Design Methods for Instructional Modules in Bioengineering

Sean Brophy and John Bransford,
Department of Biomedical Engineering / The Learning Technology Center
Vanderbilt University, Nashville TN 37235

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[1]. 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 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)[1]. 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 [2,3] 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 [4,5,6,]

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[1] 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 posses 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 subtly 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[7] 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[7], 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 inlcudes

- 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[6] 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 now 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. [8,9,10,11] 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 comprehendible 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 import 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 possibly for someone to do well on one challenge, but have difficulty transferring this knowledge to a new context[9]. However, by providing multiple contexts a learner can compare and contrast solutions allowing them to pick up subtle difference in the each problem solution. This is very much like an experts 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 form 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. [1]

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

[1] 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 identify 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.

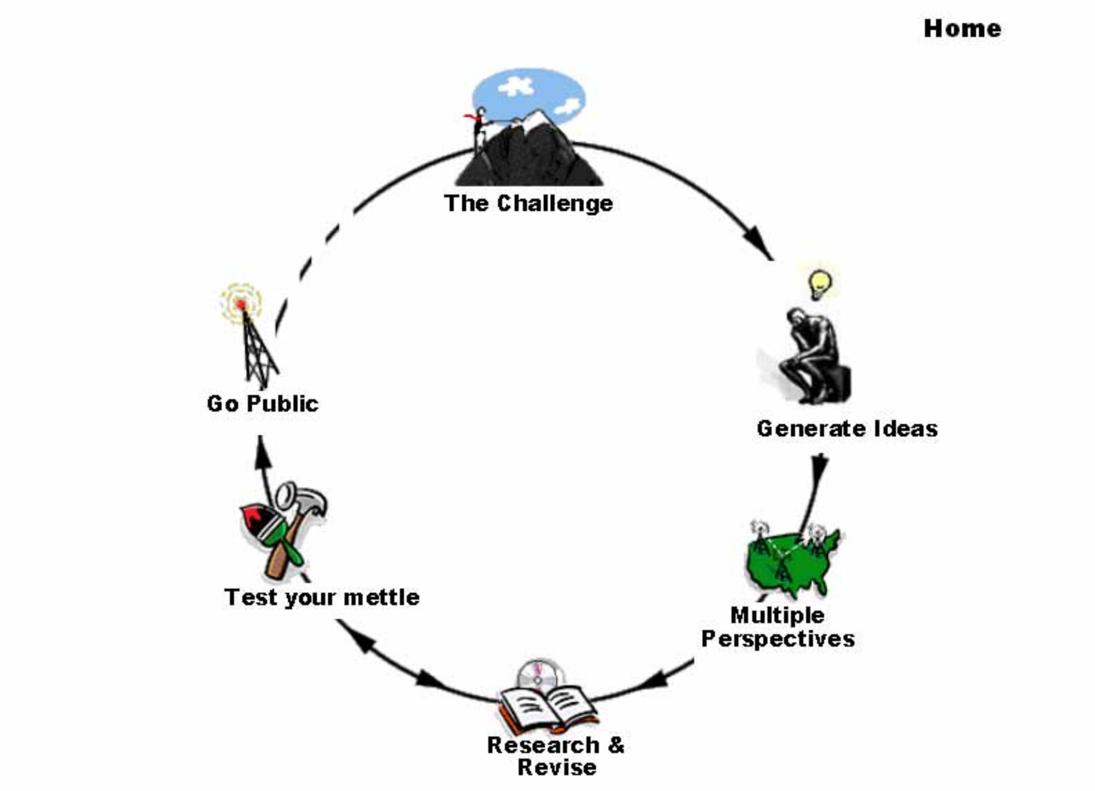

Figure 1- STAR.Legacy Software Reflection for Action and Reflection

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.[4,5,6]

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[4] 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 vise 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 rational for these designs and suggestions for how others can design their own effective learning environment.

Acknowledgements

This work was supported primarily by the Engineering Research Centers Program of the National Science Foundation under Award Number EEC-9876363.

Bibliography:

1. Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). How people learn: Brain, mind, experience, and school. Washington, DC: National Academy Press. http://www.nap.edu/html/howpeople1/ (1999).

2. Schwartz, D. L, Brophy, S., Lin, X. & Bransford, J. D. (1999). Software for managing complex learning: Examples from an educational psychology course. *Educational Technology Research and Development.* 47(2). p 39-60 http://peabody.vanderbilt.edu/ctrs/ltc/schwartzD/weblegacy

3. Schwartz, D. L., Lin, X., Brophy, S., & Bransford, J. D. *Toward the development of flexibly adaptive instructional designs*. In Reigeluth (Ed.), Instructional Design Theories and Models: Volume II. Hillsdale, NJ: Lawrence Erlbaum Associates. (1999). http://peabody.vanderbilt.edu/ctrs/ltc/brophys/legacy1.html

4. Giorgio, T. D. & Brophy, S. P. *Challenge-Based Learning in Biomedical Engineering: A Legacy Cycle for Biotechnology*. Proceedings of the 2001 American Society of Engineering Education Annual Conference & Exposition, (2001).

5. Jansen, E. D., Mahadevan-Jansen, A.,Lin, W. C., Brophy, S. P. & Machanos, M. A. *Development and Implementation of an Interactive Instructional Module of Light Distribution in Tissue*. Proceedings of the 2001 American Society of Engineering Education Annual Conference & Exposition, (2001).

6. Roselli., Brophy, S. P. *Movement from a Taxonomy-Driven Strategy of Instruction to a Challenge-Driven Strategy in Teaching Introductory Biomechanics*. Proceedings of the 2001 American Society of Engineering Education Annual Conference & Exposition, (2001).

7. Wiggins, G. & McTighe, J. *Understanding by Design*. Association for Supervision and Curriculum Developments, VA. (1997).

8. Barrows, H. S. *How to Design a Problem-Based Curriculum for the Preclinical Years*. New York: Springer, 1985.

9. Cognition and Technology Group at Vanderbilt. *The Jasper Project: Lessons in Curriculum, Instruction, Assessment, and Professional Development*. Mahwah, NJ: Erlbaum. 1997.

10. Hmelo, C. E. *Problem-base Learning: Development of knowledge and reasoning strategies*. Proceedings of the Seventeenth Annual conference of the Cognitive Science Society. Pittsburgh, PA:Erlbaum. 1995. P 404-408.

11. Williams, S. M. *Putting case-based instruction into context: Examples from legal and medical education.* The Journal of the Learning Sciences 2(4). 1992.

SEAN P. BROPHY
Sean P. Brophy received his B.S. degree in Mechanical Eningeering from the University of Michigan, an MS in Computer Science from DePaul University, and a PhD in Education and Human Development from Vanderbilt University. Dr. Brophy works with the Learning Technology Center at Vanderbilt to apply current theories of Learning Sciences to improve instruction at various educational levels. He currently is an Assistant Research Professor in the Department of Biomedical Engineering at Vanderbilt. His current research interests relate to using simulations and models to facilitate students understanding of difficult concepts within engineering as part of the VaNTH Engineering Research Center (ERC).

JOHN D. BRANSFORD
John D. Bransford is Centennial Professor of Psychology and Education and Co-Director of the Learning Technology Center at Vanderbilt University. Early work by Bransford and his colleagues in the 1970s included research in the areas of human learning, memory and problem solving, and helped shape the "cognitive revolution" in Psychology. Bransford has also worked with colleagues to develop a number of award-winning software products involving literacy, mathematics and science. An author of nine books, over 200 articles and hundreds of presentations, Bransford is an internationally renowned scholar in the areas of cognition and technology. He was awarded the Sutherland Prize for Research at Vanderbilt University, and was Co-chair of three National Academy of Science Committees that produced How People Learn: Brain, Mind, Experience & School (2000) and How People Learn, Bridging Research and Practice (1999). He is on the Board of Advisors, NSF's Division of Education and Human Resources (EHR). Bransford is the recipient of the Thorndike Award, 2001