How People Learn & Understanding by Design

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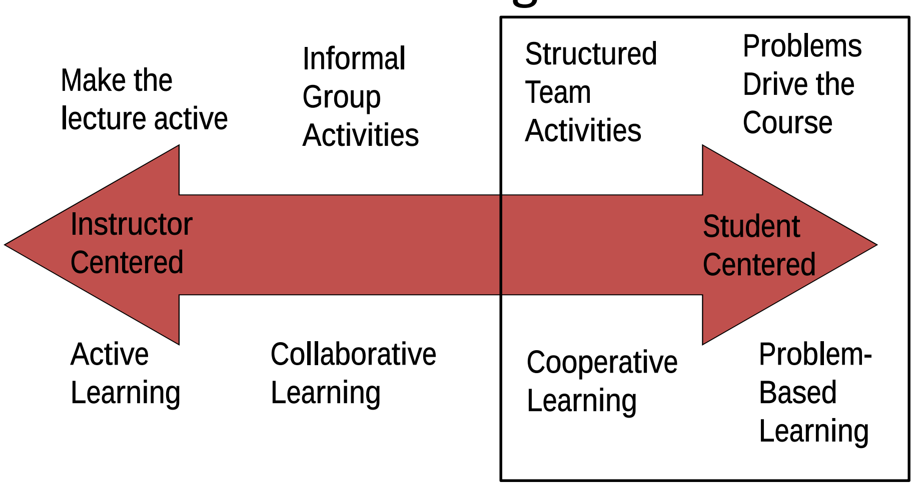
National Academy of Engineering
Frontiers of Engineering Education
December 2010

[Additional slides to annotate presentation noted by *]

The Active Learning Continuum

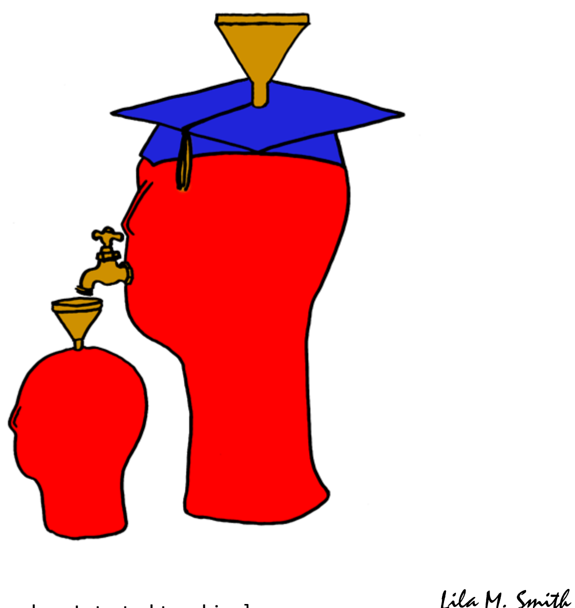


Prince, M. (2010). NAE FOEE

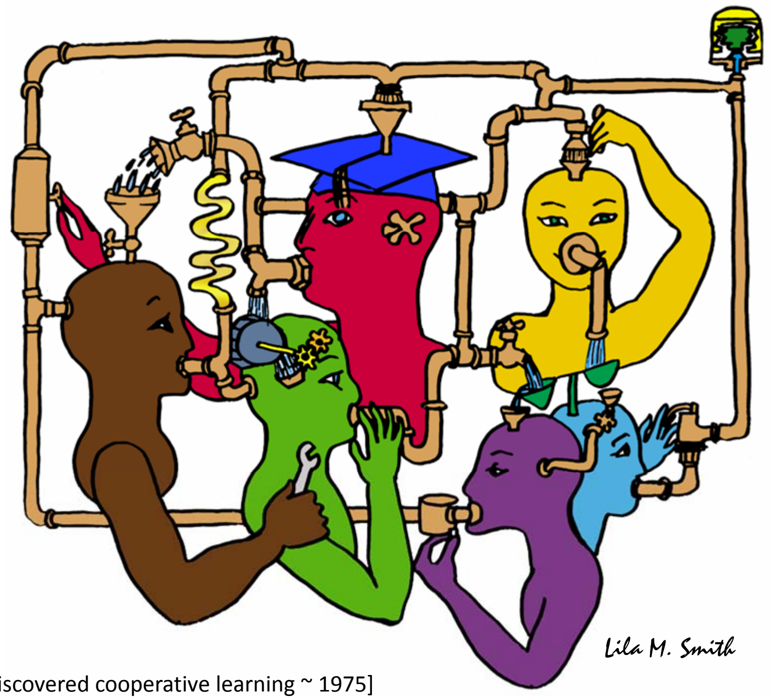
*My work is situated here – Cooperative Learning & Challenge-Based Learning

*My Engineering Education Innovation Story

- 1972 – Materials Processing Research – University of Minnesota
- 1974 – First undergraduate teaching experience – "pour it in" model
- 1974-8 coursework in College of Education – Discovered cooperative learning (CL) about 1974 – Interdependence & Accountability resonated
- 1975 – Implemented CL in my classes
- 1981 – Went public with CL – JEE paper and FIE conference presentation
- 1980s – Continued refining CL in my classes, telling others & co-developed and co-taught Into Eng course – Building Models to Solve Engineering Problems based on CL
- 1987-8 – co-wrote *How to Model* It book [McGraw-Hill, 1990]
- 1990-1 – Sabbatical – wrote first draft of *Active Learning: Cooperation in the College Classroom* [David & Roger Johnson refined and 1st edition published in 1991]
- 1991 – Materials Processing Research lab closed as did undergrad & grad programs
- 1992 – present – continued to refine CL model in engineering and spread word
- 1998-2004 – Michigan State University - Senior Consultant to Provost for Faculty Development [part time appointment] – worked with faculty and grad students
- 1998-9 – Sabbatical – wrote *Strategies for Engaging Students in Large Classes* [Wiley, 2000] & *Project Management and Teamwork* [McGraw-Hill, 2000]
- 2006 – Began phased retirement from University of Minnesota
- 2006 – present – Purdue School of Engineering Education PhD program
- 2010 – National Academy of Engineering Frontiers of Engineering Education Symposium



[*only model I knew when I started teaching]



[*discovered cooperative learning ~ 1975]

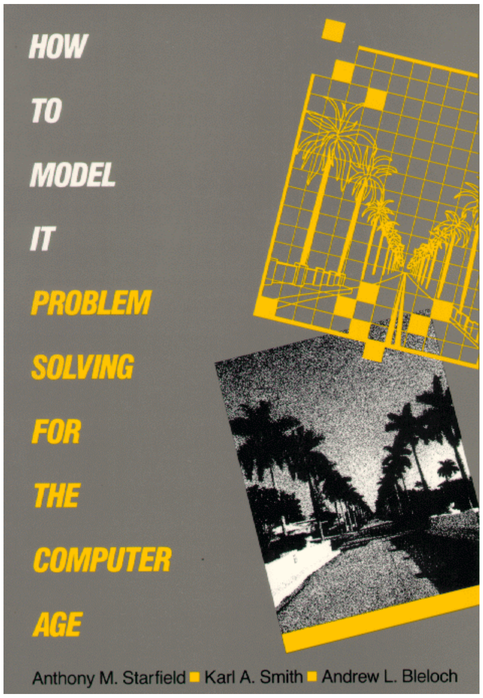
***Cooperative Learning** is instruction that involves people working in teams to accomplish a common goal, under conditions that involve both *positive interdependence* (all members must cooperate to complete the task) and *individual and group accountability* (each member is accountable for the complete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

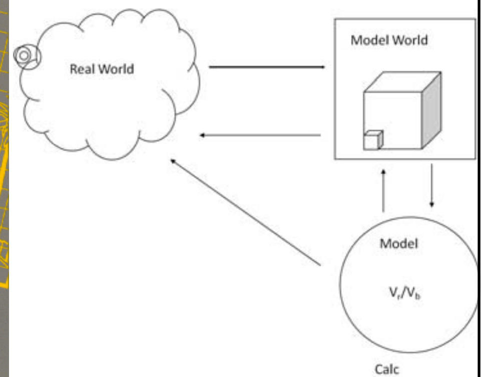
Key Concepts

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


Cooperative Learning
Positive Interdependence
Individual Accountability
Face-to-face Interaction

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





*Based on First Year Engineering course – Problem-based cooperative learning approach published in 1990.

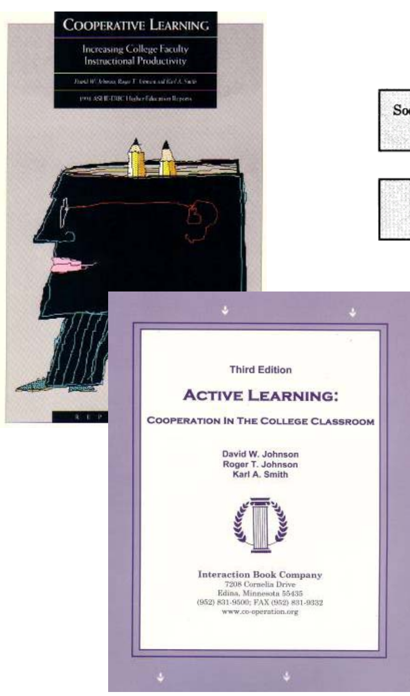
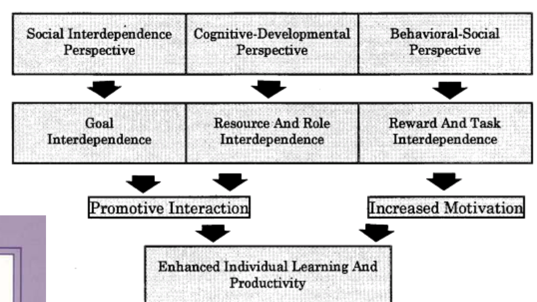


Figure A.1 A General Theoretical Framework



Cooperative Learning

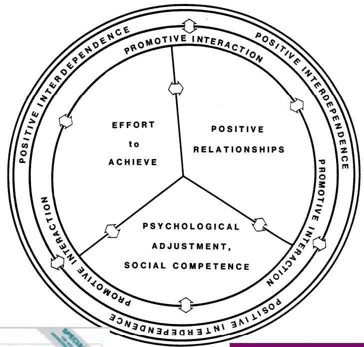
- Positive Interdependence
- Individual and Group Accountability
- Face-to-Face Promotive Interaction
- Teamwork Skills
- Group Processing

[*First edition 1991]

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.

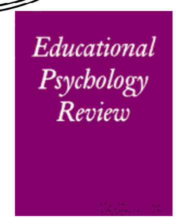
- Over 300 Experimental Studies
- First study conducted in 1924
- High Generalizability
- Multiple Outcomes



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

Active and Cooperative Learning

EDUCATION

Farewell, Lecture?

Eric Mazur

A physics professor describes his evolution from lecturing to dynamically engaging students during class and improving how they learn.

Discussions of education are generally predicated on the assumption that we know what education is. I hope to convince you otherwise by recounting some of my own experiences. When I started teaching introductory physics to undergraduates at Harvard University, I never asked myself how I would educate my students. I did what my teachers had done—I lectured. I thought that was how one learns. Look around anywhere in the world and you'll find lecture halls filled with students and, at the front, an instructor. This approach to education has not changed since before the Renaissance and the birth of scientific inquiry. Early in my career I received the first hints that something was wrong with teaching in this manner, but I had ignored it. Sometimes it's hard to face reality.

When I started teaching, I prepared lecture notes and then taught from them. Because my lectures deviated from the textbook, I provided students with copies of these lecture notes. The infuriating result was that on my end-of-semester evaluations—which were quite good otherwise—a number of students complained that I was "lecturing straight from (his) lecture notes." What was I supposed to do? Develop a set of lecture notes different from the ones I handed out? I decided to ignore the students' complaints.

Click here. Students continually discuss concepts among themselves and with the instructor during class. Discussions are spurred by multiple-choice conceptual questions that students answer using a clicker device. See supporting online text for examples of such "clicker questions."

A few years later, I discovered that the students were right. My lecturing was ineffective, despite the high evaluations. Early on in the physics curriculum—in week 2 of a typical introductory physics course—the Laws of Newton are presented. Every student in such a course can recite Newton's third law of motion, which states that the force of object A on object B in an interaction between two objects is equal in magnitude to the force of B on A—it sometimes is known as "action is reaction." One day, when the course had progressed to more complicated material, I decided to test my students' understanding of this concept not by doing traditional problems, but by asking them a set of basic conceptual questions (1, 2). One of the questions, for example, requires students to compare the forces that a heavy truck and a light car exert on one another when they collide. I expected that the students would have no trouble tackling such questions, but much to my surprise, hardly a minute after the test began, one student asked, "How should I answer these questions? According to what you taught me or according to the way I usually think about these things?" To my dismay, students had great difficulty with the conceptual questions. That was when it began to dawn on me that something was amiss.

In hindsight, the reason for my students' poor performance is simple. The traditional approach to teaching reduces education to a transfer of information. Before the industrial revolution, when books were not yet mass commodities, the lecture method was the only way to transfer information from one generation to the next. However, education is so

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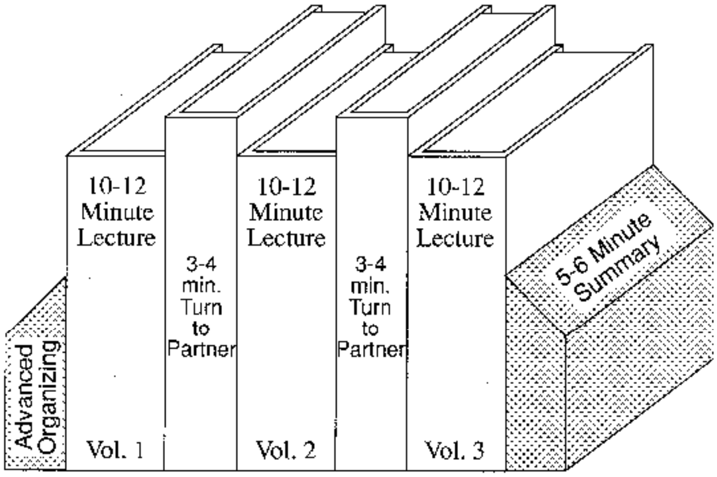
50 2 JANUARY 2009 VOL 323 SCIENCE www.sciencemag.org

January 2, 2009—Science, Vol. 323 – www.sciencemag.org

Calls for evidence-based promising practices

Book Ends on a Class Session



Thinking Together: Collaborative Learning in the Sciences – Harvard University – Derek Bok Center – www.fas.harvard.edu/~bok_cen/

More Professors Give Out Hand-Held Devices to Monitor Students and Engage Them

EVANSTON, Ill. — If any of the 70 undergraduates in Prof. Bill White's "Organizational Behavior" course here at Northwestern University are late for class, or not paying attention, he will know without having to scan the lecture hall.

Their "clickers" will tell him.

Every student in Mr. White's class has been assigned a palm-size, wireless device that looks like a TV remote but has a far less entertaining purpose. With their clickers in hand, the students in Mr. White's class automatically clock in as "present" as they walk into class.

They then use the numbered buttons on the devices to answer multiple-choice quizzes that count for nearly 20 percent of their grade, and that always begin precisely one minute into class. Later, with a click, they can signal to their teacher without raising a hand that they are confused by the day's lesson.

But the greatest impact of such devices — which more than a half-million students are using this fall on several thousand college campuses — may be cultural: they have

Post a Comment

Related

How Clickers Work (November 16, 2010)

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SEND TO PHONE
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November 15, 2010 – NY Times

How Clickers Work
By JACQUES STEINBERG
Published: November 15, 2010 At Northwestern University and on hundreds of other campuses, professors are arming students with hand-held clickers that look like a TV remote cross-bred with a calculator. Here is how they work:

1. Each clicker has a unique frequency that is assigned to a particular student.
2. Using a numbered keypad, students signal their responses to multiple-choice questions, which are tabulated wirelessly by the professor's computer.
3. Polling software then collates the data and gives the professor the ability to create various graphs and reports instantly as well as to store the data for grading and other purposes.

http://www.nytimes.com/2010/11/16/education/16clickers.html?ref=education

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Problem-Based Cooperative Learning

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

Jodi Hilton for The New York Times

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

By SARA RIMER
Published: January 12, 2009

COMMENTS (00)
E-MAIL
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SINGLE PAGE

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,

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

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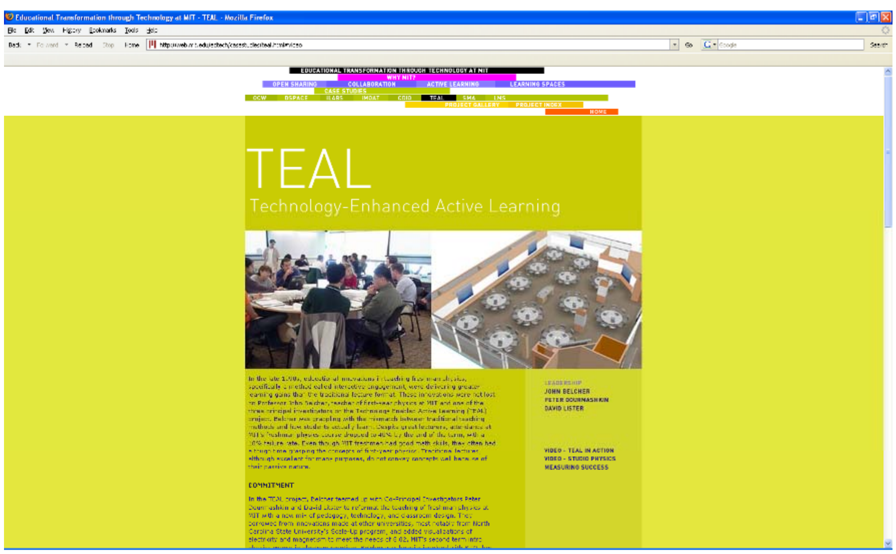

http://web.mit.edu/edtech/casestudies/teal.html#video

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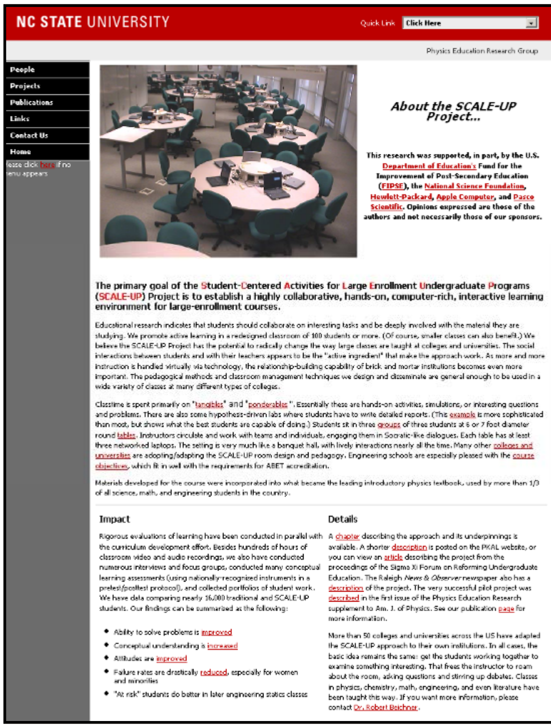

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About the SCALE-UP Project...

This research was supported, in part, by the U.S. Department of Education's Fund for the Improvement of Post-Secondary Education (FIPSE), the National Science Foundation, Hewlett-Packard, Apple Computer, and Pasco Scientific. Opinions expressed are those of the authors and not necessarily those of our sponsors.

The primary goal of the Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) Project is to establish a highly collaborative, hands-on, computer-rich, interactive learning environment for large-enrollment courses.

Educational research indicates that students should collaborate on interesting tasks and be deeply involved with the material they are studying. We promote active learning in a redesigned classroom of 100 students or more. (Of course, smaller classes can also benefit.) We believe the SCALE-UP Project has the potential to radically change the way large classes are taught at colleges and universities. The social interactions between students and with their teachers appears to be the "active ingredient" that make the approach work. As more and more instruction is handled virtually via technology, the relationship-building capability of brick and mortar institutions becomes even more important. The pedagogical methods and classroom management techniques we design and disseminate are general enough to be used in a wide variety of classes at many different types of colleges.

Classtime is spent primarily on "tangibles" and "ponderables". Essentially these are hands-on activities, simulations, or interesting questions and problems. There are also some hypothesis-driven labs where students have to write detailed reports. (This example is more sophisticated than most, but shows what the best students are capable of doing.) Students sit in three groups of three students at 6 or 7 foot diameter round tables. Instructors circulate and work with teams and individuals, engaging them in Socratic-like dialogues. Each table has at least three networked laptops. The setting is very much like a banquet hall, with lively interactions nearly all the time. Many other colleges and universities are adopting/adapting the SCALE-UP room design and pedagogy. Engineering schools are especially pleased with the course objectives, which fit in well with the requirements for ABET accreditation.

Materials developed for the course were incorporated into what became the leading introductory physics textbook, used by more than 1/3 of all science, math, and engineering students in the country.

Impact

Rigorous evaluations of learning have been conducted in parallel with the curriculum development effort. Besides hundreds of hours of classroom video and audio recordings, we also have conducted numerous interviews and focus groups, conducted many conceptual learning assessments (using nationally-recognized instruments in a pretest/posttest protocol), and collected portfolios of student work. We have data comparing nearly 16,000 traditional and SCALE-UP students. Our findings can be summarized as the following:

- Ability to solve problems is improved
- Conceptual understanding is increased
- Attitudes are improved
- Failure rates are drastically reduced, especially for women and minorities
- "At risk" students do better in later engineering statics classes

Details

A chapter describing the approach and its underpinnings is available. A shorter description is posted on the PKAL website, or you can view an article describing the project from the proceedings of the Sigma Xi Forum on Reforming Undergraduate Education. The Raleigh *News & Observer* newspaper also has a description of the project. The very successful pilot project was described in the first issue of the Physics Education Research supplement to Am. J. of Physics. See our publication page for more information.

More than 50 colleges and universities across the US have adapted the SCALE-UP approach to their own institutions. In all cases, the basic idea remains the same: get the students working together to examine something interesting. That frees the instructor to roam about the room, asking questions and stirring up debates. Classes in physics, chemistry, math, engineering, and even literature have been taught this way. If you want more information, please contact Dr. Robert Beichner.

http://www.ncsu.edu/PER/scaleup.html

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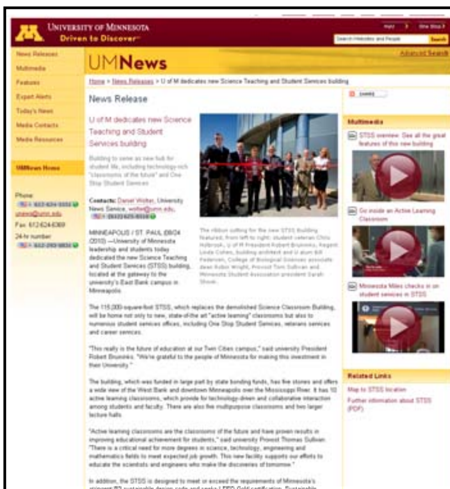

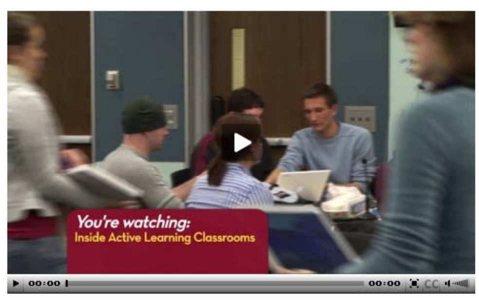

http://mediamill.cla.umn.edu/mediamill/embed/78755

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

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PROBLEM-BASED LEARNING

UD PBL articles and books

UD PBL in the news

Sample PBL problems

UD PBL courses and syllabi

PBL Clearinghouse

PBL Conferences and Other PBL sites

Institute for Transforming Undergraduate Education

Other related UD sites

"How can I get my students to think?" is a question asked by many faculty, regardless of their disciplines. Problem-based learning (PBL) is an instructional method that challenges students to "learn to learn," working cooperatively in groups to seek solutions to real world problems. These problems are used to engage students' curiosity and initiate learning the subject matter. PBL prepares students to think critically and analytically, and to find and use appropriate learning resources. -- *Barbara Duch*

PBL2002: A Pathway to Better Learning

Recipient of 1999 Hesburgh Certificate of Excellence

Please direct comments, suggestions, or requests to ud-pbl@udel.edu.
"http://www.udel.edu/pbl/"
Last updated March 13, 2004.
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http://www.udel.edu/pbl/

*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

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*Innovation Stories

- 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 as shown in previous slide
- **We can’t wait 25 years for YOUR innovations to become widely practiced!**

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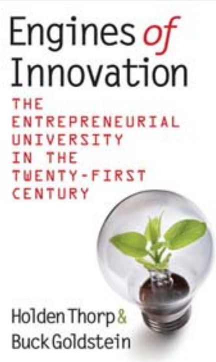
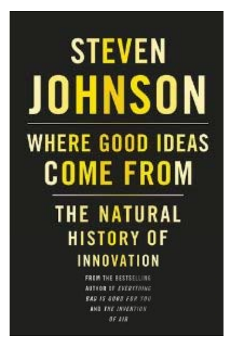
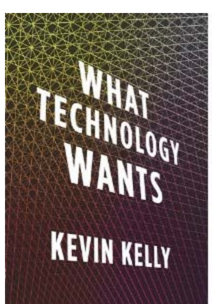
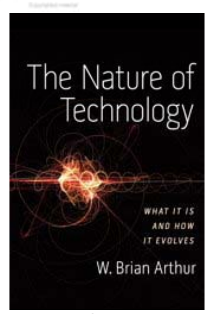
Innovation is the adoption of a new practice in a community

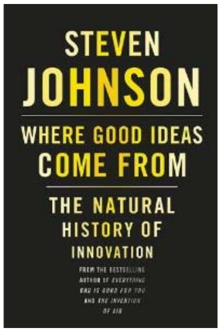








*We must focus on process of innovation



1. What is the distribution of innovations?
2. Did it change over time? If so, how?
3. Where does **your** innovation fit?

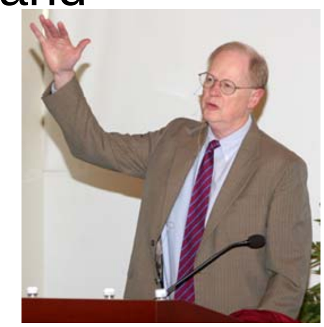
1600-1800

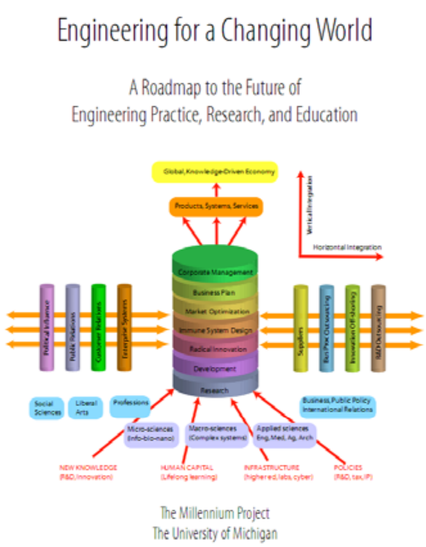
1800-present

1400-1600

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]





…objectives for engineering practice, research, and education:

To adopt a systemic, research-based approach to innovation and continuous improvement of engineering education, recognizing the importance of diverse approaches–albeit characterized by quality and rigor–to serve the highly diverse technology needs of our society

http://milproj.ummu.umich.edu/publications/EngFlex%20report/download/EngFlex%20Report.pdf

Background Knowledge Survey

- Familiarity with
  - **Course Design Models**
    - Wiggins & McTighe – Understanding by Design (Backward Design)
    - Fink – Creating Significant Learning Experiences
    - Felder & Brent – Effective Course Design
  - **Research on Learning**
    - Models of Learning (Mayer, 2010)
      - Learning as response strengthening
      - Learning as information acquisition
      - Learning as knowledge construction
    - *How People Learn*
    - Student Engagement
      - National Survey of Student Engagement (NSSE)
      - CAEE APS APPLES (academic pathways of people learning engineering survey)
      - Cooperative learning

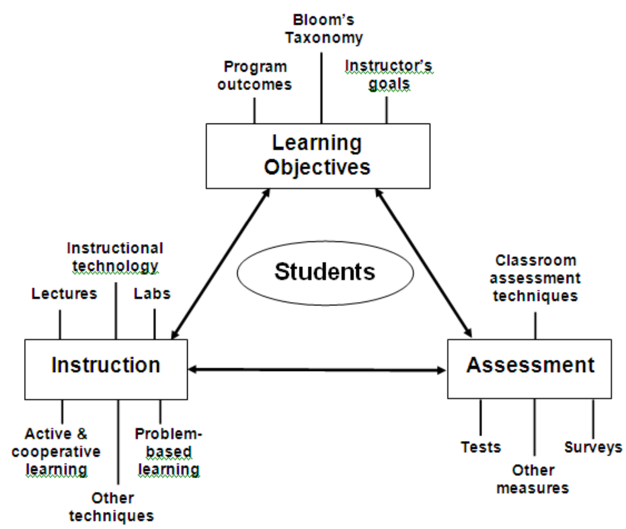
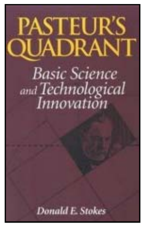


Figure 1. Elements of Course Design*

*R.M. Felder and R. Brent. (2003). Designing and Teaching Courses to Satisfy the ABET Engineering Criteria. *J. Engr. Education, 92*(1), 7–25.

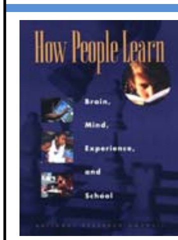
Research can be inspired by …



Understanding (Basic)	Use (Applied): No	Use (Applied): Yes
Yes	Pure basic research (Bohr)	Use-inspired basic research (Pasteur)
No		Pure applied research (Edison)

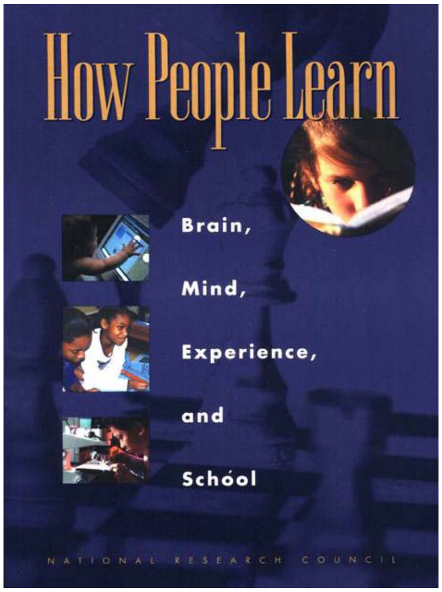
Source: Stokes, D. 1997. Pasteur's quadrant: Basic science and technological innovation. Washington, DC: Brookings Institution.

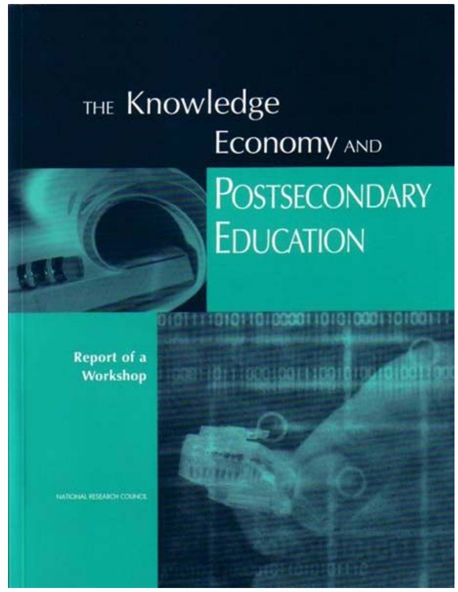
Instructional Innovation can be based on..



Science of Learning (HPL)	Science of Instruction (UbD): No	Science of Instruction (UbD): 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.

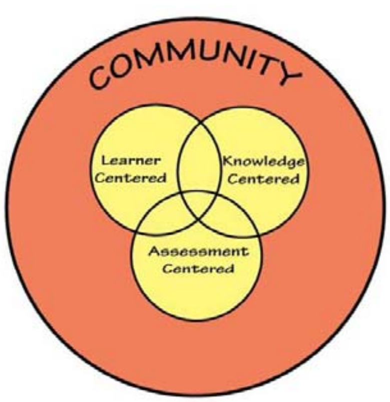




•Bransford, Vye and Bateman – Creating High Quality Learning Environments

How People Learn (HPL)

HPL Framework



- Expertise Implies (Ch. 2):
  - a set of cognitive and metacognitive skills
  - an organized body of knowledge that is deep and contextualized
  - an ability to notice patterns of information in a new situation
  - flexibility in retrieving and applying that knowledge to a new problem

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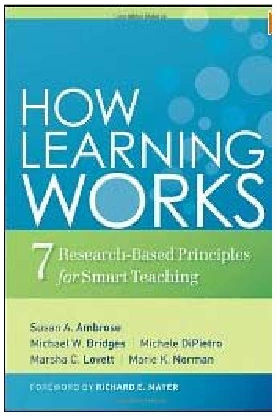
Bransford, Brown & Cocking. 1999. *How people learn.* National Academy Press.



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

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
http://learningcommons.evergreen.edu/pdf/fall1987.pdf

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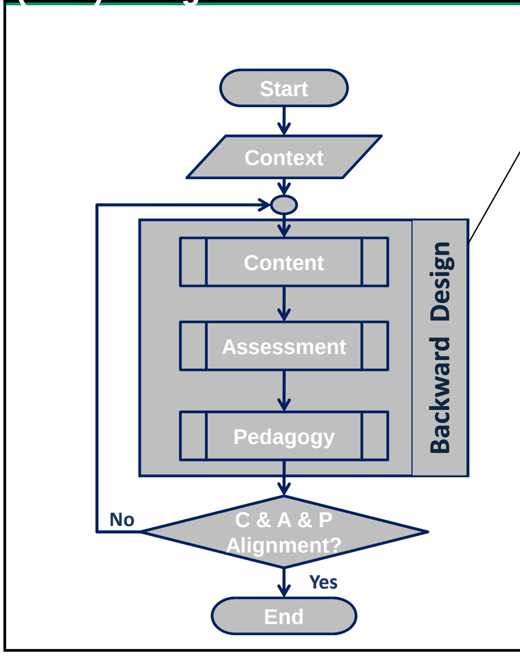
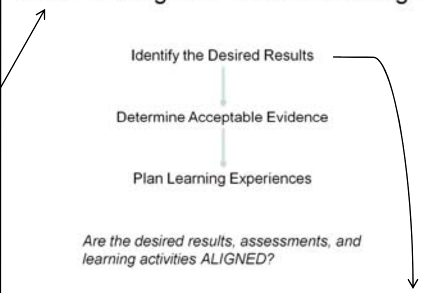
Content-Assessment-Pedagogy (CAP) Design Process Flowchart | Understanding by Design (Wiggins & McTighe, 2005)



UdB – 3 Stages of Backward Design



UbD Filters for Curricular Priorities

- Are the topics enduring and transferable big ideas having value beyond the classroom?
- Are the topics big ideas and core processes at the heart of the discipline?
- Are the topics abstract, counterintuitive, often misunderstood, or easily misunderstood ideas requiring coverage?
- Are the topics big ideas embedded in facts, skills and activities?

Understanding by Design, pp. 10-11

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

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UbD Filters for Curricular Priorities

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Understanding by Design, pp. 10-11

and Think

Revisit your engineering education innovation. Is your innovation based on HPL framework or other Learning Theory? How does your approach compare with the Understanding by Design (backward design) process?

Feedback and Assessment

- Forward Looking Assessment
  - Questions that incorporate course concepts in a real-life context
- Criteria and Standards
  - What traits or characteristics are indicative of high quality work?
- Self-Assessment
  - Allow students to gauge their own learning.
- FIDeLity Feedback
  - **F**requent, **I**mmediate, **D**iscriminating, **L**ovingly delivered

Taxonomies of Types of Learning

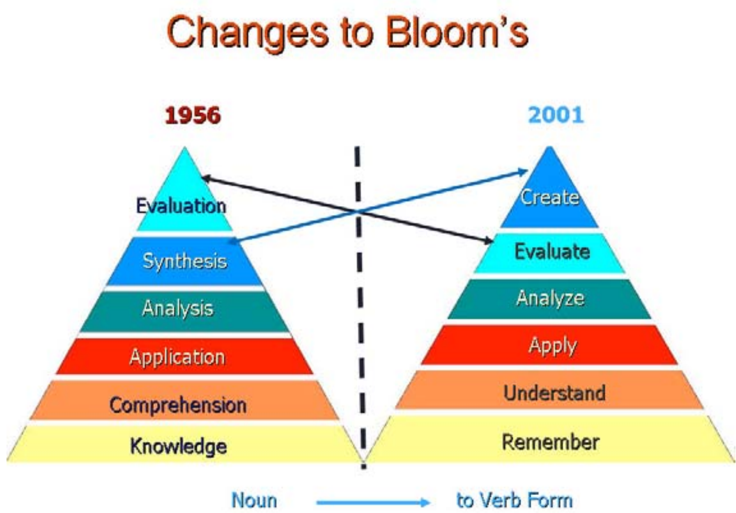
Bloom's taxonomy of educational objectives: Cognitive Domain (Bloom & Krathwohl, 1956)

A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives (Anderson & Krathwohl, 2001).

Facets of understanding (Wiggins & McTighe, 1998)

Taxonomy of significant learning (Fink, 2003)

Evaluating the quality of learning: The SOLO taxonomy (Biggs & Collis, 1982)



http://www.uwsp.edu/education/lwilson/curric/newtaxonomy.htm

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The Cognitive Process Dimension →

The Knowledge Dimension ↓

	Remember	Understand	Apply	Analyze	Evaluate	Create
Factual Knowledge – The basic elements that students must know to be acquainted with a discipline or solve problems in it. a. Knowledge of terminology b. Knowledge of specific details and elements						
Conceptual Knowledge – The interrelationships among the basic elements within a larger structure that enable them to function together. a. Knowledge of classifications and categories b. Knowledge of principles and generalizations c. Knowledge of theories, models, and structures						
Procedural Knowledge – How to do something; methods of inquiry, and criteria for using skills, algorithms, techniques, and methods. a. Knowledge of subject-specific skills and algorithms b. Knowledge of subject-specific techniques and methods c. Knowledge of criteria for determining when to use appropriate procedures						
Metacognitive Knowledge – Knowledge of cognition in general as well as awareness and knowledge of one's own cognition. a. Strategic knowledge b. Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge c. Self-knowledge						

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Reflection and Dialogue

- Individually reflect on your Engineering 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 3 minutes
  - Select Design Example, Comment, Insight, etc. that you would like to present to the whole group if you are randomly selected

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

- Learning
  - Mayer, R. E. (2010). *Applying the science of learning.* Upper Saddle River, NJ: Pearson.
  - Smith, K.A. (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, K.A., Sheppard, S.D., Johnson, D.W. & Johnson, R.T. (2005) Pedagogies of Engagement: Classroom Based Practices [Smith-Pedagogies_of_Engagement.pdf]
  - Smith, K.A., Johnson, D.W. & Johnson, R.T. (1998) Cooperative learning returns to college: What evidence is there that it works? Change, 30 (4), 26-35. [CLReturnstoCollege.pdf]
- Design Framework – How People Learn (HPL) & Understanding by Design 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/
  - Pellegrino, James W. 2006. Rethinking and redesigning curriculum, instruction and assessment: What contemporary research and theory suggests. Paper commissioned by the National Center on Education and the Economy for the *New* Commission on the Skills of the American Workforce. 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.
- 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

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- Symposium materials are posted on
  - http://www.ce.umn.edu/~smith/links.html
  - CLEERhub.org

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