

**John D. Bransford, Ph.D.**  
**James W. Mifflin Professorship**  
**Professor Education and Psychology**  
**College of Education, University of Washington, Seattle**

**Nominated by**  
**Steven R. Yussen, Ph.D.**



June, 2007

Short biographical statement

STEVEN R. YUSSEN  
PROFESSOR, INSTITUTE OF CHILD DEVELOPMENT  
THE UNIVERSITY OF MINNESOTA

Steven Yussen has a 35 year history in higher education, spanning work as a professor of Educational Psychology, Psychology, and Child Development at the Universities of Wisconsin-Madison, the University of Iowa, and the University of Minnesota. At two of these Universities he also served for 16 years as dean of their Colleges of Education, from 1991-98 (Iowa) and 1998-2006 (Minnesota). As dean, he hired more than 100 faculty, raised \$30 million in private fundraising efforts and (at Minnesota) led a unit with 500 faculty and staff; at Wisconsin, he also served as chairperson of the Department of Educational Psychology (1984-87). Dr. Yussen has published more than 70 scholarly research articles, book chapters, and books in the fields of developmental and educational psychology, and he is particularly well known for his work on cognitive development, memory, and reading comprehension. His honors include: service as Associate Editor of two major journals, *Child Development* and the *Journal of Educational Psychology*; selection as a Guggenheim Fellow; appointment as a Fulbright Fellow at the Hebrew University; selection as a Spencer Fellow; election to the Iowa Academy of Education; and service on the boards of the American Association of Colleges of Teacher Education, the Holmes Group (Midwest Vice President), the Great Cities' Council of Deans (Vice President), the Iowa Business, Education, and Labor Roundtable, and the Minnesota PreK-16 Statewide Education Partnership. He has supervised 20 Ph.D students and more than 40 M.S. students, and the 5 editions of his widely read textbook in Child Development co-authored with J. Santrock were read by more than 200,000 students worldwide.



## SUMMARY OF THE CASE

John Bransford is likely the leading "learning scientist" in the United States today, applying his knowledge and skills to advance student learning. For four decades, John has been a leading figure in the study of student learning, offering new paradigms for thinking about the nature of human memory, the transfer of learning to new situations, learning as rooted in knowledge rich understanding, how to use technology to design powerful learning opportunities, and new models for assessing learning. Along the way, he has led the development of creative new learning tools such as the Jasper Problem Solving Series, the Scientist in Action Series, and the Legacy Framework of "challenge based learning". Most recently, he has authored a series of 3 highly influential books on the nature of human learning which synthesize many of these ideas along with those of other leading scholars and practitioners of human learning.

On every dimension one typically seeks out evidence for positive impact in education, his work and legacy are extraordinarily far reaching. His seminal work defining "learning science" impacts all educational researchers studying topics such as those listed above. Every student preparing for a teaching career is impacted by the ideas, models, and examples of curriculum innovation and teaching techniques embedded in the tools and models he's developed. And those responsible for guiding our educational system and spurring innovation repeatedly turn to John for help—at the school district level, at the state level, at the national policy level, and in the technology innovation sector.

He is that rare breed of intellectual and doer in education who is simultaneously a first rate theoretical thinker, a creative empirical research scientist, a teacher tuned in to the broad, interdisciplinary perspective needed to understand student learning in its full complexity, a practical innovator of curricula and technology tools, and a boundlessly energetic collaborator.



July 30, 2007

Dr. Trent Gabert  
Brock International Education Award Committee  
University of Oklahoma  
1610 Asp Avenue, Ste. 108  
Norman, Oklahoma 73072-6405

Dear Dr. Gabert:

It is with great pleasure that I nominate Dr. John D. Bransford, currently James W. Mifflin Professor of Education and Psychology at the University of Washington, for the Brock International Prize in Education, for 2008

John Brock has said: "The most important thing to do in this life is to educate our children. The purpose of the Brock Prize is to identify the best ideas on education in the world and to expose them to our educators, teachers, administrators, and politicians."

And from my perspective, the most important way we can improve the education of our children, is to have a comprehensive and sound view of how they learn. For almost 4 decades, now, John Bransford has systematically advanced our understanding of student learning through his creative and paradigm changing ideas about the nature of memory; how we transfer our learning (learn to learn); how we learn and understand ideas in diverse fields such as mathematics, science, history, and the language arts; how we develop expertise; and how these lessons can be applied to the real world design of classroom curriculum and instruction, smart use of technology tools, the preparation of teachers and school leaders, and the assessment of high level learning.

John's contributions are seminal in the efforts of educators, during this period, to: focus on "understanding" as the foundation for learning, develop curricula that are "problem based", develop extended learning cycles through "projects", examine new ways to document how learning-as-understanding transfers across time, consider new ways to assess students' understanding following learning experiences, and to develop creative technology tools to advance these goals.

There is simply no other contemporary figure in education who has matched John Bransford's scope and impact on our current thinking about the nature of student learning. His theoretical writing, his empirical research, his design projects in science, mathematics, and other curriculum areas, and the hundreds of collaborations he's fostered among school districts, leading technology innovators (e.g., IBM, Microsoft, and Boeing), and professional educators (e.g., in Tennessee, North Carolina, and Washington) are simply staggering.

The evidence for these claims comes from three sources.

First, a close reading of his curriculum vitae shows that: he has been a prolific scholar with a range of nearly 200 published research articles, book chapters, essays, and books; that his work has been honored in various ways by esteemed Universities and educational organizations such as Vanderbilt, the U of Washington, the National

Academy of Education, the American Educational Research Association, the Carnegie Foundation, the National Science Foundation, and the National Academy of Science; that he has authored or co-authored widely adopted, state-of-the-art, technologies for learning such as the Jasper Problem Solving Series and the Legacy framework for "challenge-based" learning; that he is the "go-to" person for some of the most ambitious and smart organizations looking for help in using contemporary Learning Science to impact student learning—school districts such as Nashville, Tennessee, the state of North Carolina, Bellvue, Washington, Little Planet Learning, Microsoft, Boeing, the National Science Foundation, and many more. The number and depth of his generous collaborations to improve student learning is extraordinary.

Second, John has become the central, contemporary figure in education, to define the nature of human learning, through his lead authorship of three books, listed just below, during the past 8 years. The books offer a creative synthesis of ideas, research evidence, and the wisdom of practice, from a range of fields, and address both pre K-12 education and higher education.

Bransford, Brown, and Cocking (1999, also 2000) How people learn; Brain, mind, experience, and school. Washington, DC: National Academy Press.

Bransford & Donovan (2005). How students learn; History, mathematics, and science in the classroom. Washington, DC: National Academies Press.

Bransford & Darling-Hammond (2005). Preparing teachers for a changing world: What teachers should learn and be able to do. San Francisco, CA: Jossey-Bass.

These National Academy and Jossey Bass sponsored books now define the consensus framework among scholars and educators across the United States on the nature of school based human learning, and stand as the central, driving, force behind efforts of scholars and researchers, policy makers, schools, and technology innovators to improve public education.

As a third and final source of evidence, I offer a sample of comments from selected peers, educational leaders, and collaborators, when asked to evaluate John's work and contributions. These comments appear below and in the pages which follow.

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"For several decades John has been a visionary innovator in education. As a result of his unique ability to formulate ground breaking learning concepts that he then transforms into practical applications, he has become an internationally recognized leader in the development of 21<sup>st</sup> century teaching and learning.

During his long tenure at Vanderbilt University, John conducted research in learning and cognition that was ultimately published in *How People Learn: Brain, Mind, Experience and School*. This book has had a revolutionary impact on the preparation of teachers and the organization of schools.

Building on his learning research, John led the development of award winning curriculum and instruction projects, such as the Jasper Woodbury Mathematics series, the Scientists in Action Series, and the Little Planet series. These widely acclaimed instructional innovations are being used across the country and around the world.

In his current position as the leader of the University of Washington LIFE Center, John is spearheading a national alliance of cutting edge researchers and educators who are inventing new technologies that will meet the needs of 21<sup>st</sup> century learners.

In view of his visionary leadership and innovative application of his state-of-the art research, John Bransford is an outstanding candidate for the Brock International Prize in Education."

Thomas G. Carroll, President, National Commission on Teaching and America's Future

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"John is that rare bird in American education. He possesses a truly first rate mind; yet he expresses himself in terms the layman can easily understand. He is a gifted researcher, and original and independent thinker, a humanist of the first rank and an educator to the core. I know of no other educational theorist currently practicing at the peak of his intellectual capacity who has contributed more to our awareness and understanding of how people learn. His seminal writing and field research in this area have made a deep and lasting contribution to all those who aspire to teach and to learn. If he didn't coin the phrase 'learning scientist', he certainly is emblematic of that phrase. Like a gifted musician, John's work combines the technical skills of a master craftsman with the artistry of one who was born to play."

Richard Bell, National Executive Director, Young Audiences, Inc., New York, NY.

Academy of Education, the American Educational Research Association, the Carnegie Foundation, the National Science Foundation, and the National Academy of Science; that he has authored or co-authored widely adopted, state-of-the-art, technologies for learning such as the Jasper Problem Solving Series and the Legacy framework for "challenge-based" learning; that he is the "go-to" person for some of the most ambitious and smart organizations looking for help in using contemporary Learning Science to impact student learning--school districts such as Nashville, Tennessee, the state of North Carolina, Bellvue, Washington, Little Planet Learning, Microsoft, Boeing, the National Science Foundation, and many more. The number and depth of his generous collaborations to improve student learning is extraordinary.

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Bransford, Brown, and Cocking (1999, also 2000) How people learn; Brain, mind, experience, and school. Washington, DC: National Academy Press.

Bransford & Donovan (2005). How students learn; History, mathematics, and science in the classroom. Washington, DC: National Academies Press.

Bransford & Darling-Hammond (2005). Preparing teachers for a changing world: What teachers should learn and be able to do. San Francisco, CA: Jossey-Bass.

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"At Little Planet Learning, we develop educational programs for students and training programs for adults in the workplace. In the course of our work we have relied on the wisdom of many learning scientists, and top experts in a variety of fields. John Bransford is clearly at the forefront of experts on the subject of 'how people learn'. He has been able to apply his knowledge to many diverse subject areas, as well as many diverse audiences. He accomplishes this because he combines a vast knowledge of the science with a powerfully active imagination, astounding intuition, great empathy for the learner, a wonderful sense of humor—all guided by strong values of courage, honesty, and fairness. It has been my honor and pleasure to collaborate with John in applying his wisdom to many practical efforts over the last twenty years."

Bill Nelson, President, Little Planet Learning

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"John Bransford's impact on the Bellevue School District began with the publication of *How People Learn* in 1999. ...While I began sharing the book's ideas with our staff almost immediately, it wasn't until John moved from Vanderbilt to the University of Washington that his influence became both widely and deeply felt within the school district. In the 2005-06 school year, John and I had a number of conversations about the goals of the school district and the role learning theory might play in making our work more coherent. He also agreed to present his ideas to our leadership team— a group of about 100 principals, curriculum developers and coaches, student service administrators, and others who shape and supervise our instructional program. ...he was a great hit with our team, inspiring them with his blend of intellectual power and personal humility.

Knowing that John's expertise could play a significant role in improving our work as a school system, I started to explore ways of partnering with him. ...Given our experiences with John, we knew his work could greatly enhance the quality of our curriculum. He was excited, I believe, about the possibility of infusing learning theory into the entire curriculum of a school district so that its influence would be felt everywhere and all at once. Gates (the Gates Foundation) agreed and we have been working very closely for the past twelve months.

John and his team at the Life Center are studying our K-12 science curriculum by examining what we have posted on the Curriculum Web, along with our classroom based district assessments (roughly one for every unit we teach) and our student performance data; observing classroom instruction; conducting focus groups with teachers; and conducting study sessions with our science curriculum leaders. Their review has been intensive and thorough, and now in combination with John's team, we are experimenting with various approaches to curriculum development and staff training that are in concert with the principles spelled out in *How People Learn*. Our goal is to create a model in K-12 science that will guide our work in all disciplines.

While the study of our science program was taking place during the 2006-07 school year, John also led a class in learning theory for our

leadership team. We met several times throughout the school year in full-day sessions, first focusing on the components of the theory itself, and then moving to the ways our practice might be reformed. As we prepare for the 2007-08 school year, we are much better equipped to disseminate information to teachers, students, and parents about how we all learn and how to make the most of our ability to learn.

... John is very generous with his time and talent. It is clear to anyone who spends time with him that he is dedicated to the profession, completely focused on the well being of children, and tireless about doing his part in advancing the cause.

It is an honor and privilege to work with him.

Mike Riley, Superintendent, Bellevue (Washington) Schools

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"It has been my great pleasure and privilege to work with John Bransford in the application of his research and theories of human learning to the transformation of secondary career and technical education and post-secondary technical and technician education across the United States. Too long ignored or in the shadow of traditional academic disciplines, both areas of education are now recognized as critical for development of the emerging workforce and the nation's continued economic vitality in the 21<sup>st</sup> century.

Funded by NSF's Advanced Technological Education Program, Professor Bransford's work in shaping the professional development of these educators has grown from conducting local and regional workshops on this topic to the establishment of a recurring series of national conferences for high school and community college educators and stakeholders from across the United States. The format of these conferences is built on and incorporates his principles of "How People Learn" and "STAR Legacy Cycle" of challenge based instruction. The resulting transformation of conference participants in their understanding and practice of effective teaching and learning has subsequently affected fellow faculty members and programs of instruction throughout the United States."

David C. McNeel, Director, Center for Innovation in Technological Education, Nashville State Community College

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"I have worked with Dr. John Bransford for the past four years on a variety of programs withing Microsoft's Partners in Learning initiative. Under Partners in Learning, Microsoft is working with governments, ministries of education, and other key stakeholders in 101 countries to offer a spectrum of resources for primary and secondary education including tools, programs, and practices. The fundamental premise of the Partners in Learning vision is that technology in education can be a powerful catalyst to promote learning and that education changes lives, families, communities and ultimately nations. [www.microsoft.com/partnersinlearning](http://www.microsoft.com/partnersinlearning)

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"John Bransford has positioned his work to lead the way in a "break through" movement that will reshape the assessment world in such a fashion to move education into the 21<sup>st</sup> century. Evidence indicates that one of the most powerful ways to change teacher behavior is to change the assessment model used to determine student performance. John has been working in North Carolina to develop a "cutting edge" multi media assessment/instructional tool- an electronic arena that will allow for continuous benchmarking of student understanding of content and theory than can lead to the elimination of snapshot testing. I think his work- present and past- has influenced educational theory in a greater fashion than yet understood and is worthy of recognition."

Sam Houston, President and CEO, North Carolina Science, Mathematics, and Technology Education Center.

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"John Bransford has made significant contributions to the development of new methods in bioengineering education. His work in this area stems from his collaboration with me and the other members of the Vanderbilt-Northwestern-Texas-Harvard/MIT Engineering Research Center... in Bioengineering Educational Technologies. This project was a National Science Foundation funded Engineering Research Center focused on bioengineering education. It began in 1999 and is still funded by NSF for research in bioengineering education. It was aimed at applying the principles from the book co-edited by John, "How People Learn". John developed the ideas in learning science that led to his direction of the Learning Science Thrust of this Center and the formulation of new and effective methods for the teaching of bioengineering. His basic ideas of student-centered, knowledge-centered, assessment-centered, and community-centered emphases for new instructional designs was shown to be highly effective in controlled educational studies of bioengineering classrooms. This represents a major breakthrough in the reform of bioengineering education and the improvement of its effectiveness. These methods have been shown to be especially important in improving the adaptive expertise of engineering students and thus addressing a national concern on competitiveness of American innovation in the global market."

Thomas Harris, M.D., Ph.D., Orrin Henry Ingram Distinguished Professor of Engineering, Professor of Biomedical Engineering, Medicine, and Chemical Engineering, Vanderbilt University

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"Dr. John Bransford has made a profound impact within the training community at the Boeing Company. His publication of How People Learn, was the basis of several studies performed with groups of Boeing engineers taking Composite and Product Lifecycle Management courses. He, along with his research team at the UW LIFE center, helped in analyzing the results of these studies over the past two years. ...With his leadership and innovations within the academic community, he has continued to be a highly respectable and influential figure within the training department at the Boeing Company."

Michael C. Richey, the Boeing Company

Dr. Bransford is part of our Partners in Learning international advisory council, influencing the overall design and implementation of the program, which has now reached over 68 million teachers and students around the world. He has spoken at many events and conferences for Partners in Learning, sharing his thinking on innovation, leadership, assessment and 21<sup>st</sup> century learning with ministry of education and other senior government and organizational leaders from nearly 100 countries.

But it is Dr. Bransford's work leading the development of curriculum and training for school leaders around the world that has had the most influence on schools as they rethink the teaching and learning processes. Dr. Bransford's expertise in the areas of human learning as it applies to a school setting was put into play in the development of two curricula: *School Leader Development: Building 21<sup>st</sup> Century Schools*, and *School Leader Development: Assessing 21<sup>st</sup> Century Learning*.

These unique online courses combine video challenge questions, discussion and expert resources to focus on issues facing school leaders as they try to prepare their students for life and work in the 21<sup>st</sup> century. The scenario-based courses are not passive, but intended to directly engage participants through interactive materials. First the "Master Challenge" facing a school is presented, followed by four modules that allow the educator to explore solutions to this challenge through individual work and through productive discussion with their peers. Each module has a "Challenge Cycle" that takes the learner through initial thoughts, resources, revised thinking, and group work. After all four modules are presented, there's an opportunity to put the insights gained from this intensive work to solve the Master Challenge. Although this approach shows the example of just one school, it discusses education issues that are universal. The model relies on the knowledge and expertise of the participants, who share their insights and learn from each other. The end goal of the training is for educators to learn new practices and points of view on topics that they can then take and implement in their own institutions.

Dr. Bransford not only led development of these curricula, but he led Microsoft's international trainings for these materials as well. To date, Microsoft has conducted 4 regional master trainings for these curricula, training approximately 150 master trainers in 38 countries around the world. These trainers have then taken the curriculum back to their own countries, localized the materials into languages as diverse as Bulgarian, Korean, and Swedish, and have continued training school leaders on a local level. What is most impressive and impactful for Microsoft is that the challenge cycle model developed by Dr. Bransford and employed in these curricula is adaptable for virtually any culture or local education context around the world. This enables us to reach tens of thousands of school leaders from South Africa to Massachusetts, introducing them to the principles of how people learn and assessing adaptive expertise in students."

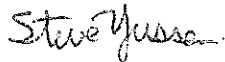
Kristen Weatherby, Academic Programs Manager, Partners in Learning,  
Microsoft Corporation

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In summary, John Bransford is arguably the leading "learning scientist" in the United States today, applying his knowledge and skills to synthesize theory, develop models for instruction and teaching, create new technology tools and frameworks, and collaborate generously and effectively with a large and extensive range of partners and organizations, to improve student learning. As one collaborator noted, the impact of his work likely extends to tens of millions of school children, teachers, and leaders, throughout the world.

I cannot think of anyone more deserving of the Brock award.

Sincerely,

A handwritten signature in cursive script that reads "Steve Yussen".

Steven R. Yussen  
Professor, Institute of Child Development  
Former dean, College of Education & Human Development  
The University of Minnesota  
syussen@umn.edu



**John D. Bransford**

**CURRICULUM VITA**

**Title:** James W. Mifflin Professorship and Professor of Education and Psychology

**Personal Information:**

**Mailing Address:**

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**URL:** <http://LIFE-SLC.org>

**Education**

B.A., Hamline University, Psychology, 1966  
Major: Psychology

Ph.D., University of Minnesota, Cognitive Psychology, 1970  
Major: Cognitive Psychology  
Minor: Child Psychology and Linguistics

**Professional Experience**

2004 - Present Principal Investigator, "LIFE Center"

2003 - Present Microsoft Partners in Learning International Advisory Council Member

2003 - Present Microsoft Partners in Learning National Advisory Council Member

2003 - Present James W. Mifflin University Professorship and Professor of Education, University of Washington

1984 - 2003 Co-Director, Learning Technology Center, Vanderbilt University

1989 - 2003 Centennial Professor of Psychology, Vanderbilt University

1983 - 2003 Professor of Education, Department of Teaching and Learning, George Peabody College at Vanderbilt

1980 - 2003 Senior Scientist, Kennedy Center, George Peabody College at Vanderbilt

1979 - 1989 Professor, Vanderbilt University, Department of Psychology

1972 - 1978 Associate Professor, Department of Psychology

**Honors**

- Centennial Professor of Psychology
- Emmonds Distinguished Scholar, Ball State University
- Peabody Roundtable Honoree
- Co-author: on three "Article of the Year" Awards
- Honorable Mention: Creative Talents Award for Ph.D. Thesis

- NIMH Predoctoral Fellow
- Magna Cum Laude with Special Honors in Psychology
- President, Torch & Cycle Honor Society
- President, Theta Chi Fraternity
- 1997 Recipient of the Sutherland Award for Research Excellence
- National Academy of Education
- Inaugural Speaker: Peabody's Distinguished Speaker Series
- President's Committee of Advisors on Science and Technology, Panel on Educational Technology
- Co-chair: Three Committees on Developments in the Science of Learning, National Academy of Science
- Board of Advisors, NSF's Division of Education and Human Resources (EHR)
- Recipient of the Thorndike Award, 2001
- National Academy of Science 2000: Lifetime Associate as advisor to the Nation in matters of science, engineering, and health
- Visiting Scholar at the Carnegie Foundation for the Advancement of Teaching 2001

### **Selected Research and Grant Support**

- 2004 - Present Principal Investigator, "LIFE Center". Funded by National Science Foundation
- 2004 - Present Principal Investigator, "Building 21<sup>st</sup> Century School Leaders" curricula project. Funded by Microsoft Partners in Learning
- 2001 - Present Principal Investigator, "Designing Arts Enhanced Literacy Curriculum and Instruction". Funded by Young Audiences, Inc.
- 1996 - 2000 Co-Principal Investigator, "American School Directory (ASD)". Funded by American Schools Directory
- 1996 - 2000 Co-Principal Investigator, "Contrasting cases in a Context of Anchored Inquiry." Funded by OERI.
- 1996 - 2000 Co-Principal Investigator, "Studying Achievement for a Whole Day Whole Year (WDWY) Perspective." Funded by OERI.
- 1996 - 2000 Co-Principal Investigator, "Whole Day Whole Year . . .
- 1999 - 2001 Co-Principal Investigator, Teachable Agents: Computer Environments for Supporting High Achievement in Science and Mathematics". Funded by NSF.
- 1997 - 2001 Co-Principal Investigator, "The Challenge Zone: Using the Internet to Support High Standards in Mathematics and Science". Funded by NSF.
- 1999 - 2002 Co-Principal Investigator, "Information Technology & Teacher Education: Leveraging the Power of Learning Theory and Technology". Funded by U.S. Department of Education.
- 1996 - 2001 Principal Investigator, "Center for Innovative Learning Technologies (CILT)". Funded by NSF through SRI
- 1996 - 2001 Co-Principal Investigator, "Multimedia-Schools for Thought." Funded by McDonnell Foundation

|             |                                                                                                                        |
|-------------|------------------------------------------------------------------------------------------------------------------------|
| 1996 - 1997 | Co-Principal Investigator, "Metro Evaluation and Assessment." Funded by Metropolitan Nashville Public Schools."        |
| 1996 - 1990 | Co-Principal Investigator, McDonnell Foundation Grant for SFT.                                                         |
| 1995 - 1997 | Co-Principal Investigator, ONR Grant on Cognitive Analysis                                                             |
| 1993 - 1996 | Co-Principal Investigator, Mellon Foundation                                                                           |
| 1993 - 1996 | Investigator, NSF Grant for Scientists in Action                                                                       |
| 1993 - 1994 | Co-Principal Investigator, McDonnell Foundation grant for Classroom Implementation                                     |
| 1992 - 1996 | Investigator, NSF Grant on Assessment                                                                                  |
| 1992 - 1995 | Principal Investigator, NSF - Extension of the Jasper Series: A Generative Approach to Improving Mathematical Thinking |
| 1991 - 1996 | Principal Investigator, NICHD Grant, At-Risk of School Failure                                                         |
| 1991 - 1994 | Co-Principal Investigator, McDonnell Foundation Award                                                                  |
| 1990 - 1993 | Investigator, Office of Naval Research                                                                                 |
| 1990 - 1992 | Principal Investigator, National Science Foundation Material Development Grant                                         |
| 1990 - 1992 | Co-Principal Investigator, NSF grant on Jasper series                                                                  |
| 1990 - 1992 | Investigator, U. S. Department of Education, Multimedia                                                                |
| 1990 - 1991 | Investigator, U. S. Department of Education, Personal Advisor                                                          |
| 1987 - 1990 | Co-Principal Investigator, McDonnell Foundation award                                                                  |
| 1987 - 1990 | Co-Principal Investigator, U.S. Department of Education Grant                                                          |
| 1987 - 1990 | Investigator, U.S. Department of Education Grant                                                                       |
| 1987 - 1990 | Co-Principal Investigator, McDonnell Foundation award                                                                  |
| 1986 - 1989 | Co-Principal Investigator, U.S. Department of Education Grant                                                          |
| 1992 - 1995 | Co-Principal Investigator, IBM Grant: Computer Museum Project, Phase II                                                |
| 1985        | Co-Principal Investigator, IBM Grant: Computer Museum Project, Phase I                                                 |
| 1984 - 1987 | Co-Principal Investigator, Army Research Institute Grant                                                               |
| 1984 - 1986 | Co-Principal Investigator, IBM Grant: Programs for Teaching Problem Solving                                            |
| 1983 - 1986 | Co-Principal Investigator, National Institute of Mental Health Research Grant                                          |

- 1983 - 1986 Co-Principal Investigator, Department of Education Research Grant
- 1980 - 1983 Co-Principal Investigator, National Institute of Education Research
- 1979 - 1982 Co-Principal Investigator, National Institute of Education Research
- 1978 - 1979 Principal Investigator, Vanderbilt University Research Council Fellowship
- 1977 - 1979 Co-Principal Investigator, National Science Foundation
- 1973 - 1976 Co-Principal Investigator, National Institute of Education Research Grant
- 1972 - 1972 Postdoctoral Fellow, University of Minnesota, Center for Research in Human Learning
- 1971 - 1971 Principal Investigator, State University of New York at Stony Brook, Summer Research Grant
- 1967 - 1970 Pre-doctoral Fellow, University of Minnesota, Center for Research in Human Learning

### **Publications**

- Franks, J.J. & Bransford, J.D. (1970). The abstraction of visual patterns. *Journal of Experimental Psychology*, 90, 65-74. Honorable Mention: Creative Talents Awards, 1970.
- Bransford, J.D. & Franks, J.J. (1971). The abstraction of linguistic ideas. *Cognitive Psychology*, 2, 331-350. Honorable Mention: Creative Talents Awards, 1970
- Bransford, J.D., Barclay, J.R. & Franks, J.J. (1972). Sentence memory: A constructive vs. interpretive approach. *Cognitive Psychology*, 3, 193-209.
- Bransford, J.D. & Johnson, M.K. (1972). Contextual prerequisites for understanding: Some investigations of comprehension and recall. *Journal of Verbal Learning and Verbal Behavior*, 11, 717-726. --Reprinted in: (a) M.C. Wittrock (Ed.), *Learning and instruction*. Berkeley, CA: McCutchan Publishing Corp., 1977. (b) *The technology of teaching English* (A Japanese Volume), Kenkyusha Limited, 1976.
- Franks, J.J. & Bransford, J.D. (1972). The acquisition of abstract ideas. *Journal of Verbal Learning and Verbal Behavior*, 11, 451-454.
- Johnson, M.K., Bransford, J.D., Nyberg, S.E. & Cleary, J.J. (1972). Comprehension factors in interpreting memory for abstract and concrete sentences. *Journal of Verbal Learning and Verbal Behavior*, 11, 451-454.
- Bransford, J.D. & Johnson, M.K. (1973). Considerations of some problems of comprehension. In W.G. Chase (Ed.), *Visual information processing* (pp. 383-438). New York: Academic Press.
- Doll, T.J., Tweedy, J.R., Johnson, M.K., Bransford, J.D. & Flatow, C. (1973). Semantic memory and sentence verification time. *Journal of Experimental Psychology*, 100, 429-431.
- Johnson, M.K., Bransford, J.D. & Solomon, S. (1973). Memory for tacit implications for sentences. *Journal of Experimental Psychology*, 98, 203-205.

- Barclay, J.R., Bransford, J.D., Franks, J.J., McCarrell, N.S. & Nitsch, K.E. (1974). Comprehension and semantic flexibility. *Journal of Verbal Learning and Verbal Behavior*, 13, 471-481.
- Bransford, J.D. & McCarrell, N.S. (1974). A sketch of a cognitive approach to comprehension. In W. Weimer & D. Palermo (Eds.), *Cognition and the symbolic processes* (pp. 189-229). Hillsdale, NJ: Lawrence Erlbaum Associates. --Reprinted in: P.N. Johnson-Laird & P.C. Watson (Eds.), *Thinking: Readings in Cognitive Science*. New York: Cambridge University Press, 1978.
- Franks, J. J. & Bransford, J.D. (1974). A brief note on linguistic integration. *Journal of Verbal Learning and Verbal Behavior*, 13, 217-219.
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### Ongoing Activities

Co-Chair of three different National Academy of Science Committees that have explored different aspects of How People Learn (two are completed, one is ongoing).

Co-Chair (with Dr. Deborah Stipek) of a MacArthur planning grant for a research network on enhancing early education and restructuring high schools.

One of the founding co-directors of CILT, the Center for Innovative Learning Technologies

Head of the Learning Sciences thrust for an Engineering Research Center on Restructuring Bioengineering Education based on principles of How People Learn

Co-developer of a number of award-winning technology-based programs and tools such as the Jasper Woodbury Problem Solving Series, The Little Planet Literacy Series, Scientists in Action, StarLegacy, Teachable Agents

Co-Developer of an on-line course on How People Learn.

Co-Director of a new web-based-enhanced project to link leadership and learning.

Co-Chair (with Linda Darling-Hammond) of a National Academy of Education project to identify Key Knowledge and Skills for future teachers.

**Videodiscs, CD-ROM and Related Software (Co-Executive Producer)**

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Complex Trip Planning

- Journey to Cedar Creek
- Rescue at Boone's Meadow
- Get Out the Vote

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- The Big Splash
- A Capital Idea
- Bridging the Gap

Geometry

- Blueprint for Success
- The Right Angle
- The Great Circle Race

Introduction to Algebra

- Working Smart
- Kim's Komet
- The Great Algebra Mystery

*Young Children's Literacy Series*

- The Little Planet and the Magic Hats
- The Little Planet and Glowbird
- Rules of the Game

*Scientists in Action Series*

- Overturned Tanker
- Mystery at Stones Rivers
- Return to Rochester
- The Lost Letters of Lazlo Clark

Co developer of the STAR Legacy Cycle and a number of programs that use that cycles as a framework for enhancing learning, self assessment and transfer





## **How People Learn: Brain, Mind, Experience, and School: Expanded Edition**

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# INTRODUCTION

How People Learn: Brain, Mind, Experience, and School: Expanded Edition  
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## Learning: From Speculation to Science

The essence of matter, the origins of the universe, the nature of the human mind—these are the profound questions that have engaged thinkers through the centuries. Until quite recently, understanding the mind—and the thinking and learning that the mind makes possible—has remained an elusive quest, in part because of a lack of powerful research tools. Today, the world is in the midst of an extraordinary outpouring of scientific work on the mind and brain, on the processes of thinking and learning, on the neural processes that occur during thought and learning, and on the development of competence.

The revolution in the study of the mind that has occurred in the last three or four decades has important implications for education. As we illustrate, a new theory of learning is coming into focus that leads to very different approaches to the design of curriculum, teaching, and assessment than those often found in schools today. Equally important, the growth of interdisciplinary inquiries and new kinds of scientific collaborations have begun to make the path from basic research to educational practice somewhat more visible, if not yet easy to travel. Thirty years ago, educators paid little attention to the work of cognitive scientists, and researchers in the nascent field of cognitive science worked far removed from classrooms. Today, cognitive researchers are spending more time working with teachers, testing and refining their theories in real classrooms where they can see how different settings and classroom interactions influence applications of their theories.

What is perhaps currently most striking is the variety of research approaches and techniques that have been developed and ways in which evidence from many different branches of science are beginning to converge. The story we can now tell about learning is far richer than ever before, and it promises to evolve dramatically in the next generation. For example:

- Research from cognitive psychology has increased understanding of the nature of competent performance and the principles of knowledge organization that underlie people's abilities to solve problems in a wide variety of areas, including mathematics, science, literature, social studies, and history.
- Developmental researchers have shown that young children understand a great deal about basic principles of biology and physical causality, about number, narrative, and personal intent, and that these capabilities make it possible to create innovative curricula that introduce important concepts for advanced reasoning at early ages.
- Research on learning and transfer has uncovered important principles for structuring learning experiences that enable people to use what they have learned in new settings.
- Work in social psychology, cognitive psychology, and anthropology is making clear that all learning takes place in settings that have particular sets of cultural and social norms and expectations and that these settings influence learning and transfer in powerful ways.
- Neuroscience is beginning to provide evidence for many principles of learning that have emerged from laboratory research, and it is showing how learning changes the physical structure of the brain and, with it, the functional organization of the brain.
- Collaborative studies of the design and evaluation of learning environments, among cognitive and developmental psychologists and educators, are yielding new knowledge about the nature of learning and teaching as it takes place in a variety of settings. In addition, researchers are discovering ways to learn from the "wisdom of practice" that comes from successful teachers who can share their expertise.
- Emerging technologies are leading to the development of many new opportunities to guide and enhance learning that were unimagined even a few years ago.

All of these developments in the study of learning have led to an era of new relevance of science to practice. In short, investment in basic research is paying off in practical applications. These developments in understanding of how humans learn have particular significance in light of changes in what is expected of the nation's educational systems.

In the early part of the twentieth century, education focused on the acquisition of literacy skills: simple reading, writing, and calculating. It was not the general rule for educational systems to train people to think and read critically, to express themselves clearly and persuasively, to solve complex problems in science and mathematics. Now, at the end of the century, these aspects of high literacy are required of almost everyone in order to successfully negotiate the complexities of contemporary life. The skill demands for

work have increased dramatically, as has the need for organizations and workers to change in response to competitive workplace pressures. Thoughtful participation in the democratic process has also become increasingly complicated as the locus of attention has shifted from local to national and global concerns.

Above all, information and knowledge are growing at a far more rapid rate than ever before in the history of humankind. As Nobel laureate Herbert Simon wisely stated, the meaning of "knowing" has shifted from being able to remember and repeat information to being able to find and use it (Simon, 1996). More than ever, the sheer magnitude of human knowledge renders its coverage by education an impossibility; rather, the goal of education is better conceived as helping students develop the intellectual tools and learning strategies needed to acquire the knowledge that allows people to think productively about history, science and technology, social phenomena, mathematics, and the arts. Fundamental understanding about subjects, including how to frame and ask meaningful questions about various subject areas, contributes to individuals' more basic understanding of principles of learning that can assist them in becoming self-sustaining, lifelong learners.

## **FOCUS: PEOPLE, SCHOOLS, AND THE POTENTIAL TO LEARN**

The scientific literatures on cognition, learning, development, culture, and brain are voluminous. Three organizing decisions, made fairly early in the work of the committee, provided the framework for our study and are reflected in the contents of this book.

- First, we focus primarily on research on human learning (though the study of animal learning provides important collateral information), including new developments from neuroscience.
- Second, we focus especially on learning research that has implications for the design of formal instructional environments, primarily preschools, kindergarten through high schools (K-12), and colleges.
- Third, and related to the second point, we focus on research that helps explore the possibility of helping all individuals achieve their fullest potential.

New ideas about ways to facilitate learning—and about who is most capable of learning—can powerfully affect the quality of people's lives. At different points in history, scholars have worried that formal educational environments have been better at selecting talent than developing it (see, e.g., Bloom, 1964). Many people who had difficulty in school might have prospered if the new ideas about effective instructional practices had been available. Furthermore, given new instructional practices, even those who

did well in traditional educational environments might have developed skills, knowledge, and attitudes that would have significantly enhanced their achievements.

Learning research suggests that there are new ways to introduce students to traditional subjects, such as mathematics, science, history and literature, and that these new approaches make it possible for the majority of individuals to develop a deep understanding of important subject matter. This committee is especially interested in theories and data that are relevant to the development of new ways to introduce students to such traditional subjects as mathematics, science, history, and literature. There is hope that new approaches can make it possible for a majority of individuals to develop a moderate to deep understanding of important subjects.

## DEVELOPMENT OF THE SCIENCE OF LEARNING

This report builds on research that began in the latter part of the nineteenth century—the time in history at which systematic attempts were made to study the human mind through scientific methods. Before then, such study was the province of philosophy and theology. Some of the most influential early work was done in Leipzig in the laboratory of Wilhelm Wundt, who with his colleagues tried to subject human consciousness to precise analysis—mainly by asking subjects to reflect on their thought processes through introspection.

By the turn of the century, a new school of behaviorism was emerging. In reaction to the subjectivity inherent in introspection, behaviorists held that the scientific study of psychology must restrict itself to the study of observable behaviors and the stimulus conditions that control them. An extremely influential article, published by John B. Watson in 1913, provides a glimpse of the behaviorist credo:

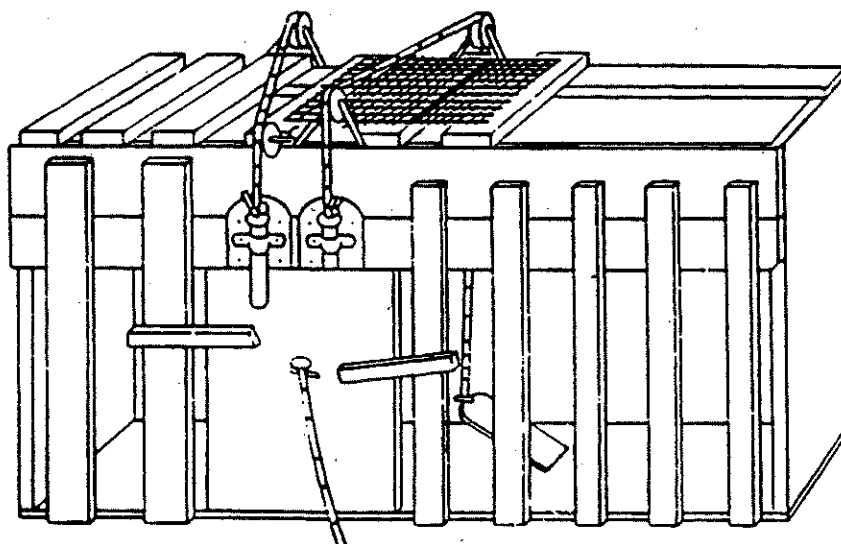
... all schools of psychology except that of behaviorism claim that "consciousness" is the subject-matter of psychology. Behaviorism, on the contrary, holds that the subject matter of human psychology is the behavior or activities of the human being. Behaviorism claims that "consciousness" is neither a definable nor a useable concept; that it is merely another word for the "soul" of more ancient times. The old psychology is thus dominated by a kind of subtle religious philosophy (p. 1).

Drawing on the empiricist tradition, behaviorists conceptualized learning as a process of forming connections between stimuli and responses. Motivation to learn was assumed to be driven primarily by drives, such as hunger, and the availability of external forces, such as rewards and punishments (e.g., Thorndike, 1913; Skinner, 1950).

In a classic behaviorist study by Edward L. Thorndike (1913), hungry cats had to learn to pull a string hanging in a "puzzle box" in order for a

door to open that let them escape and get food. What was involved in learning to escape in this manner? Thorndike concluded that the cats did not think about how to escape and then do it; instead, they engaged in trial-and-error behavior; see Box 1.1. Sometimes a cat in the puzzle box accidentally pulled the strings while playing and the door opened, allowing the cat to escape. But this event did not appear to produce an insight on the part of

### BOX 1.1 A Cat's Learning



"When put into the box, the cat would show evident signs of discomfort and impulse to escape from confinement. It tries to squeeze through any opening; it claws and bites at the wire; it thrusts its paws out through any opening and claws at everything it reaches. . . . It does not pay very much attention to the food outside but seems simply to strive instinctively to escape from confinement. . . . The cat that is clawing all over the box in her impulsive struggle will probably claw the string or loop or button so as to open the door. And gradually all the other unsuccessful impulses will be stamped out and the particular impulse leading to the successful act will be stamped in by the resulting pleasure, until, after many trials, the cat will, when put in the box, immediately claw the button or loop in a definite way" (Thorndike, 1913:13).

the cat because, when placed in the puzzle box again, the cat did not immediately pull the string to escape. Instead, it took a number of trials for the cats to learn through trial and error. Thorndike argued that rewards (e.g., food) increased the strength of connections between stimuli and responses. The explanation of what appeared to be complex problem-solving phenomena as escaping from a complicated puzzle box could thus be explained without recourse to unobservable mental events, such as thinking.

A limitation of early behaviorism stemmed from its focus on observable stimulus conditions and the behaviors associated with those conditions. This orientation made it difficult to study such phenomena as understanding, reasoning, and thinking—phenomena that are of paramount importance for education. Over time, radical behaviorism (often called “Behaviorism with a Capital B”) gave way to a more moderate form of behaviorism (“behaviorism with a small b”) that preserved the scientific rigor of using behavior as data, but also allowed hypotheses about internal “mental” states when these became necessary to explain various phenomena (e.g., Hull, 1943; Spence, 1942).

In the late 1950s, the complexity of understanding humans and their environments became increasingly apparent, and a new field emerged—cognitive science. From its inception, cognitive science approached learning from a multidisciplinary perspective that included anthropology, linguistics, philosophy, developmental psychology, computer science, neuroscience, and several branches of psychology (Norman, 1980, 1993; Newell and Simon, 1972). New experimental tools, methodologies, and ways of postulating theories made it possible for scientists to begin serious study of mental functioning: to test their theories rather than simply speculate about thinking and learning (see, e.g., Anderson, 1982, 1987; deGroot, 1965, 1969; Newell and Simon, 1972; Ericsson and Charness, 1994), and, in recent years, to develop insights into the importance of the social and cultural contexts of learning (e.g., Cole, 1996; Lave, 1988; Lave and Wenger, 1991; Rogoff, 1990; Rogoff et al., 1993). The introduction of rigorous qualitative research methodologies have provided perspectives on learning that complement and enrich the experimental research traditions (Erickson, 1986; Hammersly and Atkinson, 1983; Heath, 1982; Lincoln and Guba, 1985; Marshall and Rossman, 1955; Miles and Huberman, 1984; Spradley, 1979).

## **Learning with Understanding**

One of the hallmarks of the new science of learning is its emphasis on learning with understanding. Intuitively, understanding is good, but it has been difficult to study from a scientific perspective. At the same time, students often have limited opportunities to understand or make sense of topics because many curricula have emphasized memory rather than under-

standing. Textbooks are filled with facts that students are expected to memorize, and most tests assess students' abilities to remember the facts. When studying about veins and arteries, for example, students may be expected to remember that arteries are thicker than veins, more elastic, and carry blood from the heart; veins carry blood back to the heart. A test item for this information may look like the following:

1. Arteries
  - a. Are more elastic than veins
  - b. Carry blood that is pumped from the heart
  - c. Are less elastic than veins
  - d. Both a and b
  - e. Both b and c

The new science of learning does not deny that facts are important for thinking and problem solving. Research on expertise in areas such as chess, history, science, and mathematics demonstrate that experts' abilities to think and solve problems depend strongly on a rich body of knowledge about subject matter (e.g., Chase and Simon, 1973; Chi et al., 1981; deGroot, 1965). However, the research also shows clearly that "usable knowledge" is not the same as a mere list of disconnected facts. Experts' knowledge is connected and organized around important concepts (e.g., Newton's second law of motion); it is "conditionalized" to specify the contexts in which it is applicable; it supports understanding and transfer (to other contexts) rather than only the ability to remember.

For example, people who are knowledgeable about veins and arteries know more than the facts noted above: they also understand why veins and arteries have particular properties. They know that blood pumped from the heart exits in spurts and that the elasticity of the arteries helps accommodate pressure changes. They know that blood from the heart needs to move upward (to the brain) as well as downward and that the elasticity of an artery permits it to function as a one-way valve that closes at the end of each spurt and prevents the blood from flowing backward. Because they understand relationships between the structure and function of veins and arteries, knowledgeable individuals are more likely to be able to use what they have learned to solve novel problems—to show evidence of transfer. For example, imagine being asked to design an artificial artery—would it have to be elastic? Why or why not? An understanding of reasons for the properties of arteries suggests that elasticity may not be necessary—perhaps the problem can be solved by creating a conduit that is strong enough to handle the pressure of spurts from the heart and also function as a one-way valve. An understanding of veins and arteries does not guarantee an answer to this design question, but it does support thinking about alternatives that are not readily available if one only memorizes facts (Bransford and Stein, 1993).

## Pre-Existing Knowledge

An emphasis on understanding leads to one of the primary characteristics of the new science of learning: its focus on the processes of knowing (e.g., Piaget, 1978; Vygotsky, 1978). Humans are viewed as goal-directed agents who actively seek information. They come to formal education with a range of prior knowledge, skills, beliefs, and concepts that significantly influence what they notice about the environment and how they organize and interpret it. This, in turn, affects their abilities to remember, reason, solve problems, and acquire new knowledge.

Even young infants are active learners who bring a point of view to the learning setting. The world they enter is not a “booming, buzzing confusion” (James, 1890), where every stimulus is equally salient. Instead, an infant’s brain gives precedence to certain kinds of information: language, basic concepts of number, physical properties, and the movement of animate and inanimate objects. In the most general sense, the contemporary view of learning is that people construct new knowledge and understandings based on what they already know and believe (e.g., Cobb, 1994; Piaget, 1952, 1973a,b, 1977, 1978; Vygotsky, 1962, 1978). A classic children’s book illustrates this point; see Box 1.2.

A logical extension of the view that new knowledge must be constructed from existing knowledge is that teachers need to pay attention to the incomplete understandings, the false beliefs, and the naive renditions of concepts that learners bring with them to a given subject. Teachers then need to build on these ideas in ways that help each student achieve a more mature understanding. If students’ initial ideas and beliefs are ignored, the understandings that they develop can be very different from what the teacher intends.

Consider the challenge of working with children who believe that the earth is flat and attempting to help them understand that it is spherical. When told it is round, children picture the earth as a pancake rather than as a sphere (Vosniadou and Brewer, 1989). If they are then told that it is round like a sphere, they interpret the new information about a spherical earth within their flat-earth view by picturing a pancake-like flat surface inside or on top of a sphere, with humans standing on top of the pancake. The children’s construction of their new understandings has been guided by a model of the earth that helped them explain how they could stand or walk upon its surface, and a spherical earth did not fit their mental model. Like *Fish Is Fish*, everything the children heard was incorporated into that pre-existing view.

*Fish Is Fish* is relevant not only for young children, but for learners of all ages. For example, college students often have developed beliefs about physical and biological phenomena that fit their experiences but do not fit scientific accounts of these phenomena. These preconceptions must be

### BOX 1.2 *Fish Is Fish*

*Fish Is Fish* (Lionni, 1970) describes a fish who is keenly interested in learning about what happens on land, but the fish cannot explore land because it can only breathe in water. It befriends a tadpole who grows into a frog and eventually goes out onto the land. The frog returns to the pond a few weeks later and reports on what he has seen. The frog describes all kinds of things like birds, cows, and people. The book shows pictures of the fish's representations of each of these descriptions: each is a fish-like form that is slightly adapted to accommodate the frog's descriptions—people are imagined to be fish who walk on their tailfins, birds are fish with wings, cows are fish with udders. This tale illustrates both the creative opportunities and dangers inherent in the fact that people construct new knowledge based on their current knowledge.

addressed in order for them to change their beliefs (e.g., Confrey, 1990; Mestre, 1994; Minstrell, 1989; Redish, 1996).

A common misconception regarding “constructivist” theories of knowing (that existing knowledge is used to build new knowledge) is that teachers should never tell students anything directly but, instead, should always allow them to construct knowledge for themselves. This perspective confuses a theory of pedagogy (teaching) with a theory of knowing. Constructivists assume that all knowledge is constructed from previous knowledge, irrespective of how one is taught (e.g., Cobb, 1994)—even listening to a lecture involves active attempts to construct new knowledge. *Fish Is Fish* (Lionni, 1970) and attempts to teach children that the earth is round (Vosniadou and Brewer, 1989) show why simply providing lectures frequently does not work. Nevertheless, there are times, usually after people have first grappled with issues on their own, that “teaching by telling” can work extremely well (e.g., Schwartz and Bransford, 1998). However, teachers still need to pay attention to students' interpretations and provide guidance when necessary.

There is a good deal of evidence that learning is enhanced when teachers pay attention to the knowledge and beliefs that learners bring to a learning task, use this knowledge as a starting point for new instruction, and monitor students' changing conceptions as instruction proceeds. For example, sixth graders in a suburban school who were given inquiry-based physics instruction were shown to do better on conceptual physics problems than eleventh and twelfth grade physics students taught by conventional methods in the same school system. A second study comparing seventh-ninth grade urban students with the eleventh and twelfth grade suburban physics students again showed that the younger students, taught by the

inquiry-based approach, had a better grasp of the fundamental principles of physics (White and Frederickson, 1997, 1998). New curricula for young children have also demonstrated results that are extremely promising: for example, a new approach to teaching geometry helped second-grade children learn to represent and visualize three-dimensional forms in ways that exceeded the skills of a comparison group of undergraduate students at a leading university (Lehrer and Chazan, 1998). Similarly, young children have been taught to demonstrate powerful forms of early geometry generalizations (Lehrer and Chazan, 1998) and generalizations about science (Schauble et al., 1995; Warren and Rosebery, 1996).

### Active Learning

New developments in the science of learning also emphasize the importance of helping people take control of their own learning. Since understanding is viewed as important, people must learn to recognize when they understand and when they need more information. What strategies might they use to assess whether they understand someone else's meaning? What kinds of evidence do they need in order to believe particular claims? How can they build their own theories of phenomena and test them effectively?

Many important activities that support active learning have been studied under the heading of "metacognition," a topic discussed in more detail in Chapters 2 and 3. Metacognition refers to people's abilities to predict their performances on various tasks (e.g., how well they will be able to remember various stimuli) and to monitor their current levels of mastery and understanding (e.g., Brown, 1975; Flavell, 1973). Teaching practices congruent with a metacognitive approach to learning include those that focus on sense-making, self-assessment, and reflection on what worked and what needs improving. These practices have been shown to increase the degree to which students transfer their learning to new settings and events (e.g., Palincsar and Brown, 1984; Scardamalia et al., 1984; Schoenfeld, 1983, 1985, 1991).

Imagine three teachers whose practices affect whether students learn to take control of their own learning (Scardamalia and Bereiter, 1991). Teacher A's goal is to get the students to produce work; this is accomplished by supervising and overseeing the quantity and quality of the work done by the students. The focus is on activities, which could be anything from old-style workbook activities to the trendiest of space-age projects. Teacher B assumes responsibility for what the students are learning as they carry out their activities. Teacher C does this as well, but with the added objective of continually turning more of the learning process over to the students. Walking into a classroom, you cannot immediately tell these three kinds of teachers apart. One of the things you might see is the students working in groups to produce videos or multimedia presentations. The teacher is likely to be

found going from group to group, checking how things are going and responding to requests. Over the course of a few days, however, differences between Teacher A and Teacher B would become evident. Teacher A's focus is entirely on the production process and its products—whether the students are engaged, whether everyone is getting fair treatment, and whether they are turning out good pieces of work. Teacher B attends to all of this as well, but Teacher B is also attending to what the students are learning from the experience and is taking steps to ensure that the students are processing content and not just dealing with show. To see a difference between Teachers B and C, however, you might need to go back into the history of the media production project. What brought it about in the first place? Was it conceived from the start as a learning activity, or did it emerge from the students' own knowledge building efforts? In one striking example of a Teacher C classroom, the students had been studying cockroaches and had learned so much from their reading and observation that they wanted to share it with the rest of the school; the production of a video came about to achieve that purpose (Lamon et al., 1997).

The differences in what might seem to be the same learning activity are thus quite profound. In Teacher A's classroom, the students are learning something of media production, but the media production may very well be getting in the way of learning anything else. In Teacher B's classroom, the teacher is working to ensure that the original educational purposes of the activity are met, that it does not deteriorate into a mere media production exercise. In Teacher C's classroom, the media production is continuous with and a direct outgrowth of the learning that is embodied in the media production. The greater part of Teacher C's work has been done before the idea of a media production even comes up, and it remains only to help the students keep sight of their purposes as they carry out the project.

These hypothetical teachers—A, B, and C—are abstract models that of course fit real teachers only partly, and more on some days than others. Nevertheless, they provide important glimpses of connections between goals for learning and teaching practices that can affect students' abilities to accomplish these goals.

### **Implications for Education**

Overall, the new science of learning is beginning to provide knowledge to improve significantly people's abilities to become active learners who seek to understand complex subject matter and are better prepared to transfer what they have learned to new problems and settings. Making this happen is a major challenge (e.g., Elmore et al., 1996), but it is not impossible. The emerging science of learning underscores the importance of rethinking what is taught, how it is taught, and how learning is assessed. These ideas are developed throughout this volume.

## **An Evolving Science**

This volume synthesizes the scientific basis of learning. The scientific achievements include a fuller understanding of: (1) memory and the structure of knowledge; (2) problem solving and reasoning; (3) the early foundations of learning; (4) regulatory processes that govern learning, including metacognition; and (5) how symbolic thinking emerges from the culture and community of the learner.

These key characteristics of learned proficiency by no means plumb the depths of human cognition and learning. What has been learned about the principles that guide some aspects of learning do not constitute a complete picture of the principles that govern all domains of learning. The scientific bases, while not superficial in themselves, do represent only a surface level of a complete understanding of the subject. Only a few domains of learning have been examined in depth, as reflected in this book, and new, emergent areas, such as interactive technologies (Greenfield and Cocking, 1996) are challenging generalizations from older research studies.

As scientists continue to study learning, new research procedures and methodologies are emerging that are likely to alter current theoretical conceptions of learning, such as computational modeling research. The scientific work encompasses a broad range of cognitive and neuroscience issues in learning, memory, language, and cognitive development. Studies of parallel distributed processing, for example (McClelland et al., 1995; Plaut et al., 1996; Munakata et al., 1997; McClelland and Chappell, 1998) look at learning as occurring through the adaptation of connections among participating neurons. The research is designed to develop explicit computational models to refine and extend basic principles, as well as to apply the models to substantive research questions through behavioral experiments, computer simulations, functional brain imaging, and mathematical analyses. These studies are thus contributing to modification of both theory and practice. New models also encompass learning in adulthood to add an important dimension to the scientific knowledge base.

## **Key Findings**

This volume provides a broad overview of research on learners and learning and on teachers and teaching. Three findings are highlighted here because they have both a solid research base to support them and strong implications for how we teach.

**1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are**

**taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.**

Research on early learning suggests that the process of making sense of the world begins at a very young age. Children begin in preschool years to develop sophisticated understandings (whether accurate or not) of the phenomena around them (Wellman, 1990). Those initial understandings can have a powerful effect on the integration of new concepts and information. Sometimes those understandings are accurate, providing a foundation for building new knowledge. But sometimes they are inaccurate (Carey and Gelman, 1991). In science, students often have misconceptions of physical properties that cannot be easily observed. In humanities, their preconceptions often include stereotypes or simplifications, as when history is understood as a struggle between good guys and bad guys (Gardner, 1991). A critical feature of effective teaching is that it elicits from students their pre-existing understanding of the subject matter to be taught and provides opportunities to build on—or challenge—the initial understanding. James Minstrell, a high school physics teacher, describes the process as follows (Minstrell, 1989: 130-131):

Students' initial ideas about mechanics are like strands of yarn, some unconnected, some loosely interwoven. The act of instruction can be viewed as helping the students unravel individual strands of belief, label them, and then weave them into a fabric of more complete understanding. Rather than denying the relevancy of a belief, teachers might do better by helping students differentiate their present ideas from and integrate them into conceptual beliefs more like those of scientists.

The understandings that children bring to the classroom can already be quite powerful in the early grades. For example, some children have been found to hold onto their preconception of a flat earth by imagining a round earth to be shaped like a pancake (Vosniadou and Brewer, 1989). This construction of a new understanding is guided by a model of the earth that helps the child explain how people can stand or walk on its surface. Many young children have trouble giving up the notion that one-eighth is greater than one-fourth, because 8 is more than 4 (Gelman and Gallistel, 1978). If children were blank slates, telling them that the earth is round or that one-fourth is greater than one-eighth would be adequate. But since they already have ideas about the earth and about numbers, those ideas must be directly addressed in order to transform or expand them.

Drawing out and working with existing understandings is important for learners of all ages. Numerous research experiments demonstrate the persistence of preexisting understandings among older students even after a

new model has been taught that contradicts the naïve understanding. For example, in a study of physics students from elite, technologically oriented colleges, Andrea DiSessa (1982) instructed them to play a computerized game that required them to direct a computer-simulated object called a dynaturtle so that it would hit a target and do so with minimum speed at impact. Participants were introduced to the game and given a hands-on trial that allowed them to apply a few taps with a small wooden mallet to a tennis ball on a table before beginning the game. The same game was also played by elementary schoolchildren. DiSessa found that both groups of students failed dismally. Success would have required demonstrating an understanding of Newton's laws of motion. Despite their training, college physics students, like the elementary schoolchildren, aimed the moving dynaturtle directly at the target, failing to take momentum into account. Further investigation of one college student who participated in the study revealed that she knew the relevant physical properties and formulas, yet, in the context of the game, she fell back on her untrained conception of how the physical world works.

Students at a variety of ages persist in their beliefs that seasons are caused by the earth's distance from the sun rather than by the tilt of the earth (Harvard-Smithsonian Center for Astrophysics, 1987), or that an object that had been tossed in the air has both the force of gravity and the force of the hand that tossed it acting on it, despite training to the contrary (Clement, 1982). For the scientific understanding to replace the naïve understanding, students must reveal the latter and have the opportunity to see where it falls short.

**2. To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.**

This principle emerges from research that compares the performance of experts and novices and from research on learning and transfer. Experts, regardless of the field, always draw on a richly structured information base; they are not just "good thinkers" or "smart people." The ability to plan a task, to notice patterns, to generate reasonable arguments and explanations, and to draw analogies to other problems are all more closely intertwined with factual knowledge than was once believed.

But knowledge of a large set of disconnected facts is not sufficient. To develop competence in an area of inquiry, students must have opportunities to learn with understanding. Deep understanding of subject matter transforms factual information into usable knowledge. A pronounced difference between experts and novices is that experts' command of concepts shapes

their understanding of new information: it allows them to see patterns, relationships, or discrepancies that are not apparent to novices. They do not necessarily have better overall memories than other people. But their conceptual understanding allows them to extract a level of meaning from information that is not apparent to novices, and this helps them select and remember relevant information. Experts are also able to fluently access relevant knowledge because their understanding of subject matter allows them to quickly identify what is relevant. Hence, their attention is not over-taxed by complex events.

In most areas of study in K-12 education, students will begin as novices; they will have informal ideas about the subject of study, and will vary in the amount of information they have acquired. The enterprise of education can be viewed as moving students in the direction of more formal understanding (or greater expertise). This will require both a deepening of the information base and the development of a conceptual framework for that subject matter.

Geography can be used to illustrate the manner in which expertise is organized around principles that support understanding. A student can learn to fill in a map by memorizing states, cities, countries, etc., and can complete the task with a high level of accuracy. But if the boundaries are removed, the problem becomes much more difficult. There are no concepts supporting the student's information. An expert who understands that borders often developed because natural phenomena (like mountains or water bodies) separated people, and that large cities often arose in locations that allowed for trade (along rivers, large lakes, and at coastal ports) will easily outperform the novice. The more developed the conceptual understanding of the needs of cities and the resource base that drew people to them, the more meaningful the map becomes. Students can become more expert if the geographical information they are taught is placed in the appropriate conceptual framework.

A key finding in the learning and transfer literature is that organizing information into a conceptual framework allows for greater "transfer"; that is, it allows the student to apply what was learned in new situations and to learn related information more quickly (see Box 1.3). The student who has learned geographical information for the Americas in a conceptual framework approaches the task of learning the geography of another part of the globe with questions, ideas, and expectations that help guide acquisition of the new information. Understanding the geographical importance of the Mississippi River sets the stage for the student's understanding of the geographical importance of the Nile. And as concepts are reinforced, the student will transfer learning beyond the classroom, observing and inquiring, for example, about the geographic features of a visited city that help explain its location and size (Holyoak, 1984; Novick and Holyoak, 1991).

**3. A “metacognitive” approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.**

In research with experts who were asked to verbalize their thinking as they worked, it was revealed that they monitored their own understanding carefully, making note of when additional information was required for understanding, whether new information was consistent with what they already knew, and what analogies could be drawn that would advance their understanding. These meta-cognitive monitoring activities are an important component of what is called adaptive expertise (Hatano and Inagaki, 1986).

Because metacognition often takes the form of an internal conversation, it can easily be assumed that individuals will develop the internal dialogue on their own. Yet many of the strategies we use for thinking reflect cultural norms and methods of inquiry (Hutchins, 1995; Brice-Heath, 1981, 1983; Suina and Smolkin, 1994). Research has demonstrated that children can be taught these strategies, including the ability to predict outcomes, explain to oneself in order to improve understanding, note failures to comprehend, activate background knowledge, plan ahead, and apportion time and memory. Reciprocal teaching, for example, is a technique designed to improve students’ reading comprehension by helping them explicate, elaborate, and monitor their understanding as they read (Palincsar and Brown, 1984). The model for using the meta-cognitive strategies is provided initially by the

**BOX 1.3 Throwing Darts Under Water**

In one of the most famous early studies comparing the effects of learning a procedure with learning with understanding, two groups of children practiced throwing darts at a target under water (described in Judd, 1908; see a conceptual replication by Hendrickson and Schroeder, 1941). One group received an explanation of the refraction of light, which causes the apparent location of the target to be deceptive. The other group only practiced dart throwing, without the explanation. Both groups did equally well on the practice task, which involved a target 12 inches under water. But the group that had been instructed about the abstract principle did much better when they had to transfer to a situation in which the target was under only 4 inches of water. Because they understood what they were doing, the group that had received instruction about the refraction of light could adjust their behavior to the new task.

teacher, and students practice and discuss the strategies as they learn to use them. Ultimately, students are able to prompt themselves and monitor their own comprehension without teacher support.

The teaching of metacognitive activities must be incorporated into the subject matter that students are learning (White and Frederickson, 1998). These strategies are not generic across subjects, and attempts to teach them as generic can lead to failure to transfer. Teaching metacognitive strategies in context has been shown to improve understanding in physics (White and Frederickson, 1998), written composition (Scardamalia et al., 1984), and heuristic methods for mathematical problem solving (Schoenfeld, 1983, 1984, 1991). And metacognitive practices have been shown to increase the degree to which students transfer to new settings and events (Lin and Lehman, in press; Palincsar and Brown, 1984; Scardamalia et al., 1984; Schoenfeld, 1983, 1984, 1991).

Each of these techniques shares a strategy of teaching and modeling the process of generating alternative approaches (to developing an idea in writing or a strategy for problem solving in mathematics), evaluating their merits in helping to attain a goal, and monitoring progress toward that goal. Class discussions are used to support skill development, with a goal of independence and self-regulation.

### Implications for Teaching

The three core learning principles described above, simple though they seem, have profound implications for the enterprise of teaching and teacher preparation.

**1. Teachers must draw out and work with the preexisting understandings that their students bring with them.** This requires that:

- The model of the child as an empty vessel to be filled with knowledge provided by the teacher must be replaced. Instead, the teacher must actively inquire into students' thinking, creating classroom tasks and conditions under which student thinking can be revealed. Students' initial conceptions then provide the foundation on which the more formal understanding of the subject matter is built.
- The roles for assessment must be expanded beyond the traditional concept of testing. The use of frequent formative assessment helps make students' thinking visible to themselves, their peers, and their teacher. This provides feedback that can guide modification and refinement in thinking. Given the goal of learning with understanding, assessments must tap understanding rather than merely the ability to repeat facts or perform isolated skills.

- Schools of education must provide beginning teachers with opportunities to learn: (a) to recognize predictable preconceptions of students that make the mastery of particular subject matter challenging, (b) to draw out preconceptions that are not predictable, and (c) to work with preconceptions so that children build on them, challenge them and, when appropriate, replace them.

**2. Teachers must teach some subject matter in depth, providing many examples in which the same concept is at work and providing a firm foundation of factual knowledge.** This requires that:

- Superficial coverage of all topics in a subject area must be replaced with in-depth coverage of fewer topics that allows key concepts in that discipline to be understood. The goal of coverage need not be abandoned entirely, of course. But there must be a sufficient number of cases of in-depth study to allow students to grasp the defining concepts in specific domains within a discipline. Moreover, in-depth study in a domain often requires that ideas be carried beyond a single school year before students can make the transition from informal to formal ideas. This will require active coordination of the curriculum across school years.

- Teachers must come to teaching with the experience of in-depth study of the subject area themselves. Before a teacher can develop powerful pedagogical tools, he or she must be familiar with the progress of inquiry and the terms of discourse in the discipline, as well as understand the relationship between information and the concepts that help organize that information in the discipline. But equally important, the teacher must have a grasp of the growth and development of students' thinking about these concepts. The latter will be essential to developing teaching expertise, but not expertise in the discipline. It may therefore require courses, or course supplements, that are designed specifically for teachers.

- Assessment for purposes of accountability (e.g., statewide assessments) must test deep understanding rather than surface knowledge. Assessment tools are often the standard by which teachers are held accountable. A teacher is put in a bind if she or he is asked to teach for deep conceptual understanding, but in doing so produces students who perform more poorly on standardized tests. Unless new assessment tools are aligned with new approaches to teaching, the latter are unlikely to muster support among the schools and their constituent parents. This goal is as important as it is difficult to achieve. The format of standardized tests can encourage measurement of factual knowledge rather than conceptual understanding, but it also facilitates objective scoring. Measuring depth of understanding can pose challenges for objectivity. Much work needs to be done to minimize the trade-off between assessing depth and assessing objectively.

**3. *The teaching of metacognitive skills should be integrated into the curriculum in a variety of subject areas.*** Because metacognition often takes the form of an internal dialogue, many students may be unaware of its importance unless the processes are explicitly emphasized by teachers. An emphasis on metacognition needs to accompany instruction in each of the disciplines, because the type of monitoring required will vary. In history, for example, the student might be asking himself, "who wrote this document, and how does that affect the interpretation of events," whereas in physics the student might be monitoring her understanding of the underlying physical principle at work.

- Integration of metacognitive instruction with discipline-based learning can enhance student achievement and develop in students the ability to learn independently. It should be consciously incorporated into curricula across disciplines and age levels.
- Developing strong metacognitive strategies and learning to teach those strategies in a classroom environment should be standard features of the curriculum in schools of education.

Evidence from research indicates that when these three principles are incorporated into teaching, student achievement improves. For example, the Thinker Tools Curriculum for teaching physics in an interactive computer environment focuses on fundamental physical concepts and properties, allowing students to test their preconceptions in model building and experimentation activities. The program includes an "inquiry cycle" that helps students monitor where they are in the inquiry process. The program asks for students' reflective assessments and allows them to review the assessments of their fellow students. In one study, sixth graders in a suburban school who were taught physics using Thinker Tools performed better at solving conceptual physics problems than did eleventh and twelfth grade physics students in the same school system taught by conventional methods. A second study comparing urban students in grades 7 to 9 with suburban students in grades 11 and 12 again showed that the younger students taught by the inquiry-based approach had a superior grasp of the fundamental principles of physics (White and Frederickson, 1997, 1998).

### **Bringing Order to Chaos**

A benefit of focusing on how people learn is that it helps bring order to a seeming cacophony of choices. Consider the many possible teaching strategies that are debated in education circles and the media. Figure 1.1 depicts them in diagram format: lecture-based teaching, text-based teaching, inquiry-based teaching, technology-enhanced teaching, teaching organized

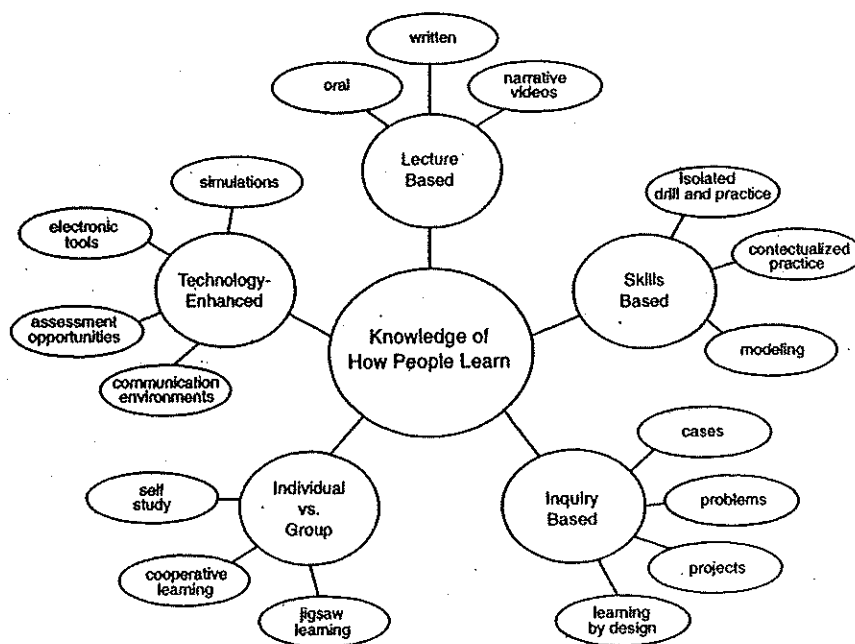


**FIGURE 1.1** With knowledge of how people learn, teachers can choose more purposefully among techniques to accomplish specific goals.

around individuals versus cooperative groups, and so forth. Are some of these teaching techniques better than others? Is lecturing a poor way to teach, as many seem to claim? Is cooperative learning effective? Do attempts to use computers (technology-enhanced teaching) help achievement or hurt it?

This volume suggests that these are the wrong questions. Asking which teaching technique is best is analogous to asking which tool is best—a hammer, a screwdriver, a knife, or pliers. In teaching as in carpentry, the selection of tools depends on the task at hand and the materials one is working with. Books and lectures *can* be wonderfully efficient modes of transmitting new information for learning, exciting the imagination, and honing students' critical faculties—but one would choose other kinds of activities to elicit from students their preconceptions and level of understanding, or to help them see the power of using meta-cognitive strategies to monitor their learning. Hands-on experiments *can* be a powerful way to ground emergent knowledge, but they do not alone evoke the underlying conceptual understandings that aid generalization. There is no universal best teaching practice.

If, instead, the point of departure is a core set of learning principles, then the selection of teaching strategies (mediated, of course, by subject matter, grade level, and desired outcome) can be purposeful. The many possibilities then become a rich set of opportunities from which a teacher constructs an instructional program rather than a chaos of competing alternatives.

Focusing on how people learn also will help teachers move beyond either-or dichotomies that have plagued the field of education. One such issue is whether schools should emphasize “the basics” or teach thinking and problem-solving skills. This volume shows that both are necessary. Students’ abilities to acquire organized sets of facts and skills are actually enhanced when they are connected to meaningful problem-solving activities, and when students are helped to understand why, when, and how those facts and skills are relevant. And attempts to teach thinking skills without a strong base of factual knowledge do not promote problem-solving ability or support transfer to new situations.

## Designing Classroom Environments

Chapter 6 of this volume proposes a framework to help guide the design and evaluation of environments that can optimize learning. Drawing heavily on the three principles discussed above, it posits four interrelated attributes of learning environments that need cultivation.

**1. *Schools and classrooms must be learner centered.*** Teachers must pay close attention to the knowledge, skills, and attitudes that learners bring into the classroom. This incorporates the preconceptions regarding subject matter already discussed, but it also includes a broader understanding of the learner. For example:

- Cultural differences can affect students’ comfort level in working collaboratively versus individually, and they are reflected in the background knowledge students bring to a new learning situation (Moll et al., 1993).
- Students’ theories of what it means to be intelligent can affect their performance. Research shows that students who think that intelligence is a fixed entity are more likely to be performance oriented than learning oriented—they want to look good rather than risk making mistakes while learning. These students are especially likely to bail out when tasks become difficult. In contrast, students who think that intelligence is malleable are more willing to struggle with challenging tasks; they are more comfortable with risk (Dweck, 1989; Dweck and Legget, 1988).

Teachers in learner-centered classrooms also pay close attention to the individual progress of each student and devise tasks that are appropriate.

Learner-centered teachers present students with “just manageable difficulties”—that is, challenging enough to maintain engagement, but not so difficult as to lead to discouragement. They must therefore have an understanding of their students’ knowledge, skill levels, and interests (Duckworth, 1987).

**2. To provide a knowledge-centered classroom environment, attention must be given to what is taught (information, subject matter), why it is taught (understanding), and what competence or mastery looks like.** As mentioned above, research discussed in the following chapters shows clearly that expertise involves well-organized knowledge that supports understanding, and that learning with understanding is important for the development of expertise because it makes new learning easier (i.e., supports transfer).

Learning with understanding is often harder to accomplish than simply memorizing, and it takes more time. Many curricula fail to support learning with understanding because they present too many disconnected facts in too short a time—the “mile wide, inch deep” problem. Tests often reinforce memorizing rather than understanding. The knowledge-centered environment provides the necessary depth of study, assessing student understanding rather than factual memory. It incorporates the teaching of meta-cognitive strategies that further facilitate future learning.

Knowledge-centered environments also look beyond engagement as the primary index of successful teaching (Prawaf et al., 1992). Students’ interest or engagement in a task is clearly important. Nevertheless, it does not guarantee that students will acquire the kinds of knowledge that will support new learning. There are important differences between tasks and projects that encourage hands-on doing and those that encourage doing with understanding; the knowledge-centered environment emphasizes the latter (Greeno, 1991).

**3. Formative assessments—ongoing assessments designed to make students’ thinking visible to both teachers and students—are essential. They permit the teacher to grasp the students’ preconceptions, understand where the students are in the “developmental corridor” from informal to formal thinking, and design instruction accordingly. In the assessment-centered classroom environment, formative assessments help both teachers and students monitor progress.**

An important feature of assessments in these classrooms is that they be learner-friendly: they are not the Friday quiz for which information is memorized the night before, and for which the student is given a grade that ranks him or her with respect to classmates. Rather, these assessments should

provide students with opportunities to revise and improve their thinking (Vye et al., 1998b), help students see their own progress over the course of weeks or months, and help teachers identify problems that need to be remedied (problems that may not be visible without the assessments). For example, a high school class studying the principles of democracy might be given a scenario in which a colony of people have just settled on the moon and must establish a government. Proposals from students of the defining features of such a government, as well as discussion of the problems they foresee in its establishment, can reveal to both teachers and students areas in which student thinking is more and less advanced. The exercise is less a test than an indicator of where inquiry and instruction should focus.

***4. Learning is influenced in fundamental ways by the context in which it takes place. A community-centered approach requires the development of norms for the classroom and school, as well as connections to the outside world, that support core learning values.***

The norms established in the classroom have strong effects on students' achievement. In some schools, the norms could be expressed as "don't get caught not knowing something." Others encourage academic risk-taking and opportunities to make mistakes, obtain feedback, and revise. Clearly, if students are to reveal their preconceptions about a subject matter, their questions, and their progress toward understanding, the norms of the school must support their doing so.

Teachers must attend to designing classroom activities and helping students organize their work in ways that promote the kind of intellectual camaraderie and the attitudes toward learning that build a sense of community. In such a community, students might help one another solve problems by building on each other's knowledge, asking questions to clarify explanations, and suggesting avenues that would move the group toward its goal (Brown and Campione, 1994). Both cooperation in problem solving (Evans, 1989; Newstead and Evans, 1995) and argumentation (Goldman, 1994; Habermas, 1990; Kuhn, 1991; Moshman, 1995a, 1995b; Salmon and Zeitz, 1995; Youniss and Damon, 1992) among students in such an intellectual community enhance cognitive development.

Teachers must be enabled and encouraged to establish a community of learners among themselves (Lave and Wegner, 1991). These communities can build a sense of comfort with questioning rather than knowing the answer and can develop a model of creating new ideas that build on the contributions of individual members. They can engender a sense of the excitement of learning that is then transferred to the classroom, conferring a sense of ownership of new ideas as they apply to theory and practice.

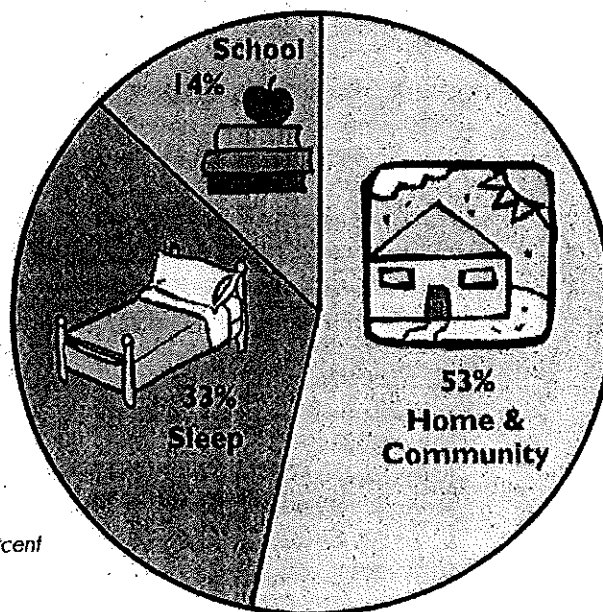


**FIGURE 1.2** Students spend only 14 percent of their time in school.

Not least, schools need to develop ways to link classroom learning to other aspects of students' lives. Engendering parent support for the core learning principles and parent involvement in the learning process is of utmost importance (Moll, 1990; 1986a, 1986b). Figure 1.2 shows the percentage of time, during a calendar year, that students in a large school district spent in school. If one-third of their time outside school (not counting sleeping) is spent watching television, then students apparently spend more hours per year watching television than attending school. A focus only on the hours that students currently spend in school overlooks the many opportunities for guided learning in other settings.

### **Applying the Design Framework to Adult Learning**

The design framework summarized above assumes that the learners are children, but the principles apply to adult learning as well. This point is particularly important because incorporating the principles in this volume into educational practice will require a good deal of adult learning. Many approaches to teaching adults consistently violate principles for optimizing

learning. Professional development programs for teachers, for example, frequently:

- *Are not learner centered.* Rather than ask teachers where they need help, they are simply expected to attend prearranged workshops.
- *Are not knowledge centered.* Teachers may simply be introduced to a new technique (like cooperative learning) without being given the opportunity to understand why, when, where, and how it might be valuable to them. Especially important is the need to integrate the structure of activities with the content of the curriculum that is taught.
- *Are not assessment centered.* In order for teachers to change their practices, they need opportunities to try things out in their classrooms and then receive feedback. Most professional development opportunities do not provide such feedback. Moreover, they tend to focus on change in teaching practice as the goal, but they neglect to develop in teachers the capacity to judge successful transfer of the technique to the classroom or its effects on student achievement.
- *Are not community centered.* Many professional development opportunities are conducted in isolation. Opportunities for continued contact and support as teachers incorporate new ideas into their teaching are limited, yet the rapid spread of Internet access provides a ready means of maintaining such contact if appropriately designed tools and services are available.

The principles of learning and their implications for designing learning environments apply equally to child and adult learning. They provide a lens through which current practice can be viewed with respect to K-12 teaching *and* with respect to preparation of teachers in the research and development agenda. The principles are relevant as well when we consider other groups, such as policy makers and the public, whose learning is also required for educational practice to change.

How People Learn: Brain, Mind, Experience, and School: Expanded Edition  
<http://www.nap.edu/catalog/9853.html>





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This review has been accessed **25** times since July 14, 2007

Donovan, M. Suzanne & Bransford, John D. (Eds.) (2005) *How Students Learn: History, Mathematics and Science in the Classroom*. Washington, D.C.: The National Academies Press.

Pp. 615 ISBN 0-309-08948-4 (papercover) ISBN 0-309-07433-9 (hardcover)

Reviewed by Ellen Burkhouse  
Marywood University

July 14, 2007

This volume is a thoughtful, practical exploration of how current research in learning theory might translate into real classroom applications.

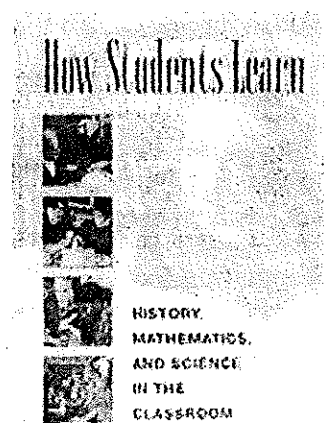
The Preface of the book provides a concise tracing of the roots of this effort beginning with the report of the Committee on Developments in the Science of Learning in 1999, through the follow-up study examining how this material could best be communicated to practitioners and policy makers, and culminating in the synthesizing volume, *How People Learn* (National Research Council, 2000)

The authors define the purpose of the present work in the following terms:

In the present book, the goal is to take the *HPL* work to the next step: to provide examples of how the principles and findings on learning can be used to guide the teaching of a set of topics that commonly appear in the K-12 curriculum. As was the case in the original work (1999), the book focuses on three subject areas: history, mathematics, and science. Each area is treated at three levels: elementary, middle, and high school.

The editors make clear that the examples provided are only that – examples. They represent the *types* of approaches, activities and sequences most likely to bring the theory to life. Providing specific, concrete illustrations of actual lessons allows the reader to envision opportunities to develop similar lesson designs for other real-world classrooms.

The guiding principles for the ensuing lessons are articulated in the Introduction. They are stated, explained and illustrated with remarkable clarity and make compelling reading for anyone involved in teaching at any level. These principles are ones highlighted in the previously mentioned, *How People Learn* (1999). They are vital for the understanding of the lessons presented. The



principles, as stated on p 1, are:

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.
2. To develop competence in an area of inquiry, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.
3. A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

In addition to the principles themselves, four implications drawn from the research base examined in *How People Learn* are reported and discussed as background for the lessons. These "lenses",



**M. Suzanne Donovan**

which can help us assess the effectiveness of the teaching/learning experience, follow: *Learner-centered classrooms* begin with what students know, think, believe, and have experienced; no assumptions can be made here and teachers must learn to truly *listen* to their students in the fullest sense of the word and to challenge them in a manner informed by the knowledge thus gained. *Knowledge-centered classrooms* focus on the nature of what is taught – what are the organizing concepts, the essential skills? how will we know when they have been mastered? how can material be presented in a context allowing the student to perceive connections and meaning? *Assessment-centered classrooms* allow teachers and learners to monitor progress in an ongoing fashion and to reexamine and revise thinking; the student's development of his or her own ability to assess progress and to develop alternate strategies when needed is

highly valued. *Community-centered classrooms* create an atmosphere in which missteps and errors are seen as a natural and an often fruitful part of learning, where mental risk taking is the norm, and where the teacher moves gradually from modeling to supporting and encouraging student initiatives.

After setting the stage with the review of the principles developed in *HPL*, the balance of this volume is devoted to the aforementioned examples of actual lessons. The editors explain their purpose in these words:

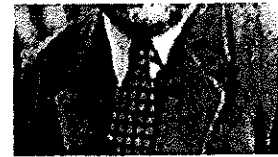
The goal is to provide for teachers what we have argued above is critical to effective learning – the application of concepts (about learning) in enough different, concrete contexts to give them deeper meaning. (p. 21)

The lessons were contributed by a variety of researchers who had extensive teaching experience of their own or who partnered with experienced teachers. Each deals with teaching a specific topic commonly encountered at the grade level used for the sample lesson. Due to the different authors, style varies greatly. However, the common theme is the illumination of the principles being exemplified.

The first section, making up Chapters 2 through 4, deals with history. Chapter 2 discusses the principles as they apply to the discipline of history. The complex nature of the study of this subject is thoroughly explored. One of the principles of *HPL* states that students need both factual knowledge and an understanding of the underlying structure, which gives coherence to those facts. History provides a challenge here, since the "facts" to be dealt with cannot be tested against a fixed,



present reality. It investigates the tracks of the past and such trails can be accidentally or deliberately misleading, and can be subject to various human interpretations. The author asserts that students should, and can, learn to question and assess the evidence used to create history. Certain concepts give order and discipline to history. Among them are *time*, *evidence*, *change*, *progress*, and *cause*. If students are to truly learn history as opposed to memorizing a list of data fragments with little understanding of their meaning, validity or connectedness, then teachers must develop strategies to scaffold students as they examine information in light of these underlying concepts. Knowledge thus mastered must be organized in such a way that it itself becomes part of the scaffold supporting the understanding of new material.



**John D. Bransford**

To this end, Chapter 3 tackles the question of whether or not this approach can be undertaken in an actual classroom, with real students, and topics determined by standards and curriculum designers. *The Pilgrim Fathers and Native Americans* is set in a sixth grade and *The Saint Brendan Voyage Task* was designed with fourth grade students in mind. The reader is able to see some of the materials used in the class and to "listen" to some of the conversations between students and teachers. These vignettes are enhanced by explanations of background details and reflections on the events as they relate to the core concepts of history and the principles of *How People Learn*. This same pattern of lesson study interspersed with analysis is employed in Chapter 4 which presents a lesson for grade 9 on "*They Thought the World Was Flat?*" This chapter also includes clear, pertinent sections entitled, *Where to Begin? Transforming Topics and Objectives into Historical Problems* and *Designing a "History-Considerate" Learning Environment: Tools for Historical Thinking*.

As the reader progresses through this book, the underlying principles become almost second nature because they are explained in varied ways and are illustrated by so many different examples. Some of the contributors chose to give explicit lesson descriptions including materials and dialogues, while others present a more essay-like approach, examining topics and issues within a discipline and how these can be enhanced by implementation of HPL principles. Even in the latter instances, examples are plentiful and meaningful. Thus, the material becomes increasingly accessible despite its weighty nature. This certainly is not a "quick read", but it has great internal consistency. For this reason, I have chosen to describe the nature of the material in the first section in some detail and let that serve as something of a template for the remaining two sections.

The second section of the book deals with mathematics and encompasses Chapters 5 through 8. Chapter 5 provides the introduction, analyzing the three principles of HPL as they apply to math in general. Common preconceptions in math are examined, as are the types of approaches that can help teachers to recognize these and to create a classroom structure that lends itself to a positive environment. The interdependence between procedural skill and conceptual understanding is addressed, as is the issue of helping students to make their thinking visible so it can be continuously revisited and assessed as learning evolves.

Chapter 6 deals with the topic, *Fostering Development of Whole-Number Sense: Teaching Mathematics in the Primary Grades*. This broad issue is followed by sections clearly titled: *Deciding What Knowledge to Teach*, *Building on Children's Current Understandings*, *Acknowledging Teachers' Concepts and Partial Understandings*, *Revisiting Question 2: Defining the Knowledge That Should Be Taught*, *How Can This Knowledge Be Taught?: The Case of Number Worlds*, and *What Sorts of Learning Does This Approach Make Possible?* The salient issues of developing number sense in young children are addressed thoroughly and with great insight. The primary source for this chapter's examples is the *Number Worlds* program, a commercial program authored by this chapter's author. This question of possible conflict at first gave me pause but, in this reviewer's opinion, deeper examination of the examples and connections offered make it evident that it would be difficult to find a better "fit" between lesson strategies and HPL principles. Chapter 7 moves ahead to fourth, fifth, sixth grade issues and examines how topics commonly encountered at these levels might be approached. The topics

addressed are: *Pipes, Tubes, and Beakers: New Approaches to Teaching the Rational-Number System, Rational-Number Learning and the Principles of How People Learn, Instruction in Rational Number, and Conclusion: How Students Learn Rational Number*. Chapter 8 is titled *Teaching and Learning Functions* and brings the reader to the high school level. The following issues are included: *Addressing the Three Principles, and Teaching Functions for Understanding*.

The third section of the book addresses science. The first chapter in this part is Chapter 9, which follows the example of the previous sections with an introduction, *Scientific Inquiry and How People Learn*. Each of the HPL principles is revisited in light of the nature of this discipline and, again, the discussion is clear and the examples meaningful. Chapter 10 is titled, *Teaching to Promote the Development of Scientific Knowledge and Reasoning About Light at the Elementary School Level*, with sections entitled: *The Study of Light, The Study of Light Through Inquiry, and, Supporting Learning Through Cycles of Investigation, the Role of Subject-Specific Knowledge in Effective Science Instruction*. This chapter returns to a more detailed examination of actual lessons employed in a classroom and includes sample materials and discussions with accompanying reflection. Chapter 11 is *Guided Inquiry in the Science Classroom* and uses a unit on gravity in a middle school classroom to demonstrate the HPL approach, followed by Chapter 12, which does the same in the context of a high school lesson on genetics and evolution.

The book concludes with a revisiting of the principles. Anyone familiar with the thinking of Bruner is not surprised to see his work frequently cited as foundational for many of these ideas. Having been a classroom teacher in the 1960's and 1970's when the principles of Inquiry and Process Learning were the subject of many a teacher development session, the echo of these ideas was felt in a very visceral way as I read this book. I had no difficulty connecting Bruner's emphasis on seeking the organizing ideas within a discipline to Ma's findings that the Chinese teacher's identification of core mathematical principles as the backbone of the mathematics curriculum is key to the significant success of that system. The impact of Vygotsky is also evident in the emphasis on the importance of student dialogue and the need to scaffold emerging abilities to grapple with the underlying concepts of disciplines. The fundamentals of constructivism, with its emphasis on the active role of the learner in building understanding, are infused throughout the volume. My own experiences in trying to design and implement social studies and science lessons exemplifying these approaches convinced me of the validity of the theories. More recent training in the 1980's and 1990's extended the concepts into the math area of my fifth grade classroom. In many ways the evolving NCTM standards and approaches reinforced this commitment. As the value of these principles became more and more evident, I was increasingly eager to try to find ways to understand and employ them more fully with my elementary students and to endorse the effectiveness of the approach with my pre-service university students. The lesson examples in this book would have been very helpful! There has also, of course, been a great deal of additional research in this area resulting in ever greater insight into the learning process and allowing more strategic implementation of key concepts. The present book gathers and unifies this body of research and extends it in a practical way. This volume offers a thoughtful, thorough, persuasive argument that learning can be made more meaningful and valid. By providing concrete examples it meets the challenge to move beyond the realm of theory and into the real world of the classroom. For any teacher who might have been tempted to make the effort but feared that the goal might be too idealistic, this work offers a helping hand and a good measure of inspiration.

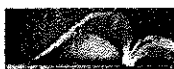
### About the Reviewer

#### Ellen Burkhouse

I am an Assistant Professor in the Education Department at Marywood University in Scranton, PA. Teaching responsibilities have included courses in Educational Psychology as well as Curriculum and Instruction courses in both Social Studies and Mathematics for elementary, early childhood and special education students. Prior to joining the Marywood faculty in my current capacity, I taught fifth grade students in the Scranton School District for over thirty years while serving as adjunct faculty at several area universities. For much of my time in Scranton, I was part of the Educational Research and Dissemination team sponsored by The American Federation of

Teachers. In that capacity, I trained as a peer coach, as a mentor teacher and in a series of three courses dealing with research and application of teaching/learning theories as applied to mathematics instruction.

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**Editors: Gene V Glass, Kate Corby, Gustavo Fischman**

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# Preparing People for Rapidly Changing Environments

JOHN BRANSFORD  
*University of Washington*

The October 2006 issue of the *Journal of Engineering Education* describes a landmark set of activities called the National Engineering Education Research Colloquies (NEERC) that explored how rapid changes in the world require new ways to educate future generations of engineers. The argument is not simply that we need more engineers than we have had in the past; instead we need a *transformation* in how we educate future engineers [1].

Many people in the learning sciences have also been exploring the need for educational transformations, and it seems clear that our different research communities have a great deal to learn from one another. Opportunities I have had to work with the VaNTH Bioengineering Center (VaNTH.org; [2]) convince me of the immense value (to me at least) of collaborations such as these.

Currently, my colleagues and I in the LIFE Center (Learning in Informal and Formal Environments (LIFE-SLC.org)) are finding it useful to juxtapose several research literatures that include: (a) expertise and its development [3–5]; (b) transfer and its implications for assessment [6–7]; (c) change and innovation [8–11]; and (d) design strategies for promoting and managing change [12–14]. The act of juxtaposing these different literatures has generated a number of interesting questions. I discuss five that I hope are useful to raise.

## I. HOW IS OUR WORLD CHANGING?

An answer to this question is not simply that we now face global competition and hence have to work harder to educate more people. My reading of the innovation literature [8–11] suggests that the major factor to address is the increasing rate of change.

Not so many years ago, companies could come up with an innovative idea for a product or service and gradually refine it for 25 years or more. People could develop particular kinds of expertise and be successful for a lifetime. This made it possible for educational institutions (e.g., community colleges, four-year institutions) to teach job-specific skills and knowledge and know that most of this would still be useful in the workplace.

Today, innovation cycles are often very short and educational systems are often insufficiently nimble. As educators, we may end up training students in specifics that are no longer useful once they reach the workplace. Some suggest that preparing people for change requires that we rethink our characterizations of “expertise”.

## II. RETHINKING CHARACTERISTICS OF EXPERTISE

It is often stated that experts are able to solve problems by applying previously learned (e.g., schematized) skills and knowledge in new settings. This is true, in part. If we encounter a problem that seems similar to previously solved problems, we are much more efficient at solving it [4, 15]. Nevertheless, people who function in rapidly changing environments must learn to navigate in situations where they are at the edges of their existing knowledge. Following the seminal work of Hatano and colleagues, a number of researchers are beginning to explore the idea of “adaptive expertise” as a concept worthy of in-depth study [16–24].

Many of the early studies of expertise [4]—while extremely useful—did not focus on the thinking and behaviors of experts when they encountered novel (for them) problems and innovations. The early studies of expertise tended to compare experts with novices, and the experts were often given problems that—because of their previous experiences—were well schematized and hence relatively routine.

Ericsson’s work on world-class experts in chess and other domains [25] provides an illuminating picture of the constant innovation and restructuring needed to be successful at high levels. As they developed their expertise, Ericsson’s experts resisted premature automatization of skills and procedures and continually pushed themselves to new heights. In contrast, others reached a plateau and failed to make further major advances. Ericsson does not refer to his world-class experts as adaptive experts, but I think it is a useful term for describing them; it highlights the process of intentionally seeking new challenges and insights rather than resting on one’s laurels.

The term adaptive expertise also seems useful for characterizing people who are not necessarily world-class in their fields but are still highly adaptive and innovative [26]. The value of exploring different expressions of expertise is illustrated by opportunities to interview leaders in technically-sophisticated workplaces. They have told us that, over time, employees often become so efficient in their jobs that they can do the work required of them in less time than their eight-hour workday. Some reinvest their spare time by pushing themselves to learn more and find ways to improve [19]. Others seem content to use their spare time in ways that are relaxing but less productive for their company. Both groups are experts at their particular jobs—but they seem to behave in different ways.

## III. NEW UNITS OF ANALYSIS?

Should we assume that some of the workers noted above are simply more motivated and adaptive than the others? Many theorists (see [24] for examples) wisely emphasize the need to consider

"people in social-cultural contexts" as the unit of analysis that we as a field need to explore.

The idea is that all of us function within a variety of settings that include social-cultural supports and barriers. These are often invisible but can have major effects. For example, it is possible that a worker who rests on his laurels during extra company time (see above) may exhibit a very different attitude and behavior in different social and organizational settings—especially those that provide strong peer support for contributing to teams.

Similar sets of social constraints affect students. Researchers in the LIFE center find that a student may look only mildly proficient in school (e.g., chemistry class), yet may spring to life in informal settings where there are opportunities to choose one's own tasks that have real consequences for the lives of family and friends (e.g., making perfumes that are tailored for particular people in their lives [27]). In addition, many students innovate in informal settings in order to pursue their chosen activities, yet may not seem innovative in school [28, 29].

Examples such as these suggest the need to study adaptive people and adaptive organizations. The two go hand-in-glove, and social-cultural analyses are important for understanding human action in settings that range from schools to workplaces to after-school [24, 30].

#### IV. HOW CAN WE HELP PEOPLE BECOME MORE ADAPTIVE AND INNOVATIVE?

How can we help people move along trajectories toward adaptive expertise? It will not be sufficient to simply have people memorize statements about different kinds of expertise. Still, knowledge and its organization is important for flexibility, and one fruitful strategy is to explore "mid-level" knowledge organizations (perhaps systems theory and systems design) that can help people tie together their knowledge in ways that support future flexibility.

Students also need to experience processes of inquiry and innovation—including the struggles and doubts. *Then* it can be helpful to make their experiences explicit by putting names to what they went through, and helping them refine their innovations by connecting them to expert knowledge [31–33]. The hard part of being adaptive and innovative is that it often forces us to change ourselves, our environments, or both. These changes can evoke strong emotions and take us away from our momentary efficiencies and comfort zones by forcing us to unlearn old skills, tolerate momentary chaos and ambiguity in order to move forward, and—at least occasionally (and perhaps frequently)—be in positions where we must take risks and be wrong [33].

Different configurations of social and organizational supports and hindrances affect the motivation and risk-taking that often accompanies innovation. Helping students learn to see how their thoughts, emotions and behaviors are influenced by particular kinds of organizational and cultural settings seems to be extremely important. They will then be in a much better position to thoughtfully design effective environments that can help them and their colleagues do their best work [12–14].

#### V. NEW METRICS FOR SUCCESS?

Exploring ways to prepare people for fast-changing environments also suggests the value of expanding our views of metrics for

success. For example, several studies show that typical "one-shot" assessments of peoples' abilities to directly apply previously acquired skills and knowledge is often too blunt an instrument to show signs of being on a trajectory toward adaptive expertise [31–33].

It is also useful to think about new metrics for judging our *teaching successes*. One might be as follows: If students are unable to show at least some examples of innovative ideas and procedures that add to our knowledge as teachers, we may be too constraining in how we teach.

In engineering, many opportunities exist beginning in the early years of the program to assign students projects that help them work—often collaboratively and *ideally with clients* under faculty guidance—to develop innovations that are truly useful (e.g., see Olin College, <http://www.olin.edu/on.asp>). These do not have to be patentable innovations, of course; they merely need to be new for the students involved in the classes [10]. Helping students explicitly articulate the processes and struggles that led to their outcomes should help prepare them to function more effectively in new environments [33].

Another metric for successful course design might involve a greater emphasis on the degree to which we truly prepare students for future learning. As an illustration, O'Mahony and colleagues [34] redesigned workplace courses for engineers to learn about new kinds of materials such as composites. The people in any particular course often came from many different parts of the company and did not know one another. One of the most positive outcomes of course was the chance to form new social networks that they could utilize later in the workplace (e.g., people knew whom to contact for more information). During the course, these networks were established by giving people chances to work collaboratively on job relevant problems to see how their particular sets of skills and knowledge complimented one another.

To make this collaboration happen, new approaches to instruction had to be developed that supplemented the older "lecture only" instruction which—while brilliantly taught—provided almost no opportunities for people to interact and learn from and about one another so that they could use technology to continue to connect later on.

Overall, it seems clear that we could also do more in our classes to prepare students for future learning. For example, we could help them learn to innovate in order to work smarter [33], and we can help them build digital suites of information, tools, and access to networks of expertise (e.g., fellow students with particular sets of skills) that they can draw upon and add to as they go through school, and then use after they graduate.

#### SUMMARY

The work of the NEERC is exemplary and this journal is doing an outstanding job of building a new, collaborative learning community. As a learning scientist, it is exciting to have the opportunity to interact with this community and work on issues that can help us all succeed.

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## **Design Methods for Instructional Modules in Bioengineering**

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### **Abstract**

The objective of this paper is to describe a design method and rational for creating instructional modules in bioengineering. As part of a new Engineering Research Center (ERC), called VaNTH, experts from learning sciences, biomedical engineering, assessment, and learning technology have been collaborating to define a new method for designing effective learning environments for bioengineering education. The design of these modules is based on current research on human learning and educational settings detailed in a report from the National Academy of Science called *How People Learn: Mind, Brain, Experience and School*<sup>1</sup>. The report provides insights into what is necessary to design an effective learning environment and provides a framework that can be used to evaluate a learning environment. This paper describes the method we use to apply these criteria to the design of "instructional modules" for bioengineering education. The VaNTH ERC is using a challenge based instructional method supported by a software template called STAR.Legacy. This template has been used to create several modules reported in these proceedings. This document expands on how these modules are designed and the rational for the pedagogy for using these materials in a course. The final results are learning modules that can be shared and refined by others in the ERC and beyond.

### **Introduction**

Many people are working on methods to share instructional resources with others that teach similar content. For example, various web sites are collecting Java Applets and other resources that are useful in a variety of different content areas. However, these resources alone are not necessarily used in ways that optimize people's abilities to learn. We are designing a web-based method to organize learning activities and resources into cohesive, pedagogically sound *modules of instruction* that can be shared by the members of our VaNTH Engineering Research Center (ERC) (see [vanth.org](http://vanth.org) for more information) and beyond. The objective is to create a method that allows these modules to be highly integrated with other modules --with the ultimate goal being to formulate a cohesive course. The VaNTH ERC has assembled a team of experts from the Learning Sciences, Bioengineering domains, Assessment and Evaluation and Learning Technologies to work together to define an effective learning environment that will optimize both instruction and learning. One of our initial steps has been to share our expertise across disciplines and discuss the implications on instruction. The Learning Scientists, Assessment

specialists and Learning Technology people bring years of experience in research on how people learn and research on classroom practices that work. The engineering domain experts (both researchers and professors) bring a wealth of knowledge about their domain and their classroom. The initial results of our collaboration have lead to one method of thinking about how to organize domain knowledge that promotes student learning and is easily sharable with other instructors.

The goal of this paper is to outline some the critical factors we've identified and the method we've used to guide the design and delivery of our learning materials. By the end of the article the reader should have a better understanding of our rational for organizing instruction around challenges and how these challenges lend themselves to a modular design approach. Much of our methodology for designing learning materials is founded on the principles for designing effective learning environments discussed in a recent report called *How People Learn: Mind, Brain, Experiences and School* (Bransford et. al. 2000)<sup>1</sup>. Therefore we start with a quick summary of these principles. We are using a "challenge based" approach to instruction as a method to achieve these principles of an effective learning environment. Next, we explore the need to identify clear learning objectives for a course and criteria for defining challenges that target these objectives. Organizing learning activities around challenges can be a difficult design activity. We have developed a software template called STAR.Legacy<sup>2,3</sup> to organize instructional materials around challenges. This template provides a structure and guidelines to help think about how to apply the principles defined in the *How People Learn* report. We are using these principles and methods to redesign several courses including introductory biomechanics, biotechnology, and biooptics. Several papers in this proceeding provide explicit examples of how the principles are applied to these domains<sup>4,5,6</sup>.

### Principles for Designing Effective Learning Environments

New principles of learning and instruction presented in the National Academy of Science report called *How People Learn: Mind, Brain, Experience and School*<sup>1</sup> provides important insights into rethinking the design of a learning environment. One of the major components of the report is the "How People Learn (HPL) Framework" which focuses attention on four dimensions that can be used to evaluate the effectiveness of learning environments and criteria to improve the design of a learning environment. These dimensions include the degree to which environments are knowledge centered (in the sense of teaching for understanding in a way that supports transfer), learner centered, assessment centered (especially opportunities for formative assessment, feedback and revision) and community centered. Each of these dimensions has specific criteria a designer needs to consider when creating a learning environment. Obtaining a balance of these criteria can lead to a learning environment with the potential to enhance students learning with understanding. The following details some of the principles for each of these dimensions, then we discuss how to implement these principles in the design of a learning environment.

Every learning environment is inherently knowledge centered. The goal of instruction is to teach students the domain knowledge and how to apply it. This knowledge includes

the common representation experts in a field use to communicate with other experts. This can include learning the nomenclature, equations and how to use analytical tools such as graphs, and computer models to conduct investigations within a given domain. Experts possess a highly organized set of knowledge that they use to make assumptions and predictions about events in their domain. However, this knowledge is often tacit; therefore, the subtlety of the relationship between concepts in a domain is difficult to share with young learners. One of the goals of instruction is to help students develop their own organization of the concepts associated with a domain so they can apply these ideas to new problems.

Learner centeredness focuses on building up the knowledge learners bring to any learning environment. This requires identifying what conceptions or lack of knowledge students have prior to instruction and identify how these conceptions relate to the goals of the knowledge centeredness. The goal of instruction is to help students bridge the gap between what they currently know toward a more thorough, well organized structure of domain knowledge that they can operate on to solve problems. As we will discuss later, students may not create a useful structure of their knowledge if the domain information is presented as a description of each concept and a string of examples demonstrating how to solve problems. Learners need to understand the conditions in which the concepts apply and how they apply.

Learning is a gradual process, therefore, we need to monitor students progress from what they currently understand toward what we want them to know and be able to do at the end of a course. Therefore, we need to center on assessment, specifically formative assessment. Students need multiple opportunities to understand how they are progressing toward an ultimate goal, our outcome, of the instruction. Feedback on homework is one method, however, there are many other opportunities where students can challenge their understanding and reflect on what more they need to know. An important point to remember is that assessments should be opportunities for students to learn and don't always need to be associated with a grade. Students should come to value these opportunities and become less focused on getting a grade as a motivator for doing an activity. As we will explore later some of these activities should occur more under the supervision of the professor who can provide immediate feedback and answer students questions.

Finally, community centeredness encompasses a range of issues relative to how a community is defined. Students need to learn how to use their peers as resources for their own learning. This occurs as they work in small groups, participate in class discussions, meet in professional group etc. An effective learning environment should strive to foster a sense of community within a class. In addition to developing life long skills of working with others, fostering community has great potential for facilitating instruction. For example, students can draw on each other's experiences to expand their own understanding. Also, large class projects can emulate industry by having students develop specific expertise that they must bring to the group. It is the groups responsibility to bring the ideas together.

## Identifying Domain Content and Course Learning Objectives

One of our first steps in designing a course is to clearly identify the learning objectives. That is, what do we want to student to know and to be able to do by the end of the course. We have explored several strategies to identifying these objectives. Wiggins and McTighe<sup>7</sup> recommend identifying the major objects around specific outcomes students need to display. For example, "describe three major classification of lever systems" or "analyze the force on a knee joint walking up stairs". These objectives can be prioritized by how important the concepts are toward the goals of the course. They recommend that these objectives be rank ordered with labels like "Familiar, Import or Fundamental" concepts. This classification helps identify how much time should be spent on the concept and how it could be assessed (e.g multiple choice for familiar versus and open ended problem solving task for fundamental knowledge to be learned).

Bransford uses a similar approach for defining key objectives to help define a road map for a course. Like Wiggins and McTighe<sup>7</sup>, he works backward in the design by defining what students should know and do at the end of the course, then work to more specific knowledge to design instructional material for students to use in and out of class time. In other words, his approach is to identify a major outcome for the students to demonstrate by the end of a course. Then define a series of learning objectives necessary to achieve that goal. For example, in his Cognition and Instruction course, the major objective for the students is to apply the principles of the HPL framework to evaluate the effectiveness a learning environment. In order for students to achieve this goal, they need to understand the nature of expertise and how to achieve it, factors associated with good classroom practice, the role of technology and methods for putting this together. The result is a course outline designed to achieve this goal. He uses these lists of objectives as a road map for what students will learn in the course, which includes

- Introduction to HPL and designing Effective learning Environments
- The Nature of Expertise
- How to Develop Expertise
- Methods for Organizing Instruction
- The Role of Technology
- Establishing Classroom Practice
- Designing a Course (be able to understand the role of expertise in learning an how to develop)

This course outline provides students with a set of goals and objectives they can use to monitor their ability toward evaluating the effectiveness of a learning environment. Note that this course outline provides a level of structure for understanding the domain of Cognition and Instruction. This explicit representation is one of the elements that will help students develop a deeper understanding of the domain. In each of these categories of objectives is a sequence of challenges designed to help students explore fundamental principles related to that objective. As students progress through the course they should be continually refining their representation for how these pieces fit together. In fact, the course outline is an explicit representation that they can use to think about the domain. Also, he has special events (a formative assessment) where students can test their ability

to evaluate a learning environment. If they keep up with their studies, then their sophistication of evaluation should increase with each new opportunity.

This process of evaluating major course objects that relate to a higher goal is part of what we are doing to rethink bioengineering education. As Roselli and Brophy<sup>6</sup> point out, traditional introductory biomechanics course design revolves around defining a taxonomy of things students should know starting with basics, such as fundamental laws of mechanics, vector operation, free body diagrams etc. Then, typically the content of the instruction gradually increases the complexity of problems that target the application of these fundamental laws as the course progress. One of the major concerns with this approach is that students do not make connections between concepts and how to use them to solve problems. Creating a clear course outline that provides a roadmap toward achieving a desired goal can provide students with right tools they need to monitor their progress and make connection between concepts. The next step is to define challenges that target the concepts of a taxonomy and provides a context for how to apply the concepts in novel situations.

#### Identifying Challenges to Target Outcomes.

The HPL framework provides a structure for thinking about the critical issues related to designing an effective learning environment. Many examples of problem based instruction illustrate a balance of the four major dimensions of an effective learning environment.<sup>8,9,10,11</sup> The VaNTH ERC is building on this experience to explore the use of challenges to organize the instruction for students. Our goal is to identify challenges that illustrate how the fundamental principles of a domain relate to each other and how they can be used to interpret real world problems. This first step in this process is to clearly identify the knowledge we want students to understand and how to apply it in multiple applications.

Designing a good challenge requires careful consideration of the desired outcome, and the background knowledge of the learners. The challenge is what establishes a goal for the students that they will continually reflect on as they research the domain knowledge they need to define potential solutions to the challenge. Also, as students explore domain concepts to prepare them to solve the problem, they should easily make association between the learning activities and the initial challenge. If they don't, then the students will view these as a series of isolated events and will become confused and not understand the relevance of the task. Therefore, once the major learning objectives are established, the designer needs to identify interesting challenges that will engage students in meaningful problem solving and inquiry for new information. We are still exploring the critical dimensions for creating effective challenges, but there are several key things to keep in mind. First, the challenge should be relatively complex and require a sustained period of time to solve. However, a challenge must be comprehensible by the students. A designer should provide enough background information within the statement so students can generate some intuitions about challenge. These intuitions could include potential solutions, theories about how something works or questions about what more they need to know. This will ensure that the learners can get into the game. Also, this

background information could be presented using a range of resources including text description, movies, demonstrations, or interactive simulations.

Another important concept we have determined is a course should have multiple challenges defined to illustrate various dimensions of concepts in a domain and how they are applied. Research has demonstrated the possibility for someone to do well on one challenge, but have difficulty transferring this knowledge to a new context<sup>9</sup>. However, by providing multiple contexts a learner can compare and contrast solutions allowing them to pick up subtle differences in each problem solution. This is very much like an expert's ability to notice important features of a problem which helps them retrieve valuable information that will help solve that problem.

The art of defining an interesting challenge can be quite illusive. There are several schools of thought on the "authenticity" of a challenge. For example, challenges need to be actual real world cases versus crafting a believable scenario that helps make specific points. We are of the view that challenges should be designed to help learners develop the expertise (ie knowledge structure, or organization) that allows them to use the knowledge in new context and learn how to do research when they don't have sufficient information. Therefore, challenges can come from real world experiences of instructors, or published cases in newspapers or journals. The key principle in choosing a challenge that targets the desired learning objectives and help students organize new concepts into a their own knowledge structure.<sup>1</sup>

#### Sequencing Learning Activities around Challenges.

Organizing the content around interesting challenges provides students with the opportunity to enhance their problem solving and inquiry skills while exploring new content. However, using complex challenges for instruction requires a systematic approach that requires students to sustain their inquiry as they explore potential solutions. One method for determining what to do and when to do it is to organize instruction using a template called STAR.Legacy, often referred to as Legacy. The structure of Legacy is founded on the principles of the How People Learn (HPL) Framework.

The Legacy framework uses a "*learning cycle*" (based on an inquiry cycle) to define critical phases of exploring a complex challenge as part of learning activity. Figure 1 is a visual representation of the learning cycle. This visual helps students, and professors, keep track of where they are in their inquiry of a challenge. Briefly, the cycle begins with the presentation of the **Challenge Statement** using a variety of media formats ranging from text to interactive simulations. Students view this challenge then go on to **Generate Ideas** (or initial thoughts). This phase provides students with the opportunity

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<sup>1</sup> Chris Reisbak, a colleague of ours at Northwestern, highlighted the necessity of choosing the right challenge to meet the learning objectives. He mentioned a time when he was involved in designing an environment for student to learn about DNA sequencing. They created a mystery story around finding evidence that someone was present at the scene of the crime using DNA matching. The difficulty is that DNA matching requires identifying the entire DNA unique to an individual where DNA sequencing focuses on identifying all the DNA common to everyone. Therefore, this challenge was not well suited to the desired learning objective.

to explore what they currently know about the challenge. This includes their naïve concepts, or models, of the domain. Students can work together and they should record their ideas in a journal or online journal. They can use this later as an assessment of how much they've learned. Next, they can compare their thoughts with those of experts in the **Multiple Perspectives** phase of the cycle. Experts provide their thoughts about the challenge based on their experiences. They never provide enough information to solve the challenge directly, but they provide insights into ideas that need to be researched. Once students have compared what they know with the experts, then they are ready to research new information and revise their thinking. **Research and Revise** contains a series of learning activities designed to help students focus on the important dimensions of the challenge. These *learning activities* are designed to help students make a link to the original "Challenge". **Test your Mettle** provides students with the opportunity to apply what they know and evaluate what they need to study more. This assessment method helps students reflect on how well they've learned the content of Research and Revise and to evaluate whether they are ready to Go Public with what they know. If they aren't ready, then they can return to Research and Revise to review. Last, **Go Public** is the final assessment of what students know at the end of the module. This assessment could be a presentation of the content, a quiz or test, an essay or homework assignment, etc. This is more of a summative assessment of what they've learned so far.

**Home**

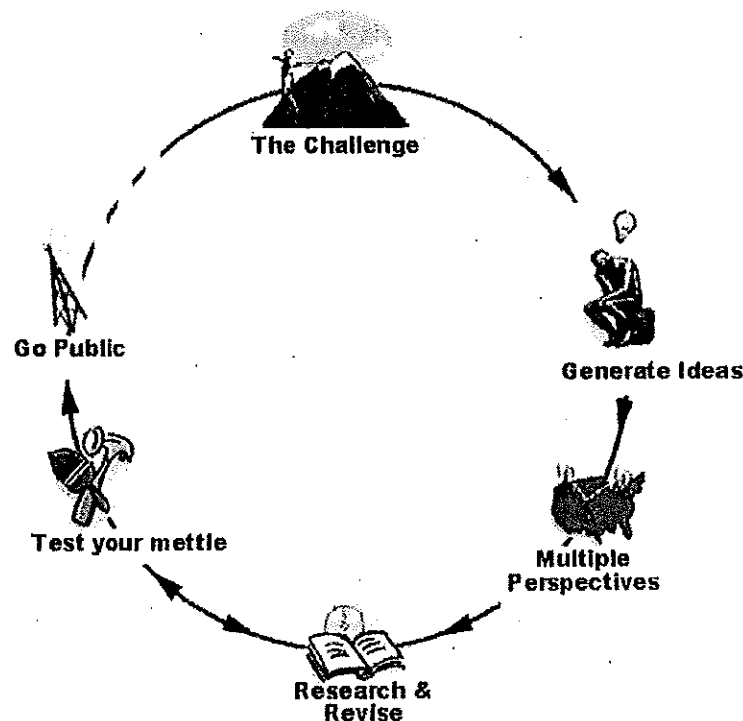


**Figure 1- STAR.Legacy Software Reflection for Action and Reflection**

The elements of the learning cycle are designed to encourage students to take "action" on their own learning and to "reflect" on their learning process. We feel this framework provides a structure that designers can use to guide their creation of instructional materials for a course.

### Designing the Instructional Sequence of Learning Activities

Legacy provides a structure for defining and organizing learning activities relative to the HPL framework, but does not necessarily define the actual timing of the instruction. A traditional model of instruction makes some basic assumptions about how people learn which we need to understand in order to define a new method. The traditional model for instruction often follows a pattern of 1) students reading materials before class 2) professor lectures in class 3) students apply and practice what they learned by doing homework. In more general terms the process follows a pattern of determining

- How to prepare students for class?
- What students do during class?
- What students do after class?

This may seem obvious, but thinking through and prioritizing the learning activities can be a complicated task.

We are experimenting with various methods for organizing in-class and out of class activities using the Legacy Cycle. The major factors governing our decisions center on the complexity of the challenges, the difficulty of specific concepts to comprehend and overall flexibility of time. Some Cycles could be completed in a single class time, but the complexity of some challenges may require weeks to explore. Therefore, students must become familiar with the Legacy Cycle, its organization and purpose. Then, they can use the interface to navigate through the lessons. We have collaborated with several domain leaders to develop examples of Legacy for Modular design. These examples include challenges in the domains, biotechnology, biooptics and introductory biomechanics and are included in these proceedings.<sup>4,5,6</sup>

### Modular Structure of Challenges

As we mentioned earlier, one of VaNTH's goals is to create instructional materials that can be shared by others within the VaNTH institutions and beyond. Each Legacy Cycle can be independent of any other cycle making it a nature unit size for *a modular unit of instruction*. However, there are multiple ways for decomposing or combining the challenge based modules into sharable resources. For example, each phase of the Legacy Cycle can be linked to a vast array of instructional resources that can be used for a variety of applications. The resources could include text passages, movies, audio sounds, interactive simulations, models etc. We call these general resources, *granules* and they are the smallest unit of sharable resources. These granules are not tied to any domain or specific utility. In fact, a granule's instructional intent is not defined until it is incorporated into a challenge.

Alternatively, several challenges can be linked together to help students explore concepts related to one of the course's learning objectives. The clustering of modules forms a *Mosaic of Modules* and takes on many forms. The juxtapositions of modules could be to provide students with multiple contexts in which to explore the subtle difference in the application of certain concepts as mentioned earlier. The focus for the *mosaic* is to explore the multiple dimensions of a specific concept or learning objective. Another reason for a *mosaic* of challenges is to manage the complexity of larger challenge, like a design task. This mosaic of challenges would consist of a collection of sub problems necessary for solving the larger challenge. In this situation the mosaic has it's own challenge associated with a grand challenge (see Giorgio<sup>4</sup> for an example).

### Summary and Conclusion

Granules, Modules, and Mosaics of Modules can all be combined to create a course. However, before we can begin to assemble these pieces several things must be defined first. In this article we have presented a methodology we are using to redefine our instructional approach to biomedical engineering education. This process includes –

- Identifying a major learning objective(s) for the course (ie, what should student be able to do at the end of the course)
- Define specific learning objectives necessary to achieve the major objective(s)
- Identify challenges that target these learning objectives
- Use STAR Legacy to organize learning activities (including assessment events) to systematically explore the problem space of a challenge.
- Define a sequence of pre-class, in-class and post-class learning activities.

This process will result in creating a modular unit that can be shared with others. If portions of the module do not suit the needs of the new instructor, then they can modify the materials with their own materials. These challenges can be mixed and matched, or altered slightly to make them appropriate for other domains. For examples, many biomechanical challenges could easily be used in a physics course and vice versa. We have begun to create these modules and mosaics for several courses and will be evaluating them during the Spring of 2001. Several examples of Modules and Mosaics of modules are presented in these proceedings. The purpose of this paper has been to articulate the rationale for these designs and suggestions for how others can design their own effective learning environment.

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