

Evidence-Based Practices for Innovative STEM Education

Karl A. Smith

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STEM Education Seminar
teaching & learning collaborative

The George Washington University
School of Engineering and Applied Science

January 27, 2012

Reflection and Dialogue

- Individually reflect on your mental image of an innovative teacher. Write for about 1 minute.
 - Jot down words or phrases
 - Construct a figure or diagram
- Discuss with your neighbor for about 2 minutes
 - Describe your mental image and talk about similarities and differences
 - Select one Element, Image, Comment, Story, etc. that you would like to present to the whole group if you are randomly selected
- Whole group discussion

Teacher Mental Images About Teaching - Axelrod (1973)

Mental Image	Motto	Characteristics	Disciplines
Content	I teach what I know	Pour it in, Lecture	Science, Math
Instructor	I teach what I am	Modeling, Demonstration	Many
Student – Cognitive Development	I train minds	Active Learning, Discussion	English, Humanities
Student – Development of Whole Person	I work with students as people	Motivation, Self-esteem	Basic Skills Teachers

Axelrod, J. *The University Teacher as Artist*. San Francisco: Jossey-Bass, 1973.

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Engineering Education: Advancing the Practice Karl Smith

Research

- Process Metallurgy 1970 -1992
- Learning ~1974
- Design ~1995
- Engineering Education Research & Innovation ~ 2000
- STEM Education ~ 2010

Innovation – Cooperative Learning

- Need identified ~1974
- Introduced ~1976
- FIE conference 1981
- JEE paper 1981
- Research book 1991
- Practice handbook 1991
- Change paper 1998
- Teamwork and project management 2000
- JEE paper 2005

National Academy of Engineering - Frontiers of Engineering Education Symposium - December 13-16, 2010 - Slides PDF [[Smith-NAE-FOEE-HPL-UbD-12-10-v8.pdf](#)]

Process Metallurgy

- Dissolution Kinetics – liquid-solid interface
- Iron Ore Desliming – solid-solid interface
- Metal-oxide reduction roasting – gas-solid interface

Dissolution Kinetics

- Theory – Governing Equation for Mass Transport
- Research – rotating disk
- Practice – leaching of silver bearing metallic copper

$$(\nabla c \bullet \underline{v}) = D \nabla^2 c$$

$$v_y \frac{dc}{dy} = D \frac{d^2c}{dy^2}$$

First Teaching Experience

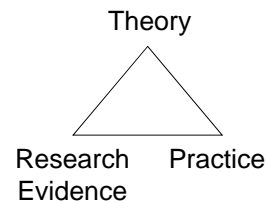
- Practice – Third-year course in metallurgical reactions – thermodynamics and kinetics



Lila M. Smith

Engineering Education

- Practice – Third-year course in metallurgical reactions – thermodynamics and kinetics
- Research – ?
- Theory – ?



Pedago-pathologies

Amnesia

Fantasia

Inertia



Lee Shulman – MSU Med School – PBL Approach (late 60s – early 70s), President Emeritus of the Carnegie Foundation for the Advancement of College Teaching

Shulman, Lee S. 1999. Taking learning seriously. *Change*, 31 (4), 11-17.

What do we do about these pathologies?

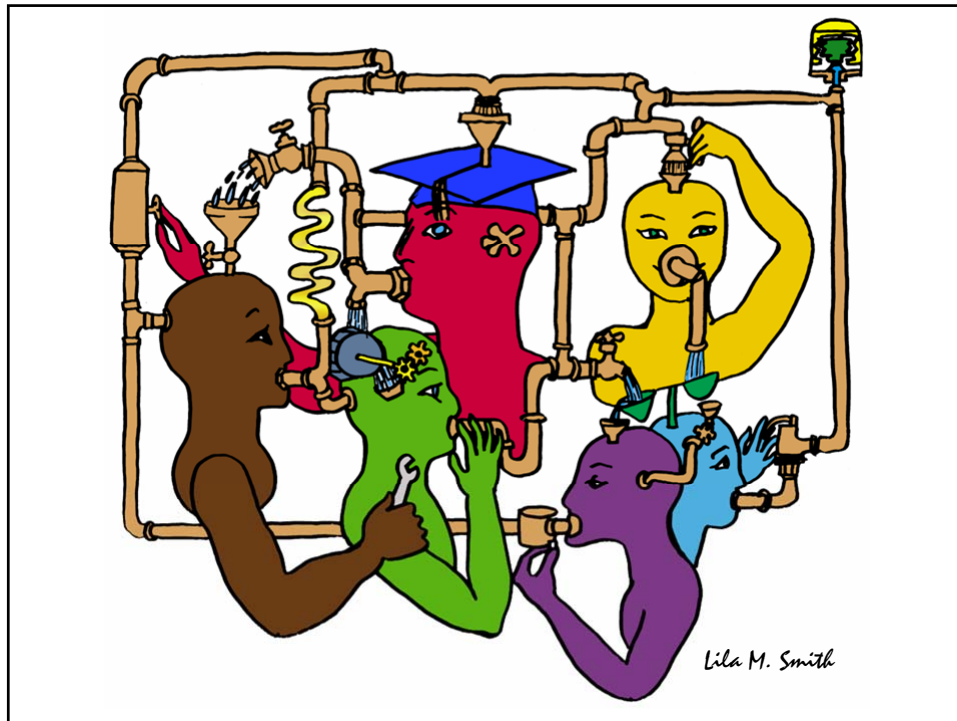
- **Activity** – Engage learners in meaningful and purposeful activities
- **Reflection** – Provide opportunities
- **Collaboration** – Design interaction
- **Passion** – Connect with things learners care about

Shulman, Lee S. 1999. Taking learning seriously. Change, 31 (4), 11-17.

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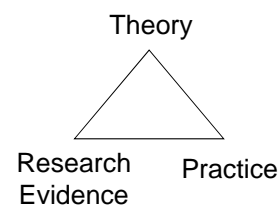
University of Minnesota College of Education
Social, Psychological and Philosophical
Foundations of Education

- Statistics, Measurement, Research Methodology
- Assessment and Evaluation
- Learning and Cognitive Psychology
- Knowledge Acquisition, Artificial Intelligence, Expert Systems
- Social psychology of learning – student – student interaction



Cooperative Learning

- Theory – Social Interdependence – Lewin – Deutsch – Johnson & Johnson
- Research – Randomized Design Field Experiments
- Practice – Formal Teams/Professor's Role



Lewin's Contributions

- Founded field of social psychology
- Action Research
- Force-Field analysis
- $B = f(P, E)$
- Social Interdependence Theory
- “There is nothing so practical as a good theory”

Seven Principles for Good Practice in Undergraduate Education

- Good practice in undergraduate education:
 - Encourages student-faculty contact
 - Encourages cooperation among students
 - Encourages active learning
 - Gives prompt feedback
 - Emphasizes time on task
 - Communicates high expectations
 - Respects diverse talents and ways of learning

Chickering & Gamson, June, 1987

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Comparison of Old and New Paradigm of Teaching (Johnson, Johnson & Smith, 1991)

	Old Paradigm	New Paradigm
Knowledge	Transferred from Faculty to Students	Jointly Constructed by Students and Faculty
Students	Passive Vessel to be Filled by Faculty's Knowledge	Active Constructor, Discoverer, Transformer of Knowledge
Faculty Purpose	Classify and Sort Students	Develop Students' Competencies and Talents
Relationships	Impersonal Relationship Among Students and Between Faculty and Students	Personal Transaction Among Students and Between Faculty and Students
Context	Competitive/Individualistic	Cooperative Learning in Classroom and Cooperative Teams Among Faculty
Teaching Assumption	Any Expert can Teach	Teaching is Complex and Requires Considerable Training



Johnson, D.W., Johnson, R.T., and Smith, K.A. *Active Learning: Cooperation in the College Classroom* (1st ed.). Edina, MN: Interaction Book Company, 1991.

Robert Barr & John Tagg.
From teaching to learning:
A new paradigm for
undergraduate education.
Change, 27(6), 1995.

Wm. Campbell & Karl
Smith. *New Paradigms for
College Teaching*.
Interaction Books, 1997.

New Paradigms For College Teaching

edited by
Wm. E. Campbell
& Karl A. Smith

contributors

Parker J. Palmer	Donald F. Dansereau
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Edward B. Nuhfer	Roger T. Johnson
	Valerie Ann Bystrom

	Old Paradigm	New Paradigm
Knowledge	Transferred from Faculty to Students	Jointly Constructed by Students and Faculty
Students	Passive Vessel to be Filled by Faculty's Knowledge	Active Constructor, Discoverer, Transformer of Knowledge
Mode of Learning	Memorizing	Relating
Faculty Purpose	Classify and Sort Students	Develop Students' Competencies and Talents
Student Goals	Complete Requirements, Achieve Certification within a Discipline	Grow, Focus on Continual Lifelong Learning within a Broader System
Relationships	Impersonal Relationship Among Students and Between Faculty and Students	Personal Transaction Among Students and Between Faculty and Students
Context	Competitive/Individualistic	Cooperative Learning in Classroom and Cooperative Teams Among Faculty
Climate	Conformity/Cultural Uniformity	Diversity and Personal Esteem/ Cultural Diversity and Commonality
Power	Faculty Holds and Exercises Power, Authority, and Control	Students are Empowered; Power is Shared Among Students and Between Students and Faculty
Assessment	Norm-Referenced (i.e., Graded "On the Curve"); Typically Multiple Choice Items; Student rating of instruction at end of course	Criterion-Referenced; Typically Performances and Portfolios; Continual Assessment of Instruction
Ways of Knowing	Logico-Scientific	Narrative
Technology Use	Drill and Practice; Textbook Substitute; Chalk and Talk Substitute	Problem Solving, Communication, Collaboration, Information Access, Expression
Teaching Assumption	Any Expert can Teach	Teaching is Complex and Requires Considerable Training

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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; Dean, Provost and President of the University of Michigan]



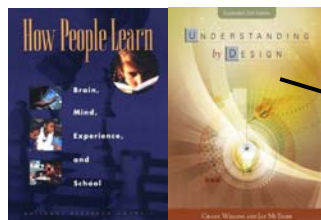
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Carnegie Preparation for the Professions Program



<http://www.carnegiefoundation.org/publications/educating-engineers-designing-future-field>

Design Foundations



Science of Learning (HPL)

Science of Instruction (UbD)

No

Yes

Yes

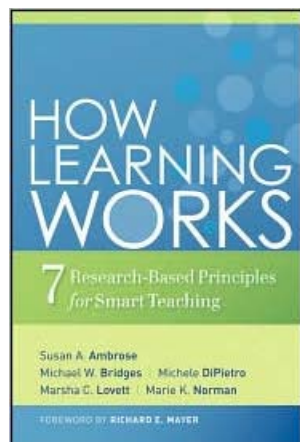
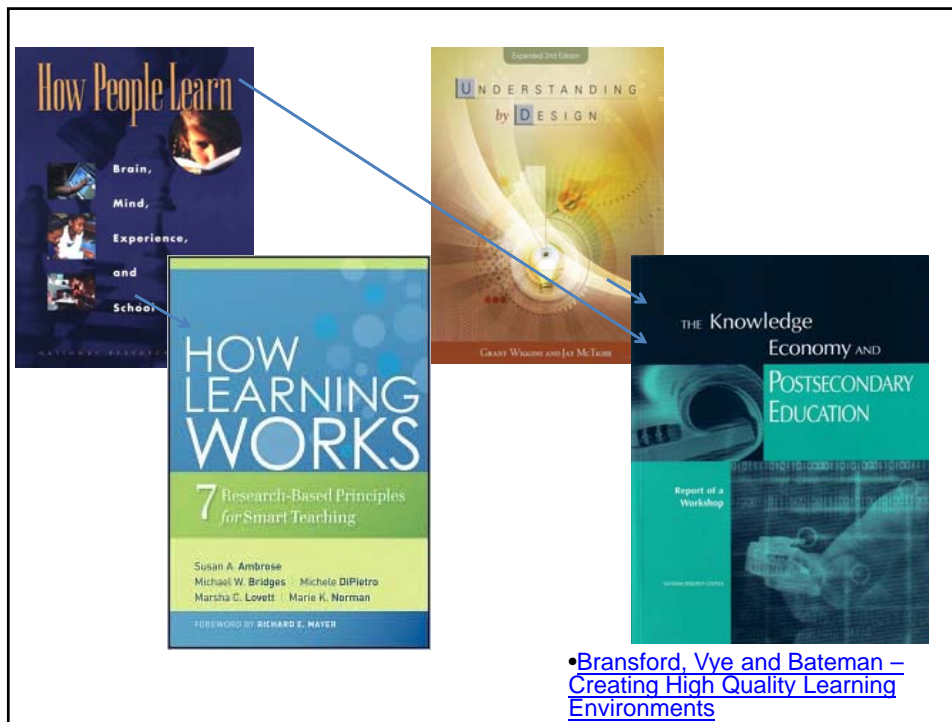
Good Theory/
Poor Practice

Good Theory &
Good Practice

No

Good Practice/
Poor Theory

Sources: Bransford, Brown & Cocking. 1999. *How people learn*. National Academy Press.
Wiggins, G. & McTighe, J. 2005. *Understanding by design*, 2ed. ASCD.



1. Students prior knowledge can help or hinder learning
2. How student organize knowledge influences how they learn and apply what they know
3. Students' motivation determines, directs, and sustains what they do to learn
4. To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned
5. Goal-directed practice coupled with targeted feedback enhances the quality of students' learning
6. Students' current level of development interacts with the social, emotional, and intellectual climate of the course to impact learning
7. To become self-directed learners, students must learn to monitor and adjust their approach to learning

Understanding by Design

Wiggins & McTighe (1997, 2005)

Stage 1. Identify Desired Results

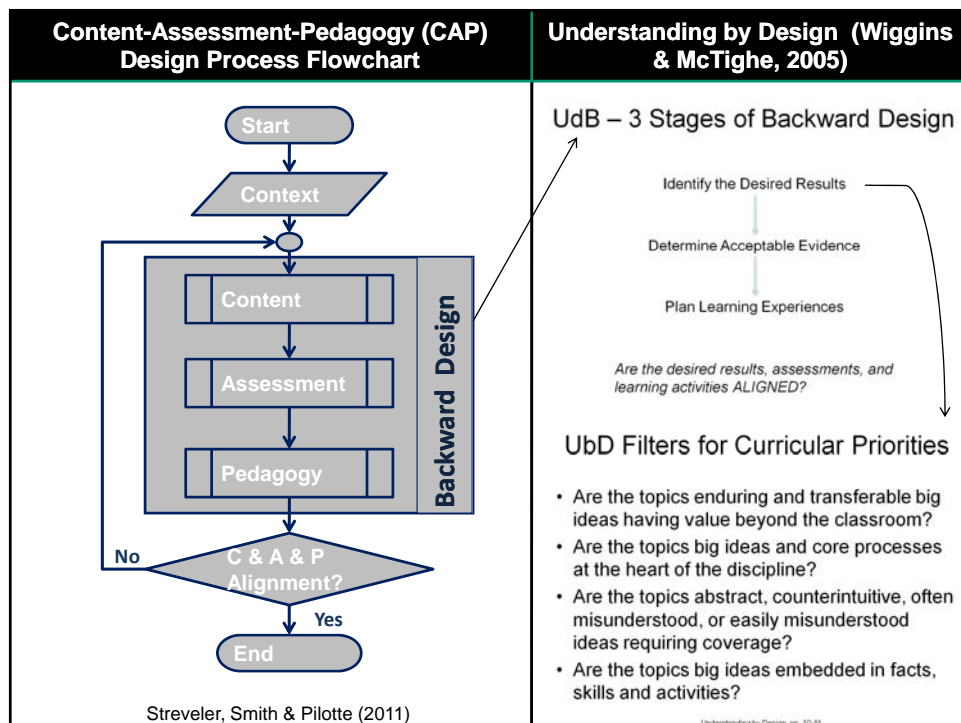
- Enduring understanding
- Important to know and do
- Worth being familiar with

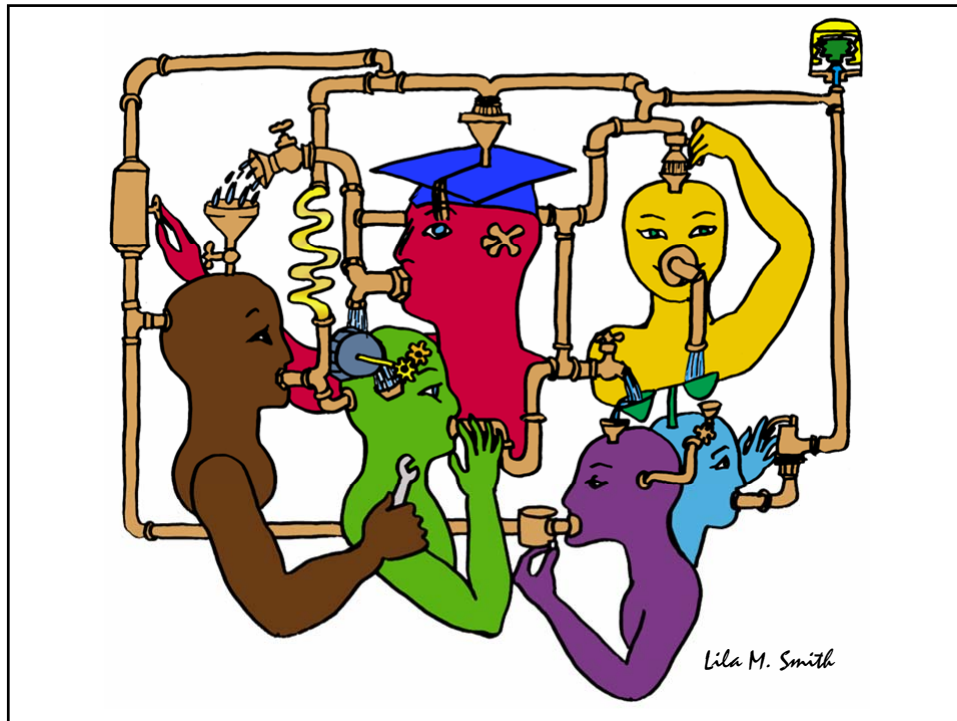
Stage 2. Determine Acceptable Evidence

Stage 3. Plan Learning Experiences and Instruction

Overall: *Are the desired results, assessments, and learning activities ALIGNED?*

From: Wiggins, Grant and McTighe, Jay. 1997. *Understanding by Design*. Alexandria, VA: ASCD

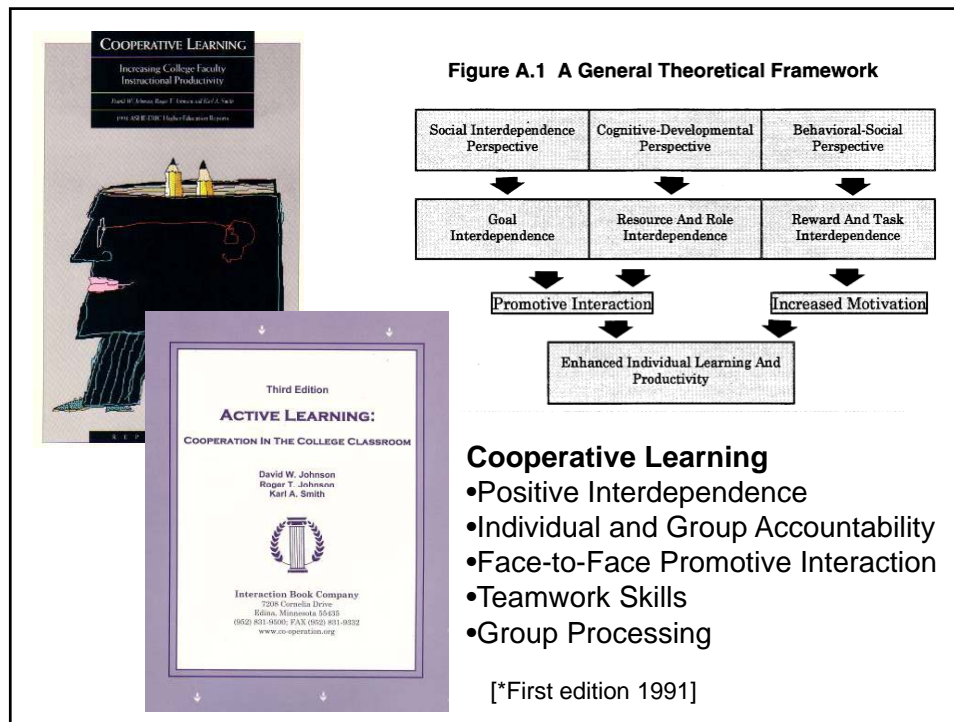




Student Engagement Research Evidence

- Perhaps the strongest conclusion that can be made is the least surprising. Simply put, the greater the student's involvement or engagement in academic work or in the academic experience of college, the greater his or her level of knowledge acquisition and general cognitive development ... (Pascarella and Terenzini, 2005).
- Active and collaborative instruction coupled with various means to encourage student engagement invariably lead to better student learning outcomes irrespective of academic discipline (Kuh et al., 2005, 2007).

See Smith, et.al, 2005 and Fairweather, 2008, Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education - http://www7.nationalacademies.org/bose/Fairweather_CommissionedPaper.pdf



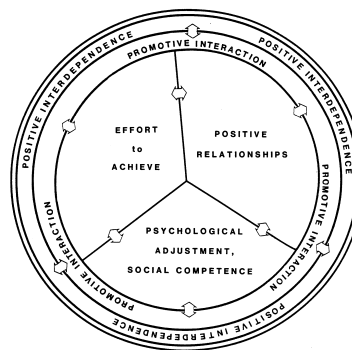
Cooperative Learning Research Support

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.

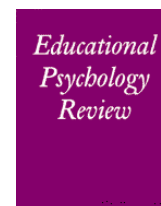
- Over 300 Experimental Studies
- First study conducted in 1924
- High Generalizability
- Multiple Outcomes

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



January 2005



March 2007

Small-Group Learning: Meta-analysis

Springer, L., Stanne, M. E., & Donovan, S. 1999. Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research*, 69(1), 21-52.

Small-group (predominantly cooperative) learning in postsecondary science, mathematics, engineering, and technology (SMET). 383 reports from 1980 or later, 39 of which met the rigorous inclusion criteria for meta-analysis.

The main effect of small-group learning on achievement, persistence, and attitudes among undergraduates in SMET was significant and positive. Mean effect sizes for achievement, persistence, and attitudes were 0.51, 0.46, and 0.55, respectively.

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).

Key Concepts

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

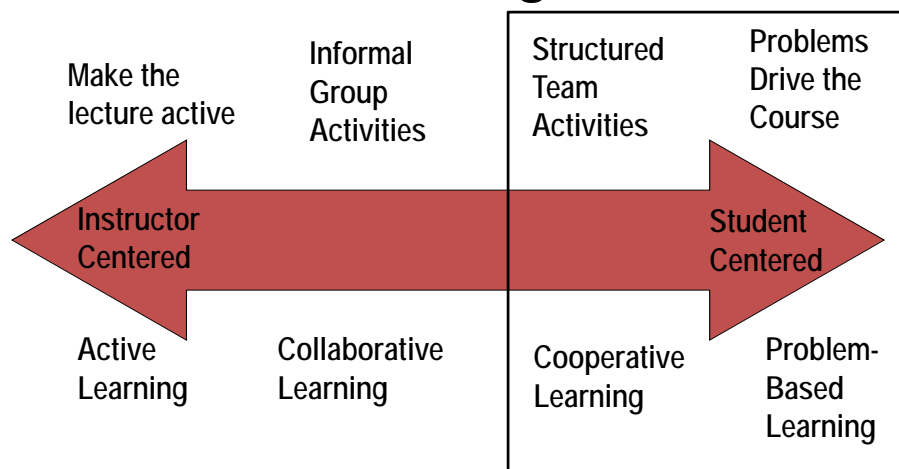
<http://www.ce.umn.edu/~smith/docs/Smith-CL%20Handout%2008.pdf>

Cooperative Learning	
Positive Interdependence	Individual Accountability
<ul style="list-style-type: none"> • All members share resources • All members share responsibility • All group members share to get the most out of the group • All group members share to get the most out of the group • All group members share to get the most out of the group 	<ul style="list-style-type: none"> • Each member is responsible for the group's success • Each member is responsible for the group's success • Each member is responsible for the group's success • Each member is responsible for the group's success • Each member is responsible for the group's success
Face-to-Face Interaction	Group Processing
<ul style="list-style-type: none"> • All members share resources • All members share responsibility • All group members share to get the most out of the group • All group members share to get the most out of the group • All group members share to get the most out of the group 	<ul style="list-style-type: none"> • All members share resources • All members share responsibility • All group members share to get the most out of the group • All group members share to get the most out of the group • All group members share to get the most out of the group

Pedagogies of Engagement



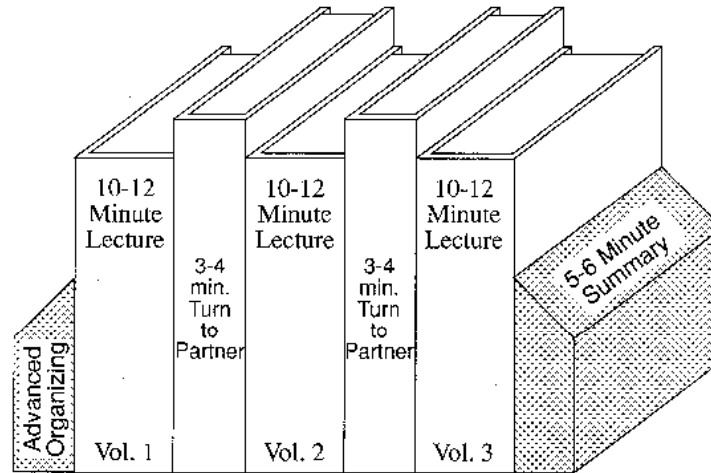
The Active Learning Continuum



Prince, M. (2010). NAE FOEE

My work is situated here – Cooperative Learning & Challenge-Based Learning

Book Ends on a Class Session



10-12

Problem-Based Cooperative Learning

At M.I.T., Large Lectures Are Going the Way of the Blackboard



Josh Hillis for The New York Times

The Massachusetts Institute of Technology has changed the way it offers some introductory classes. Prof. Gabriela Scobie at a class on electricity and magnetism.

By SARA RIMER

Published: January 12, 2009

CAMBRIDGE, Mass. — For as long as anyone can remember, introductory physics at the Massachusetts Institute of Technology was taught in a vast windowless amphitheater known by its number,

COMMENTS (00)

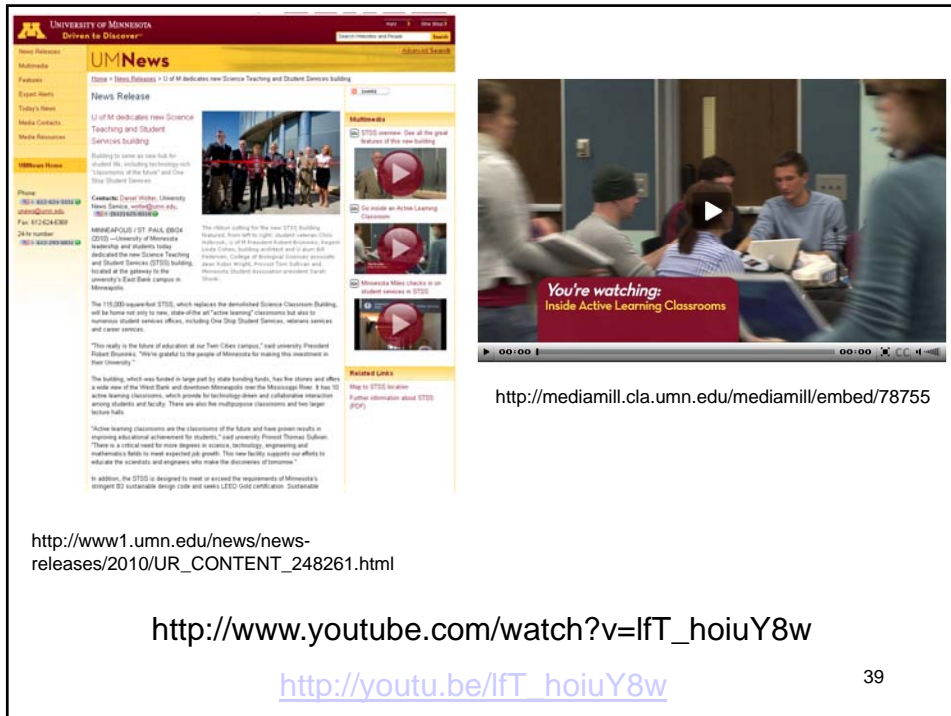
E-MAIL

PRINT

SINGLE PAGE

January 13, 2009—New York Times — <http://www.nytimes.com/2009/01/13/us/13physics.html?em>

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UNIVERSITY OF MINNESOTA
Driven to Discover™

UMNews

Home » News Releases » U of M dedicates new Science Teaching and Student Services building

News Release

U of M dedicates new Science Teaching and Student Services building

Building to serve as new hub for student life, including technology-rich "laboratories of the mind" and One Stop Student Services

Contacts: Daniel Wilton, University News Service, wilton@umn.edu, 612-625-4633

MINNEAPOLIS / ST. PAUL, MN (JSTN) — University of Minnesota faculty and students today dedicated the new Science Teaching and Student Services (STSS) building, located at the gateway to the university's East Bank campus in Minneapolis.

The 115,000-square-foot STSS, which replaces the demolished Science Classroom Building, will be home not only to new laboratories and "active learning" classrooms but also to numerous student services offices, including One Stop Student Services, retention services and career services.

"This really is the kind of education at our Twin Cities campus," said university President Robert Dornhoefer. "We're grateful to the people of Minnesota for making this investment in their University."

The building, which was funded in large part by state bonding funds, has the steepest and a wide view of the West Bank and downtown Minneapolis over the Mississippi River. It has 10 active learning classrooms, which provide for technology-driven and collaborative interaction among students and faculty. There are also five multimedia classrooms and two large lecture halls.

"Active learning classrooms are the classrooms of the future and have proven results in improving educational achievement for students," said university Provost Thomas Sullivan. "There is a critical need for more degrees in science, technology, engineering and mathematics fields to meet regional job growth. This new facility supports our efforts to educate the scientists and engineers who make the difference of tomorrow."

In addition, the STSS is designed to meet or exceed the requirements of Minnesota's stringent LEED sustainable design code and meets LEED Gold certification. Sustainable

Related Links

Map to STSS location
Further information about STSS (PDF)

Video Player: You're watching: Inside Active Learning Classrooms

<http://mediamill.cla.umn.edu/mediamill/embed/78755>

http://www1.umn.edu/news/news-releases/2010/UR_CONTENT_248261.html

http://www.youtube.com/watch?v=IfT_hoiuY8w

http://youtu.be/IfT_hoiuY8w

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UNIVERSITY OF DELAWARE

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UD Home | A-Z | Find It | Maps | People | My UD

PBL@UD Institute for Transforming Undergraduate Education
Problem-Based Learning at University of Delaware

Why PBL? | Our Workshops | Resources | Leaders & Fellows | Partners | In the News

The Motivation to Learn Begins with a Problem

In a problem-based learning (PBL) model, students engage complex, challenging problems and collaboratively work toward their resolution. PBL is about students connecting disciplinary knowledge to real-world problems—the motivation to solve a problem becomes the motivation to learn.

PBL@UD

For more than ten years, the Leaders and Fellows of the Institute for Transforming Undergraduate Education (ITUE) have encouraged the adoption of student-centered and active classroom pedagogies—and in particular—the use of PBL in the undergraduate classroom. On- and off-campus workshops are held for faculty and students to enhance their understanding of PBL.

Recipient of a Hesburgh Certificate of Excellence

The Theodore M. Hesburgh Award was created to acknowledge and reward successful, innovative faculty development programs that enhance undergraduate teaching. ITUE is a recipient of the Hesburgh Certificate of Excellence for its work in implementing problem-based learning in the classroom.

What we offer

PBL Clearinghouse

Find great problems for your

In this peer-reviewed online resource, educators have the opportunity to submit and publish their own problems and articles on problem-based learning.

[Learn more](#)

PBL Training at a lower cost: Attend our January 4-6 Workshop for an Introduction to PBL!

This workshop will demonstrate problem-based learning (PBL) and model ways that PBL can be used effectively in all disciplines. We will begin with a problem, and participants will work in teams to experience first hand what this instructional approach entails. We will then move to the main focus of this program: writing effective problem-based materials. Participants will leave the session with new or revised problems for use in their courses.

[Learn more](#)

<http://www.udel.edu/inst/>

PBL@UD • info@pbludel.edu

UNIVERSITY OF DELAWARE

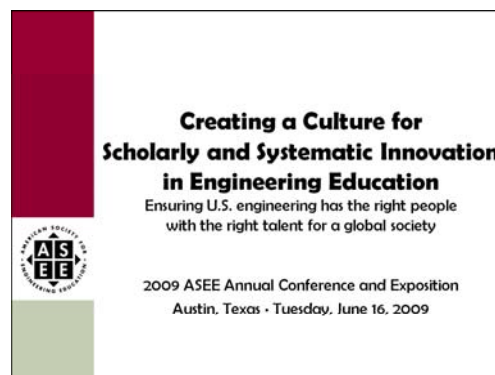
Cooperative Learning Adopted

The American College Teacher:
National Norms for 2007-2008

Methods Used in "All" or "Most"	All – 2005	All – 2008	Assistant - 2008
Cooperative Learning	48	59	66
Group Projects	33	36	61
Grading on a curve	19	17	14
Term/research papers	35	44	47

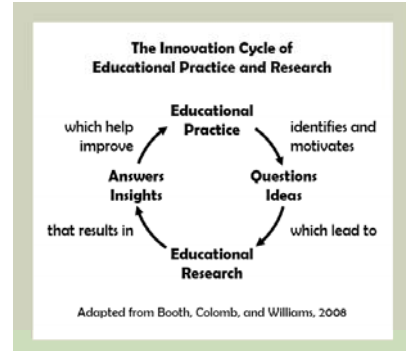
<http://www.heri.ucla.edu/index.php>

Celebration of Two Major ASEE Milestones



2011 ASEE Annual Conference and Exposition
Vancouver, British Columbia • Monday, June 27, 2011

One BIG Idea; Two Perspectives



Jamieson & Lohmann (2009)

Engineering Education Innovation

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:

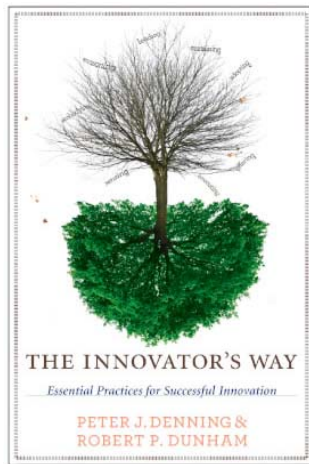
Monday's **Main Plenary** by Karl A. Smith, Cooperative Learning Professor of Engineering Education at Purdue University and Morse–Alumni Distinguished Teaching Professor & Professor of Civil Engineering at the University of Minnesota, focused on six highlighted topics (presented by six different educators)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



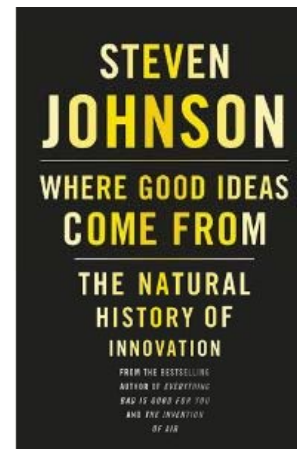
Video: <https://secure.vimeo.com/27147996>

Slides: <http://www.ce.umn.edu/~smith/links.html>

<http://www.asee.org/conferences-and-events/conferences/annual-conference/2011/program-schedule/conference-highlights>



Innovation is the adoption
of a new practice in a community
- Denning & Dunham (2010)



*Education Innovation

- Stories supported by evidence are essential for adoption of new practices
 - Good ideas and/or insightful connections
 - Supported by evidence
 - Spread the word
 - Patience and persistence
- Cooperative learning took over 25 years to become widely practiced in higher education
- **We can't wait 25 years for YOUR innovations to become widely practiced!**

Reflection and Dialogue

- Individually reflect on your STEM Education Innovation. Write for about 1 minute
 - Are the student learning outcomes clearly articulated?
 - Are they BIG ideas at the heart of the discipline?
 - Are the assessments aligned with the outcomes?
 - Is the pedagogy aligned with the outcomes & assessment?
- Discuss with your neighbor for about 2 minutes
 - Select Design Example, Comment, Insight, etc. that you would like to present to the whole group if you are randomly selected

Good teaching comes from the identity and integrity of the teacher.

Good teachers possess a capacity for connectedness.

Parker J. Palmer in *The courage to teach: Exploring the inner landscape of a teacher's life*. Jossey-Bass, 1998.

College Teaching: What do we know about it?

- Five assertions about what we know about college teaching
 - Good teaching makes a difference
 - Teachers vary markedly
 - Some characteristics/methods are present in all good teaching
 - Teaching can be evaluated and rewarded
 - There is ample room for improvement.
- K. Patricia Cross, 1991 ASEE ERM Distinguished Lecture

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- Four factors in good teaching, based on student ratings*:
 - Skill. Communicates in an exciting way.
 - Rapport. Understands and emphasizes with students.
 - Structure. Provides guidance to course and material.
 - Load. Requires moderate work load.
- *Student ratings of teaching are consistent (with other measures), unbiased, and useful. Students agree on good teaching and their views are consistent with faculty.

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The biggest and most long-lasting reforms of undergraduate education will come when individual faculty or small groups of instructors adopt the view of themselves as reformers within their immediate sphere of influence, the classes they teach every day.

K. Patricia Cross

Resources

- Design Framework – How People Learn (HPL) & Understanding by Design (UdB) Process
 - Bransford, John, Vye, Nancy, and Bateman, Helen. 2002. Creating High-Quality Learning Environments: Guidelines from Research on How People Learn. *The Knowledge Economy and Postsecondary Education: Report of a Workshop*. National Research Council. Committee on the Impact of the Changing Economy of the Education System. P.A. Graham and N.G. Stacey (Eds.). Center for Education. Washington, DC: National Academy Press. <http://www.nap.edu/openbook/0309082927/html/>
 - Mayer, R. E. 2010. *Applying the science of learning*. Upper Saddle River, NJ: Pearson.
 - Pellegrino – Rethinking and redesigning curriculum, instruction and assessment: What contemporary research and theory suggests. <http://www.skillscommission.org/commissioned.htm>
 - Smith, K. A., Douglas, T. C., & Cox, M. 2009. Supportive teaching and learning strategies in STEM education. In R. Baldwin, (Ed.). Improving the climate for undergraduate teaching in STEM fields. [New Directions for Teaching and Learning, 117](#), 19-32. San Francisco: Jossey-Bass.
 - Wiggins, G. & McTighe, J. 2005. *Understanding by Design: Expanded Second Edition*. Prentice Hall.
- Content Resources
 - Donald, Janet. 2002. Learning to think: Disciplinary perspectives. San Francisco: Jossey-Bass.
 - Middendorf, Joan and Pace, David. 2004. Decoding the Disciplines: A Model for Helping Students Learn Disciplinary Ways of Thinking. *New Directions for Teaching and Learning*, 98.
- Cooperative Learning
 - Cooperative Learning (Johnson, Johnson & Smith) - Smith web site – www.ce.umn.edu/~smith
 - Smith (2010) Social nature of learning: From small groups to learning communities. *New Directions for Teaching and Learning*, 2010, 123, 11-22 [[NDTL-123-2-Smith-Social Basis of Learning-.pdf](#)]
 - Smith, Sheppard, Johnson & Johnson (2005) Pedagogies of Engagement [[Smith-Pedagogies of Engagement.pdf](#)]
 - Johnson, Johnson & Smith. 1998. Cooperative learning returns to college: What evidence is there that it works? *Change*, 1998, 30 (4), 26-35. [[CLReturnstoCollege.pdf](#)]
- Other Resources
 - University of Delaware PBL web site – www.udel.edu/pbl
 - PKAL – Pedagogies of Engagement – <http://www.pkal.org/activities/PedagogiesOfEngagementSummit.cfm>
 - Fairweather (2008) Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education :http://www7.nationalacademies.org/bose/Fairweather_CommissionedPaper.pdf

Thank you!

An e-copy of this presentation is posted to:
<http://www.ce.umn.edu/~smith/links.html>

George Washington University – January 27, 2012



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