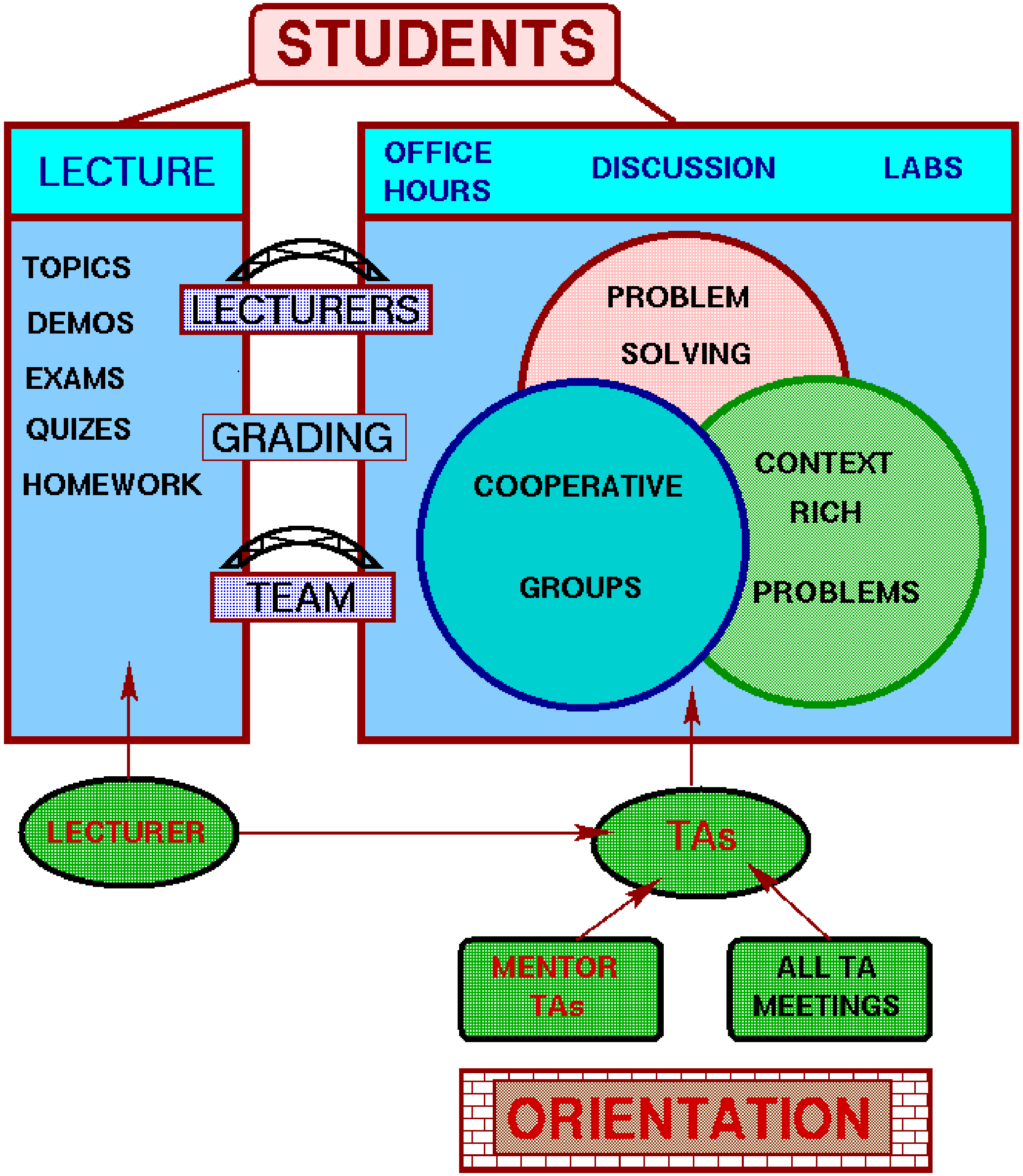
Design and Implementation of Cooperative Learning in Introductory Physics

Karl A. Smith

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

University of Minnesota Collaborative Model
for Large Introductory Courses



University of MN, Physics Education Research and Development, 1996

Problem Solving *a la* Martinez

"Process of Moving Toward a Goal When Path is Uncertain."

- **If you know how to do it, it's not a problem.**

(Exercise vs Problem)

"Problem Solving Involves Error and Uncertainty"

A problem for your students is not a problem for you.

M. Martinez, Phi Delta Kappan, April, 1998

It is strange that we expect students to learn, yet seldom teach them anything about learning. We expect students to solve problems, yet seldom teaching them anything about problem solving. And, similarly, we sometimes require students to remember A considerable body of material, yet seldom teach them the art of memory. **It is time we made up for this lack…**

D.A. Norman. 1980. Cognitive engineering and education. In D.T. Tuma and F. Reif (Eds.), *Problem solving and education: Issues in teaching and research. Erlbaum, pp. 97-107.*

Learning: Emphasize Big Ideas (Enduring Outcomes)*

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

*See Streveler and Smith (2021), Course design in the time of coronavirus: Put on your designer's CAP. *Advances in Engineering Education*.

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

Learning Requires*

deliberate

distributed

practice

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

Key Implications

Deliberate

Attention must be paid

Attention and processing power = cognitive load (bandwidth)

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

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

Key Implications

Distributed

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

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

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

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

Key Implications

Practice what you want to learn

Attentive – doing something

Constructive – adding to your prior knowledge

Interactive – working with others to add to your prior knowledge

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

I-C-A-P Framework

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

Interactive > Constructive > Attentive > Passive

ICAP framework, Michelene T.H. Chi

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

Cognitive apprenticeship (1 of 3)

1. Authentic tasks/situations
2. Narrated modeling
   - Challenges of this approach
     - Expert not used to explaining thinking
     - Expert forgets what is it like to be learning the material, “expert blind spot”
     - Subconscious or intuitive knowledge - “mystery of expert judgment”

Cognitive apprenticeship (2 of 3)

3. Scaffolded and coached practice
   - Scaffold from learner's prior knowledge to new info
   - Coach can diagnose "problems" and correct
   - Immediate feedback – important for motivation
   - Informational feedback

Cognitive apprenticeship (3 of 3)

3. Articulation of the steps by the learner
    - Self-explanation
4. Reflection on the process by the learner
    - Consolidates the skill, improves retention

Collins, A., Brown, J. S., & Newman, S. E. (1987). Cognitive apprenticeship: Teaching the craft of reading, writing and mathematics (Technical Report No. 403). BBN Laboratories, Cambridge, MA.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational Researcher, 18, 32-42.

Session Layout

Welcome & Overview

Cooperative Learning

- Description & Rationale
- Cooperative Learning
  - Key Concepts
  - Types of Cooperative Learning

Teamwork – High Performing Teams & Teamwork Skills

Implementing Cooperative Learning

- Practice
- Examples
- Applications

Overall Goals

- Build your knowledge of Cooperative Learning and your implementation repertoire
- Implement practices to improve student learning, especially their problem solving skills

Cooperative Learning Objectives

Participants will be able to list and describe essential features of the instructor's role in implementing cooperative learning

Participants will be able to elaborate on multiple ways Positive Interdependence and Individual Accountability were structured

Participants will identify features to implement in their own courses

Reflection and Dialogue

Individually reflect on your experience **as an undergraduate student** with Interactive (cooperative) learning. Write for about 1 minute.

- First time you heard the term in a class setting *or* the first time you were asked to work with others in a class setting
- What did the instructor ask you to do?
- What rationale did the instructor provide?

Discuss with your neighbor for about 2 minutes

- Select/create a response to present to the whole group if you are randomly selected

Karl's Experience

First Teaching Experience – Third-year course in metallurgical reactions – thermodynamics and kinetics

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

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

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

Research – rotating disk

Practice – leaching of silver bearing metallic copper and printed circuit board waste

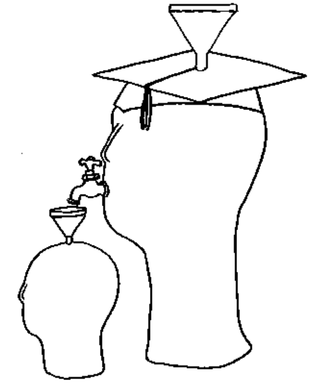
Lila M. Smith

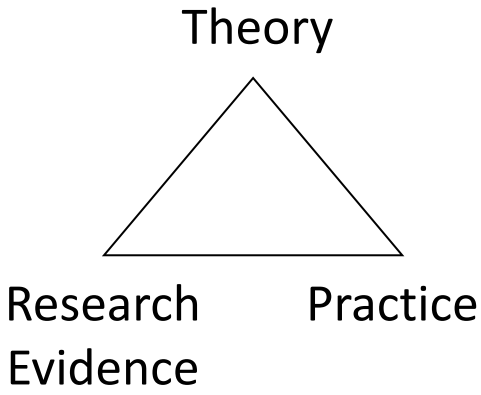
Karl's Quandry

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

Theory – ?

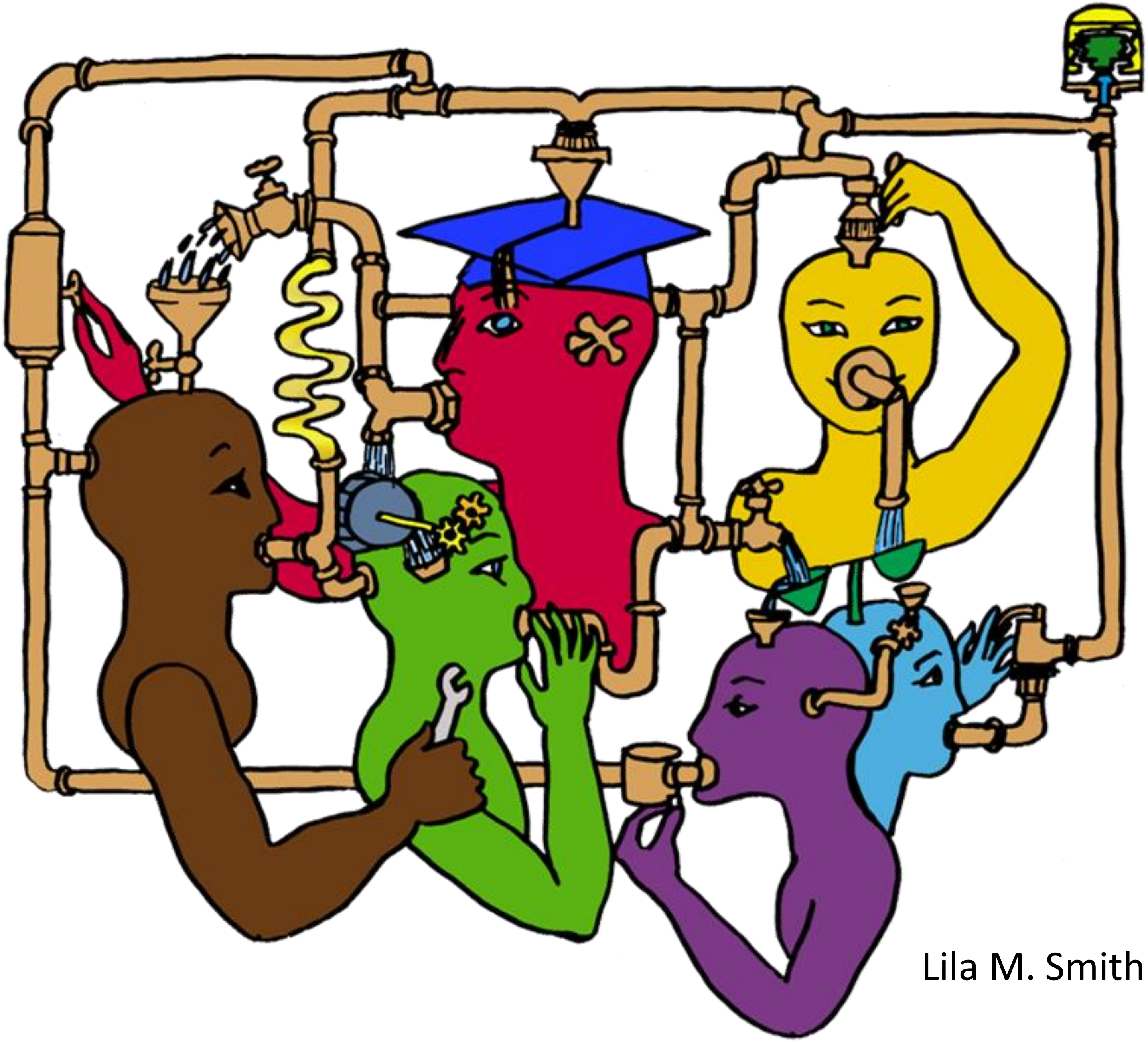
Research – ?





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
- Development Theories
- Motivation Theories
- Social psychology of learning – student – student interaction



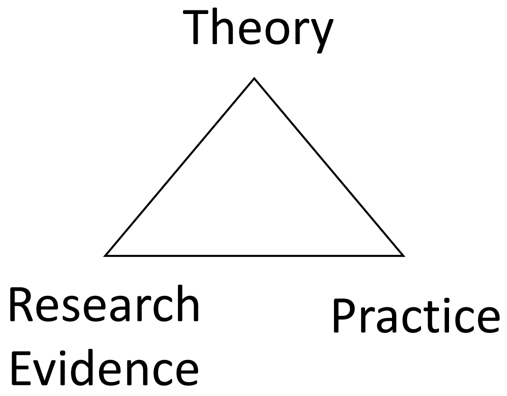
Lila M. Smith

Cooperative Learning

Theory – Social Interdependence – Lewin – Deutsch – Johnson & Johnson

Research Evidence – Randomized Design Field Experiments

Practice – Formal Teams/Professor's Role



Cooperative Learning: An Evidence-Based Practice for Interactive Learning

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

Cooperative Learning

Positive Interdependence

Goal Interdependence (essential)

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

Role (Duty) Interdependence

Assign each member a role and rotate them

Resource Interdependence

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

Task Interdependence

1. Factory-line
2. Chain Reaction

Outside Challenge Interdependence

1. Intergroup competition
2. Other class competition

Identity Interdependence

Mutual identity (name, motto, etc.)

Environmental Interdependence

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

Fantasy Interdependence

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

Reward/Celebration Interdependence

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

Individual Accountability

Ways to ensure no slackers:

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

Ways to ensure that all members learn:

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

Face-to-Face Interaction

Structure:

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

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

Key Concepts:

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

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

Cooperative Learning Introduced to Engineering – 1981

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

Structuring Learning Goals To Meet the Goals of Engineering Education

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

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

Goals of Engineering Education

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

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

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

Needs of Engineering Graduates

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

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

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

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

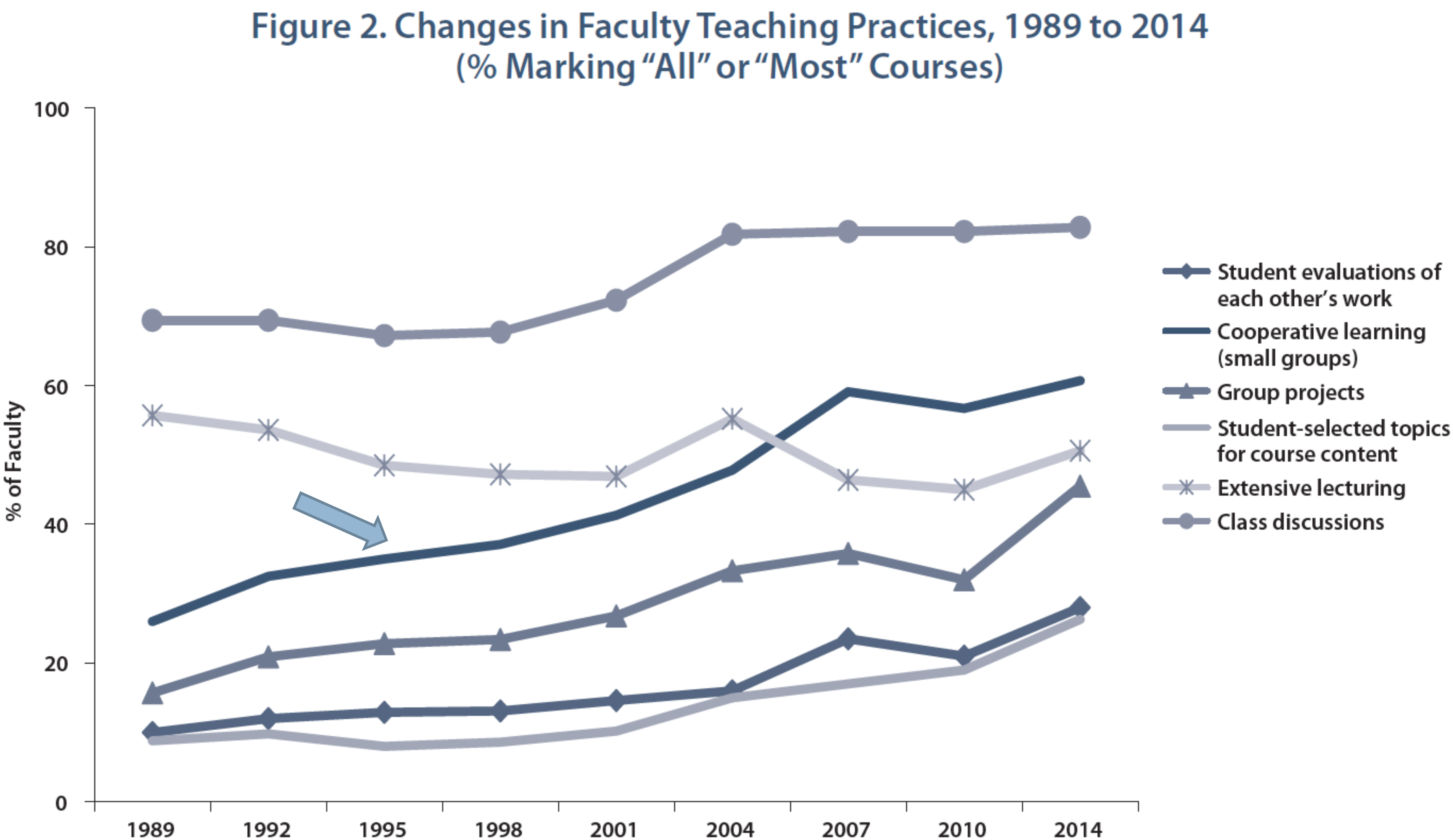
The recommendations of these studies are similar and recurrent, but the need for change in engineering education remains. Currently, there appears to be a move away from the image of applied science in engineering education.[5] The basis of this apparent change is the growing realization that technological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

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

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

http://personal.cege.umn.edu/~smith/docs/Smith-Pedagogies_of_Engagement.pdf

Undergraduate Teaching Faculty: The 2013–2014 HERI Faculty Survey



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.

Effectiveness of Interactive Learning

- Meta-analyses in the *Proceedings of the National Academy of Sciences (PNAS)* summarize the importance of interactive learning for
  - reducing the failure rate (Freeman, et.al. 2014) https://www.pnas.org/content/111/23/8410
  - narrowing the achievement gap for underrepresented students (Theobald, et.al. 2019) https://www.pnas.org/content/117/12/6476

INSIGHTS

POLICY FORUM

SCIENCE EDUCATION

Anatomy of STEM teaching in North American universities

Lecture is prominent, but practices vary

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

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

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

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

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

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Published by AAAS

Observational study of over 2000 classes – most common behaviors:

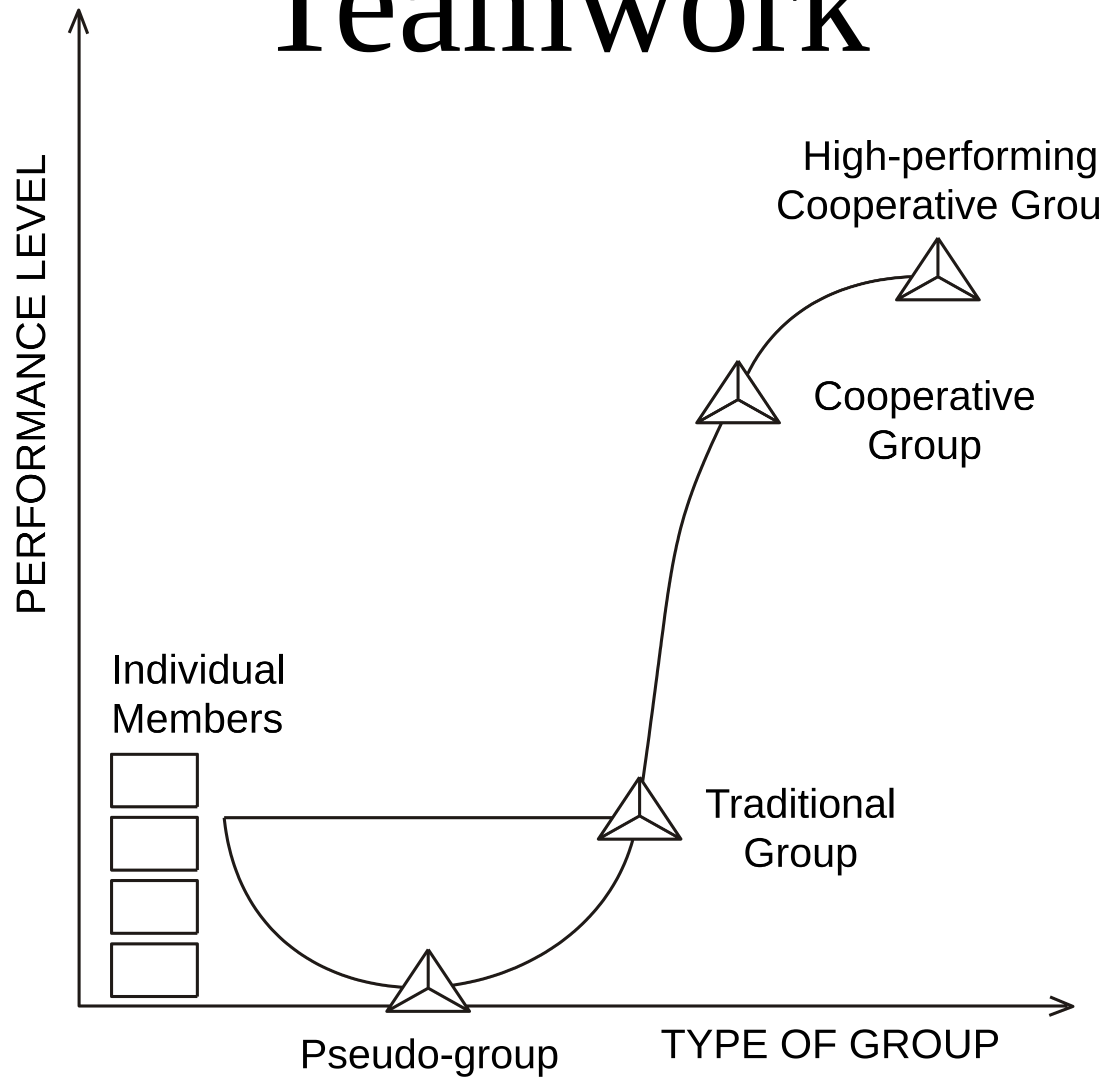
- Faculty
  - Lecturing
  - Writing in real time
  - Posing nonrhetorical questions
  - Following-up on questions
  - Answering student questions
  - Clicker questions
- Students
  - Listening to instructor
  - Answering instructor questions
  - Asking questions

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

Structuring Teamwork in the Classroom

Formal Cooperative Learning Task Groups

Teamwork



PERFORMANCE LEVEL
High-performing
Cooperative Group
Cooperative
Group
Individual
Members
Traditional
Group
Pseudo-group
TYPE OF GROUP

Reflection and Dialogue

Individually reflect on the Characteristics of High Performing Teams. Think/Write for about 1 minute

- Base on your experience on high performing teams,
- Or your facilitation of high performing teams in your classes,
- Or your imagination

Discuss with your team for about 2 minutes and record a list

Characteristics of High Performing Teams

- ?

Characteristics of High Performing Teams – Physics TAs - 2019

- Respect for one another
- Good leadership
- Diversity of ideas and diversity of skills
- Common work ethic
- Health conflict
- Sense of comraderies, actual cooperative group, good participation
- Common goal
- Motivation
- Systematic organization
- No ego
- External check
- To agree/not be afraid of being wrong

Characteristics of High Performing Teams – Physics TAs - 2018

- Diversity of experience
- People had one another's backs
- Feel safe presenting ideas – cooperative not competitive
- Group members pushing one another to do well
- Holding one another accountable
- Respecting one another's idea
- Levity – sense of humor
- People aren't afraid to ask question
- Help shy people to talk, e.g., ask shy folks what they think
- Responsibility and flexibility –responsible for own work. Flexible in tacking issues
- Come to a conclusion as a group – make sure everyone understands
- Similar motivations

A team is a small number of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable:

- SMALL NUMBER
- COMPLEMENTARY SKILLS
- COMMON PURPOSE & PERFORMANCE GOALS
- COMMON APPROACH
- MUTUAL ACCOUNTABILITY

--Katzenbach & Smith (1993)

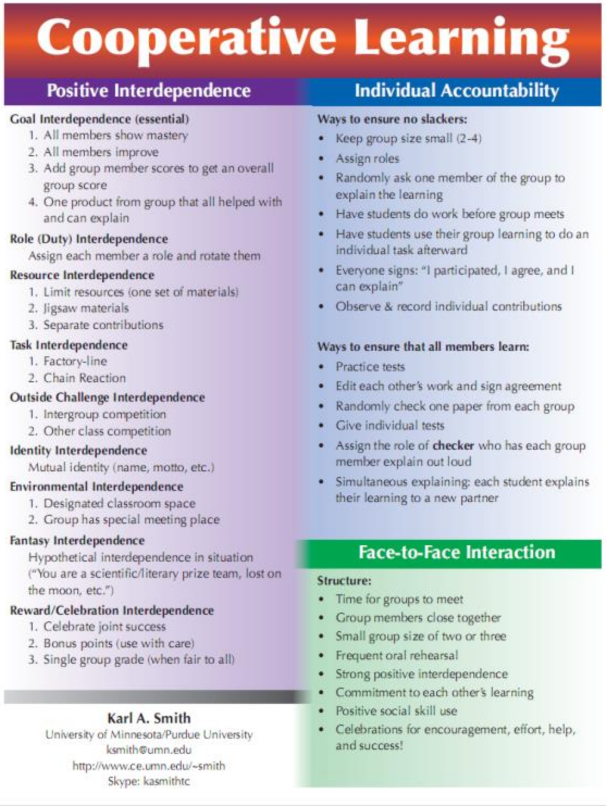
The Wisdom of Teams

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

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



Cooperative Learning

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Goal Interdependence (essential)
1. All members show mastery
2. All members improve
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Role (Duty) Interdependence
Assign each member a role and rotate them

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

Task Interdependence
1. Factory-line
2. Chain Reaction

Outside Challenge Interdependence
1. Intergroup competition
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Mutual identity (name, motto, etc.)

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

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3. Single group grade (when fair to all)

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

Individual Accountability

Ways to ensure no slackers:
- Keep group size small (2-4)
- Assign roles
- Randomly ask one member of the group to explain the learning
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Face-to-Face Interaction

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

Six Basic Principles of Team Discipline

Keep membership small

Ensure that members have complimentary skills

Develop a common purpose

Set common goals

Establish a commonly agreed upon working approach

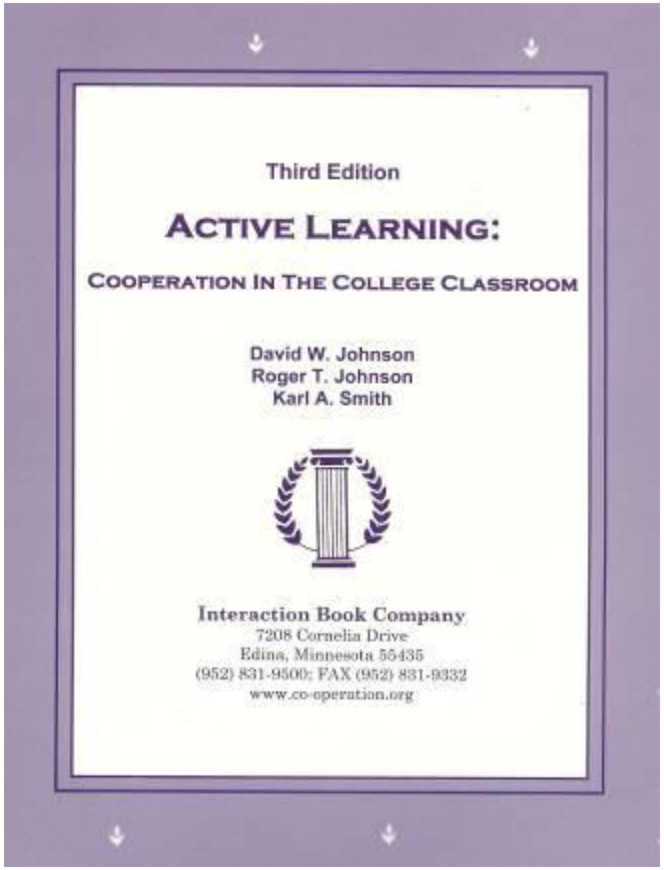
Integrate mutual and individual accountability

Katzenbach & Smith (2001) *The Discipline of Teams*

Cooperation in the College Classroom

- **Informal** Cooperative Learning Groups
- **Formal** Cooperative Learning Groups
- Cooperative **Base** Groups

Notes: Cooperative Learning Notes



Instructor’s Role in Formal Cooperative Learning

1. Specifying **Objectives** (Academic and Interpersonal/Teamwork)
2. Making **Decisions**
3. Explaining **Task**, **Positive Interdependence**, and **Individual Accountability**
4. **Monitoring** and Intervening to Teach Skills
5. **Evaluating** Students' Achievement and Group Effectiveness

Cooperative Problem-Based Learning Format

TASK: Solve the problem(s) or Complete the project.

INDIVIDUAL: Develop ideas, Initial Model, Estimate, etc. Note strategy.

COOPERATIVE: One set of answers from the group, strive for agreement, make sure everyone is able to explain the strategies used to solve each problem.

EXPECTED CRITERIA FOR SUCCESS: Everyone must be able to explain the model and strategies used to solve each problem.

EVALUATION: Best answer within available resources or constraints.

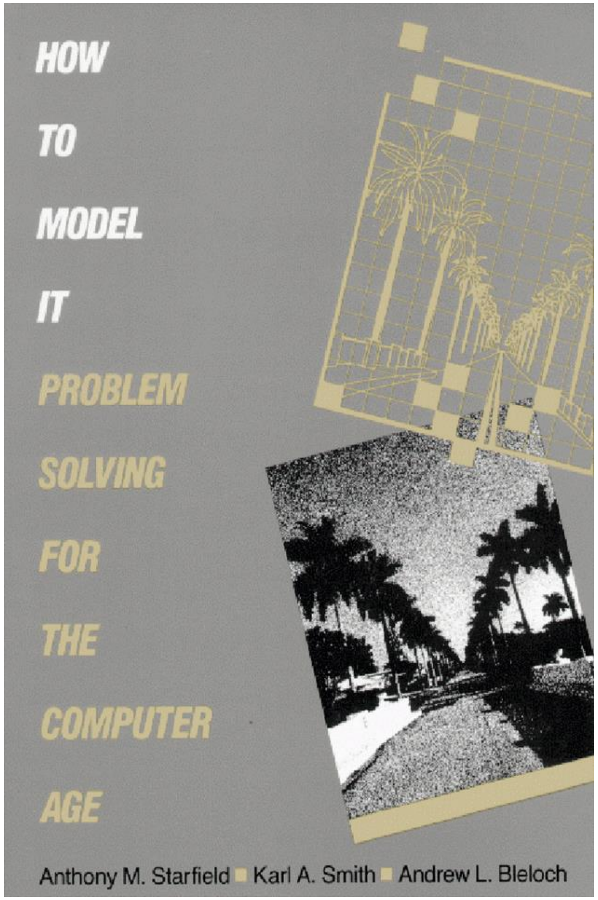
INDIVIDUAL ACCOUNTABILITY: One member from your group may be randomly chosen to explain (a) the answer and (b) how to solve each problem.

EXPECTED BEHAVIORS: Active participating, checking, encouraging, and elaborating by all members.

INTERGROUP COOPERATION: Whenever it is helpful, check procedures, answers, and strategies with another group.

Building Models to Solve Engineering Problems – UMN – Institute of Technology course (~1978 – 2000)

- Thinking Like an Engineer
- Problem Identification
- Problem Formulation
- Problem Representation
- Problem Solving



Team Member Roles

- Task Recorder
- Skeptic/Prober
- Process Recorder/facilitator

Technical Estimation Problem

TASK:

INDIVIDUAL: Quick Estimate (10 seconds). Note strategy.
Note strategy.

COOPERATIVE: Improved Estimate (~5 minutes). One set of answers from the group, strive for agreement, make sure everyone is able to explain the strategies used to arrive at the improved estimate.

EXPECTED CRITERIA FOR SUCCESS: Everyone must be able to explain the strategies used to arrive at your improved estimate.

EVALUATION: Best answer within available resources or constraints.

INDIVIDUAL ACCOUNTABILITY: One member from your group may be randomly chosen to explain (a) your estimate and (b) how you arrived at it.

EXPECTED BEHAVIORS: Active participating, checking, encouraging, and elaborating by all members.

INTERGROUP COOPERATION: Whenever it is helpful, check procedures, answers, and strategies with another group.

Group Reports

Estimate

- Group 1
- Group 2
- . . .

Strategy used to arrive at estimate – assumptions, model, method, etc.

Number of Ping Pong Balls

Gr 1 –

Gr 2 –

Gr 3 –

Gr 4 –

Gr 5 –

Gr 6 –

Gr 7 –

Gr 8 –

Gr 9 –

Model 1 (lower bound)

let L be the length of the room,
let W be its width,
let H be its height,
and let D be the diameter of a ping pong ball.

Then the volume of the room is

$$V_{room} = L * W * H,$$

and the volume of a ball (treating it as a cube) is

$$V_{ball} = D^3,$$

so number of balls = $(V_{room}) / (V_{ball}) = (L * W * H) / (D^3)$.

Model 2 (upper bound)

let L be the length of the room,
let W be its width,
let H be its height,
and let D be the diameter of a ping pong ball.

Then the volume of the room is

$$V_{room} = L * W * H,$$

and the volume of a ball (treating it as a sphere) is

$$V_{ball} = 4/3 \pi r^3,$$

so number of balls = $(V_{room}) / (V_{ball}) = (L * W * H) / (4/3 \pi r^3)$.

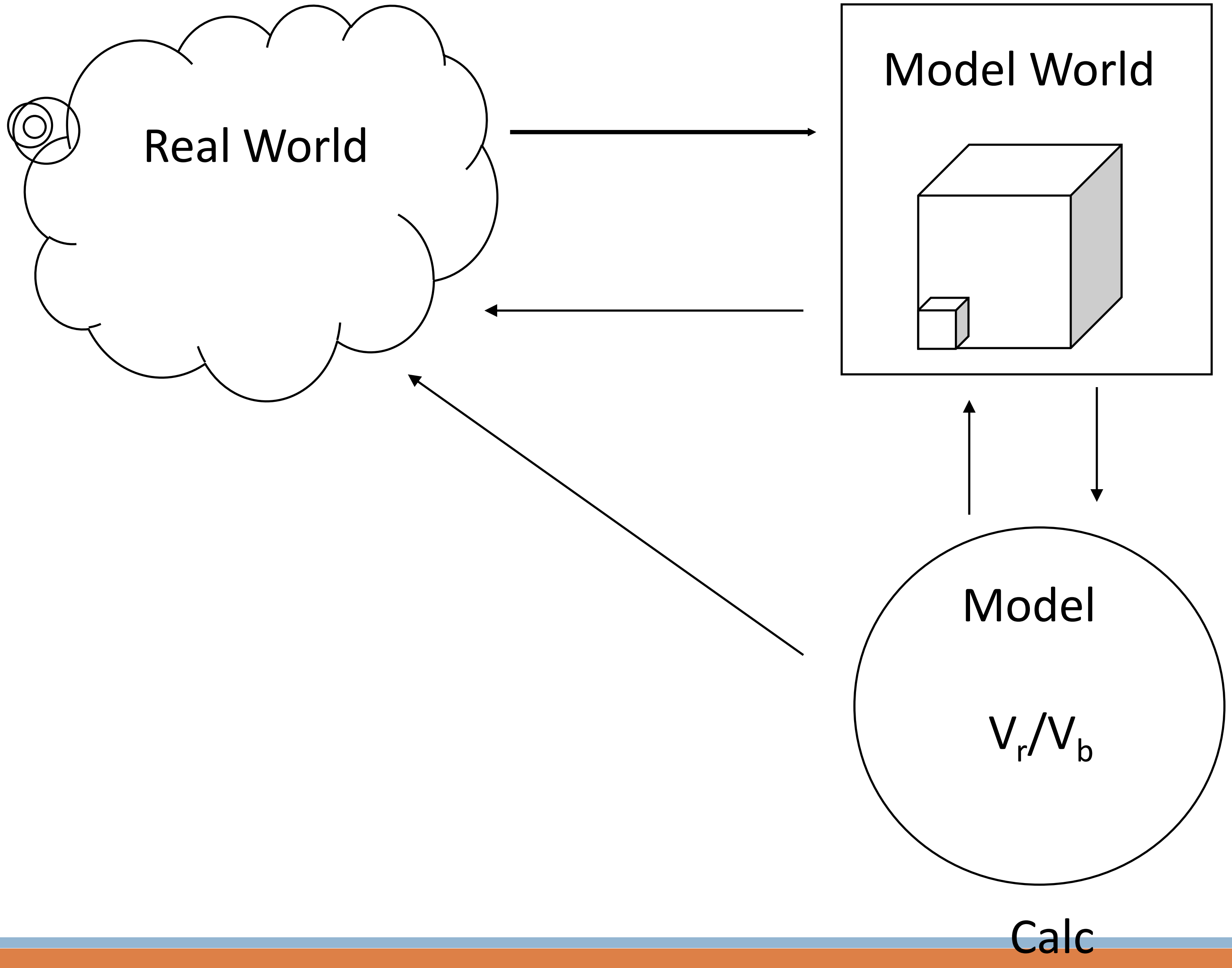
Model 1 (V_{room} / D^3_{ball}) = Lower Bound

Model 2 (V_{room} / ($4/3\ \pi r^3_{ball}$)) = Upper Bound

Upper Bound/Lower Bound = $6/\pi \approx 2$

How does this ratio compare with

1. The estimation of the diameter of the ball?
2. The estimation of the dimensions of the room?


Real World
Model World
Model
V_r/V_b
Calc

Modeling

Modeling in its broadest sense is the cost-effective use of something in place of something else for some cognitive purpose (Rothenberg, 1989). A model represents reality for the given purpose; the model is an abstraction of reality in the sense that it cannot represent all aspects of reality.

Any model is characterized by three essential attributes: (1) *Reference*: It is *of* something (its "*referent*"); (2) *Purpose*: It has an intended cognitive *purpose* with respect to its referent; (3) *Cost-effectiveness:* It is more *cost-effective* to use the model for this purpose than to use the referent itself.

Rothenberg, J. 1989. The nature of modeling. In L.E. Widman, K.A. Laparo & N.R. Nielson, Eds., *Artificial intelligence, simulation and modeling*. New York: Wiley

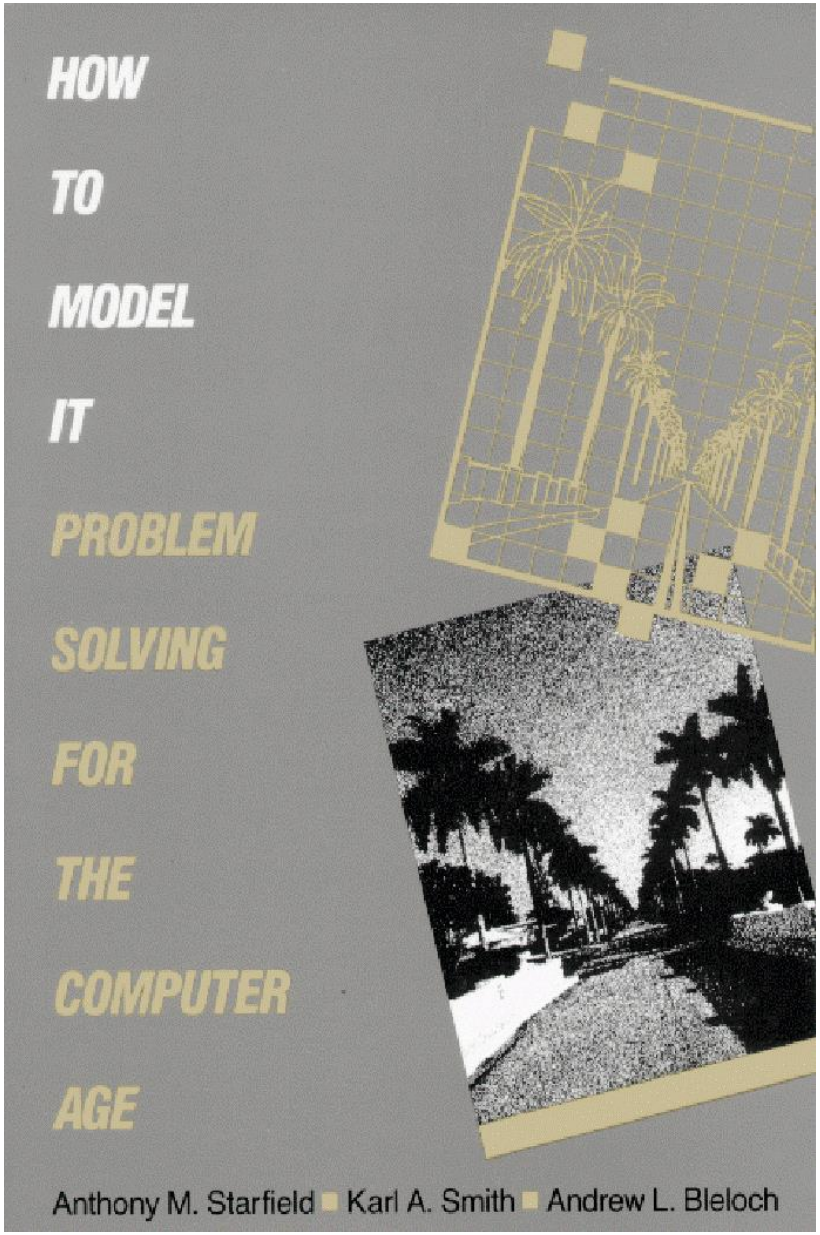
Modeling Heuristics

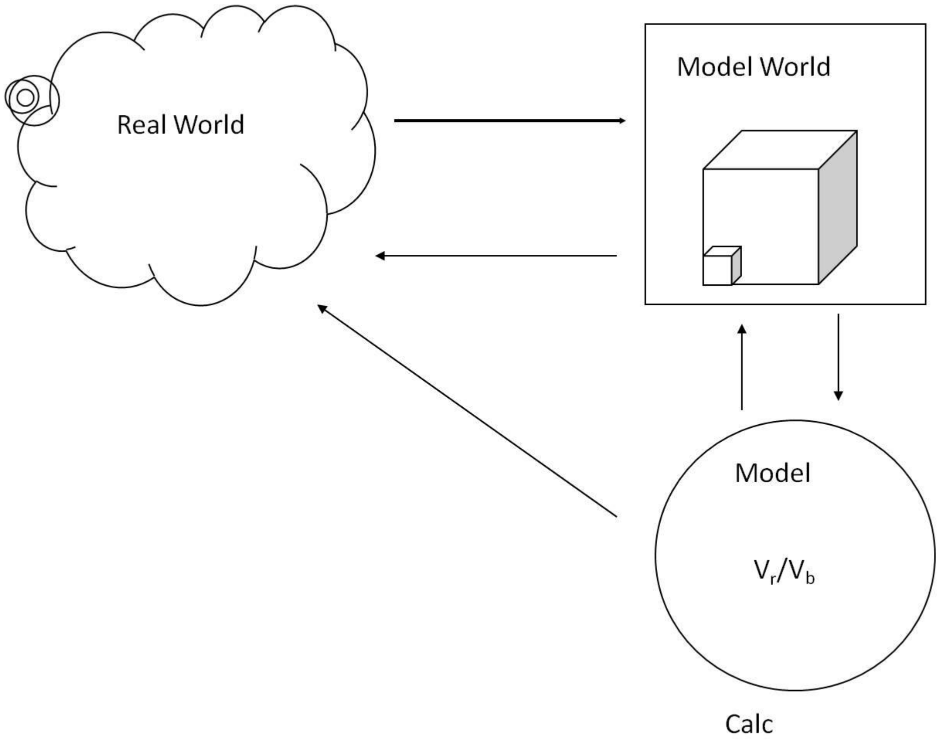
Ravindran, Phillips, and Solberg (1987):

1. **Do not build a complicated model when a simple one will suffice.**
2. Beware of molding the problem to fit the technique.
3. The deduction phase of modeling must be conducted rigorously.
4. Models should be validated prior to implementation.
5. A model should never be taken too literally.
6. A model should neither be pressed to do, nor criticized for failing to do, that for which it was never intended.
7. Beware of overselling a model.
8. **Some of the primary benefits of modeling are associated with the process of developing the model.**
9. **A model cannot be any better than the information that goes into it.**
10. Models cannot replace decision makers.

Group Processing Plus/Delta Format

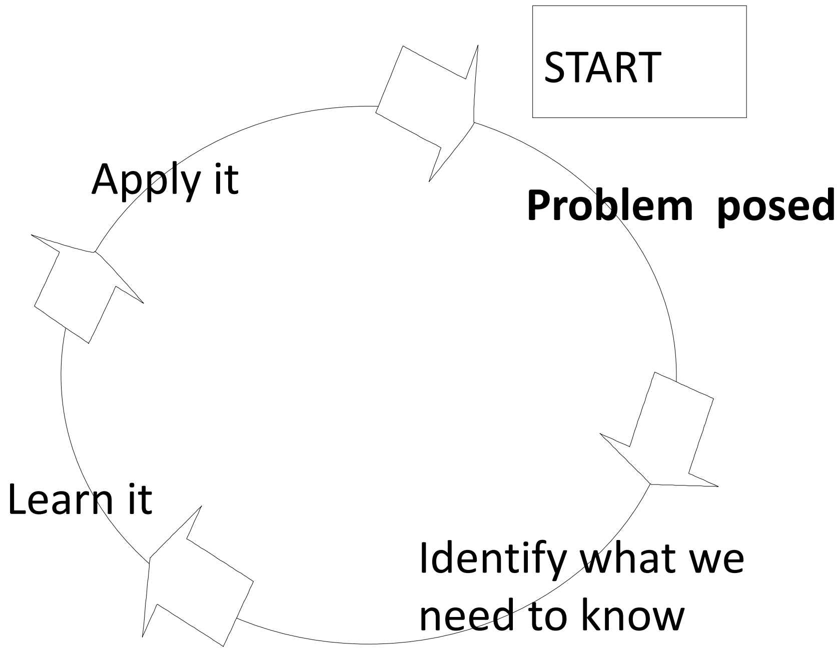
Plus (+) Things That Group Did Well	Delta (Δ) Things Group Could Improve



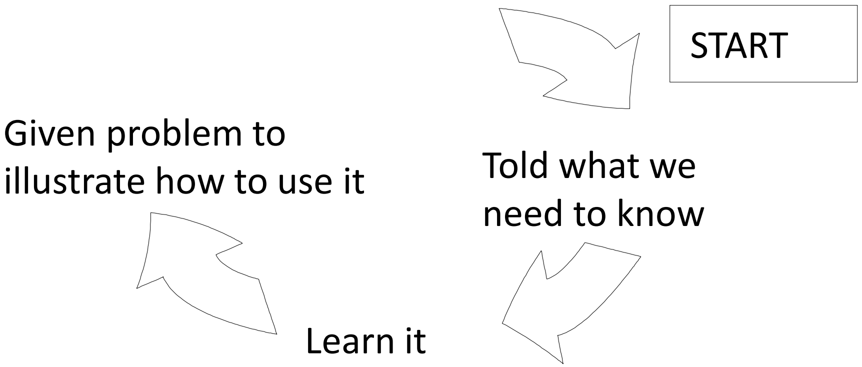


*Based on First Year Engineering course – Problem-based cooperative learning *How to Model It* published in 1990.

Problem-Based Learning



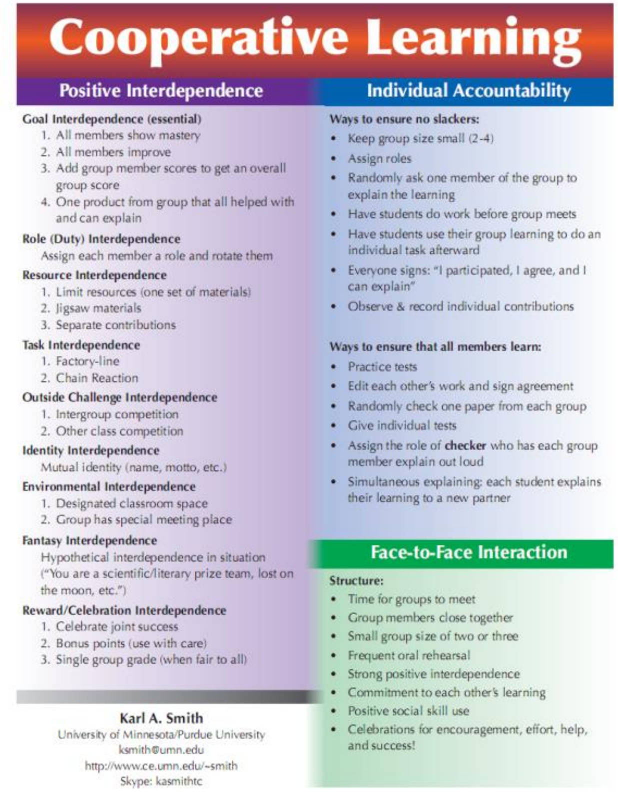
Subject-Based Learning



Normative Professional Curriculum:

1. Teach the relevant basic science,
2. Teach the relevant applied science, and
3. Allow for a practicum to connect the science to actual practice.

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).


Cooperative Learning

Positive Interdependence

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

Role (Duty) Interdependence
Assign each member a role and rotate them

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

Task Interdependence
1. Factory-line
2. Chain Reaction

Outside Challenge Interdependence
1. Intergroup competition
2. Other class competition

Identity Interdependence
Mutual identity (name, motto, etc.)

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

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

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

Individual Accountability

Ways to ensure no slackers:
- Keep group size small (2-4)
- Assign roles
- Randomly ask one member of the group to explain the learning
- Have students do work before group meets
- Have students use their group learning to do an individual task afterward
- Everyone signs: "I participated, I agree, and I can explain"
- Observe & record individual contributions

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

Face-to-Face Interaction

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

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

Key Concepts

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

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

Instructor’s Role in Formal Cooperative Learning

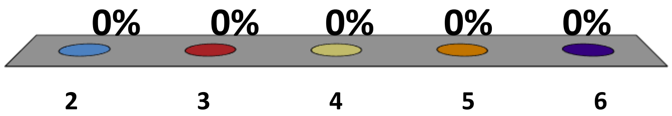
1. Specifying **Objectives** (Academic and Social/Teamwork)
2. Making **Decisions**
3. Explaining **Task**, **Positive Interdependence**, and **Individual Accountability**
4. **Monitoring** and Intervening to Teach Skills
5. **Evaluating** Students' Achievement and Group Effectiveness

Decisions, Decisions…

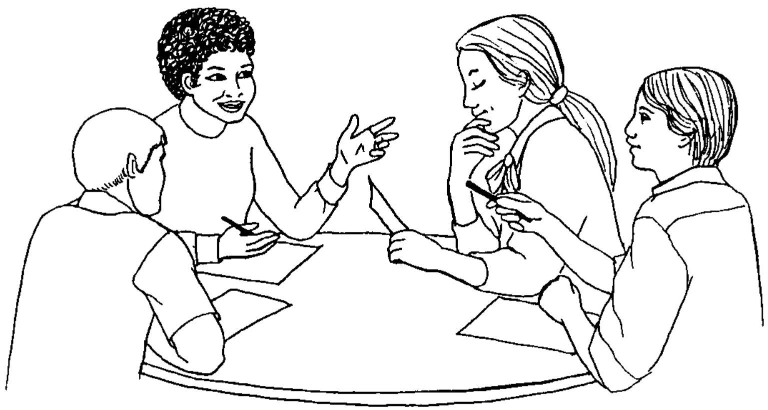
- Group size?
- Group selection?
- Group member roles?
- How long to leave groups together?
- Arranging the room?
- Providing materials?
- Time allocation?

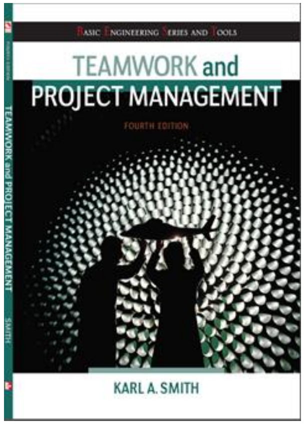
Optimal Group Size?

A. 2
B. 3
C. 4
D. 5
E. 6

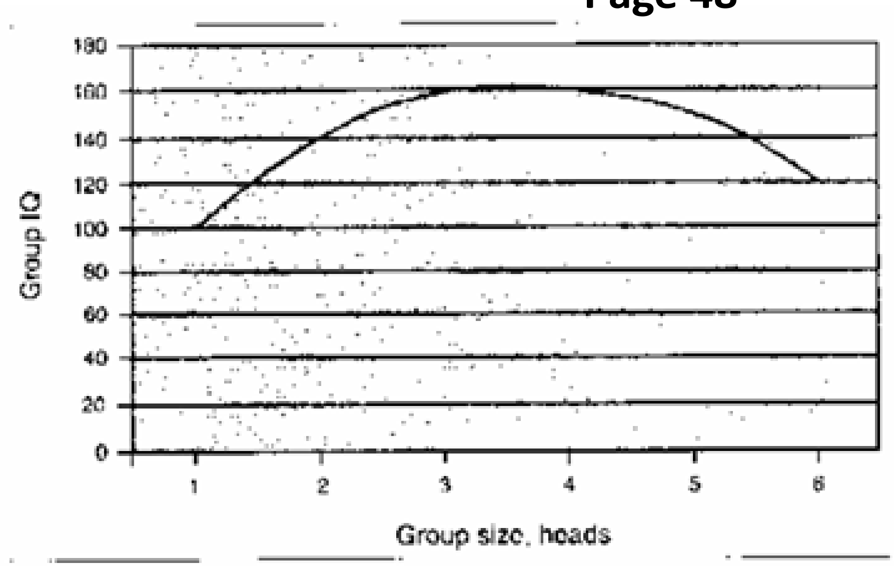


Formal Cooperative Learning Task Groups





Page 48

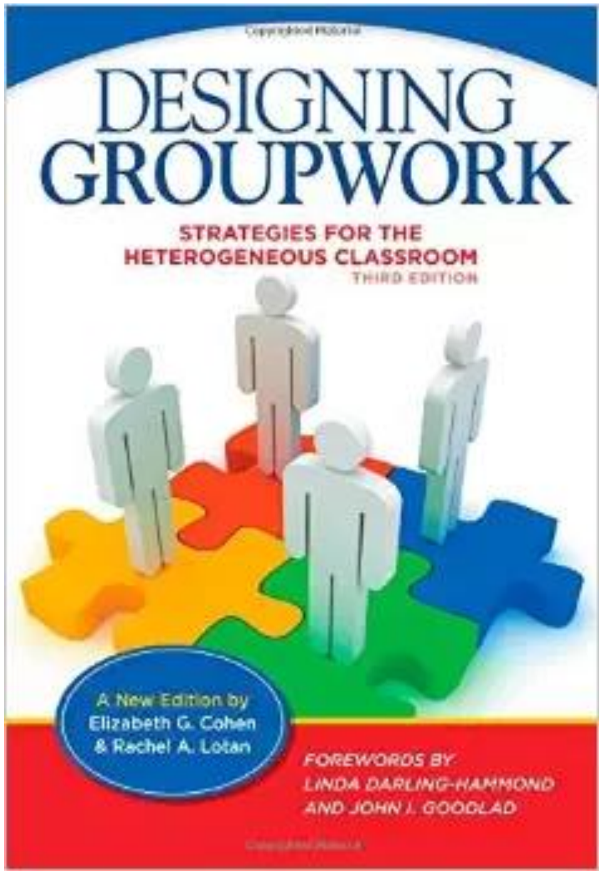


Perkins, David. 2003. *King Arthur's Round Table: How collaborative conversations create smart organizations.* NY: Wiley.

Group Selection?

A. Self selection
B. Random selection
C. Stratified random
D. Instructor assign
E. Other

Assigning Roles

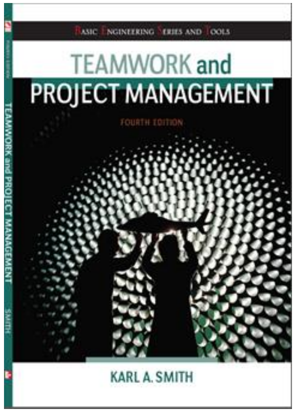


Chapter 8: Group Roles and Responsibilities

- Roles
  - Facilitator
  - Checker
  - Set-Up
  - Materials Manager
  - Safety Officer
  - Reporter
- Dividing the labor

Teamwork Skills

- Communication
  - Listening and Persuading
- Decision Making
- Conflict Management
- Leadership
- Trust and Loyalty



Chapters 3, **4**, 5 & 6

Cooperative Teamwork Skills

Forming Skills
Initial Management Skills

- Move Into Groups Quietly
- Stay With the Group
- Use Quiet Voices
- Take Turns
- Use Names, Look at Speaker
- No "Put-Downs"

Functioning Skills
Group Management Skills

- Share Ideas and Opinions
- Ask for Facts and Reasoning
- Give Direction to the Group's Work (state assignment purpose, provide time limits, offer procedures)
- Encourage Everyone to Participate
- Ask for Help or Clarification
- Express Support and Acceptance
- Offer to Explain or Clarify
- Paraphrase Other's Contributions
- Energize the Group
- Describe Feelings When Appropriate

Formulating Skills
Formal Methods for Processing Materials

- Summarize Out Loud Completely
- Seek Accuracy by Correcting/Adding to Summaries
- Help the Group Find Clever Ways to Remember
- Check Understanding by Demanding Vocalization
- Ask Others to Plan for Telling/Teaching Out Loud

Fermenting Skills
Stimulate Cognitive Conflict and Reasoning

- Criticize Ideas Without Criticizing People
- Differentiate Ideas and Reasoning of Members
- Integrate Ideas into Single Positions
- Ask for Justification on Conclusions
- Extend Answers
- Probe by Asking In-depth Questions
- Generate Further Answers
- Test Reality by Checking the Group's Work

Teaching Cooperative Skills

1. Help students see the **need** to learn the skill.
2. Help them **know how** to do it (T-chart).
3. Encourage them to **practice** the skill daily.
4. Help them **reflect on**, process, & refine use.
5. Help them **persevere** until skill is automatic

Monitoring, Observing, Intervening, and Processing

Monitor to promote academic & cooperative success

Observe for appropriate teamwork skills: praise their use and remind students to use them if necessary

Intervene if necessary to help groups solve academic or teamwork problems.

Process so students continuously analyze how well they learned and cooperated in order to continue successful strategies and improve when needed

Ways of Processing

Positive Feedback:

1. Have volunteer students tell the class something their partner(s) did which helped them learn today.
2. Have all students tell their partner(s) something the partner(s) did which helped them learn today.
3. Tell the class helpful behaviors you saw today.

Group Analysis:

1. Name 3 things your group did today which helped you learn and work well together.
2. Name 1 thing you could do even better next time.

Cooperative Skill Analysis:

1. Rate your use of the target cooperative skill: *Great! - Pretty Good - Needs work*
2. Decide how you will encourage each other to practice the target skill next time.

Start: *"Tell your partners you're glad they're here."*
End: *"Tell your partners you're glad they were here today. Thank them for helping."*

Interaction Book Company
5028 Halifax Ave S, Edina, MN 55424
(952)831-9500 Fax (952)831-9332
www.co-operation.org

REFERENCES

K.A. Smith, S.D. Sheppard, D.W. Johnson, R.T. Johnson. 2005. Pedagogies of engagement: Classroom-based practices. *Journal of Engineering Education*, 94 (1), 87-102.

D.W. Johnson, R.T. Johnson, & K.A. Smith, 2006. Active Learning: Cooperation in the College Classroom, 3ed Ed. Edina, MN; Interaction Book Company.

TEAMWORK

Teaching Cooperative Skills

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2. Help them **know how** to do it (T-chart).
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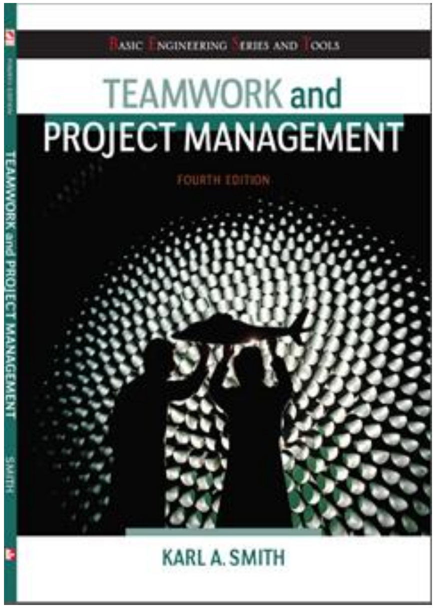
Process so students continuously analyze how well they learned and cooperated in order to continue successful strategies and improve when needed

Team Charter

- Team name, membership, and roles
- Team mission
- Anticipated results (goal)
- Specific tactical objectives
- **Ground rules/ Guiding principles for team participation**
- Shared expectations/aspirations



pp. 60-61, 204-205

Group Ground Rules Contract Form

(Adapted from a form developed by Dr. Deborah Allen, University of Delaware)

Project groups are an effective aid to learning, but to work best they require that all groups members clearly understand their responsibilities to one another. These project group ground rules describe the general responsibilities of every member to the group. You can adopt additional ground rules if your group believes they are needed. Your signature on this contract form signifies your commitment to adhere to these rules and expectations.

All group members agree to:

1. Come to class and team meetings on time.
2. Come to class and team meetings with assignments and other necessary preparations done.

Additional ground rules:

1.

2.

If a member of the project team repeatedly fails to meet these ground rules, other members of the group are expected to take the following actions:

Step 1: (fill in this step with your group)

If not resolved:

Step 2: Bring the issue to the attention of the teaching team.

If not resolved:

Step 3: Meet as a group with the teaching team.

The teaching team reserves the right to make the final decisions to resolve difficulties that arise within the groups. Before this becomes necessary, the team should try to find a fair and equitable solution to the problem.

Member's Signatures: Group Number:______________

1.____________________________ 3.____________________________

2.____________________________ 4.____________________________

Reflection and Dialogue

Individually reflect on **rationale** for Interactive (Cooperative) Learning and Teamwork. Write for about 1 minute.

- Context/Audience – Introductory Physics course
- Why cooperative learning and teamwork are important?
- What support do you have for your rationale?

Discuss with your neighbor for about 2 minutes

- Select/create a response to present to the whole group if you are randomly selected

Why Emphasize Cooperative Learning and Teamwork?

- **Student learning**
- Essential **transferrable skill** development
- Key to **innovation**
- High priority for **Employers**

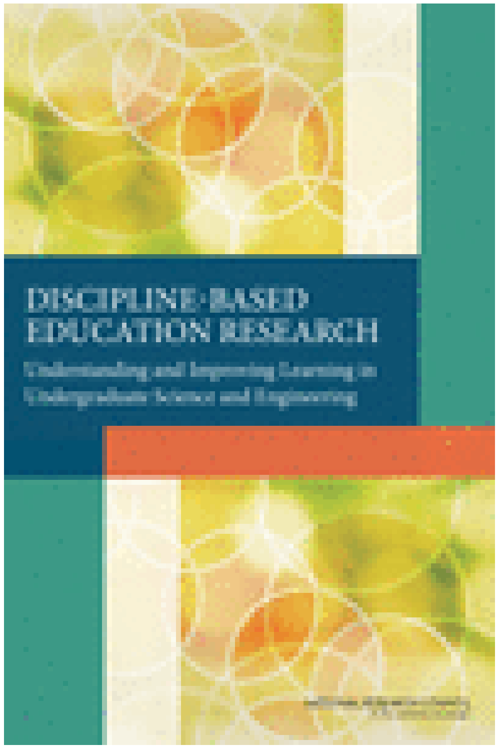
Seven Principles for Good Practice in Undergraduate Education

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. (1987). https://files.eric.ed.gov/fulltext/ED282491.pdf

Discipline-Based Education Research (DBER) Report



National Research Council Summer 2012 – http://www.nap.edu/catalog.php?record_id=13362

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.

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

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.

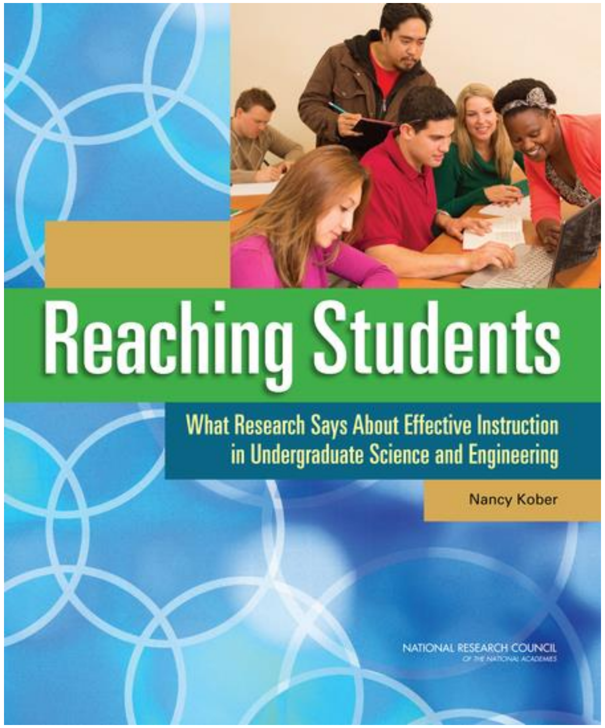
The report urges universities, disciplinary organizations, and professional societies to support faculty efforts to use evidence-based teaching strategies in their classrooms. It also recommends collaboration to prepare future faculty members who understand research findings on learning and teaching 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/

092 PRISM-MAGAZINE.ORG

ASEE *Prism Summer 2013*

Journal of Engineering Education – October, 2013



National Research Council – 2015 http://www.nap.edu/catalog/18687/reaching-students-what-research-says-about-effective-instruction-in-undergraduate

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.*

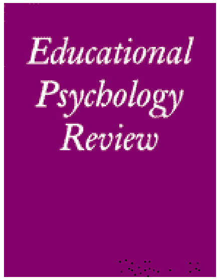
- Over 300 Experimental Studies
- First study conducted in 1924
- High Generalizability
- Multiple Outcomes

Outcomes

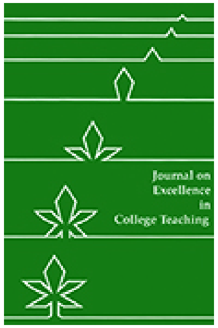
1. Achievement and retention
2. Critical thinking and higher-level reasoning
3. Differentiated views of others
4. Accurate understanding of others' perspectives
5. Liking for classmates and teacher
6. Liking for subject areas
7. Teamwork skills

*[CLReturnstoCollege.pdf]

January 2005



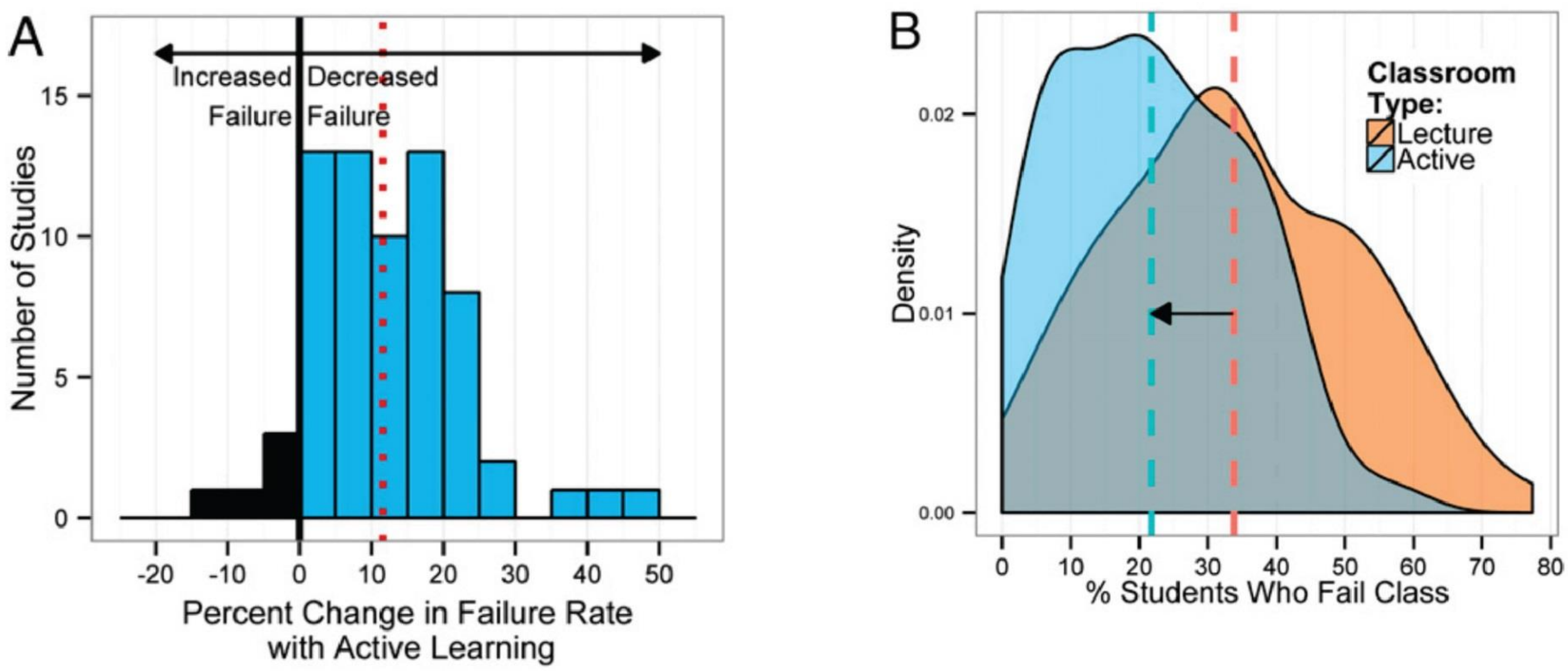
March 2007



25 (3&4) 2014

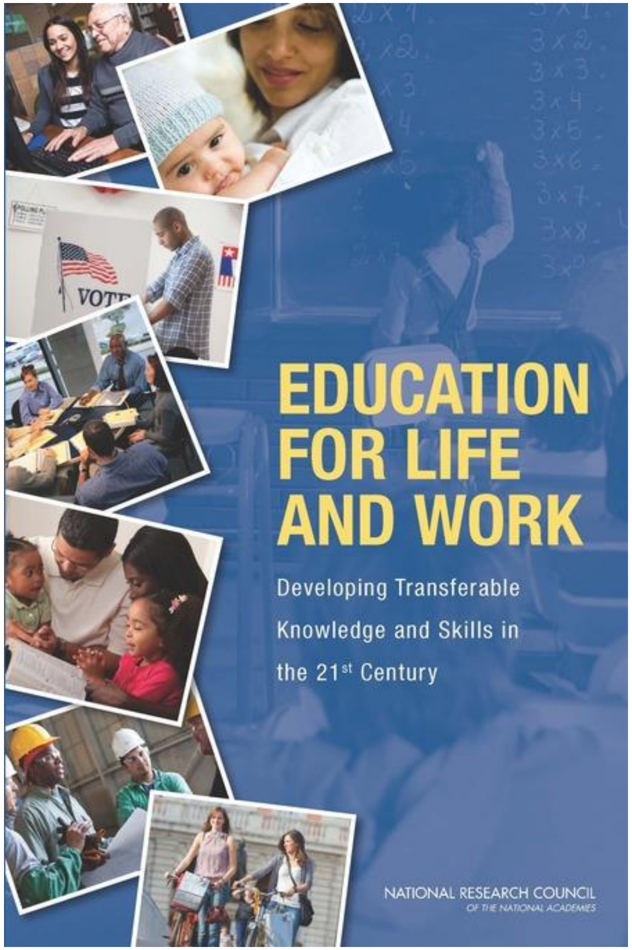
Engaged Pedagogies = Reduced Failure Rates

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

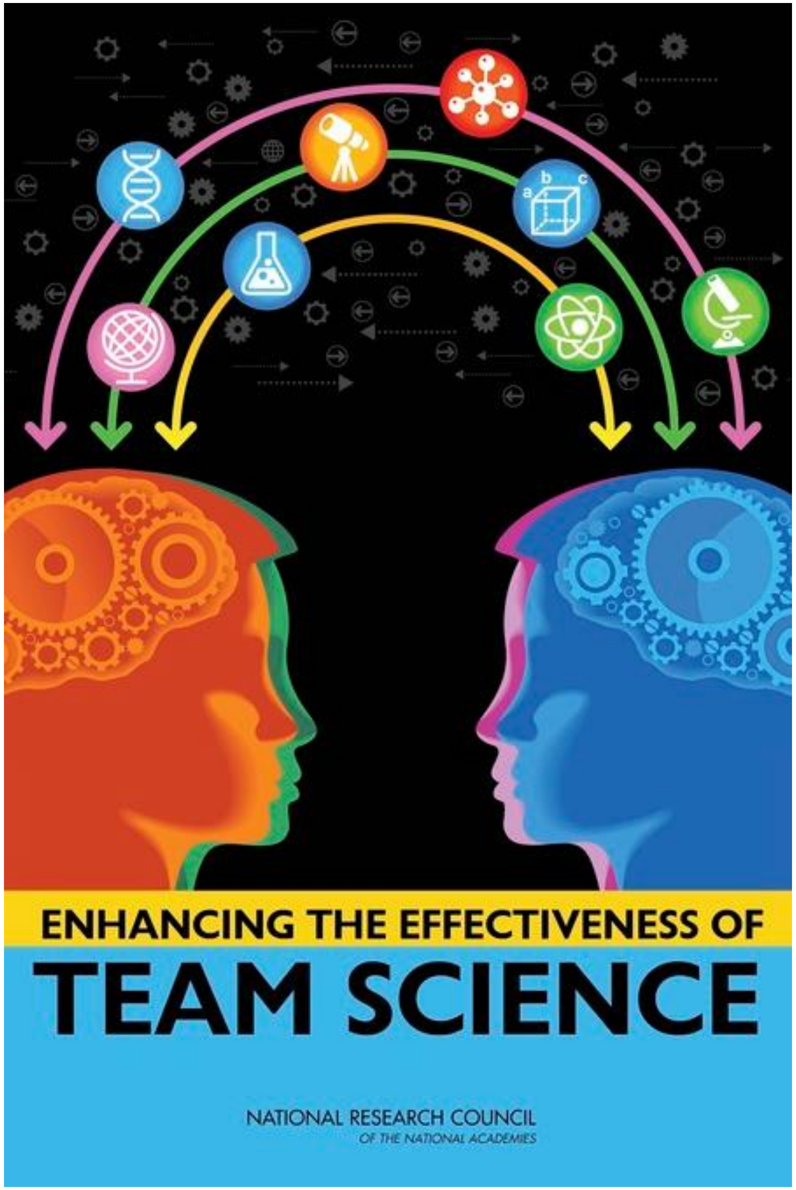


Freeman, Scott; Eddy, Sarah L.; McDonough, Miles; Smith, Michelle K.; Okoroafor, Nnadozie; Jordt, Hannah; Wenderoth, Mary Pat; Active learning increases student performance in science, engineering, and mathematics, 2014, Proc. Natl. Acad. Sci.

Education for Life and Work

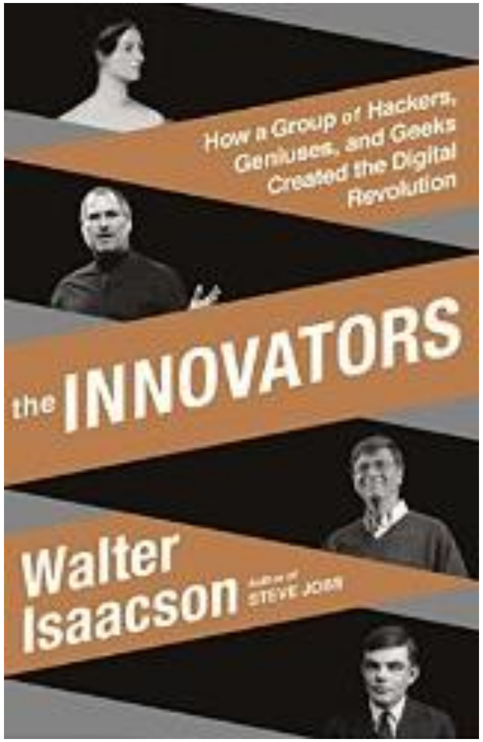


http://www.nap.edu/catalog/13398/education-for-life-and-work-developing-transferable-knowledge-and-skills



*Conclusion. A strong body of research conducted over several decades has demonstrated that **team processes** (e.g., shared understanding of team goals and member roles, conflict) **are related to team effectiveness**. Actions and interventions that foster positive team processes offer the most promising route to enhance team effectiveness; they target three aspects of a team: team composition (assembling the right individuals), team professional development, and team leadership. (p. 7)*

http://www.nap.edu/catalog/19007/enhancing-the-effectiveness-of-team-science



This is the story of these pioneers, hackers, inventors, and entrepreneurs – who they were, how their minds worked, and what made them so creative. It's also a narrative of **how they collaborated and why their ability to work as teams made them even *more* creative.** The tale of their teamwork is important because we don't often focus on how central that skill is to innovation.

The College Degrees And **Skills** Employers Most Want In 2015 (National Association of Colleges and Employers (NACE))

The NACE survey also asked employers to rate **the skills they most value in new hires**. Companies want candidates who can think critically, solve problems, work in a team, maintain a professional demeanor and demonstrate a strong work ethic. Here is the ranking in order of importance:

Competency	Essential Need Rating*
Critical Thinking/Problem Solving	4.7
Teamwork	4.6
Professionalism/Work Ethic	4.5
Oral/Written Communications	4.4
Information Technology Application	3.9
Leadership	3.9
Career Management	3.6

*Weighted average. Based on a 5-point scale where 1=Not essential, 2=Not very essential; 3=Somewhat essential; 4=Essential; 5=Absolutely essential

http://www.forbes.com/sites/susanadams/2015/04/15/the-college-degrees-and-skills-employers-most-want-in-2015/

Designing and Implementing Cooperative Learning

Think like a designer

Ground practice in robust theoretical framework

Start small, start early and iterate

Celebrate the successes; problem-solve the failures

The Instructor's Role in Cooperative Learning

Make Pre-Instructional Decisions

Specify Academic and Teamwork Skills Objectives: Every lesson has both (a) academic and (b) interpersonal and small group (teamwork) skills objectives.

Decide on Group Size: Learning groups should be small (groups of two or three members, four at the most).

Decide on Group Composition (Assign Students to Groups): Assign students to groups randomly or select groups yourself. Usually you will wish to maximize the heterogeneity in each group.

Assign Roles: Structure student-student interaction by assigning roles such as Reader, Recorder, Encourager of Participation and Checker for Understanding.

Arrange the Room: Group members should be "knee to knee and eye to eye" but arranged so they all can see the instructor at the front of the room.

Plan Materials: Arrange materials to give a "sink or swim together" message. Give only one paper to the group or give each member part of the material to be learned.

Explain Task And Cooperative Structure

Explain the Academic Task: Explain the task, the objectives of the lesson, the concepts and principles students need to know to complete the assignment and the procedures they are to follow.

Explain the Criteria for Success: Student work should be evaluated on a criteria-referenced basis. Make clear your criteria for evaluating students' work.

***Structure Positive Interdependence:** Students must believe they "sink or swim together." Always establish mutual goals (students are responsible for their own learning and the learning of all other group members). Supplement, goal interdependence with celebration/reward, resource, role, and identity interdependence.

Structure Intergroup Cooperation: Have groups check with and help other groups. Extend the benefits of cooperation to the whole class.

***Structure Individual Accountability:** Each student must feel responsible for doing his or her share of the work and helping the other group members. Ways to ensure accountability are frequent oral quizzes of group members picked at random, individual tests, and assigning a member the role of Checker for Understanding.

***Specify Expected Behaviors:** The more specific you are about the behaviors you want to see in the groups, the more likely students will do them. Social skills may be classified as **forming** (staying with the group, using quiet voices), **functioning** (contributing, encouraging others to participate), **formulating** (summarizing, elaborating), and **fermenting** (criticizing ideas, asking for justification). Regularly teach the interpersonal and small group skills you wish to see used in the learning groups.

Monitor and Intervene

***Arrange Face-to-Face Promotive Interaction:** Conduct the lesson in ways that ensure that students promote each other's success face-to-face.

Monitor Students' Behavior: This is the fun part! While students are working, you circulate to see whether they understand the assignment and the material, give immediate feedback and reinforcement, and praise good use of group skills. Collect observation data on each group and student.

Intervene to Improve Taskwork and Teamwork: Provide **taskwork assistance** (clarify, reteach) if students do not understand the assignment. Provide **teamwork assistance** if students are having difficulties in working together productively.

Evaluate and Process

Evaluate Student Learning: Assess and evaluate the quality and quantity of student learning. Involve students in the assessment process.

***Process Group Functioning:** Ensure each student receives feedback, analyzes the data on group functioning, sets an improvement goal, and participates in a team celebration. Have groups routinely list three things they did well in working together an done thing they will do better tomorrow. Summarize as a whole class. Have groups celebrate their success and hard work.

Cooperative Lesson Planning Form

Subject Area: ______________________ Date: ____________

Lesson: ____

Objectives

Academic: ____

Social Skills: ____

Preinstructional Decisions

Group Size: _______ Method Of Assigning Students: ____________

Roles: ____

Room Arrangement: ____

Materials: ____

- ◊ One Copy Per Group
- ◊ One Copy Per Person
- ◊ Jigsaw
- ◊ Tournament
- ◊ Other: ______________

Explain Task And Cooperative Goal Structure

1. Task: ____
2. Criteria For Success: ____
3. Positive Interdependence: ____
4. Individual Accountability: ____
5. Intergroup Cooperation: ____
6. Expected Behaviors: ____

Monitoring And Intervening

1. Observation Procedure: _____ Formal _____ Informal
2. Observation By: _____ Teacher _____ Students _____ Visitors
3. Intervening For Task Assistance: ____
4. Intervening For Teamwork Assistance: ____
5. Other: ____

Evaluating And Processing

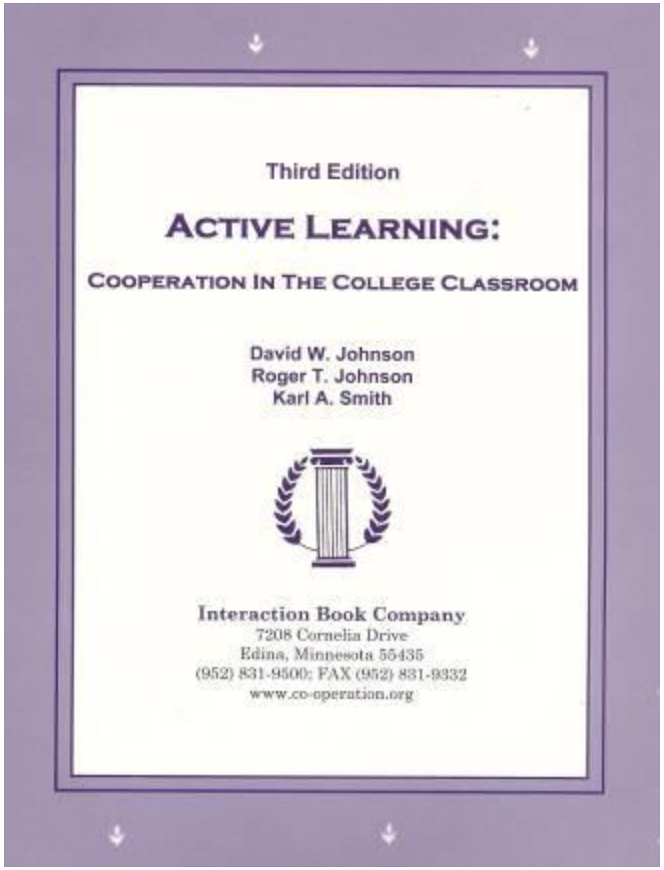
1. Assessment Of Members' Individual Learning: ____
2. Assessment Of Group Productivity: ____
3. Small Group Processing: ____
4. Whole Class Processing: ____
5. Charts And Graphs Used: ____
6. Positive Feedback To Each Student: ____
7. Goal Setting For Improvement: ____
8. Celebration: ____
9. Other: ____

Active Learning: Cooperation in the College Classroom

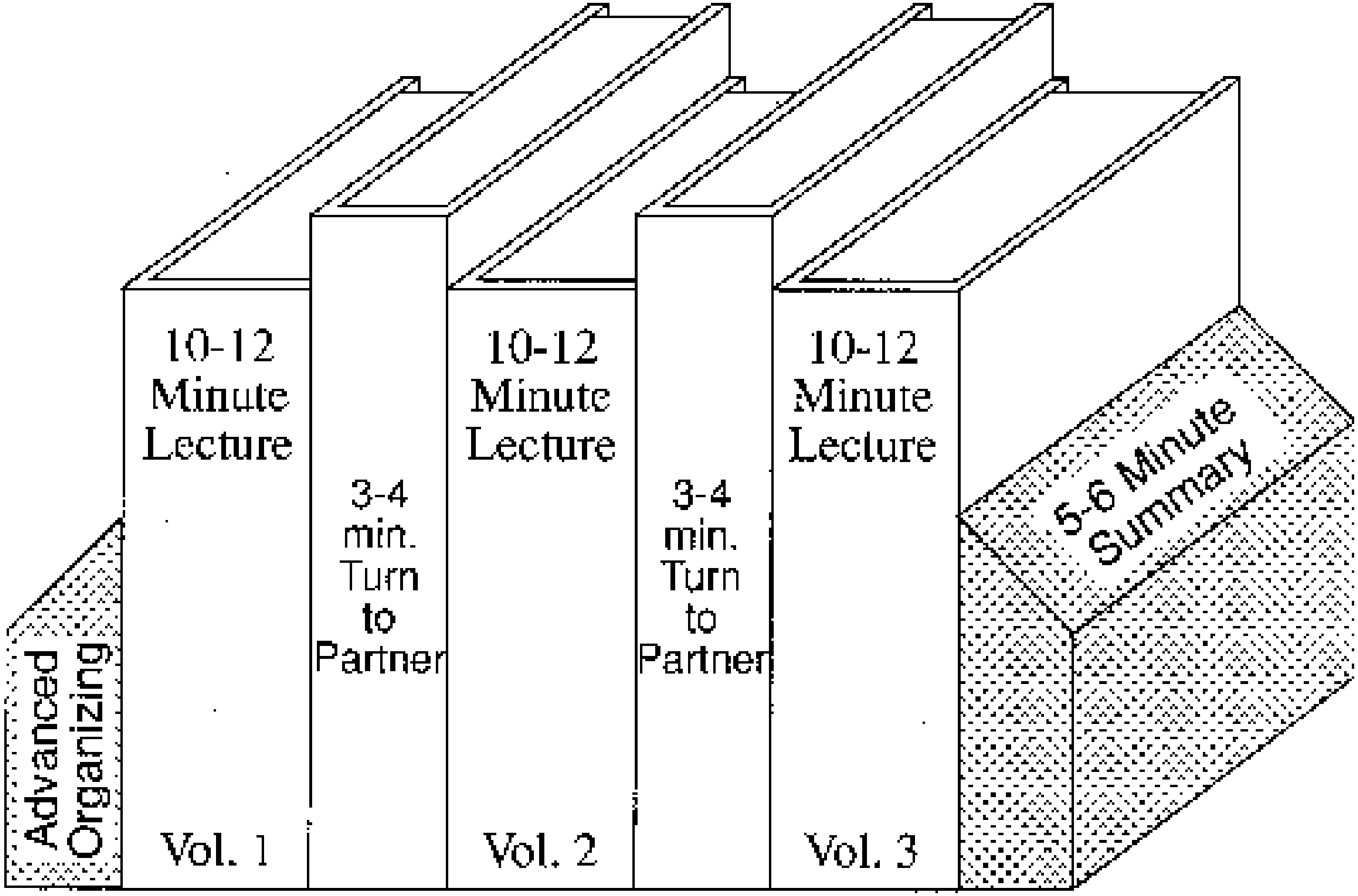
Informal Cooperative Learning Groups

Formal Cooperative Learning Groups

Cooperative **Base** Groups



Book Ends on a Class Session



Smith, K.A. 2000. Going deeper: Formal small-group learning in large classes. Energizing large classes: From small groups to learning communities. *New Directions for Teaching and Learning*, 2000, 81, 25-46. [NDTL81Ch3GoingDeeper.pdf]

Informal Cooperative Learning Groups

Can be used at any time

Can be short term and ad hoc

May be used to break up a long lecture

Provides an opportunity for students to process material they have been listening to (Cognitive Rehearsal)

Are especially effective in large lectures

Include "book ends" procedure

Are not as effective as Formal Cooperative Learning or Cooperative Base Groups

Informal Cooperative Learning Planning Form

Description of the Lecture

1. Lecture Topic: ______________________________

2. Objectives (Major Understandings Students Need To Have At The End Of The Lecture):

   a. ______________________________

   b. ______________________________

3. Time Needed: ______________________________

4. Method For Assigning Students To Pairs Or Triads: __________

5. Method Of Changing Partners Quickly: __________

6. Materials (such as transparencies listing the questions to be discussed and describing the **formulate, share, listen, create** procedure):

   ____

Advanced Organizer Question(s)

Questions should be aimed at promoting **advance organizing** of what the students know about the topic to be presented and **establishing expectations** as to what the lecture will cover.

1. ______________________________
2. ______________________________
3. ______________________________

Cognitive Rehearsal Questions

List the specific questions to be asked every 10 or 15 minutes to ensure that participants understand and process the information being presented. Instruct students to use the **formulate, share, listen, and create** procedure.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________

Monitor by systematically observing each pair. Intervene when it is necessary. Collect data for whole class processing. Students' explanations to each other provide a window into their minds that allows you to see what they do and do not understand. Monitoring also provides an opportunity for you to get to know your students better.

Summary Question(s)

Give an ending discussion task and require students to come to consensus, write down the pair or triad's answer(s), sign the paper, and hand it in. Signatures indicate that students agree with the answer, can explain it, and guarantee that their partner(s) can explain it. The questions could (a) ask for a summary, elaboration, or extension of the material presented or (b) precue the next class session.

1. ______________________________
2. ______________________________