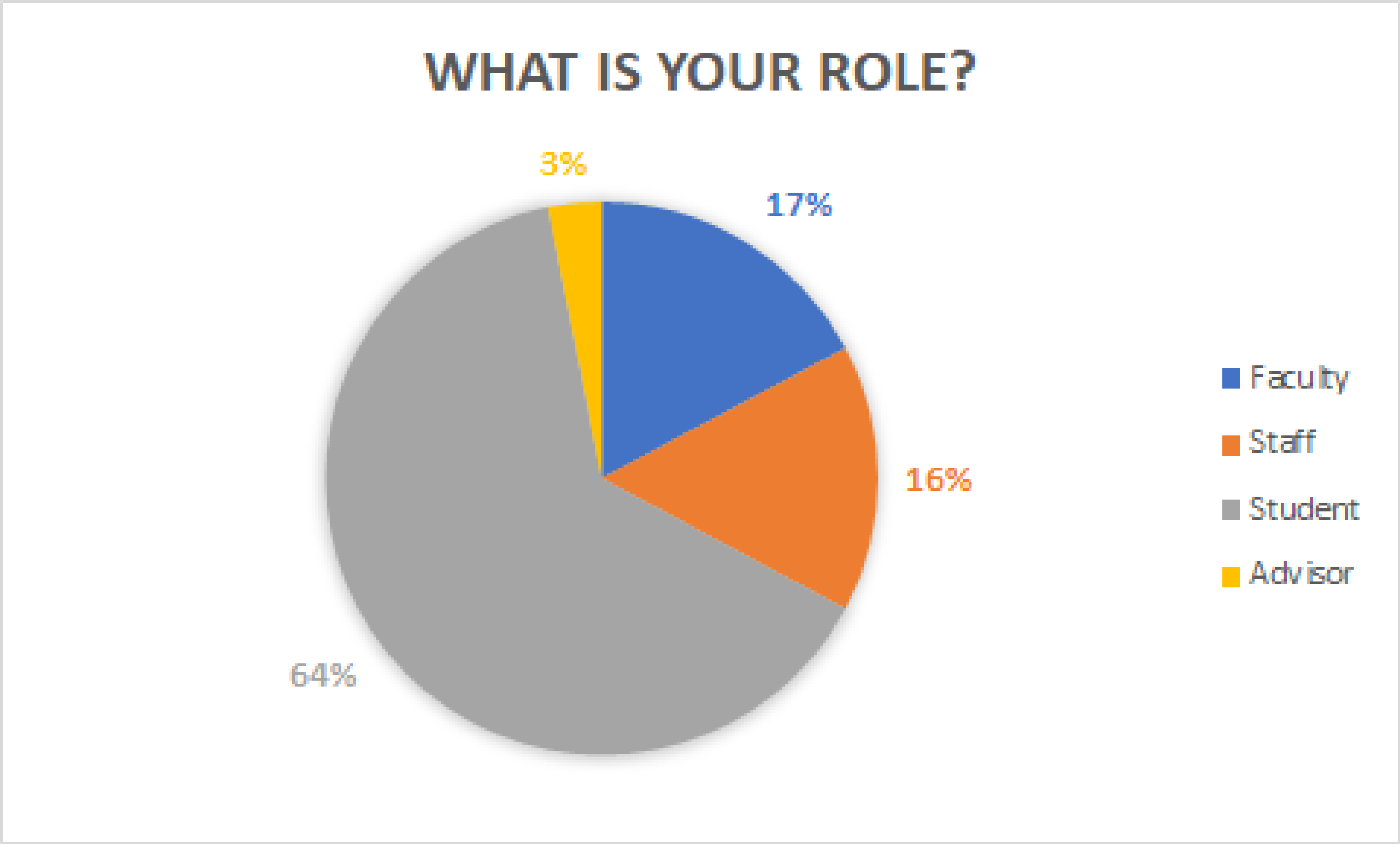
Learning in the Time of Coronavirus
Keynote: International Symposium on Engineering Education

Karl A. Smith
Engineering Education – Purdue University
& Civil, Environmental and Geo-Engineering – University of Minnesota
ksmith@umn.edu
https://karlsmithmn.org/

Poll: Participant Roles



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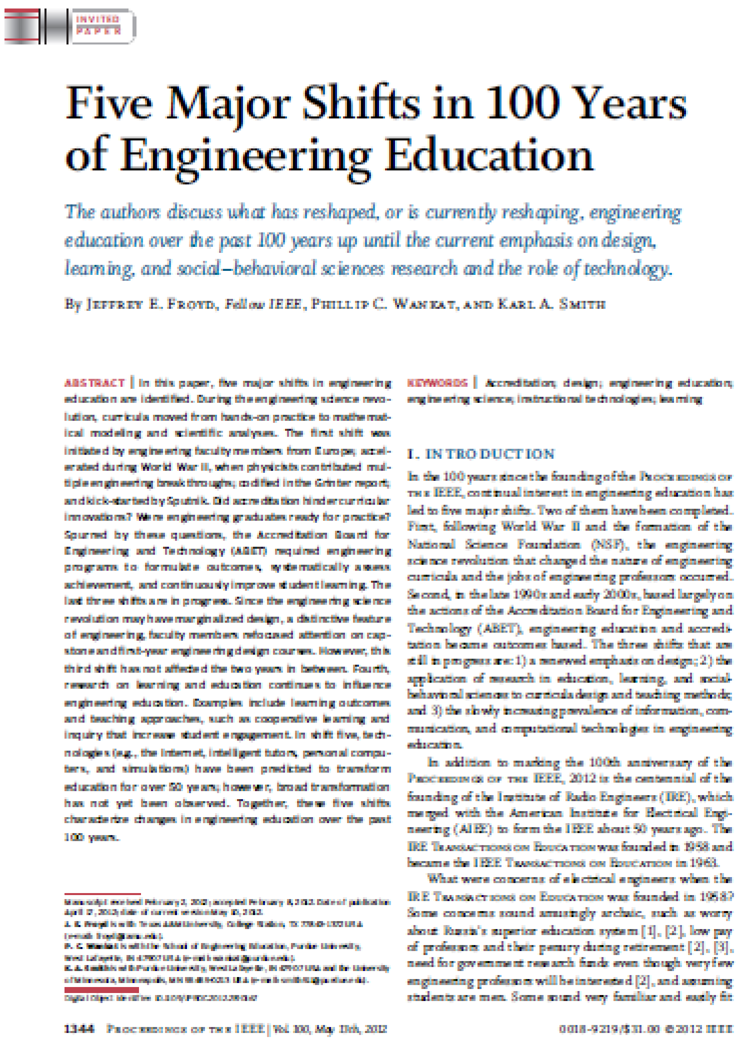


INVITED PAPER

Five Major Shifts in 100 Years of Engineering Education

The authors discuss what has reshaped, or is currently reshaping, engineering education over the past 100 years up until the current emphasis on design, learning, and social–behavioral sciences research and the role of technology.

By Jeffrey E. Froyd, *Fellow IEEE*, Phillip C. Wankat, and Karl A. Smith

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 social-behavioral sciences research**;
5. a shift to integrating information, computational, and communications technology in education.

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

Previous Shifts

- Were prompted by outside forces
- Were met with resistance
- Were eventually embraced (to varying degrees)
- They did not change core values/practices

Studies of Engineering Education

- Mann, Charles Riborg. 1918. "A Study of Engineering Education." Carnegie Foundation for the Advancement of Teaching, New York.
- Society for the Promotion of Engineering Education. 1930. "Report of the Investigation of Engineering Education 1923-1929."Pittsburgh, PA. (Wickenden Report)
- Hammond Report. 1940.
- Report on Evaluation of Engineering Education. 1955. (Grinter)
- Goals Committee. 1968. "Goals of Engineering Education: Final Report of the Goals Committee." American Society for Engineering Education, Washington DC.
- Engineering Education for a Changing World. 1994. (Green)

https://www.asee.org/member-resources/reports

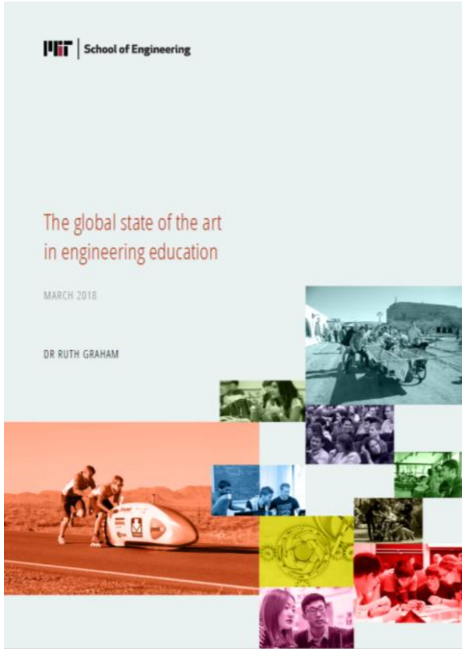
Mann Report (1918) Principal Points

- Waste occurring in educational efforts arising from lack of coordination
- Regulation of admission – At present sixty percent of those who enter fail to graduate
- Packed curriculum and lock-step course sequences
- Necessity of a common core
- Emphasize the problems of values and costs

Global Calls for Reform

K-12 Engineering

Research-based Transformation



- What is the future direction for the engineering education sector?
  - The **first anticipated trend** is a tilting of the global axis of engineering education leadership.
  - The **second anticipated trend** is a move towards socially-relevant and outward-facing engineering curricula.
  - The **third anticipated trend** for the sector is therefore the emergence of a new generation of leaders in engineering education that delivers integrated student-centered curricula at scale.

"This is the future of the field, where you put the student at the center and use the resources to facilitate team projects and authentic experiences, and then put the taught curriculum online."

https://jwel.mit.edu/sites/mit-jwel/files/assets/files/neet_global_state_of_eng_edu_180330.pdf

INSIGHTS

Despite numerous calls to improve student engagement, supported by a large body of evidence, STEM classes are often still dominated by lectures.

SCIENCE EDUCATION

Anatomy of STEM teaching in North American universities

Lecture is prominent, but practices vary

By **M. Stains, J. Harshman, M. K. Barker, S. V. Chasteen, R. Cole, S. E. DeChenne-Peters, M. K. Eagan Jr., J. M. Esson, J. K. Knight, F. A. Laski, M. Levis-Fitzgerald, C. J. Lee, S. M. Lo, L. M. McDonnell, T. A. McKay, N. Michelotti, A. Musgrove, M. S. Palmer, K. M. Plank, T. M. Rodela, E. R. Sanders, N. G. Schimpf, P. M. Schulte, M. K. Smith, M. Stetzer, B. Van Valkenburgh, E. Vinson, L. K. Weir, P. J. Wendel, L. B. Wheeler, A. M. Young**

A large body of evidence demonstrates that strategies that promote student interactions and cognitively engage students with content (*1*) lead to gains in learning and attitudinal outcomes for students in science, technology, engineering, and mathematics (STEM) courses (*1*, *2*). Many educational and governmental bodies have called for and supported adoption of these student-centered strategies throughout the undergraduate STEM curriculum. But to the extent that we have pictures of the STEM undergraduate instructional landscape, it has mostly been provided through self-report surveys of faculty members, within a particular STEM discipline [e.g., (*3*–*6*)]. Such surveys are prone to reliability threats and can underestimate the complexity of classroom environments, and few are implemented nationally to provide valid and reliable data (*7*). Reflecting the limited state of these data, a report from the U.S. National Academies of Sciences, Engineering, and Medicine called for improved data collection to understand the use of evidence-based instructional practices (*8*). We report here a major step toward a characterization of STEM teaching practices in North American universities based on classroom observations from over 2000 classes taught by more than 500 STEM faculty members across 25 institutions.

Our study used the Classroom Observation Protocol for Undergraduate STEM (COPUS) (*9*), which can provide consistent assessment of instructional practices and document impacts of educational initiatives. COPUS requires documenting the co-occurrence of 13 student behaviors (e.g., listening, answering questions) and 12 instructor behaviors (e.g., lecturing, posing questions) during each 2-min interval of a class. Our large-scale COPUS data allow generalizations beyond institution-level descriptions and suggest an opportunity to resolve inconsistent findings from recent discipline-based education research (DBER) studies. For example, STEM faculty report that it is more difficult to use student-centered techniques in large classrooms or less amenable physical layouts (*10*),

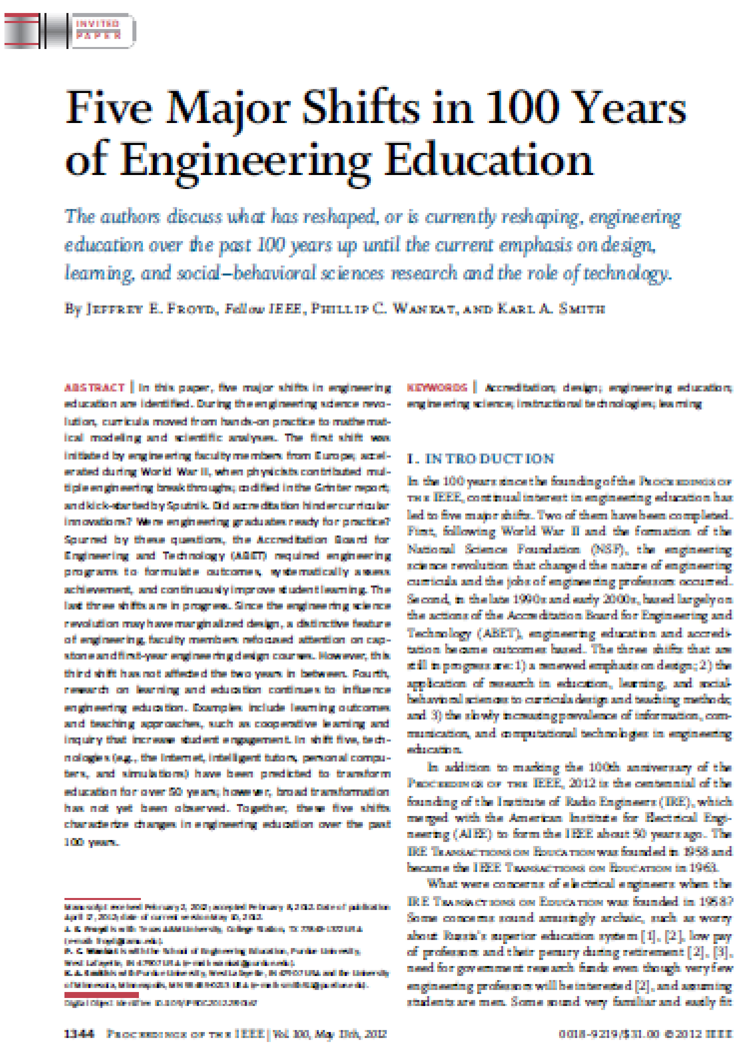
The list of author affiliations is provided in the supplementary materials. Email: mstains2@unl.edu

Published by AAAS

Observational study of over 2000 classes – most common behaviors:

- Faculty
  - Lecturing
  - Writing in real time
  - Posing nonrhetorical questions
  - Following-up on questions
  - Answering student questions
  - Clicker questions
- Students
  - Listening to instructor
  - Answering instructor questions
  - Asking questions

http://science.sciencemag.org/content/sci/359/6383/1468.full.pdf


INVITED PAPER

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ABSTRACT | In this paper, five major shifts in engineering education are identified. During the engineering science revolution, curricula moved from hands-on practice to mathematical modeling and scientific analyses. The first shift was initiated by engineering faculty members from Europe, accelerated during World War II, when physicists contributed multiple engineering breakthroughs, codified in the Grinter report, and kick-started by Sputnik. Did accreditation hinder curricular innovations? Were engineering graduates ready for practice? Spurred by these questions, the Accreditation Board for Engineering and Technology (ABET) required engineering programs to formulate outcomes, systematically assess achievement, and continuously improve student learning. The last three shifts are in progress. Since the engineering science revolution may have marginalized design, a distinctive feature of engineering, faculty members refocused attention on capstone and first-year engineering design courses. However, this third shift has not affected the two years in between. Fourth, research on learning and education continues to influence engineering education. Examples include learning outcomes and teaching approaches, such as cooperative learning and inquiry that increase student engagement. In shift five, technologies (e.g., the Internet, intelligent tutors, personal computers, and simulations) have been predicted to transform education for over 50 years; however, broad transformation has not yet been observed. Together, these five shifts characterize changes in engineering education over the past 100 years.

KEYWORDS | Accreditation; design; engineering education; engineering science; instructional technologies; learning

I. INTRODUCTION

In the 100 years since the founding of the Proceedings of the IEEE, continual interest in engineering education has led to five major shifts. Two of them have been completed. First, following World War II and the formation of the National Science Foundation (NSF), the engineering science revolution that changed the nature of engineering curricula and the jobs of engineering professors occurred. Second, in the late 1990s and early 2000s, based largely on the actions of the Accreditation Board for Engineering and Technology (ABET), engineering education and accreditation became outcomes based. The three shifts that are still in progress are: 1) a renewed emphasis on design; 2) the application of research in education, learning, and social-behavioral sciences to curricula design and teaching methods; and 3) the slowly increasing prevalence of information, communication, and computational technologies in engineering education.

In addition to marking the 100th anniversary of the Proceedings of the IEEE, 2012 is the centennial of the founding of the Institute of Radio Engineers (IRE), which merged with the American Institute for Electrical Engineering (AIEE) to form the IEEE about 50 years ago. The IRE Transactions on Education was founded in 1958 and became the IEEE Transactions on Education in 1963.

What were concerns of electrical engineers when the IRE Transactions on Education was founded in 1958? Some concerns sound amusingly archaic, such as worry about Russia's superior education system [1], [2], low pay of professors and their penury during retirement [2], [3], need for government research funds even though very few engineering professors will be interested [2], and assuming students are men. Some sound very familiar and easily fit

1. a shift from hands-on and practical emphasis to engineering science and analytical emphasis;
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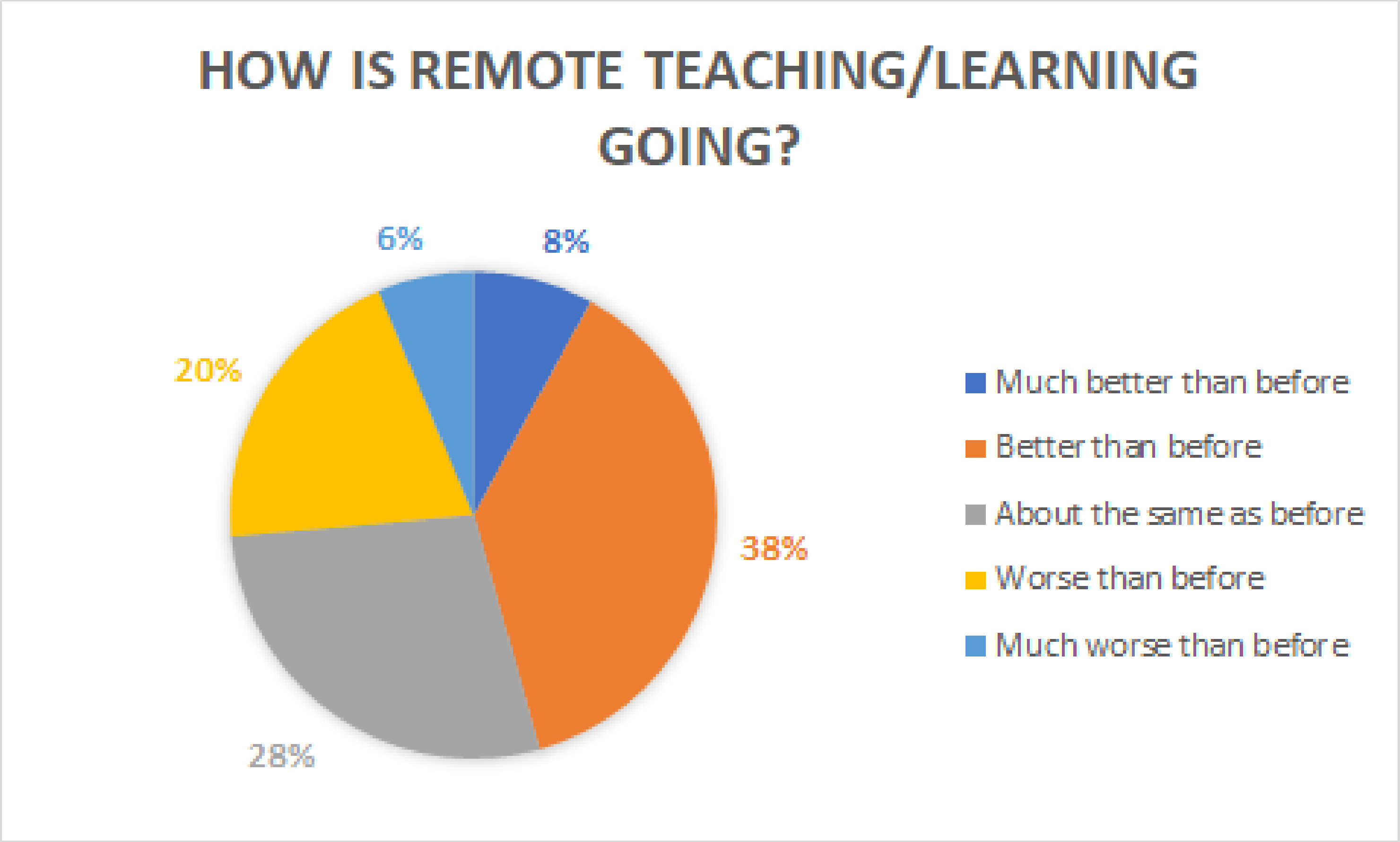
4. **a shift to applying education, learning, and social-behavioral sciences research**;
5. a shift to integrating information, computational, and communications technology in education.

Current Shift – Remote Learning

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

Poll: How is remote teaching/learning going?



N = 125

Remote Learning: Emphasize Big Ideas (Enduring Outcomes)*

- How People Learn
- Streamlined Course Design
  - Alignment of Outcomes, Assessment and Instruction
- Interactive Learning

*See Streveler and Smith (2020), Course design in the time of coronavirus: Put on your designer's CAP. *Advances in Engineering Education*.

https://advances.asee.org/opinion-course-design-in-the-time-of-coronavirus-put-on-your-designers-cap/

Learning Requires*

deliberate

distributed

practice

***Thanks to Ruth Streveler for these slides**
Also see Brown, P.C., Henry L. Roediger III, H.L., & Mark A. McDaniel, M.A. (2014). *Make It Stick: The Science of Successful Learning*. Belknap Press: An Imprint of Harvard University Press

Key Implications

Deliberate

Attention must be paid

Attention and processing power = cognitive load (bandwidth)

- LIMITED – need to be careful how one uses the learner's bandwidth
  - Link to Curricular Priorities
- Continuous partial attention

- Reflection is needed
  - Need for feedback
    - Link to assessment

Key Implications

Distributed

Repetition <u>over time</u>
- Spaced vs. massed practice*
- Spiral curriculum**

Multiple modes of input
- Visual
- Audio
- Kinesthetic
- Self-explanation
- Explaining to others

*Kandel, E.B. 2007. In Search of Memory: The Emergence of a New Science of Mind. New York: Norton.

**a concept widely attributed to Jerome Bruner, refers to a curriculum design in which key concepts are presented repeatedly throughout the curriculum, but with deepening layers of complexity, or in different applications.

Key Implications

Practice what you want to learn

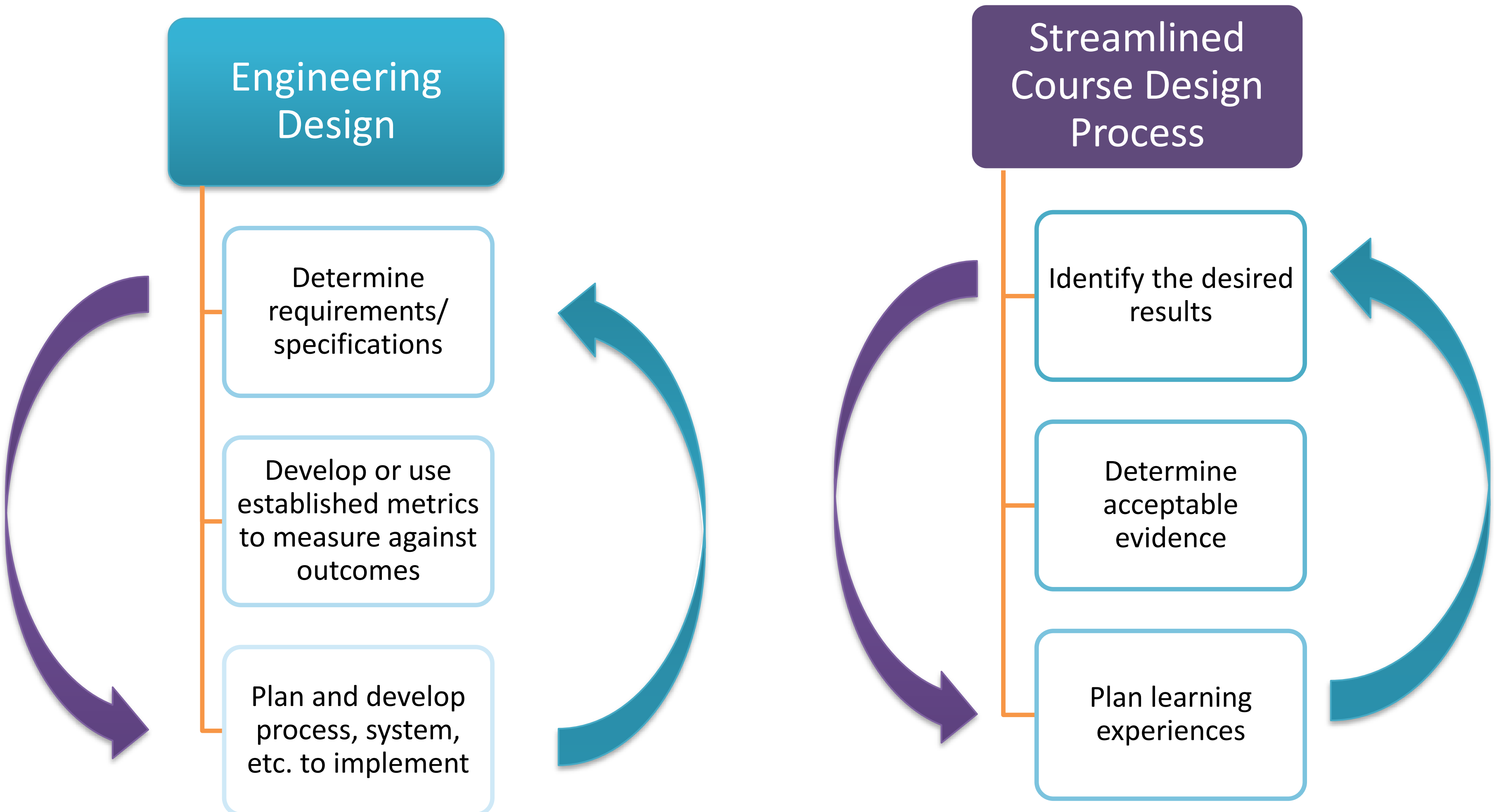
Attentive – doing something

Constructive – adding to your prior knowledge

Interactive – working with others to add to your prior knowledge

Chi, M.T.H. 2009. Active-Constructive-Interactive: A Conceptual Framework for Differentiating Learning Activities. *Topics in Cognitive Science 1*, 73–105.

The Engineering Design Process vs. Streamlined Course Design Process



"It could well be that faculty members of the twenty-first century college or university will find it necessary to set aside their roles as teachers and instead become **designers** of learning experiences, processes, and environments."

James Duderstadt, 1999
Nuclear Engineering Professor; Former Dean, Provost and President of the University of Michigan

I-C-A-P Framework

~~ACTIVE~~ ATTENTIVE	CONSTRUCTIVE	INTERACTIVE
Doing something physically Paying Attention	Producing outputs that go beyond presented information	Dialoguing substantively on the same topic, and not ignoring a partner's contribution
Engaging activities	Self-construction	Guided-construction
Attending processes	Creation processes	Joint creation processes

Interactive > Constructive > Attentive > Passive

ICAP framework, Michelene T.H. Chi

Chi, M.T.H. (2009). Active-Constructive-Interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science, 1*, 73-105

Cooperative Learning: An Evidence-Based Practice for Interactive Learning

Cooperative learning is instruction that involves people working in teams to accomplish a common goal, under conditions that involve both *positive interdependence* (all members must cooperate to complete the task) and *individual and group accountability* (each member is accountable for the complete final outcome).

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Cooperative Learning

Positive Interdependence

Goal Interdependence (essential)

1. All members show mastery
2. All members improve
3. Add group member scores to get an overall group score
4. One product from group that all helped with and can explain

Role (Duty) Interdependence

Assign each member a role and rotate them

Resource Interdependence

1. Limit resources (one set of materials)
2. Jigsaw materials
3. Separate contributions

Task Interdependence

1. Factory-line
2. Chain Reaction

Outside Challenge Interdependence

1. Intergroup competition
2. Other class competition

Identity Interdependence

Mutual identity (name, motto, etc.)

Environmental Interdependence

1. Designated classroom space
2. Group has special meeting place

Fantasy Interdependence

Hypothetical interdependence in situation ("You are a scientific/literary prize team, lost on the moon, etc.")

Reward/Celebration Interdependence

1. Celebrate joint success
2. Bonus points (use with care)
3. Single group grade (when fair to all)

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

Individual Accountability

Ways to ensure no slackers:

- Keep group size small (2-4)
- Assign roles
- Randomly ask one member of the group to explain the learning
- Have students do work before group meets
- Have students use their group learning to do an individual task afterward
- Everyone signs: "I participated, I agree, and I can explain"
- Observe & record individual contributions

Ways to ensure that all members learn:

- Practice tests
- Edit each other's work and sign agreement
- Randomly check one paper from each group
- Give individual tests
- Assign the role of **checker** who has each group member explain out loud
- Simultaneous explaining: each student explains their learning to a new partner

Face-to-Face Interaction

Structure:

- Time for groups to meet
- Group members close together
- Small group size of two or three
- Frequent oral rehearsal
- Strong positive interdependence
- Commitment to each other's learning
- Positive social skill use
- Celebrations for encouragement, effort, help, and success!

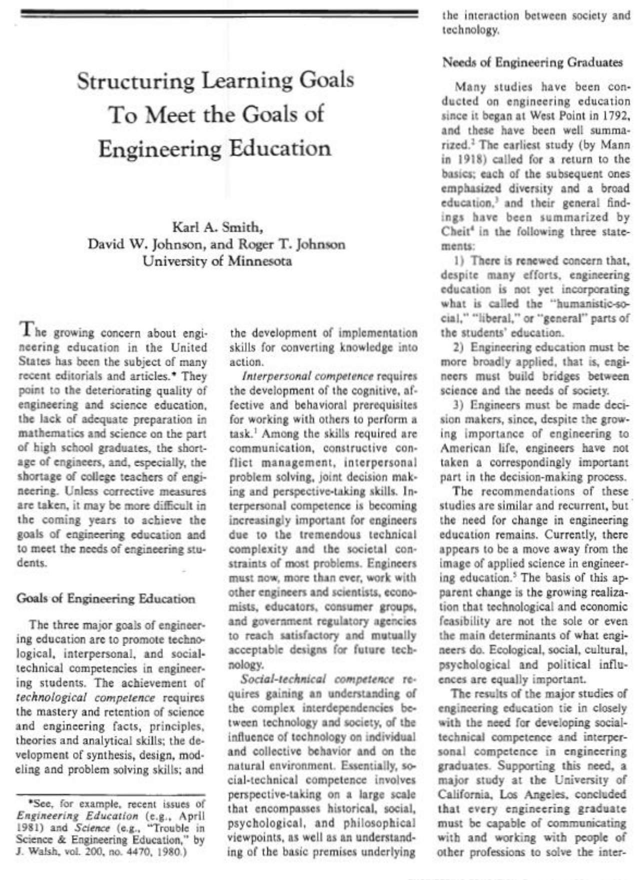
Key Concepts:

- **Positive Interdependence**
- **Individual and Group Accountability**
- Promotive Interaction (Face-to-Face)
- Teamwork Skills
- Group Processing

https://karlsmithmn.org/wp-content/uploads/2017/08/CLHks.pdf

Cooperative Learning Introduced to Engineering – 1981

Smith, K.A., Johnson, D.W. and Johnson, R.T., 1981. The use of cooperative learning groups in engineering education. In L.P. Grayson and J.M. Biedenbach (Eds.), *Proceedings Eleventh Annual Frontiers in Education Conference*, Rapid City, SD, Washington: IEEE/ASEE, 26-32.



Structuring Learning Goals To Meet the Goals of Engineering Education

Karl A. Smith,
David W. Johnson, and Roger T. Johnson
University of Minnesota

The growing concern about engineering education in the United States has been the subject of many recent editorials and articles.* They point to the deteriorating quality of engineering and science education, the lack of adequate preparation in mathematics and science on the part of high school graduates, the shortage of engineers, and, especially, the shortage of college teachers of engineering. Unless corrective measures are taken, it may be more difficult in the coming years to achieve the goals of engineering education and to meet the needs of engineering students.

Goals of Engineering Education

The three major goals of engineering education are to promote technological, interpersonal, and social-technical competencies in engineering students. The achievement of *technological competence* requires the mastery and retention of science and engineering facts, principles, theories and analytical skills; the development of synthesis, design, modeling and problem solving skills; and the development of implementation skills for converting knowledge into action.

Interpersonal competence requires the development of the cognitive, affective and behavioral prerequisites for working with others to perform a task.[1] Among the skills required are communication, constructive conflict management, interpersonal problem solving, joint decision making and perspective-taking skills. Interpersonal competence is becoming increasingly important for engineers due to the tremendous technical complexity and the societal constraints of most problems. Engineers must now, more than ever, work with other engineers and scientists, economists, educators, consumer groups, and government regulatory agencies to reach satisfactory and mutually acceptable designs for future technology.

Social-technical competence requires gaining an understanding of the complex interdependencies between technology and society, of the influence of technology on individual and collective behavior and on the natural environment. Essentially, social-technical competence involves perspective-taking on a large scale that encompasses historical, social, psychological, and philosophical viewpoints, as well as an understanding of the basic premises underlying the interaction between society and technology.

Needs of Engineering Graduates

Many studies have been conducted on engineering education since it began at West Point in 1792, and these have been well summarized.[2] The earliest study (by Mann in 1918) called for a return to the basics; each of the subsequent ones emphasized diversity and a broad education,[3] and their general findings have been summarized by Cheit[4] in the following three statements:

1) There is renewed concern that, despite many efforts, engineering education is not yet incorporating what is called the "humanistic-social," "liberal," or "general" parts of the students' education.

2) Engineering education must be more broadly applied, that is, engineers must build bridges between science and the needs of society.

3) Engineers must be made decision makers, since, despite the growing importance of engineering to American life, engineers have not taken a correspondingly important part in the decision-making process.

The recommendations of these studies are similar and recurrent, but the need for change in engineering education remains. Currently, there appears to be a move away from the image of applied science in engineering education.[5] The basis of this apparent change is the growing realization that technological and economic feasibility are not the sole or even the main determinants of what engineers do. Ecological, social, cultural, psychological and political influences are equally important.

The results of the major studies of engineering education tie in closely with the need for developing social-technical competence and interpersonal competence in engineering graduates. Supporting this need, a major study at the University of California, Los Angeles, concluded that every engineering graduate must be capable of communicating with and working with people of other professions to solve the inter-

*See, for example, recent issues of *Engineering Education* (e.g., April 1981) and *Science* (e.g., "Trouble in Science & Engineering Education," by J. Walsh, vol. 200, no. 4470, 1980.)

ENGINEERING EDUCATION: December 1981 / 221

https://karlsmithmn.org/wp-content/uploads/2017/08/Smith-Johnson-Johnson-Structuring_Learning-JEE-1981.pdf

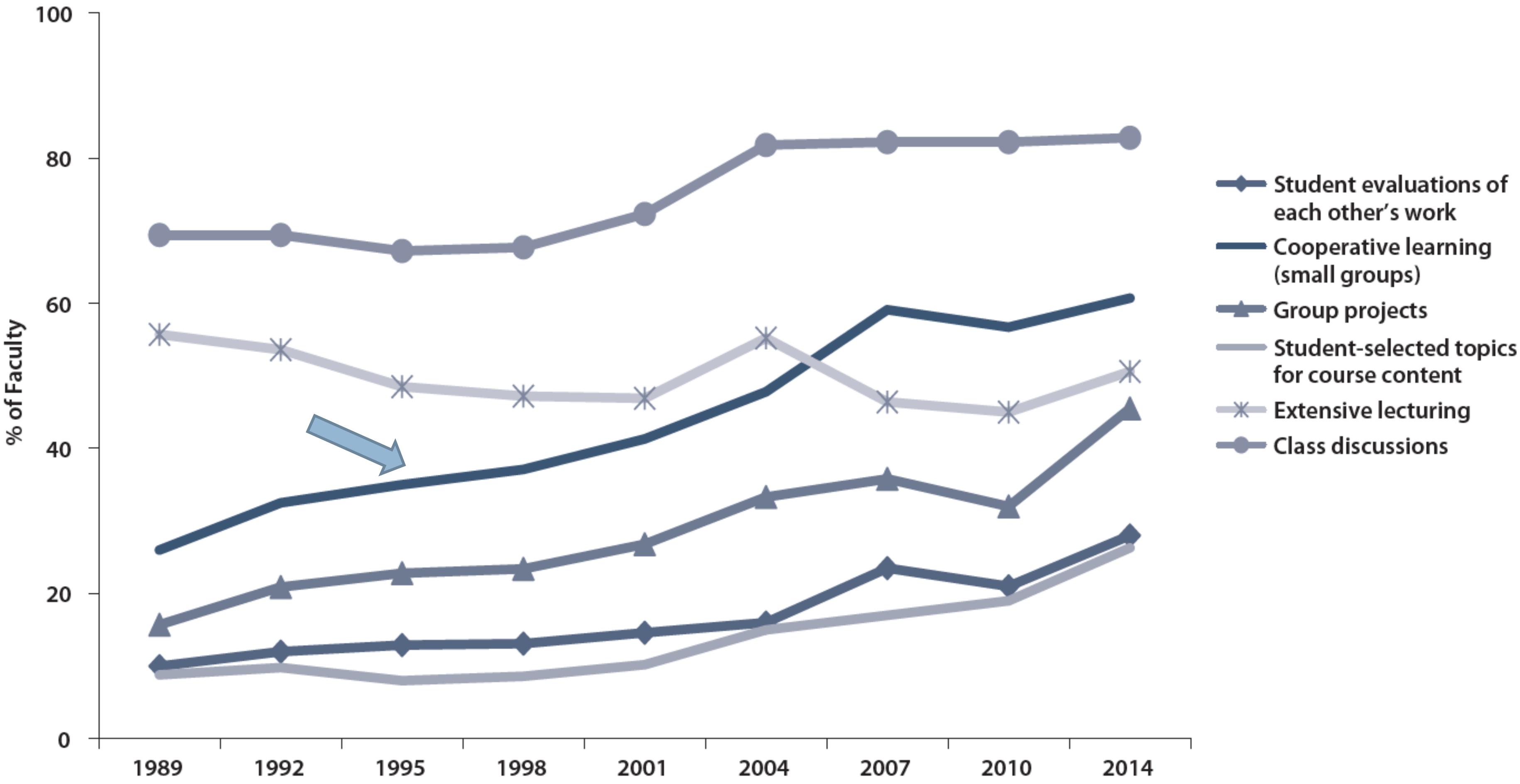
What Matters in College

- Environmental factors most predictive of positive change in students' academic development, personal development, and satisfaction:
  - **Interaction among students and**
  - **Interaction between faculty and students**

Astin (1985) *What Matters in College: Four Critical Years Revisited. Jossey-Bass*

Undergraduate Teaching Faculty: The 2013–2014 HERI Faculty Survey

Figure 2. Changes in Faculty Teaching Practices, 1989 to 2014
(% Marking "All" or "Most" Courses)



http://heri.ucla.edu/monographs/HERI-FAC2014-monograph.pdf

Undergraduate Teaching Faculty, 2011*

Methods Used in "All" or "Most"	STEM women	STEM men	All other women	All other men
Cooperative learning	60%	41%	72%	53%
Group projects	36%	27%	38%	29%
Grading on a curve	17%	31%	10%	16%
Student inquiry	43%	33%	54%	47%
Extensive lecturing	50%	70%	29%	44%

*Undergraduate Teaching Faculty. National Norms for the 2010-2011 HERI Faculty Survey, www.heri.ucla.edu/index.php.

Cooperative Learning: Lessons and Insights from Thirty Years of Championing a Research-Based Innovative Practice

Karl A. Smith
Purdue University & University of Minnesota, ksmith@umn.edu

***Abstract* - Innovation according to Denning and Dunham (2010) is "the adoption of a new practice in a community." I argue that our innovations need to be based on good learning theory and good instructional practice. The Johnson and Johnson conceptual model of cooperative learning is an excellent example of a widely adopted evidence-based practice. I identified cooperative learning as important for engineering education in about 1974, tried it in my classes and did some systematic research on it with David and Roger Johnson, introduced it to the engineering education community in 1981 (FIE conference and JEE paper), and it took over 25 years for it to become widespread practice. My point in presenting this story is I don't think we can afford to wait 25 or more years for the current innovations to make it into practice. This paper summarizes the history of the emergence of cooperative learning in engineering education; documents the development of the theoretical, empirical, and practical support; maps the milestones and lessons learned; and provides insights and guidance for engineering education researchers and innovators especially concerning increasing the rate of adoption of evidence-based promising practices.**

Index Terms – cooperative learning, evidence-based promising practice, engineering education research and innovation

Clarification

Since there is the possibility of a confusion of terms, I'm starting with the definition of cooperative learning and highlighting how it is different from collaborative learning and cooperative education (or co-op). [Note: Thanks to the anonymous reviewer who recommended this addition]

Cooperative learning is the instructional use of small groups so that students work together to maximize their own and each others' learning (Johnson and Johnson, 1974; Smith, Johnson and Johnson, 1981; Johnson, Johnson and Smith, 1991). Carefully structured cooperative learning involves people working in teams to accomplish a common goal, under conditions that involve both positive interdependence (all members must cooperate to complete the task) and individual and group accountability (each member individually as well as all members collectively accountable for the work of the group).

A common question is, "What is the difference between cooperative and collaborative learning?" Both pedagogies are aimed at "marshalling peer group influence to focus on intellectual and substantive concerns" (Matthews, et.al, 1995). The principal difference is that cooperative learning requires carefully structured individual accountability, whereas collaborative learning does not. Oxford (1997) summarizes the differences as follows, "Cooperative learning refers to a particular set of classroom techniques that foster learner interdependence as a route to cognitive and social development. Collaborative learning has a "social constructivist" philosophical base, which views learning as construction of knowledge within a social context and which therefore encourages acculturation of individuals into a learning community."

Another potential source of confusion is cooperative education (or co-op), which is "is a structured method of combining classroom-based education with practical work experience. A cooperative education experience, commonly known as a "co-op", provides academic credit for structured job experience" (Auld, 1972).

History

[Note: History and Concurrent Developments sections were adapted from Smith (2010)]
My first encounter with cooperative learning occurred in about 1974 in a Social Psychology of Education course taught by one of David Johnson's PhD students, Dennis Falk who is currently a Professor of Social Work at the University of Minnesota – Duluth. I began taking courses in the College of Education in the early 70s because I had an overwhelming sense that there was a better way to help engineering students learn than what I was doing, which was essentially what had been done to me, that is, lecture, homework assignments and individual exams. This overwhelming sense of a better way of doing things was prompted by questions the students asked, which revealed that they had no idea what I was talking about. A representative setting was a course in thermodynamics and kinetics – very abstract areas involving a lot of mathematics – where I was "teaching as taught." My sense that there was a better way was grounded in my training and experience as an engineer, where one of the fundamental ideas is "advancing the state-of-the-art". What I encountered in the

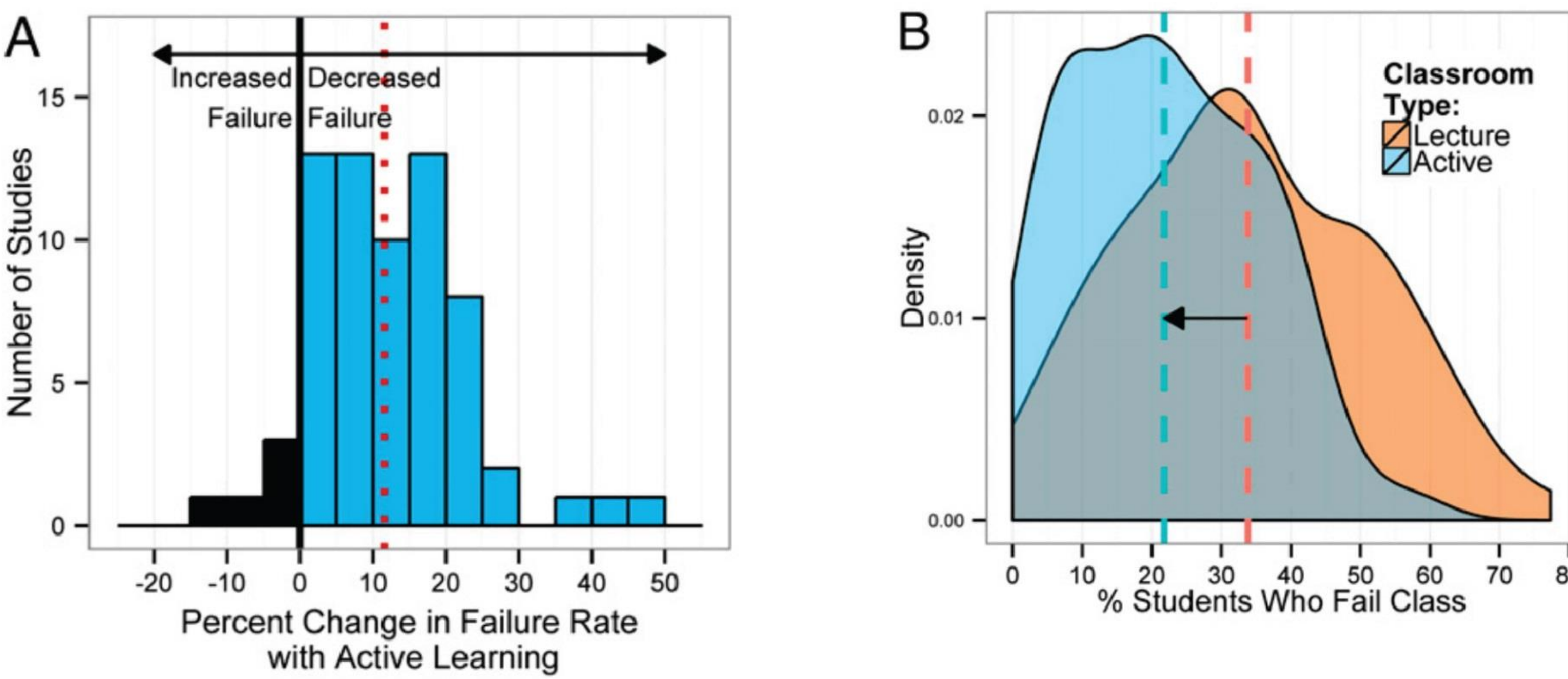
https://karlsmithmn.org/wp-content/uploads/2017/08/Smith-FIE-CL-1240-10-draft.pdf

Effectiveness of Interactive Learning

- Johnson, D. W., R. T. Johnson, and K. A. Smith. 2014. Cooperative Learning: Improving University Instruction by Basing Practice on Validated Theory. In Small-group Learning in Higher Education: Cooperative, Collaborative, Problem-based, and Team-based Learning, *Journal on Excellence in College Teaching 35*, nos.3 and 4.
- Meta-analyses in the *Proceedings of the National Academy of Sciences (PNAS)* summarize the importance of interactive learning for
  - reducing the failure rate (Freeman, et.al. 2014) https://www.pnas.org/content/111/23/8410
  - narrowing the achievement gap for underrepresented students (Theobald, et.al. 2019) https://www.pnas.org/content/117/12/6476

Engaged Pedagogies = Reduced Failure Rates

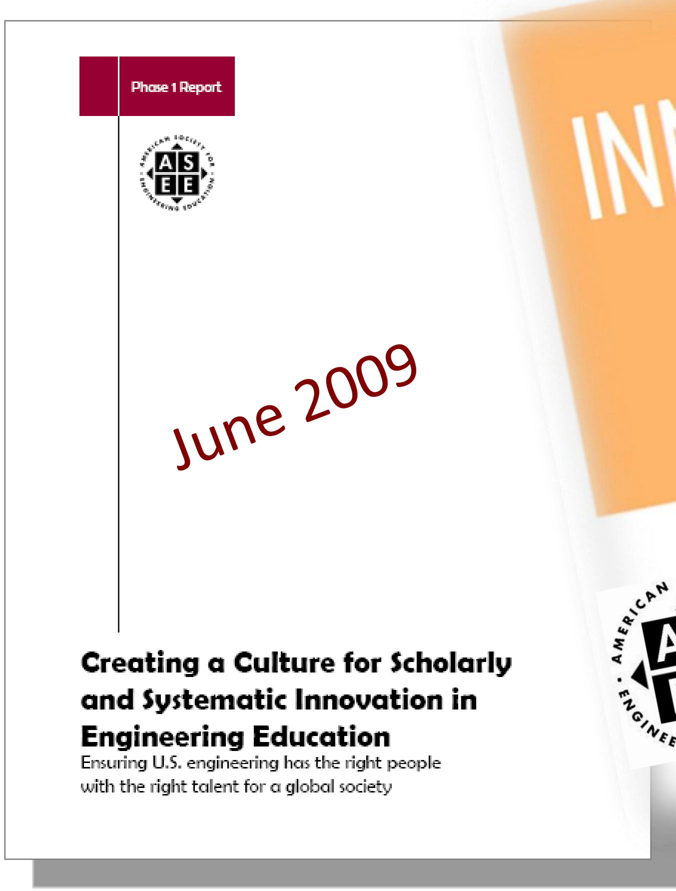
Evidence-based research on learning indicates that when students are actively involved in their education they are more successful and less likely to fail. A new PNAS report by Freeman et al., shows a significant decrease of failure rate in active learning classroom compared to traditional lecture



Freeman, Scott; Eddy, Sarah L.; McDonough, Miles; Smith, Michelle K.; Okoroafor, Nnadozie; Jordt, Hannah; Wenderoth, Mary Pat; Active learning increases student performance in science, engineering, and mathematics, 2014, Proc. Natl. Acad. Sci.

Pedagogies of Engagement

ASEE Reports - A Path Forward



Phase 1 Report

Creating a Culture for Scholarly and Systematic Innovation in Engineering Education

Ensuring U.S. engineering has the right people with the right talent for a global society

June 2009

INNOVATION WITH IMPACT

Creating a Culture for Scholarly and Systematic Innovation in Engineering Education

June 2012

Seven Recommendations for Innovation with Impact

Who

1. Grow professional development in teaching and learning.
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.
7. Conduct periodic community-wide self-assessments.

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

Follow the Evidence

Discipline-based education research dispels myths about learning and yields results – if only educators would use it.

Last year, the National Research Council released the report *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*. That consensus study, on which we served as committee members, brought together experts in physics, chemistry, biology, the geosciences, astronomy, and engineering, as well as higher education researchers, learning scientists, and cognitive scientists to focus on how students learn in particular scientific and engineering disciplines. Our key conclusion: Findings from the growing field of discipline-based education research (DBER) have yet to spur widespread changes in the teaching of science and engineering.

For example, research-based instructional approaches to teaching that actively engage students in their own learning, such as group projects, have been shown to be more effective than traditional lectures. Yet science and engineering faculty still cling to familiar practice. While there's no magic solution for adopting evidence-based teaching practices, finding out what is known about undergraduate learning in engineering and science—and identifying impediments to implementation in the classroom—can point the way.

First, many students have incorrect understanding about fundamental concepts—particularly phenomena that are not directly observable, such as those involving very large or small scales of time and space. Understanding how educators can help students change these misconceptions is in the early stages, but DBER has uncovered some effective instructional techniques. One promising approach is to use "bridging analogies" that link students' correct knowledge with the situation about which they harbor false beliefs. For instance, a student may not believe that a table can exert a force on a book resting on its surface but accepts the notion if a spring is placed under the same book. Linking these two ideas, with perhaps an intermediate of a book resting on a foam block, can move the student toward a correct understanding of forces.

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Students also are challenged by important aspects of engineering and science that can seem easy or obvious to experts. When tackling a problem, for instance, students tend to focus on the superficial rather than on its deep structure. Instructors may have an "expert blind spot" and not recognize how different the student's approach is from their own, which can impede effective instruction. Several strategies appear to improve problem-solving skills, such as providing support and prompts—known as "scaffolding"—as students work their way through problems. Another common issue for students in all disciplines is difficulty in extracting information from graphs, models, and simulations. Using multiple representations in instruction is one way to move students toward expertise.

The report recommends future DBER research that explores similarities and differences in learning among various student populations, and longitudinal studies that shed additional light on how students acquire and retain an understanding (or misunderstanding) of concepts. However, we also need strategies that translate the findings of DBER and related research into practice. That includes finding ways around barriers, such as the faculty reward system, the relative value placed on teaching versus research, lack of support for faculty learning to use research-based practices, problems with student evaluations, and workload concerns.

The report urges universities, disciplinary organizations, and professional societies to support faculty efforts to use evidence-based teaching strategies in their classrooms. It also recommends collaboration to prepare future faculty members who understand research findings on learning and teaching and who value effective teaching as part of their career aspirations. By implementing these recommendations, engineering and science educators will make a major first step toward using DBER to improve their practice—and learning outcomes.

Susan Singer, the Laurence McKinley Gould Professor of the Natural Sciences at Carleton College, chaired the National Research Council committee that prepared the consensus study. Karl Smith, the Cooperative Learning Professor of Purdue University's School of Engineering Education and emeritus professor of civil engineering at the University of Minnesota, represented engineering on the committee. To view the report, visit http://www.nap.edu/

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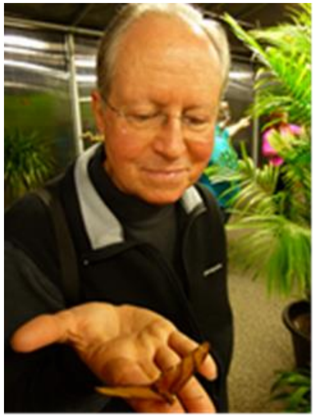

Karl A. Smith
Purdue University and
University of Minnesota

ksmith@umn.edu