How to Teach and Why

Teaching Theory and Practice 1893-2018

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ASEE 125th Anniversary Distinguished Panel June 27, 2018

Studies of Engineering Education

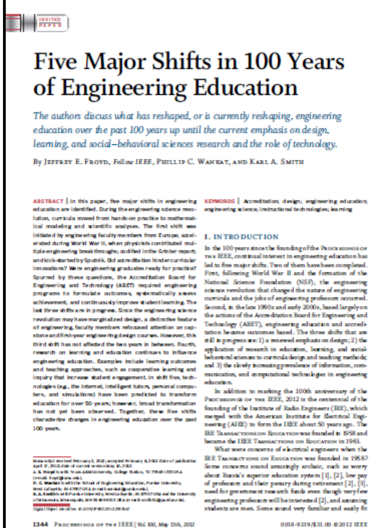
- Mann, Charles Riborg. 1918. "A Study of Engineering Education." Carnegie Foundation for the Advancement of Teaching, New York.
- Society for the Promotion of Engineering Education. 1930. "Report of the Investigation of Engineering Education 1923-1929."Pittsburgh, PA. (Wickenden Report)
- Hammond Report. 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 2

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

https://www.asee.org/member-resources/reports 3


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

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

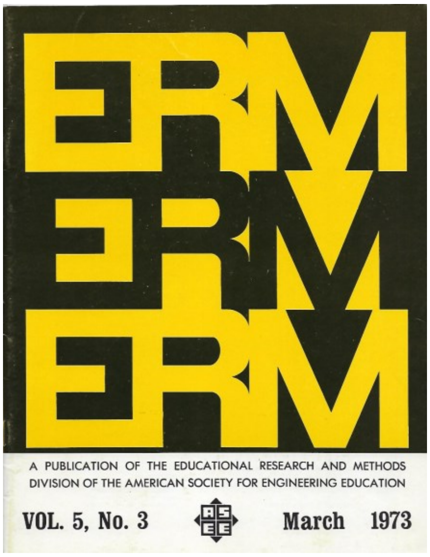
KEYWORDS | Accreditation; design; engineering education; engineering science; instructional technologies; learning

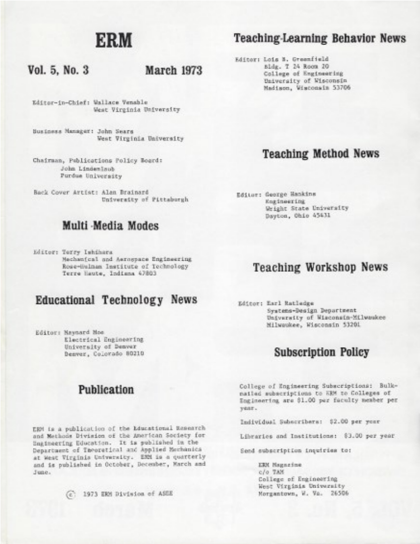
I. INTRODUCTION

In the 100 years since the founding of the Proceedings of the IEEE, continual interest in engineering education has

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





ERM

Vol. 5, No. 3 March 1973

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ASEE ERM Distinguished Lectures

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1981	Robert F. Mager	Academic Applications of Educational Methods Developed in Industry
1982	Wilbert J. McKeachie	Student Anxiety, Learning and Achievement
1983	Samuel N. Postlewait	Using Science and Technology to Teach Science and Technology
1985	Fred F. Keller	Testimony of an Educational Reformer
1986	Moshe F. Rubinstein	Rational and Imaginative Thinking in the Computer Age
1987	Benjamin S. Bloom	A Search for Methods of Instruction as Effective as One-on-One Tutoring
1988	Donald A. Schon	Marrying Applied Science and Artistry in Engineering Education
1989	William G. Perry, Jr.	Students' Evolution of their Definition of Knowledge and Their Expectations of Teachers
1990	Frederick Reif	Engineering Human Knowledge and Thinking: Opportunities for Better Engineering Education
1991	K. Patricia Cross	College Teaching: What Do We Know About It?

https://erm.asee.org/conferences/distinguished-lecturers/

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Otis Lancaster's Influences

- Developed and hosted Summer Institute on Effective Teaching for Young Engineering Teachers in the 1960s.
  - Mentioned by Larry Grayson and Dave Voltmer in Engineering Education Profiles as very influential - http://depts.washington.edu/celtweb/pioneers-wp/
- *Effective Teaching and Learning.* Gordon & Breach Science Pub, 1974
- ASEE President's Messages – "Do we Believe in…"
  - Teaching? December 1977
  - Laboratories? January 1978
  - The Social-Humanistic Stem? February 1978
  - Engineering Research? March 1978
  - ASEE? April 1978
  - Communications? May 1978

President's Message

Do We Believe in ENGINEERING RESEARCH?

You had better believe it!

At promotion time someone in some group somewhere believes in research. For them it is one of the main criteria. I don't say "*engineering* research" because frequently the pressure for research comes from the university as a whole and not only from the engineering component. In fact, these external pressures are in part the cause for the shift in requirements from practice to doctor's degrees.

Our belief in research should not be like a religion which is practiced only on Sundays. It should be practiced after promotions as well as before. Yet, there are some who relax on their oars after they have paddled their way through research to full professorships.

Often, slight improvements in the physical properties of materials (strength, conductivity, etc.) or in the fabrication or production environment would make the difference between success or failure of a design.

It is this critical "cutting edge of engineering" that leads engineers into research. Searches are made to fill the gaps or to advance the knowledge in the field thought to be useful in design and development. Engineering research is important. It is an essential activity, for without it the profession would become stagnant and log-bound. Without increased knowledge society would become dormant. Engineering would not be able to design to meet future problems.

Knowledge vs. use

The question still remains. How much time should be devoted to the pursuit of engineering knowledge and how much time devoted to use? To paraphrase a Biblical statement, "What does it profit a profession to gain all of knowledge and not be able to use it?"

If we believe in engineering research, why not be honest about it? Why not make clear to the world the proportion of faculty time that is or should be devoted to engineering research? Why not establish within the general funds budget of engineering colleges the amount of money needed to support this research? When one wants to teach a new course in engineering, one

President's Message

Do We Believe in ASEE?

We believe in effective teaching, that laboratories are essential, that design is the essence of engineering, that engineering research has a fundamental role in education, that engineering technology is an integral part of the engineering spectrum, and that social-humanistic values and modes of reasoning are required for successful engineering.

In the previous editorials I suggested steps *we* should take to support each of these beliefs. Nowhere was *we* defined, but it was tacitly implied that *we* included all engineering professors, all professors teaching supporting subjects, employers of engineers, engineers, and professional engineering groups. All should and will have an impact on engineering in the future. In our civilization, engineering is important to all of us. All must lend a helping hand to support it.

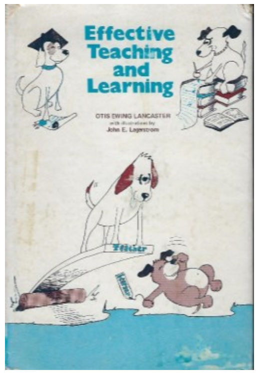
the responsibility of using concepts, principles, laws and facts to produce improved living conditions for our society. All should have an interest in education.

The one society formed to concentrate strictly on the education of those entering the engineering profession, regardless of the field, is the American Society for Engineering Education. It is concerned with what to teach and how to teach at all levels. More accurately expressed, it is concerned with what should be learned and how to achieve knowledge in an efficient manner (learning per unit time)* with a desired retention (storage) for future use. ASEE recognizes that the main issue is teaching people how to learn so that each can learn alone, thereby meeting the objective of life-long learning. However, one can only learn to learn through practice; the content is essential. Because of the interre-

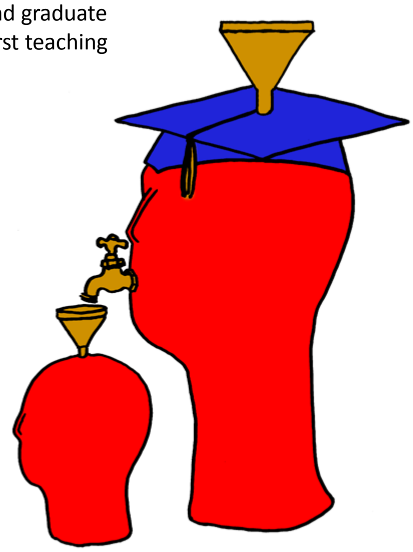
Do we believe in …

- Theory? E.g., Learning theory?
- Evidence? E.g., Evidence-based instructional practices?

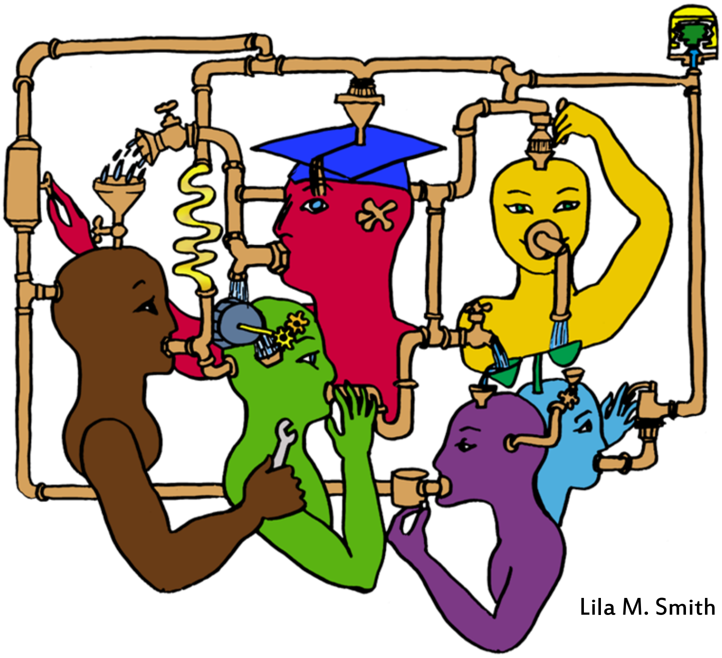
Chapter 1. Learning Objectives
Chapter 2. Concepts About Learning
Chapter 5. Planning for Achievement
Chapter 15. Measuring Teaching Effectiveness
Chapter 16. Curriculum Design
    Let's be engineers in our educational work
    Let's engineer education
Chapter 17. **Research for Learning Achievement**
    The battle cry for this book is "Become Better Learning Leaders"



My undergraduate and graduate experience and my first teaching experience



Lila M. Smith



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

http://personal.cege.umn.edu/~smith/docs/Smith-Pedagogies_of_Engagement.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. A. (1985) *What Matters in College: Four Critical Years Revisited. Jossey-Bass*

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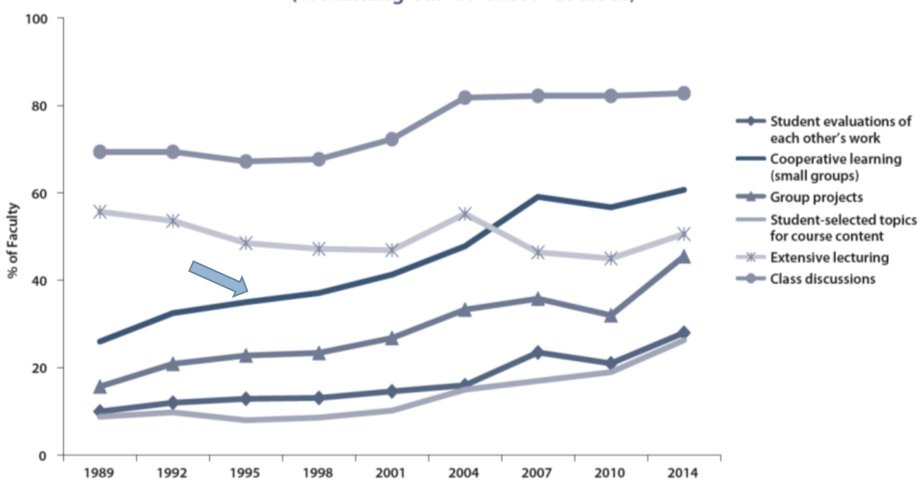
Undergraduate Teaching Faculty: The 2013–2014 HERI Faculty Survey

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



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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.

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Cooperative Learning Research Support

Johnson, D.W., Johnson, R.T., & Smith, K.A. 1998. Cooperative learning returns to college: What evidence is there that it works? *Change*, *30* (4), 26-35.*

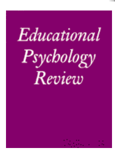
- Over 300 Experimental Studies
- First study conducted in 1924
- High Generalizability
- Multiple Outcomes

Outcomes

1. Achievement and retention
2. Critical thinking and higher-level reasoning
3. Differentiated views of others
4. Accurate understanding of others' perspectives
5. Liking for classmates and teacher
6. Liking for subject areas
7. Teamwork skills

*[CLReturnstoCollege.pdf]

January 2005



March 2007

25 (3&4) 2014

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INSIGHTS

POLICY FORUM

SCIENCE EDUCATION

Anatomy of STEM teaching in North American universities

Lecture is prominent, but practices vary

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

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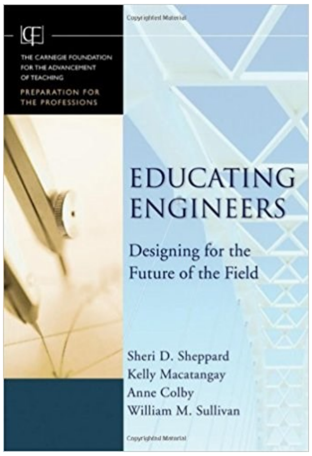
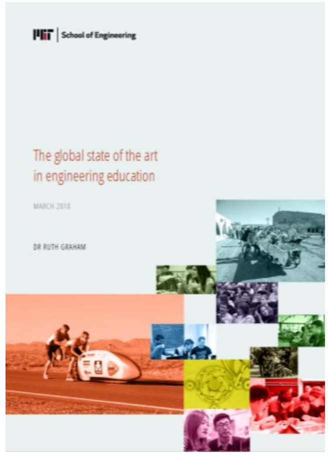
Global Calls for Reform

K-12 Engineering

Research-based Transformation



Sheppard, S.D., Macatangay, K., Colby, A., Sullivan, W.M. 2008. Educating Engineers: Designing for the Future of the Field. Jossey-Bass.



New Engineering Education Transformation
Massachusetts Institute of Technology
neet.mit.edu

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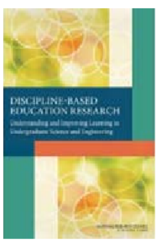
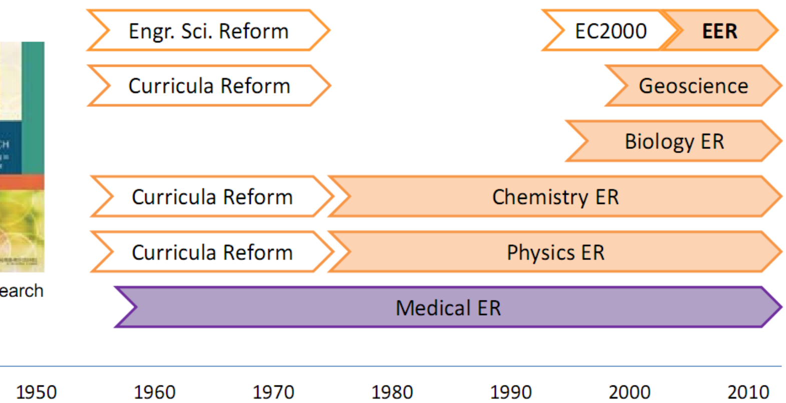
Discipline-Based Education Research Timeline

DBER Departments and Graduate Programs



National Research Council
2012



PURDUE ENGINEERING EDUCATION

DBER is **located** in the relevant disciplinary school, e.g. medicine, physics.

152 centers & groups

68 graduate programs

82 conferences & workshops

66 journals

...and more

engineering education community resource

Adam Carberry
Ken Yasuhara

http://bit.ly/engredu

ASEE Main Plenary - 2011

ASEE Main Plenary, 8:45 a.m. – 10:15 a.m.
Vancouver International Conference Centre, West Ballroom CD
Expected to draw over 2,000 attendees, this year's plenary features Karl A. Smith, Cooperative Learning Professor of Engineering Education at Purdue University and Morse–Alumni Distinguished Teaching Professor & Professor of Civil Engineering at the University of Minnesota.
Smith has been at the University of Minnesota since 1972 and has been active in ASEE since he became a member in 1973. For the past five years, he has been helping start the engineering education Ph.D. program at Purdue University. He is a Fellow of the American Society for Engineering Education and past Chair of the Educational Research and Methods Division. He has worked with thousands of faculty all over the world on pedagogies of engagement, especially cooperative learning, problem-based learning, and constructive controversy.
On the occasion of the 100th anniversary of the Journal of Engineering Education and the release of ASEE's Phase II report *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education* (Jamieson/Lohmann report), the plenary will celebrate these milestones and demonstrate rich, mutual interdependences between practice and inquiry into teaching and learning in engineering education. Depth and range of the plenary will energize the audience and reflects expertise and interests of conference participants. **One of ASEE's premier educators and researchers, Smith will draw upon our roots in scholarship to set the stage and weave the transitions for six highlighted topics selected for their broad appeal across established, evolving, and emerging practices in engineering education**.

Highlights from Monday:

Monday's **Main Plenary** by Karl A. Smith, Cooperative Learning Professor of Engineering Education at Purdue University and Morse–Alumni Distinguished Teaching Professor & Professor of Civil Engineering at the University of Minnesota, focused on six highlighted topics (presented by six different educators) selected for their broad appeal across established, evolving, and emerging practices in engineering education.

ASEE Reports - A Path Forward

- 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."

Thoughts on the Future: Emphasize Big Ideas (Enduring Outcomes)

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

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

The Engineering Design Process vs. Streamlined Course Design Process

Engineering Design
- Determine requirements/ specifications
- Develop or use established metrics to measure against outcomes
- Plan and develop process, system, etc. to implement

Streamlined Course Design Process
- Identify the desired results
- Determine acceptable evidence
- Plan learning experiences

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Pedagogies of Engagement

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LAST WORD · OPINION BY SUSAN SINGER & KARL SMITH

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.

STUDENTS ARE CHALLENGED BY KEY ASPECTS OF ENGINEERING AND SCIENCE THAT CAN SEEM EASY OR OBVIOUS TO EXPERTS.

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.

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/

Thank you!

An e-copy of this presentation will be posted to:

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University of Minnesota

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