Building Engineering Education Research Capabilities

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College of Engineering Seminar

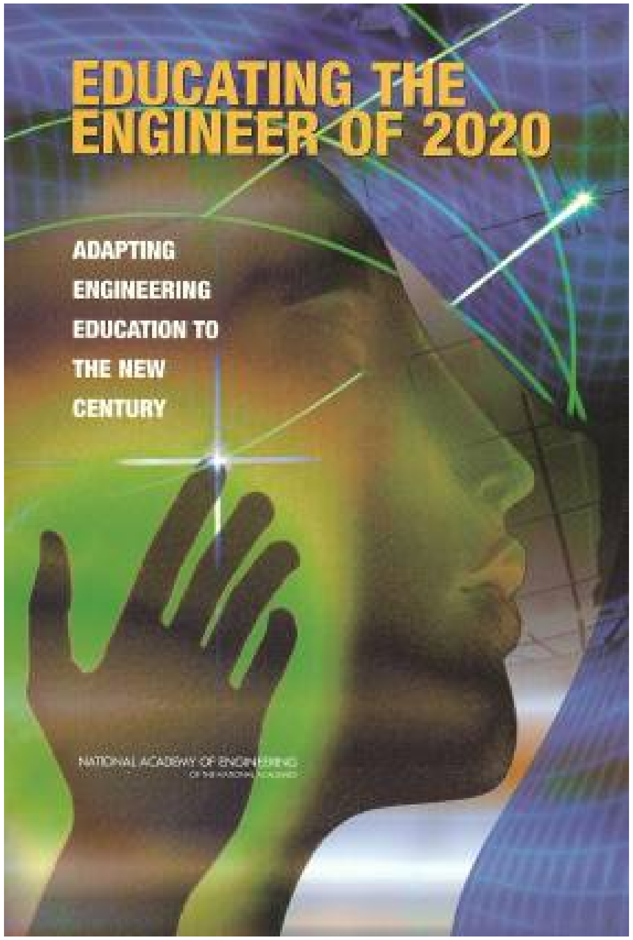
Boise State University

October 9, 2008

Building Engineering Education Research Capabilities: Overview

- Why Bother? Why Now?
  - ABET/ASEE/Carnegie Foundation/NAE/NSF Emphasis
  - Globalization
    - Outsourcing of Engineering
    - Engineering Capabilities
  - Demographics
    - Interest in Engineering
    - Current Workforce
  - Learning Sciences Research, e.g., expertise
- Engineering Education as a Field of Research
  - Engineering Education Levels of Inquiry
  - Features of Scholarly and Professional Work
  - Characteristics of Disciplines – Kuhn & Fensham
- Current Activities – NSF/NAE/Departments of Engineering Education

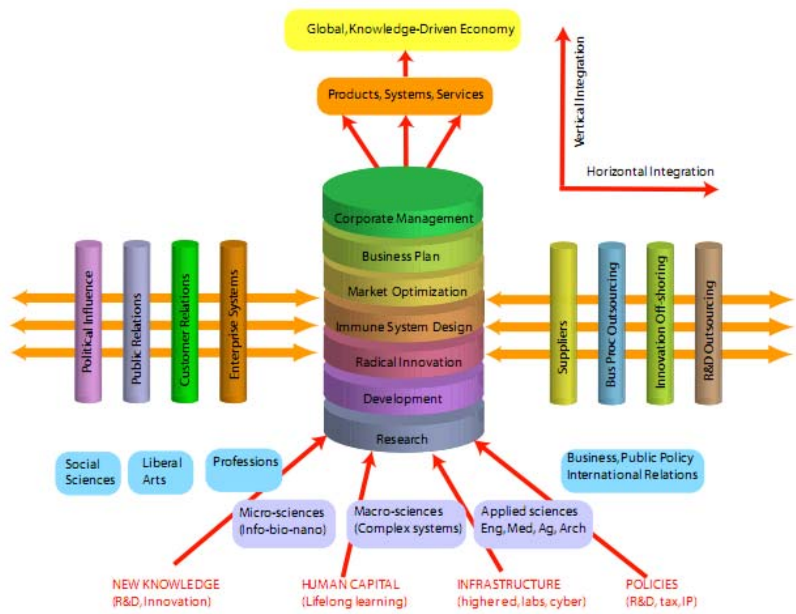
Engineering Education Research



Colleges and universities should endorse research in engineering education as a valued and rewarded activity for engineering faculty and should develop new standards for faculty qualifications.

Engineering for a Changing World

A Roadmap to the Future of
Engineering Practice, Research, and Education



The Millennium Project
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

Emerging Global Labor Market

- Engineering occupations are the most amenable to remote location
- Offshore talent exceeds high-wage countries' potential by a factor of 2
- 17% of engineering talent in low-wage countries is suitable* for work in a multinational company.
- At current suitability rates, and an aggressive pace of adoption in demand, supply of engineers could be constrained by 2015.

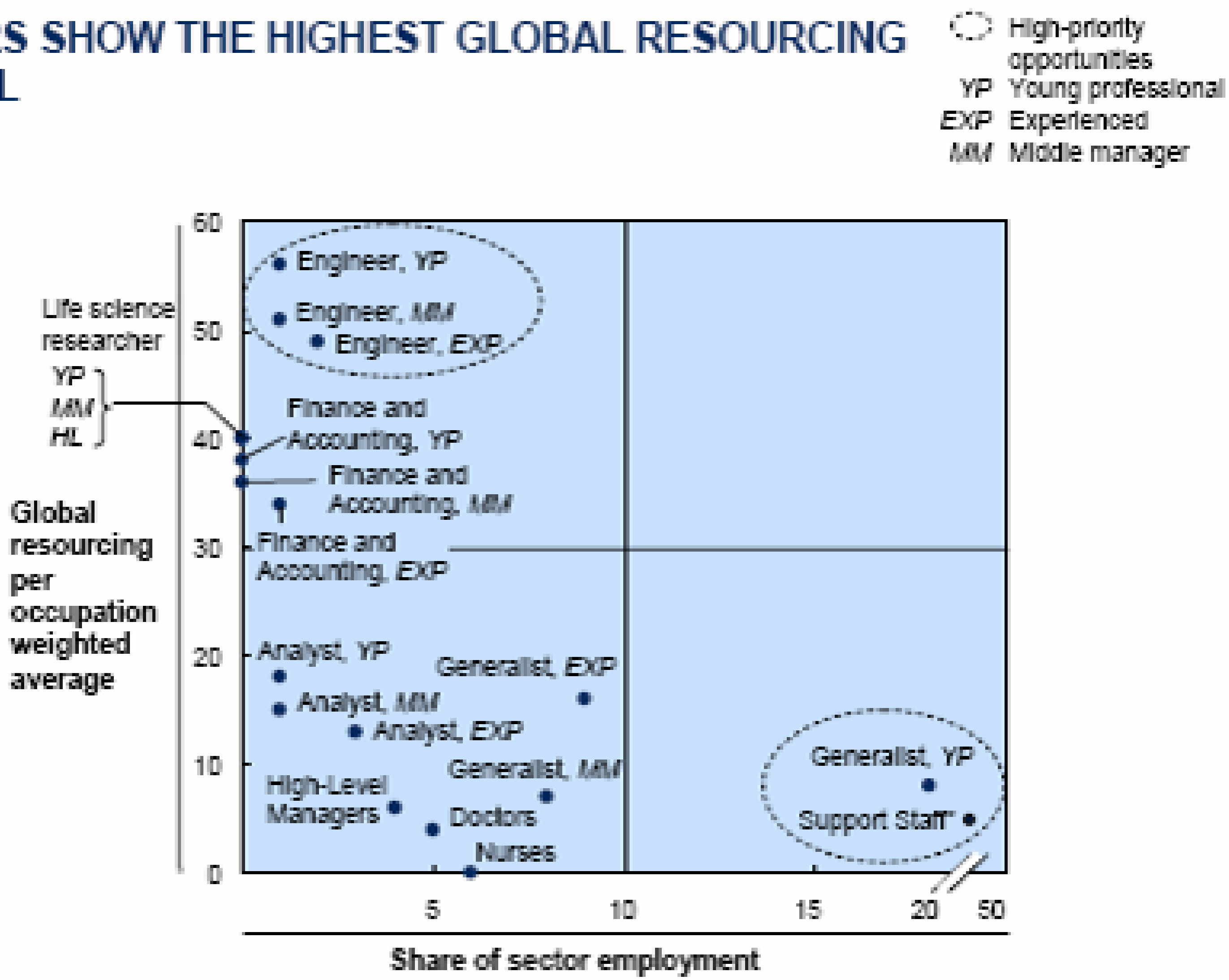
"The Emerging Global Labor Market"

*Suitable = quality of education, location, domestic competition

Exhibit 10

ENGINEERS SHOW THE HIGHEST GLOBAL RESOURCING POTENTIAL

%,2003



* Support staff accounts for 41% of employment in sectors analyzed.

Source: McKinsey Global Institute analysis

Lynn & Salzman – The Real Global Technology Challenge & Collaborative Advantage

THE REAL GLOBAL TECHNOL CHALLENGE

BY LEONARD LYNN AND HAROLD SALZMAN

At one of the renowned Indian Institutes of Technology, we recently asked a class of 80 engineering and science undergraduates how many wanted to go to the United States for graduate school or a job. A decade ago nearly everyone in the classroom would have a hand in the air. Now, not a single hand was raised. "Why go to the U.S.," they asked, "when all the opportunity is in India?"

In China when we visited software, telecommunications, and heavy-equipment companies owned by U.S. multinational corporations, we met managers born and raised in Asia but with U.S. engineering degrees. They had expected to spend their entire working lives in the United States. So why had they gone back to China? Because these days not only were the new career opportunities there as good as those in the U.S., but the technology-development projects were even more challenging.

Clearly the U.S. is no longer the universally preferred home for the global technology elite. Increasing numbers of scientists and engineers who were educated and have built successful careers here are returning to China, India, and other countries. Many in the younger generation never come here in the first place.

Leonard Lynn is a professor of management policy at Case Western Reserve University, where he specializes in research on technology policy and management. Harold Salzman is a sociologist and senior research associate at the Urban Institute in Washington, D.C. His research focuses on labor markets, workplace restructuring, skill requirements, and globalization of innovation, engineering, and technology design. Over the past five years, Lynn and Salzman have led several multinational teams in a series of projects looking at the impacts of the globalization of technology on emerging and first-world economies, multinational enterprises, entrepreneurs, and education systems. The authors retain the copyright for this article.

CHANGE • JULY/AUGUST 2007

Collaborative Advantage: New Horizons for a Flat World – *Issues in Science & Technology*

*www.nsf.gov/attachments/105652/public/**Collaborative**-**Advantage**-1205.pdf*

Collaborative Advantage

The days of U.S. technological domination are over. The nation must learn to thrive through working with others.

Acrylic on canvas. 36 x 72 inches. 2004.

Issues in Science and Technology
(National Academies of Science: www.issues.org)
The research this paper is based on was generously supported by the National Science Foundation, Societal Dimensions of Engineering, Science, and Technology (SDEST) Program, Grant #0431753, and the Kauffman Foundation.

NEW HORIZONS FOR A FLAT WORLD

LEONARD LYNN
HAL SALZMAN

Almost daily, news reports feature multinational companies—many based in the United States—that are establishing technology development facilities in China, India, and other emerging economies. General Electric, General Motors, IBM, Intel, Microsoft, Motorola—the list grows steadily longer. And these new facilities no longer focus on low-level technologies to meet Third World conditions. They are doing the cutting-edge research once done only in the United States, Japan, and Europe. Moreover, the multinationals are being joined by new firms, such as Huawei, Lenovo, and Wipro, from the emerging economies. This current globalization of technology development is, we believe, qualitatively different from globalization of the past. But the implications of the differences have not sunk in with key U.S. decisionmakers in government and industry.

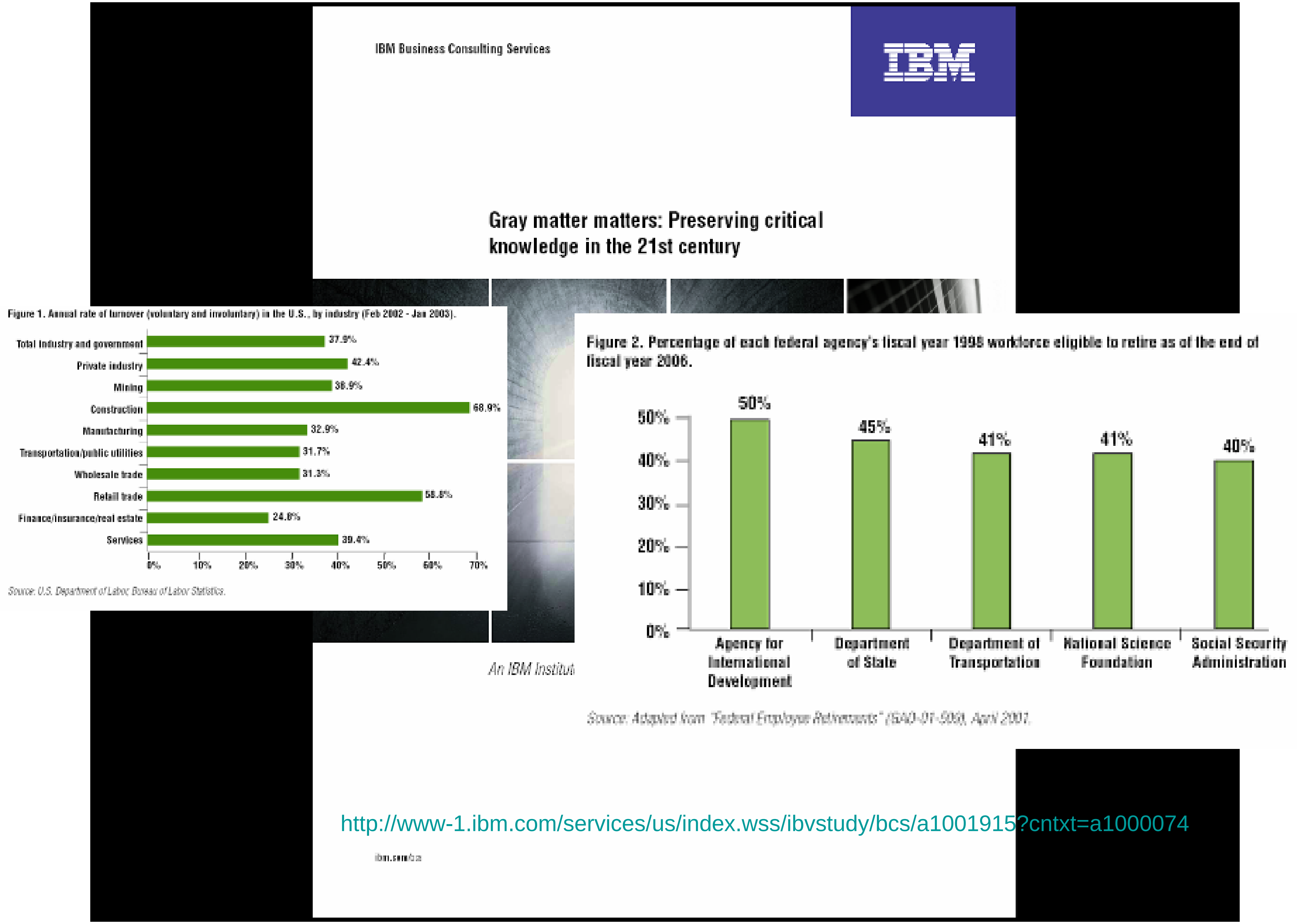
It is not that the new globalization has gone unnoticed. Many observers are concerned that the United States is beginning to fall into a vicious cycle of disinvestment in and weakening of its innovation systems. As U.S. firms move their engineering and R&D activities offshore, they may be disinvesting not just in their own facilities but also in colleges and regions of the country that now form critical innovation clusters. These forces may combine to dissolve the bonds that form the basis of U.S. innovation leadership.

A variety of policies have been proposed to protect and restore the preeminent position of U.S. technology. Some of these proposals are most concerned with building up U.S. science and technology (S&T) human resources by strengthening the nation's education system from kindergarten through high school; encouraging more U.S. students to study engineering and science, specifically inducing more women and minorities to pursue science and technology careers; and easing visa restrictions that form barriers to talented foreigners who want to enter U.S. universities and industries. Other proposals include measures to outbid other countries as they offer benefits to attract R&D activities. Still others call for funneling public funds into the

WINTER 2006 75

Change Magazine – July/August 2007

Demographics – Aging Workforce



http://www-1.ibm.com/services/us/index.wss/ibvstudy/bcs/a1001915?cntxt=a1000074

Creating and Preserving What We Know

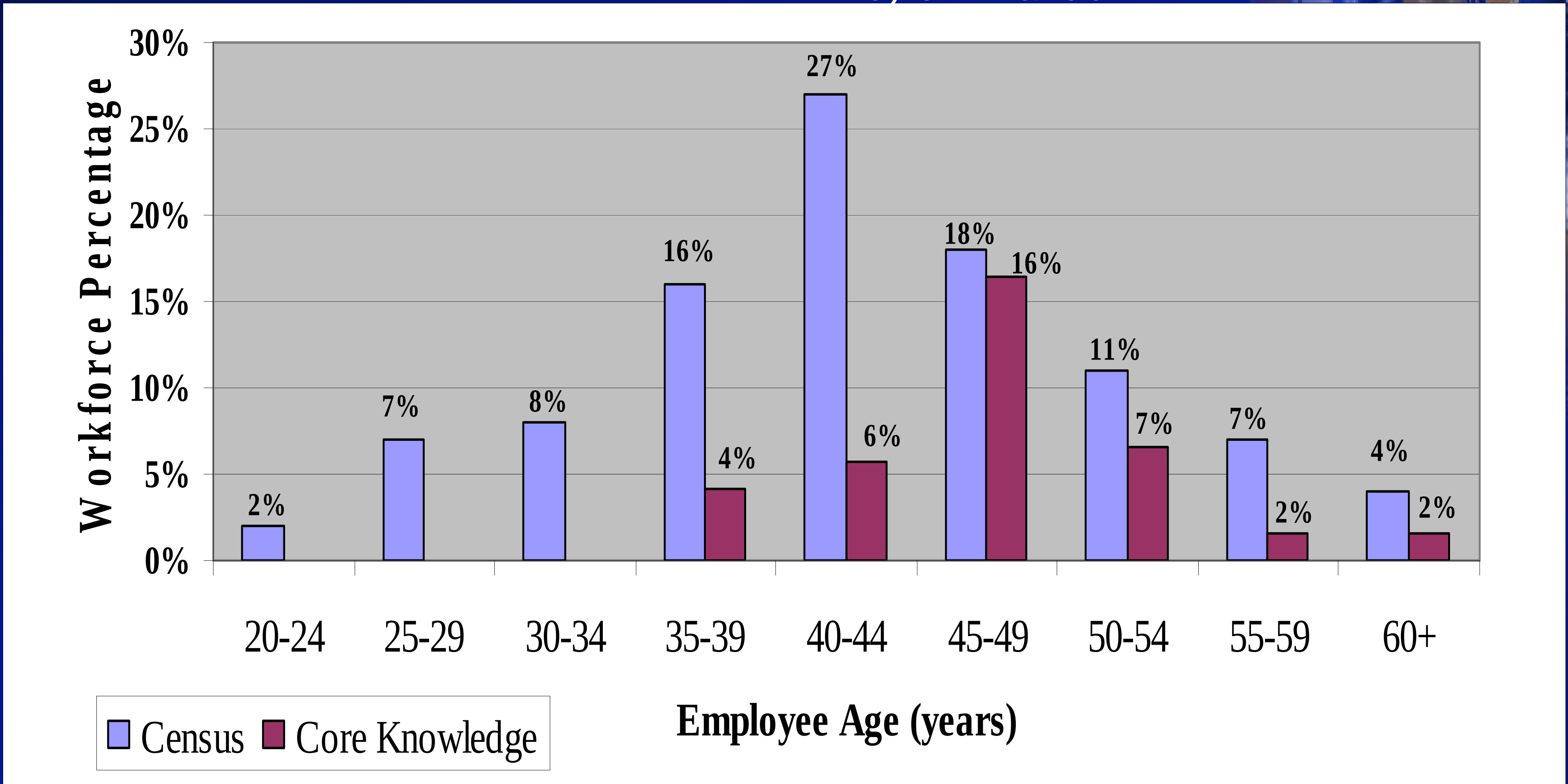
A Knowledge Management Plan and Implementation for Honeywell

by Jim Landon

Capstone Project
MOT 2003

Base of Experience

Creating and Preserving What we Know: A Knowledge Management Plan and Implementation for Honeywell CAP
by Jim Landon

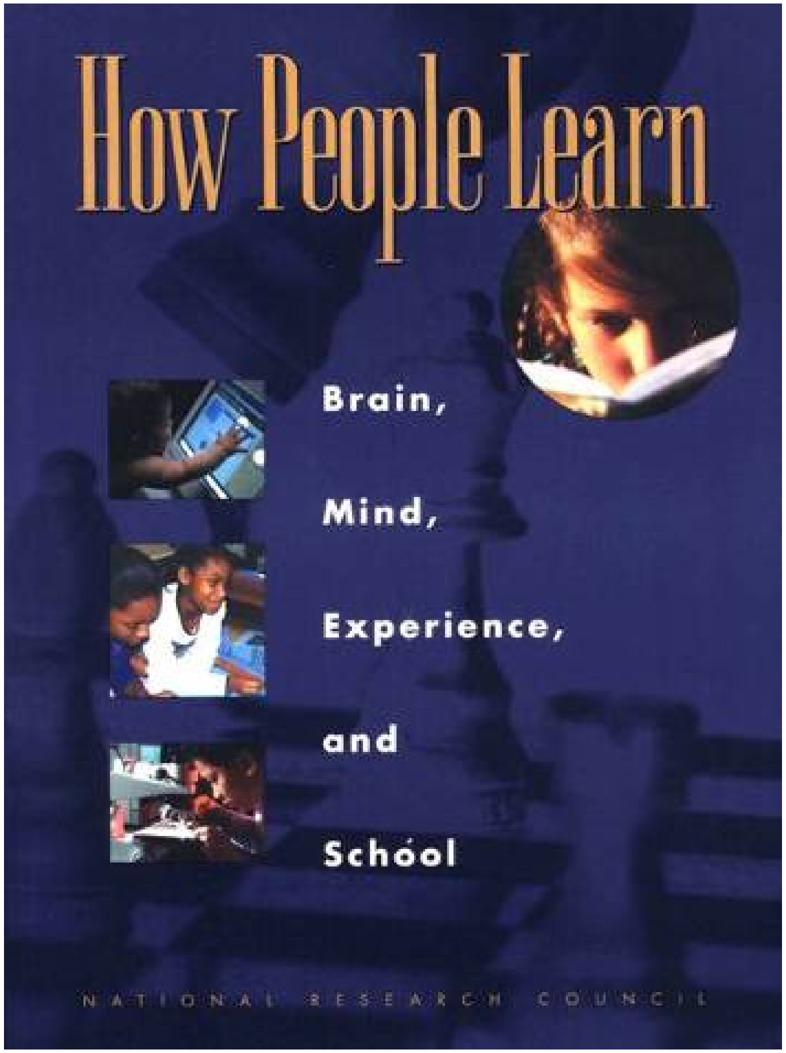


Strategy Proposal

- Embrace Knowledge Management as a unified, operational strategy for CAP Engineering and Technology department

Center on Four
tactical cornerstones

Expertise Implies:



- 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

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

Acquisition of Expertise

Fitts P, & Posner MI. Human Performance. Belmont, CA: Brooks/Cole, 1967.

- Cognition: Learn from instruction or observation what knowledge and actions are appropriate
- Associative: Practice (with feedback) allowing smooth and accurate performance
- Automaticity: “Compilation” or performance and associative sequences so that they can be done without large amounts of cognitive resources

“The secret of expertise is that there is no secret. It takes at least 10 years of concentrated effort to develop expertise.” Herbert Simon

Classic Studies in Expertise Research

- Fitts and Posner (1967) - model with three phases and for acquiring acceptable (not expert) performance
- Simon and Chase (1973) - theory of expertise acquisition where time spent leads to acquisition of patterns, chunks, and increasingly-complex knowledge structures
- Ericsson and Smith (1991) - expert performance must be studied with individuals who can reliably and repeatedly demonstrate superior performance
- Ericsson, Krampe, & Tesche-Romer (1993) - expert levels of performance are acquired gradually over time through use of deliberate practice and are mediated by mental representations developed during the deliberate practice period

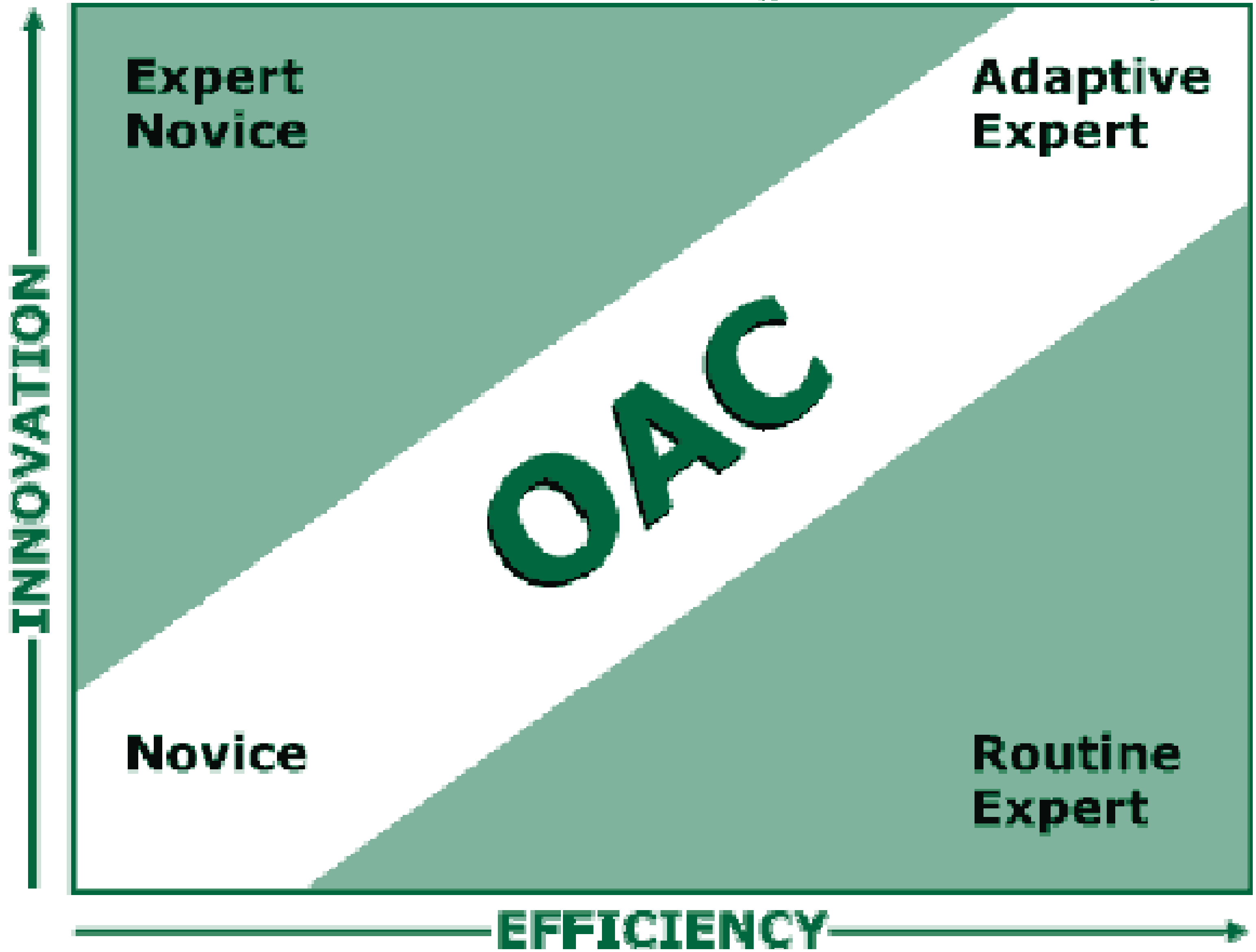
Stages of Skill Acquisition

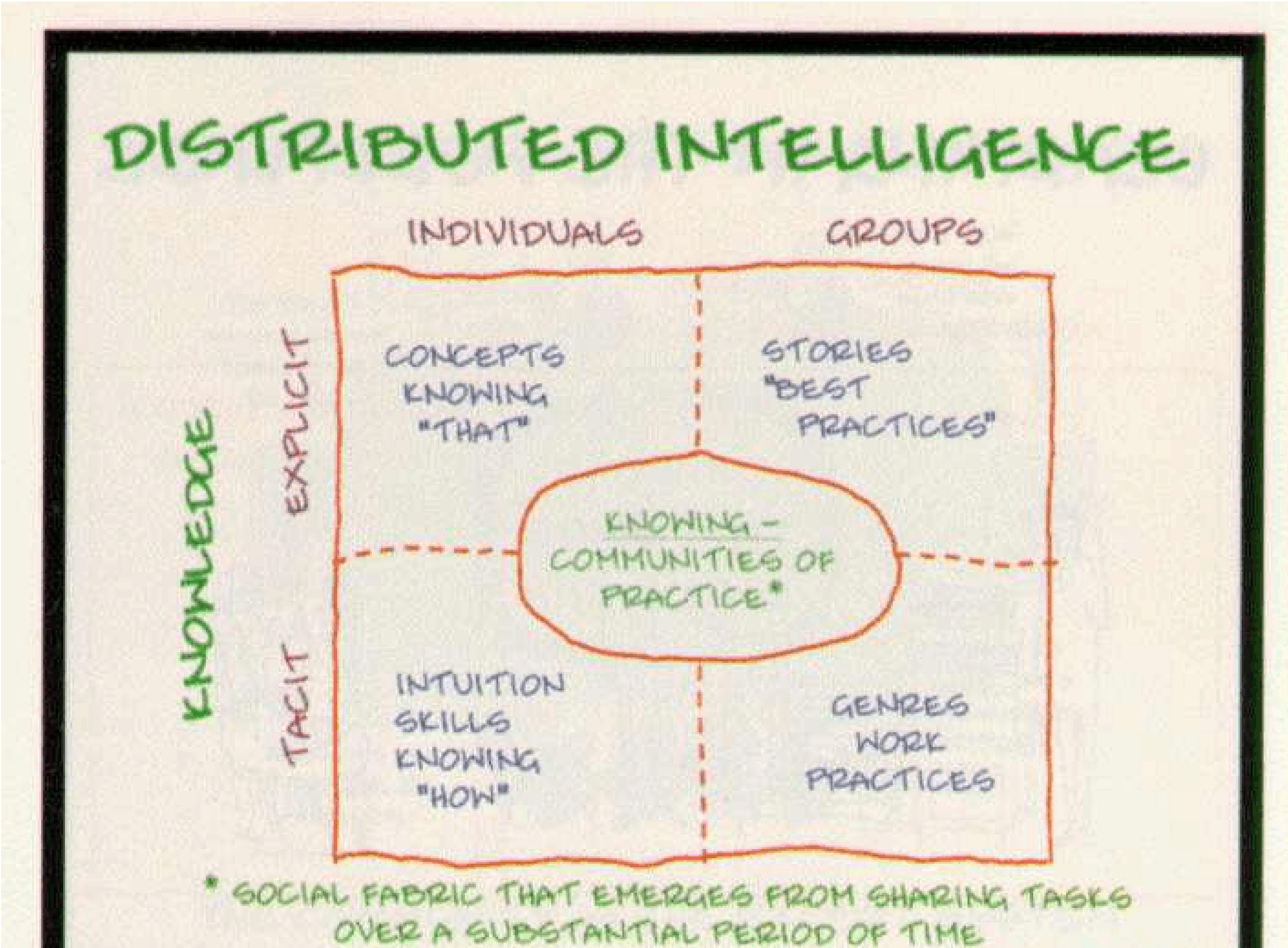
(Dreyfus & Dreyfus, 1986, Mind over machine: The power of human intuition and expertise in the era of the computer, p. 50)

Skill Level	Components	Perspective	Decision	Commitment
1. Novice	Context-free	None	Analytical	Detached
2. Advanced Beginner	Context-free and Situational	None	Analytical	Detached
3. Competent	Context-free and Situational	Chosen	Analytical	Detached understanding and deciding. Involved in outcome
4. Proficient	Context-free and Situational	Experienced	Analytical	Involved understanding Detached deciding
5. Expert	Context-free and Situational	Experienced	Intuitive	Involved

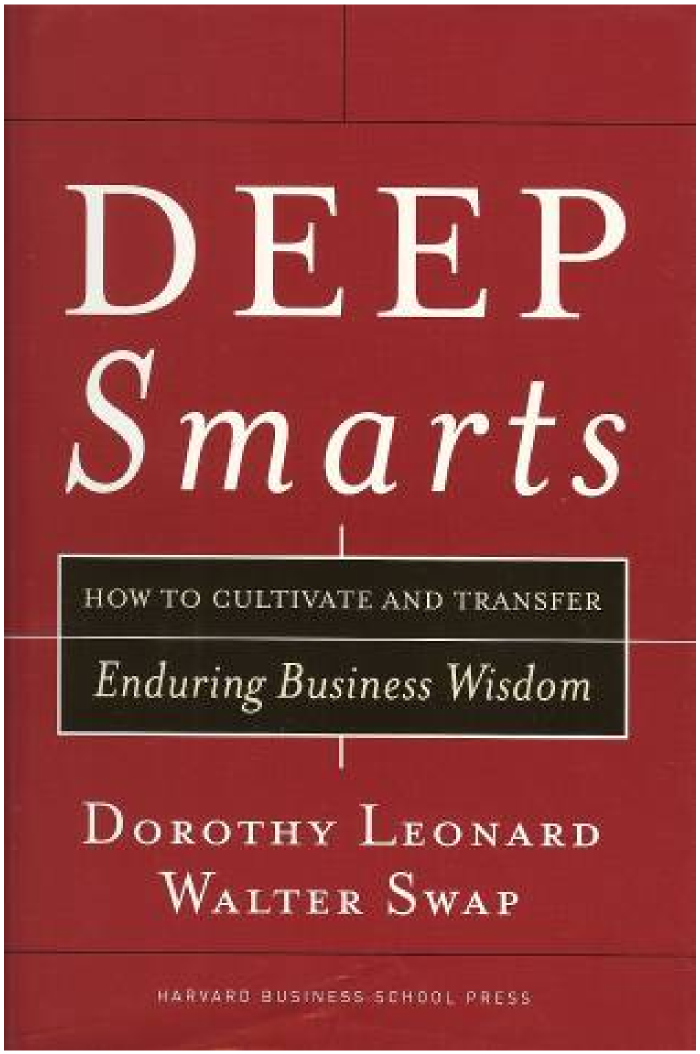
"Optimal Adaptability Corridor" (OAC)

From Dan Schwartz & John Bransford (personal communication)





John Seely Brown. Growing up digital: The web and a new learning ecology. Change, March/April 2000.



Characteristics and Limitations of Deep Smarts

Sometimes an expert is the key actor in a managerial setting. Sometimes a novice is. Give them both a managerial task, and they'll approach it in characteristically different ways. And the experts aren't always right—they run risks, too.

Tasks	Novice	Expert	Expert's Limitations
Making decisions	Needs to review all facts and choose deliberately among alternatives	Makes decisions swiftly, efficiently, without reviewing basic facts	Overconfidence; expert may ignore relevant data
Considering context	Relies on rules of thumb that minimize context	Takes context into account when solving problems	Difficulty transferring expert knowledge, because it is highly contextualized
Extrapolating information	Lacks receptors and thus has limited basis for extrapolation	Can extrapolate from a novel situation to find a solution	May base solution on inappropriate pattern
Exercising discrimination	Uses rules of thumb to obscure fine distinctions	Can make fine distinctions	May not communicate well to a novice who lacks receptors to understand distinctions
Being aware of knowledge gaps	Doesn't know what he doesn't know	Knows when rules don't apply	May assume expertise where none exists
Recognizing patterns	Has limited experience from which to draw patterns	Has large inventory of patterns drawn from experience	May be no better than novice when no patterns exist
Using tacit knowledge	Relies largely on explicit knowledge	Uses extensive tacit knowledge to drive decision making	May have a hard time articulating and thus transferring tacit knowledge

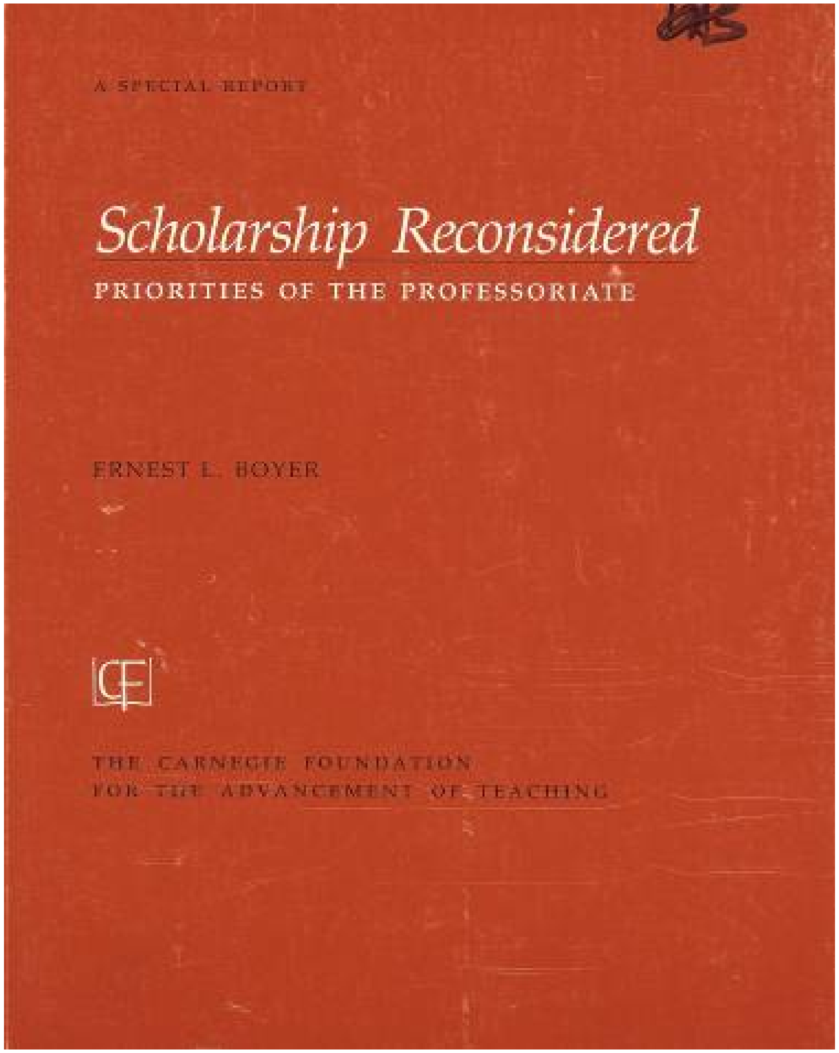
Leonard, Dorothy & Swap, Walter. 2004. Deep Smarts. *Harvard Business Review,* September

Paradox of Expertise

- The very knowledge we wish to teach others (as well as the knowledge we wish to represent in computer programs) often turns out to be the knowledge we are least able to talk about.

Scholarship Reconsidered: Priorities of the Professoriate Ernest L. Boyer

- The **Scholarship of Discovery**, research that increases the storehouse of new knowledge within the disciplines;
- The **Scholarship of Integration**, including efforts by faculty to explore the connectedness of knowledge within and across disciplines, and thereby bring new insights to original research;
- The **Scholarship of Application**, which leads faculty to explore how knowledge can be applied to consequential problems in service to the community and society; and
- The **Scholarship of Teaching**, which views teaching not as a routine task, but as perhaps the highest form of scholarly enterprise, involving the constant interplay of teaching and learning.



Engineering Education Levels of Inquiry

- Teach as Taught ("distal pedagogy")
- Level 1: Effective Teacher
- Level 2: Scholarly Teacher
- Level 3: Scholarship of Teaching and Learning (SoTL)
- Level 4: Engineering Education Research

Streveler, R., Borrego, M. and Smith, K.A. 2007. Moving from the "Scholarship of Teaching and Learning" to "Educational Research:" An Example from Engineering. Silver Anniversary Edition of *To Improve the Academy,* Vol. 25, 139-149.

Level of inquiry	Attributes of that level
Level 1: Excellent teaching	Involves the use of good content and teaching methods
Level 2: Scholarly Teaching	Good content and methods *and* classroom assessment and evidence gathering, informed by best practice and best knowledge, inviting of collaboration and review.
Level 3: Scholarship of Teaching	Is public and open to critique and evaluation, is in a form that others can build on, involves question-asking, inquiry and investigation, particularly about student learning.
Level 4: Rigorous Research in Engineering Education	Also is public, open to critique, and involves asking questions about student learning, but it includes a few unique components. (1) Begin with a *research* question not an *assessment* question. Assessment questions often deal with the "what" or "how much" of learning, while research questions more often focus on the "why" or "how" of learning (Paulsen, 2001). (2) Tying the question to learning, pedagogical, or social theory and interpreting the results of the research in light of theory. This will allow for the research to build theory and can increase the significance of the findings. For example, studies about teaching thermodynamics can be redesigned to become studies, based on cognitive theory, which can help explain why certain concepts in thermodynamics are so difficult to learn. (3) Paying careful attention to design of the study and the methods used. This will enable the study to hold up to scrutiny by a broad audience, again creating a potential for greater impact of results.

Table 7. Levels of rigor in inquiry representation. Reproduced from Streveler, Borrego, and Smith (2007). The authors credit Hutchings and Shulman (1999) for levels 1–3.

Borrego, M., Streveler, R.A., Miller, R.L. and Smith, K.A. 2008. A new paradigm for a new field: Communicating representations of engineering education research. *Journal of Engineering Education*, 97(2), 147-162.

Guiding Principles for Scientific Research in Education

1. **Question**: pose ***significant*** question that can be investigated ***empirically***
2. **Theory**: link research to relevant theory
3. **Methods**: use methods that permit direct investigation of the question
4. **Reasoning**: provide coherent, explicit chain of reasoning
5. **Replicate and generalize** across studies
6. **Disclose** research to encourage professional scrutiny and critique

National Research Council, 2002

The Basic Features of Scholarly and Professional Work

1. Requires a high level of discipline-related expertise;
2. Is conducted in a scholarly manner with clear goals, adequate preparation, and appropriate methodology;
3. Has significance beyond the setting in which the research is conducted;
4. Is innovative;
5. Can be replicated or elaborated on;
6. Is appropriately and effectively documented, including a thorough description of the research process and detailed summaries of the outcomes and their significance;
7. Is judged to be meritorious and significant by a rigorous peer review process.

Adapted from: Diamond and Adam (1993) and Diamond (2002).

Engineering Education as a Field of Research


Guest Editorial

Conducting Rigorous Research in Engineering Education

RUTH A. STREVELER

KARL A. SMITH

ENGINEERING EDUCATION BECOMES A DISCIPLINE

Guest Editorial

Quiet No Longer: Birth of a New Discipline

KAMYAR HAGHIGHI

Head, Department of Engineering Education

Purdue University

Journal of Engineering Education

SPECIAL ISSUE:

Journal of Engineering Education: Guest Editorials

- Felder, R.M., S.D. Sheppard, and K.A. Smith, “A New Journal for a Field in Transition,” *Journal of Engineering Education*, Vol. 93, No. 1, 2005, pp. 7–12.
- Kerns, S.E., “Keeping Us on the Same Page,” *Journal of Engineering Education*, Vol. 93, No. 2, 2005, p. 205.
- Gabriele, G., “Advancing Engineering Education in a Flattened World,” *Journal of Engineering Education*, Vol. 94, No. 3, 2005, pp. 285–286.
- Haghighi, K., “Quiet No Longer: Birth of a New Discipline,” *Journal of Engineering Education*, Vol. 94, No. 4, 2005, pp. 351–353.
- Fortenberry, N.L., “An Extensive Agenda for Engineering Education Research,” *Journal of Engineering Education*, Vol. 95, No. 1, 2006,pp. 3–5.
- Streveler, R. A. and K.A. Smith, “Conducting Rigorous Research in Engineering Education, *Journal of Engineering Education*, Vol. 95, No. 2, 2006.
- Wormley, D.N. “A Year of Dialogue Focused on Engineering Education Research,” *Journal of Engineering Education*, Vol. 95, No. 3, 2006.

Fensham, P.J. 2004. *Defining an identity.* The Netherlands: Kluwer

CRITERIA FOR A FIELD

1. **Structural Criteria**
   1. Academic recognition
   2. Research journals
   3. Professional associations
   4. Research conferences
   5. Research centers
   6. Research training
2. **Intra-Research Criteria**
   1. Scientific knowledge
   2. Asking questions
   3. Conceptual and theoretical development
   4. Research methodologies
   5. Progression
   6. Model publications
   7. Seminal publications
3. **Outcome Criteria**
   1. Implications for practice

Building Engineering Education Research Capabilities:

- NSF Initiated Engineering Education Scholars Program (EESP)
- NSF – Centers for Learning and Teaching (CLT)
  - Center for the Advancement of Engineering Education (CAEE)
  - Center for the Integration of Research, Teaching, and Learning (CIRTL)
  - National Center for Engineering and Technology Education (NCETE)
- NAE: Center for the Advancement of Scholarship on Engineering Education (CASEE)
  - AREE: Annals of Research on Engineering Education
- NSF CCLI ND: Rigorous Research in Engineering Education (RREE)
- NSF CCLI Phase III project, Collaborative research: Expanding and sustaining research capacity in engineering and technology education: Building on successful programs for faculty and graduate students
- Engineering Education Research Colloquies (EERC)

Departments of Engineering Education

- Purdue University - https://engineering.purdue.edu/ENE/
- Virginia Tech - http://www.enge.vt.edu/main/index.php
- Utah State University - http://www.engineering.usu.edu/ete/

Annals of Research on Engineering Education (AREE)

- Link journals related to engineering education
- Increase progress toward shared consensus on quality research
- Increase awareness and use of engineering education research
- Increase discussion of research and its implications

- Resources – community recommended
  - Annotated bibliography
  - Acronyms explained
  - Conferences, Professional Societies, etc.
- Articles – education research
  - Structured summaries
  - Reflective essays
  - Reader comments

www.areeonline.org

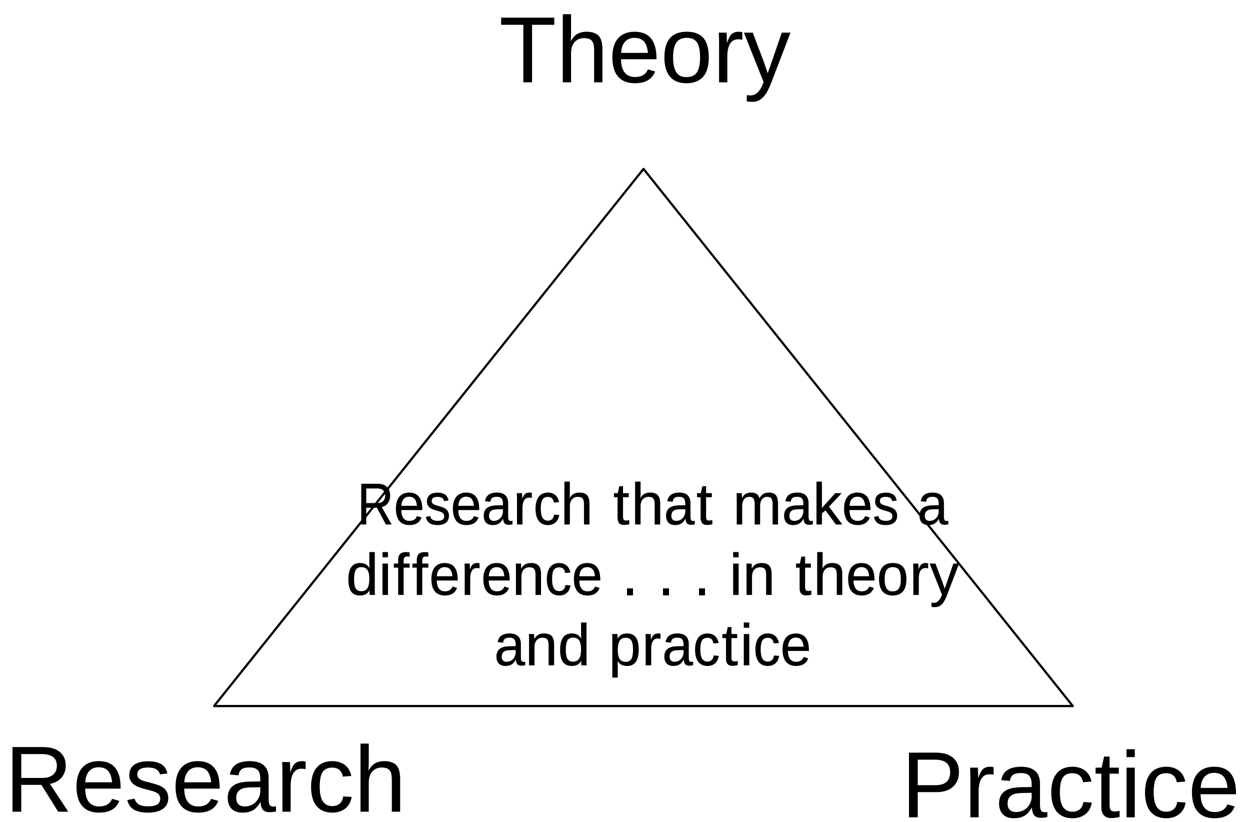
Conducting Rigorous Research in Engineering Education: Creating a Community of Practice (RREE)

NSF-CCLI-ND
American Society for Engineering Education
Karl Smith & Ruth Streveler
University of Minnesota/Purdue University &
Colorado School of Mines/Purdue University

Rigorous Research in Engineering Education

- Summer Workshop - Initial Event for year-long project
- Presenters and evaluators representing
  - American Society for Engineering Education (ASEE)
  - American Educational Research Association (AERA)
  - Professional and Organizational Development Network in Higher Education (POD)
- Faculty funded by two NSF projects:
  - Conducting Rigorous Research in Engineering Education (NSF DUE-0341127)
  - Strengthening HBCU Engineering Education Research Capacity (NSF HRDF-041194)
    - Council of HBCU Engineering Deans
    - Center for the Advancement of Scholarship in Engineering Education (CASEE)
    - National Academy of Engineering (NAE)

Engineering Education Research



Cooperative Learning

Kurt Lewin - Social Interdependence Theory (~1935)

1. The essence of a group is the interdependence among members (created by common goals) which results in the group being a "dynamic whole" so that a change in the state of any member of subgroup changes the state of any other member or subgroup

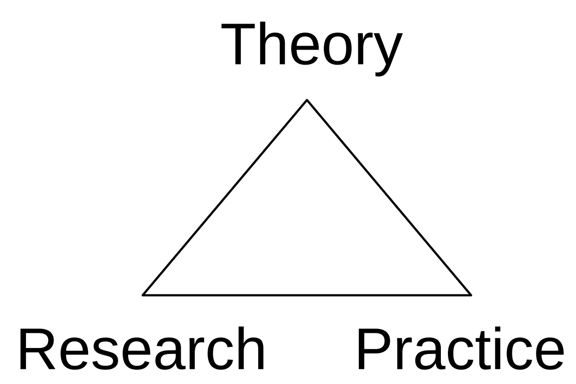
2. An intrinsic state of tension within group members motivates movement toward the accomplishment of the desired common goals.

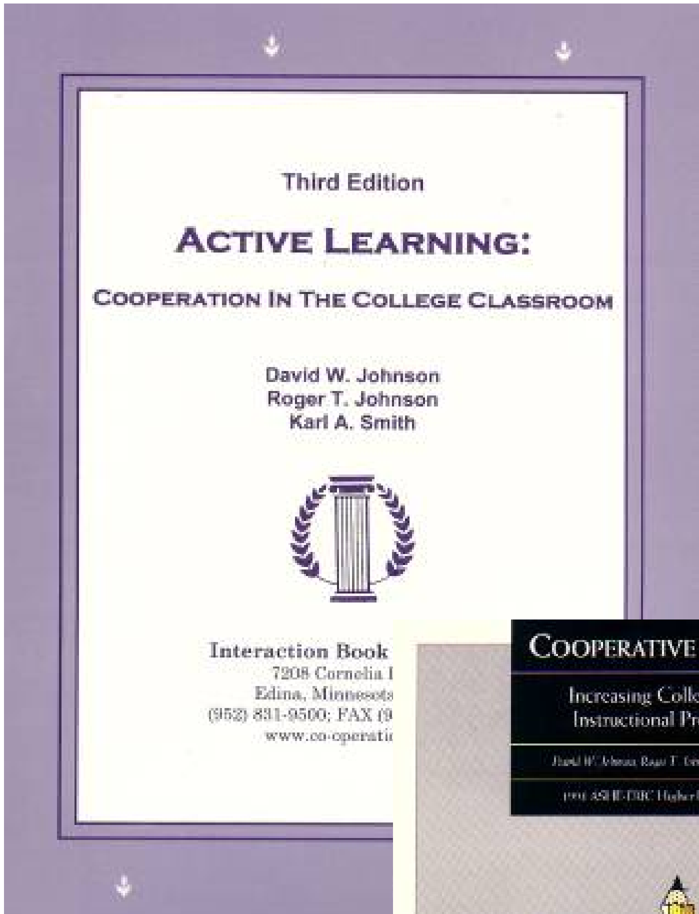
Student – Student Interaction Lewin's Contributions

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

Cooperative Learning

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





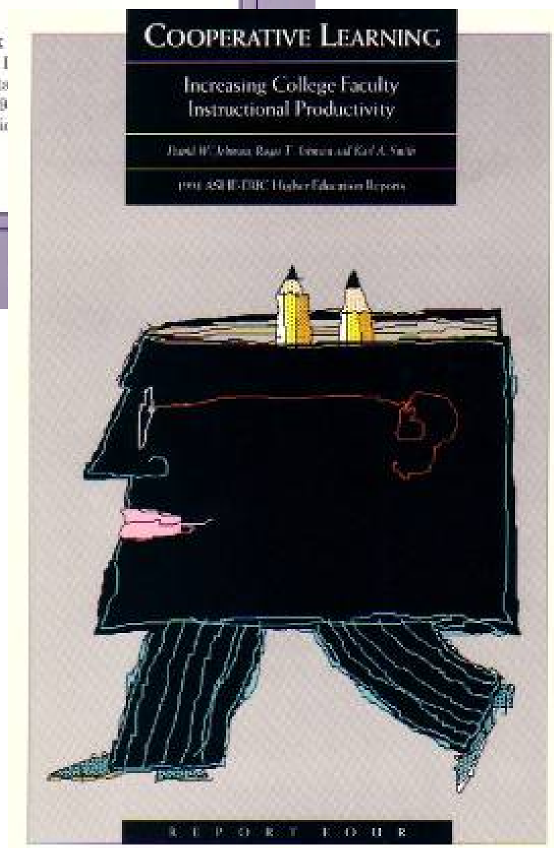
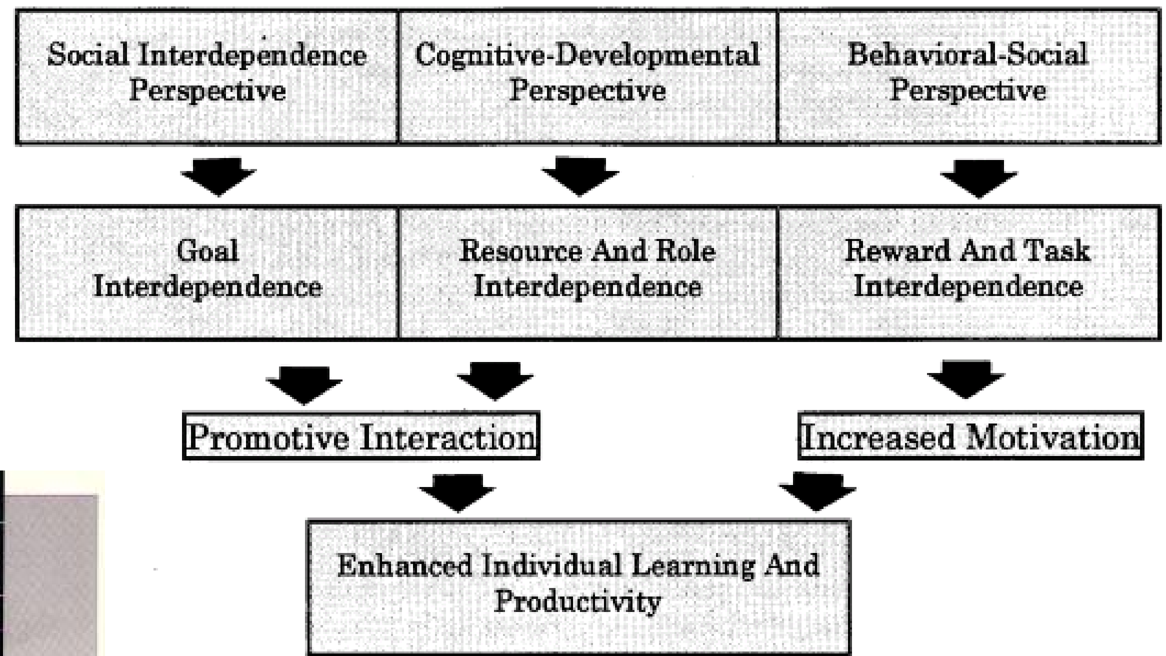


Figure A.1 A General Theoretical Framework



Cooperative Learning

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

Cooperative Learning Research Support

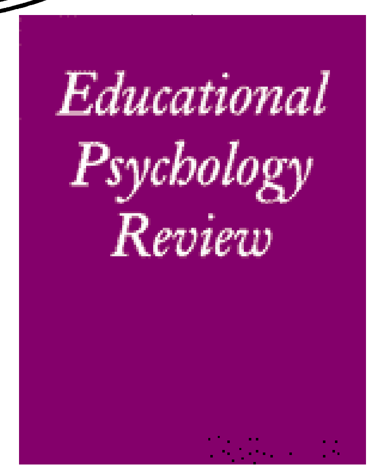
Johnson, D.W., Johnson, R.T., & Smith, K.A. 1998. Cooperative learning returns to college: What evidence is there that it works? *Change*, *30* (4), 26-35.

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

Outcomes

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

January 2005



March 2007

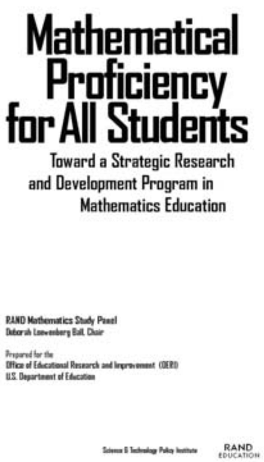
Small-Group Learning: Meta-analysis

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

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

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

Engineering Education Research – Closing the Loop



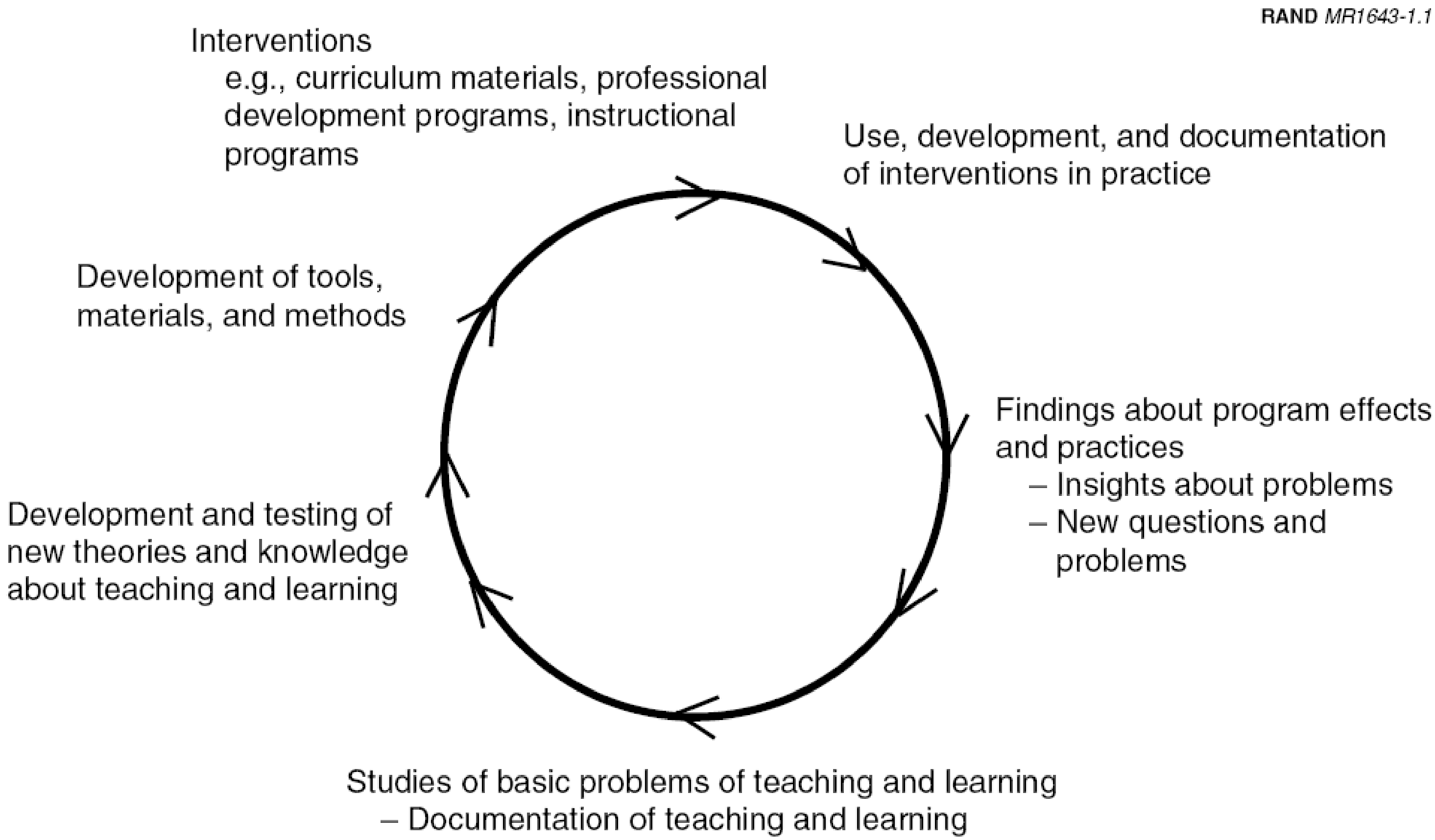
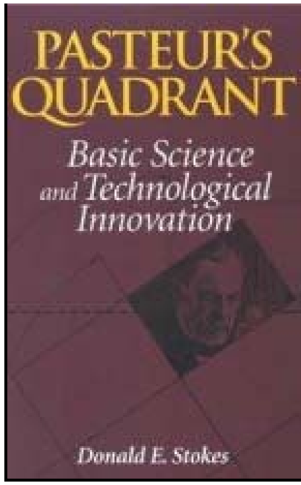


Figure 1.1—Cycle of Knowledge Production and Improvement of Practice

Research Inspired By:



Use (Applied)

Understanding (Basic)

	No	Yes
Yes	Pure basic research (Bohr)	Use-inspired basic research (Pasteur)
No		Pure applied research (Edison)

Stokes, Donald. 1997. Pasteur's quadrant: Basic science and technological innovation. Wash, D.C., Brookings.

Engaged Scholarship

1. Design the project to addresses a big question or problem that is grounded in reality.
2. Design the research project to be a collaborative learning community.
3. Design the study for an extended duration of time.
4. Employ multiple models and methods to study the problem.
5. Re-examine assumptions about scholarship and roles of researchers.

"Knowledge For Theory and Practice" by Andrew H. Van de Ven and Paul E. Johnson. Carlson School of Management, University of Minnesota,
Academy of Management Review, October 2006

Boyer, Ernest L. 1990. *Scholarship reconsidered: Priorities for the* professoriate. Princeton, NJ: The Carnegie Foundation for the Advancement of Teaching.

Diamond, R. 2002. The Mission-Driven Faculty Reward System. *Field Guide to Academic Leadership*, San Francisco: Jossey-Bass.

Diamond R. & Adam, B. 1993. Recognizing faculty work: Reward systems for the year 2000. San Francisco, CA: Jossey-Bass.

National Research Council. 2002. *Scientific research in education*. Committee on Scientific Principles in Education. Shavelson, R.J., and Towne, L., Editors. Center for Education. Division of Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.

Centers for Learning and Teaching Network. http://cltnet.org/cltnet/index.jsp

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

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