognize…
  - that listening to students is important,
  - that what we assess signals what we value, and
  - that when we reinforce one narrow model of engineering, we lose important voices and talent.

DISCUSSION

How are you supporting student pathways on your campus?

Many pathways



Paving walkways

- Student experiences vary widely.
- It is important to support the many pathways that students take.

Building sidewalks where paths are worn

Selected APS references

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