Implementation of a Problem-Based Approach in an Undergraduate Cognitive Neuroscience Course

KATHY SCHUH[1] & THOMAS A. BUSEY
Indiana University, Bloomington, Indiana

In this article we describe a modified implementation of an instructional strategy known as problem-based learning (PBL) in an introductory cognitive neuroscience course (Brain and Cognition). Our goal in this paper is to describe the principles of PBL that we found effective and then demonstrate how these principles fostered our continued restructuring of this undergraduate course. We share the details of our evolution over a three-year period because we found that the implementation of PBL is not an easy transition. However, we found it a very positive experience for us and our students, and the course is now very well received. Although we have implemented these principles for a cognitive neuroscience course, any course in which the content can be introduced through large problems could take advantage of this approach.

Prior to the first year of our course restructuring, the instructional method for Brain and Cognition was largely lecture and demonstration. We were concerned that students didn't participate actively in class discussions and that they appeared to transcribe the lecture without much synthesis or analysis. The rote memorization strategy adopted by our students typically does not support long-term retention (Ausubel 1963; Siegl and Shaughnessy 1994). In addition, this transcription/memorization approach does not work well in a domain like cognitive neuroscience where there are few hard facts about how the brain works to support higher mental functions like memory, language, or intelligence. We also wanted the undergraduates to become more engaged in the learning experience and begin to use the tools of neuroscience to solve problems in their own domains. In an attempt to increase student interaction, decrease lecture time, and provide students meaningful learning activities, we began to change the instructional format to include the use of authentic problems in a PBL format. We use our case to describe principles of PBL that we found most critical to consider when meeting the instructional goals for the course.

Goals and Principles of PBL

Problem-based learning is an instructional strategy that places students in problem solving situations (Albanese and Mitchell 1993; Barrows and Myers 1993; Hmelo 1998; Savery and Duffy 1996). Originally implemented as an alternate curriculum in medical schools, the use of PBL has been extended to an increasing number of areas including business, education, architecture, law, engineering, social work, and high school (Savery and Duffy 1996). This method uses less lecture-based learning while placing more emphasis on independent learning and problem solving. Goals of this strategy include allowing learners to develop an integrated knowledge base that is better retained in memory for later use in real-world situations and to develop skills for effective collaboration with peers (Barrows and Myers 1993).

In contrast to other methods, a problem is presented prior to the concepts needed to solve the problem. The problem provides the context from which the need to understand the concepts and issues emerges. In this process, students

[1]Please send correspondence to:
Kathy Schuh, now at:
361 Lindquist Center N.
University of Iowa
Iowa City, IA 52242
email: kathy-schuh@uiowa.edu

develop their own questions and frame the concepts necessary to solve the problem in their own words, rather than passively absorbing these from the instructor's lecture (Albanese and Mitchell 1993; Savery and Duffy 1996).

PBL, along with other constructivist instructional strategies, adopts several instructional principles. These principles address the role of the problem, the learning environment, the learners, the teacher, and the learning process (Honebein, Duffy, and Fishman 1993; Savery and Duffy 1996). In our implementation we focused on three aspects of the PBL: the problem, learners as collaborators, and learners as directors of their own learning.

The Problem: Contexts for Concepts

Learning activities should be anchored in a larger problem or context that includes an authentic task. Problems used in PBL are often ill-structured in that they are vaguely defined and have unstated constraints, and may include not only multiple viable solutions but also multiple solution paths (Barrows and Myers 1993; Jonassen 1997). In contrast, well-structured problems are like those that are typically found at the end of textbook chapters in which there is a known goal state (answer) and the student provides that answer. In these traditional problems, all of the elements of the problem are presented, and there exist convergent, correct answers with a preferred solution process through which this answer is obtained. In addition, the use of authentic problems "should help learners develop ways of thinking and acting that characterize the culture or professional community" (Lebow and Wager 1994, p. 233).

Given that the problems are authentic, the learning environment should reflect the environment in which that type of problem would normally occur. However, the complexity of that environment may be reduced so that it is at a level appropriate for the students (Savery and Duffy 1996). For example, in our class the students did not deal with real patients, but rather with simulated situations and case studies.

Students as Collaborators: Considering Alterative Perspectives

The learning environment should also prompt students to consider alternative hypotheses (Honebein, Duffy, and Fishman 1993; Savery and Duffy 1996). Working in groups provides the opportunity to generate and investigate multiple perspectives, rather than merely being a means to share the workload (Duffy and Cunningham 1996).

Student-directed Learning: Learner Ownership

In PBL, students must come to realize that they need to take responsibility for seeking resources in order to solve the problem, while the instructor provides support so that students make progress. In this, the learner will develop ownership of the process that leads to development of the solution. Therefore, problems should be developed in such a way that students will adopt the problem as their own (Savery and Duffy, 1996).

The Effects of PBL

Research on PBL shows promising results. In studies on the use of problems in college (Arambula-Greenfield 1996; Duch 1996; Mierson, 1998) and college-prep courses (Roth 1992) student satisfaction was high. Although not all students respond favorably to PBL, in a meta-analysis of PBL literature, student satisfaction with PBL was generally high (Albanese and Mitchell 1993) and students with PBL instruction (e.g., Percac and Armstrong 1998;Verhoeven et al. 1998) do as well as students in non-PBL courses. Further, Hmelo (Hmelo 1998; Hmelo, Gotterer, and Bransford 1997) found that learning strategies and reasoning processes were more expert-like in students in PBL than non-PBL medical school students.

Given others' positive results with PBL and our own assessment that our undergraduate cognitive neuroscience course would lend itself well to the use of problems, we began a restructuring effort. In our course restructuring we gleaned aspects of the PBL approach that we considered most critical: the use of authentic problems to provide a context for learning concepts, that learning be student-directed, and that student collaboration be fostered as a means to generate and share alternative perspectives.

Modifications of PBL for Cognitive Neuroscience

The Course

The central goal of Brain and Cognition is to provide students with an appreciation of how researchers draw conclusions about the human brain on the basis of behavioral and neuroscience data. In addition to providing an introduction to neurons and brain areas, we cover a range of human abilities including perception, memory, attention, consciousness and language. This three-credit course typically has an enrollment of about 12-24 undergraduates from a variety of majors.

During our implementation, data were gathered through observation, instructor and student interviews, student questionnaires, and document analysis. The first author (KLS) conducted the interviews and gathered the observation data, the second author (TAB) was the course instructor. During the 1997 class, observation took place during regular class over a five-week period. During the 1998 class, observation extended across the entire semester. The first author interviewed three student volunteers at the end of each semester and interviewed the instructor twice each semester. Students also completed questionnaires both semesters, although the questions were adjusted each year to reflect the changes in the course. Each year, students completed the university course evaluation as well. During the third year the instructor continued the implementation, relying on traditional university course evaluations to gather information about its success.

Development of Initial Version of Problems

In our course restructuring we initially chose to focus on problem development. Because the problems would provide a context for learning the information typically offered through lecture in the course, we attempted to develop problems that captured the relevant concepts and principles of the domain and were similar to the types of problems cognitive neuroscientists in various venues of the field might address (Duffy and Cunningham 1996; Savery and Duffy 1996). In this, our goal was for students to understand the concepts and learn the process of doing science.

The problems for the first year placed students in a number of roles. First they were on a development team for a virtual neuron. The intent of this problem was to provide a context for understanding basic neuron functions. The text of the second problem described a patient with epilepsy (Jane Doe) who was considering brain surgery to remove part of her temporal lobe. The students predicted what cognitive functions might be lost as a result of the brain surgery and communicated their findings to the fictitious patient in a research symposium. Students completed these two problems working in groups. The final problem was more reflective in nature. The students were assigned the task of writing a letter to their Congressman requesting funding for cognitive neuroscience research. In this problem we hoped that the reflection process, another characteristic of constructivist learning and PBL (Savery and Duffy, 1995), would allow the students an opportunity to synthesize what they had learned, and communicate it to a layperson.

Our problems, we believe, were all ill-structured because each had a number of solutions and solution paths. In addition, one or more problem elements were not known at the outset of the problem (e.g., we did not list the viable neuroscience tools that could be used to gather the necessary data, and we provided little or no information about the content areas or background literature needed to solve the problem). Finally, all problems had unstated constraints in that we provided no limitations in choosing neuroscience equipment or experimental tasks. We embedded the problems in writing assignments that provided an opportunity for students to communicate their synthesized understanding of the material and a justified problem solution.

After our first year we felt that the course modification was successful given student feedback and the quality of the papers submitted. However, as expected, the course and the problems were in need of further refinement to better align with the principles of PBL. Our first round of problem development began our PBL implementation. In a formative process, we continued to refine the course to become more fully problem-based.

Adjusting the Problems: Improving the Context

Perhaps the most critical outcome from the first year was our growing concern about the problems providing a context for the course content, a foundational characteristic of PBL. During the first year, lecture occurred more often than we had hoped. In addition, creating problems that prompted students to ask questions and seek information to address the problem issues was difficult. Further, we believed that if we improved the problems to be better catalysts for the content, the instructor could minimize his role as information provider and learning would become more student directed (Arambula-Greenfield 1996; Barrows and Myers 1993; Duffy and Cunningham 1996; Savery and Duffy 1996). Given these concerns, the next step in our process was to find a way to have the course more closely organized around four problems.

To begin our next phase of problem development, we used the patient with epilepsy problem as a model because it had fostered the best student papers and had best integrated the concepts during the first year. In our symposium following this paper, we found that many of our students had become passionate about the research and topic areas they had researched, showing ownership of their own learning process. In addition, students articulated key concepts (e.g., implications of the lesion to cognitive functions) related to our course objectives. The other two problems used during our first year were discarded and new problems developed. When developing the problem, we began with the learning outcomes and content that we wanted to emerge in the problem. We also had to anticipate and understand the types of questions that we wanted the students to encounter while solving the problem. Although it would have been ideal to develop this type of problem in our initial effort, it was only after our first implementation that we could identify *how* the problem would require these issues to arise. We briefly explain the new problems to clarify this idea.

Following an individual problem where students were to speculate about the role of the brain's influence on a particular behavior of interest to them, students were placed in the role of consultant to a group of engineers developing a face recognition component for an ATM machine. In this problem, the students examined the human visual system and extracted out those essential functions that might be useful to copy in the machine implementation. This replaced the more abstract problem of designing a virtual neuron and provided a context from which many of the concepts related to the human visual system would *need* to arise and be understood. The problem could not be addressed without this understanding.

In the third problem students proposed an assessment for an amnesic patient to determine the extent of the individual's disability and clarify the role of particular brain areas in human memory. Because memory had not been discussed prior to the problem, students were prompted to find out what had gone wrong with the patient regarding the role and relationships among different types of memory. This problem provided a context in which the brain functioning related to memory would be explored. In the previous year, this content had largely been addressed through lecture.

We ended the course with the successful problem about the patient with epilepsy we had used the previous year. We kept the problem specification the same and continued to include the research symposium as the capstone activity for the problem. We also added a video-tape of a child who had undergone radical surgery (removal of her left hemisphere) as treatment for a severe case of epilepsy. Although not our fictitious patient Jane Doe, the video provided an authentic component to the problem—patients are placed in situations where they have concerns about reduced post-lesion cognitive functioning.

In addition to more careful specification of the problems, during the second year we also provided more time in class for the students to work together. In the second year, the lectures that occurred were more likely to introduce a new problem (set the context) or provide clarification and demonstration on an aspect of the problem with which the students had struggled as evident in their group work during class. Thus, the problems were not an "addition" to the class: they *were* the means to gain the content.

Another concern we had after the first year centered around the type of questions students asked as they worked on the problems. We felt these questions were an indication that the learning was not student-directed.

Allowing for Student-Directed Learning

Although our problems were ill-structured, during the first year we found that the specifications for the papers (the product submitted following a problem) were too broadly defined in terms of the evaluation criteria. During that year student concerns arose from an under-specification of the papers, illustrating an important aspect of PBL that we had failed to capture. We had hoped that questions about the content and problem solving process would arise as students sought resources and information to solve the problems. However, student concerns focused on what the instructor wanted and how the students' solutions would be assessed. We wanted ill-structured problems, as PBL prescribes, but we didn't want student efforts directed toward the product rather than the content and problem-solving process. Based on student feedback we continued to develop a process through which we could ensure that the problem specifications and criteria for assessing the papers were more carefully described without restricting the possibility of multiple solutions. Table 1 provides the rubric used for the Counseling an Epileptic Patient problem. The problems continued to be ill-structured. However, the assignment criteria were well-defined in that the classroom and assessment questions were anticipated and specified up front (e.g., in general terms what constitutes a successful solution to the problem, how the solution would be evaluated, and what resources were available to the students).

We have adapted this method of assessment from other colleagues and found that it works well with the use of problems in this course. The rubric, which the students received along with the problem specification, covertly reinforced the process of science and provided a structure that guided students in a way that allowed many possible solutions to the problem. Although briefly outlined, the rubric specified a structure for the assessment of the paper, a structure for reporting a research plan, and a method for solving problems within the neuroscience community. For example, the criteria prompted students to include justification for the tasks included in their designs. The students provided previous evidence (thus a need to seek other sources) that their proposed tasks addressed the problem, and developed and described a design that supported this task. Although students did not collect the data, they reflected on the experiment they proposed. They justified the data collection equipment used, the implications of the equipment use for the patient (many are invasive), considered how to advise the patient, and expressed limitations and flaws of their study. Although the process outlined in the criteria was not discussed with the students in the class, by providing the criteria they were introduced to the process of doing science and participated in it at a level that was appropriate for this course.

Although this well-defined specification may seem to be a misnomer in terms of problem-based learning, it is in fact one way to provide students with an outline of the process that cognitive neuroscientists embark on when approaching problems. This allows them to experience the process while setting aside the performance goals of the assignment.

Managing Group Interactions

The improved problems provided opportunities for student directed learning. In addition, we wanted to foster group interactions, particularly to provide students opportunities to generate and gain multiple perspectives, as recommended for PBL. Assigning students to work in groups often provides a number of learning and organizational issues that are not typically addressed in traditional classrooms. Concerns include how to assign students to groups, how to manage in-class group work time, and how to address social-loafing (Meyers 1997). Our decision to assign students to groups was influenced by the multi-disciplinary make-up of the class. At the beginning of the semester we gathered personal information from students regarding their major, minor, and areas of interest. We typically assigned individuals to groups of three or four, a recommended size for productive group work in problem solving (Woolfolk 1998) maintaining the multi-disciplinary nature within each group as much as possible. In this way, we were able to "load" the groups with individuals with a variety of skill strengths. For example, in the machine vision problem, we believed that computer science majors would be particularly helpful for the project and distributed these individuals among the groups.

Meyers (1997), in his review of student participation in small-group activities in psychology classes, offered the following suggestions for enhancing the effectiveness of small groups: ensure that the task structure is amenable to group work, use formal student evaluations, and support the group structure. We believe our problems were amenable to group work in that students were able to divide up tasks without our assistance. Our evaluation strategy included instructor, peer, and individual evaluation corresponding with Meyers' second suggestion. Although there were occasional problems within individual groups (scheduling, etc.), overall, the students responded favorably to the group process. One student stated that he learned a little more in completing the group problems because "you were able to do research on specific areas and then you learned what the other people in the group found out also" (Student D, January 19, 1999). Although minor problems existed, the group process and group diversity provided an opportunity for sharing of multiple perspectives and information among our students.

Given our concentrated focus on the characteristics of PBL: the problem, student-directed learning, and the use of collaboration, we feel that our own process has resulted in a course that engaged students in the learning process. However, it is also important to consider the response of the students to the new instructional strategy as well.

Evaluation of the Course

Assessment

Traditional evaluations often use assessment techniques and statistical analysis that, we believe, are inappropriate for the evaluation of problems in our course. This said, we consider assessment and evaluation to be a critical step in course development, so we relied on a more qualitative approach. A goal of our restructuring was to move away from rote memorization by students and focus more on the understanding of concepts and the process of science. Given this, the quantitative measures that had been used in the course prior to the restructuring (quizzes, exams) no longer aligned with the instructional format. Rather than memorization of facts, we sought indicators of the students' development as problem-solvers considering the overall quality and insight in their papers and their enthusiasm as learners. We asked whether the students were participating in the process of doing science and engaging the material through this mechanism.

Our qualitative assessment of the papers indicated that the concepts were more likely to be understood within the context of the problem. In the second year, the students understood the concepts better and at a deeper level. Further, the content that had previously been isolated bits of information in the course was now integrated into the context of the problems. Students described cognitive functions, not from a textbook point-of-view, but to provide information to Jane Doe (in the epileptic patient problem for example). We found greater personal synthesis, evaluation, and reflection. In part it was because we felt the problem criteria were better specified allowing the students' efforts to be applied to solving the problems rather than being caught up in the performance goals of the assignment (i.e., what was needed to get a good grade).

Addressing the PBL Principles

Given the framework for our implementation of PBL, we consider the problems, student-directed learning, and collaboration among students from the students' perspective. Some students indicated that the problems did prompt the learning of the concepts. For example, Student F shared, "It [would be] really easy [for the instructor] to sit down and say, 'OK, this is how the visual system works' but by requiring us to write a paper about how a computer could recognize faces, I was forced to think about how it was the visual system worked and try and represent it in a logical way that would be, you know, a good argument for how a computer could go about using that. I think it's really easy to package the information, but you never learn how to use it" (Student F, January 21, 1999).

This same student provided an explanation of how the learning that occurred in the papers provided a foundation of concepts stating, "I learned the most from that paper [machine vision] out of all the other assignments because I kept coming back to that for every other assignment because that gave me a basic understanding of all the other structures that we studied." He also stated that this project was the most frustrating. Thus, the project better allowed for the emergence of the course content than the problem the previous year. Another student, who also identified the machine vision problem as his favorite, stated, "I believed because I enjoyed it more so I was more apt to look into it in depth" (Student D, January 19, 1999).

We also found that the motivation of the students who were interviewed hinged around the problems and the responsibility for their own learning that they imposed (i.e., self-directed). In the first year evaluation, one student referred to this ownership as our "throwing the ball into their court." As Student F stated, "[I]t was my responsibility, that it was my job and I really liked that" (Student F, January 21, 1999). Another student (Student D) mentioned that the papers were specifically the source of what motivated him in class. This type of internal motivation is not unusual in PBL. Barrows and Myers (1993) stated that student motivation in PBL is not superficial (based on grades), but is intrinsic, the motivation is to understand the problem and study, based on perceived relevance of the problem. The students that were interviewed didn't express any concern about being presented problems that were not solvable in the conventional sense. In fact, all three of these second year students felt that it was a positive aspect, stating that having unsolvable problems was fun. Student F explained, "It's always fun to work on things like that because nobody knows, so you can say just about anything as long as you can give a logical reason for it and a way to test it."

Students commented on the time commitment of the projects, but also how they had freedom to make decisions about the projects. "It was more labor intensive because of that [not being presented information], we looked up things, but looked at what we were interested in. If he would have assigned an area, we wouldn't have been free to decide what we wanted to do. Since it wasn't specific we could do what we wanted. If he had talked about it we would just rely on our notes. This way we could be creative" (Student C, December 8, 1997).

During the two years when students were interviewed, there were various reactions to solving problems in the groups. In each of the semesters, student worked on half of the problems individually. There were problems with "social loafing" where students would not complete their tasks. Students acknowledged positive aspects to the process as well. They commented that the problems went quicker, they could bounce ideas off of one another, and they could capitalize on one another's strengths. Thus, although there were problems with the group collaboration, there were also gains in terms of sharing perspectives and also the workload.

Traditional Course Evaluations

Given the formative process of the course modification, each year providing different means of assessment for the students, the constant across the years (including years prior to the restructuring) were university course evaluations. In our evaluations we identified four questions that were answered each year and seemed least likely to reflect only the improved teaching skills of the instructor. The questions and the mean values for a five-year period are included in table 2. During the first two years the course was taught traditionally—largely lecture and demonstration. The implementation began in 1997. A one-way ANOVA reveals that the improvement seen in the data is statistically significant ($F(4,15)=4.64$; $p<0.05$). In addition, the values for 1999 were greater than the ratings for 90% of the courses taught at Indiana University. Thus, this course is very well received by the students.

A mid-semester questionnaire during 1998 supported the improved course evaluation results as well. Student responses (N=7; 50% response rate) were positive about the course stating that they learned as much (43%) or more (57%) in this course as they did in other higher level courses and they also enjoyed the course as much (43%) or more (57%).

Lessons Learned

Implementing a new instructional strategy, as is clear from the description of our efforts, is not simple and easy. In our restructuring of an undergraduate cognitive neuroscience course, we chose aspects of PBL that we could implement in small scale initially, gathering data that would guide the development of the course as it progressed. This process provided an opportunity for the course to gradually evolve into a format that allowed greater student responsibility for learning, use of problems similar to those that specialist in the field would have, and use of group work during class-time to help us determine what content needed to be explicitly addressed in full class lecture and discussion.

Our own activities were instrumental in this. Our weekly conversations revolved around the day-to-day functioning of the class: was there too much lecturing, did the students understand the material, were the concepts emerging, were the students on a path to a problem solution that was viable?

Through our own questions we learned a number of lessons. A critical factor in our own development was the realization that the problems, although ill-structured and aligned with the subject area, did not in and of themselves necessitate that the concepts be understood. Working from our learning objectives and course goals to develop authentic problems was more successful than beginning with an authentic problem and trying to structure it to meet the objectives and goals.

Second, the idea that an ill-structured problem could require well-structured product specifications was critical. In this, we found that if we provided a framework for reporting the problem solution (while not limiting the process or the potential solutions) students asked us different types of questions. It seems students will ask a certain amount of questions. If they are not about the "assignment," then they can be on the content.

Finally, student ownership, either individually or as a group, will emerge if the problems are interesting and enjoyable, and if students have no other alternative but to fend for themselves. Although we provided support for the students, getting out of their way so they could stumble across questions in which they were interested was necessary to drive the learning process in PBL.

Recommendations

Cognitive neuroscience is a course for which many faculty have a limited understanding of the concepts and problems. Given that, it may be difficult to generalize our description to other disciplines. However, we believe the underlying issue does not deal with the content, but in acknowledging that we are problem solvers within our fields. Given that, we need to first acknowledge that there are ill-structured problems in our fields, thus making PBL a valid instructional strategy for our own use. Table 3 provides a summary of potential problems in a number of domains.

Following the realization that there are problems to be solved and that concepts with which our students should be familiar can be embedded in those problems, our recommendation for those who are ready to take the initial step to restructure their course into a problem-based format is to choose those principles that best align with your focus and begin to address those, developing the course in a formative manner, gathering a variety of data, reflecting, and continuing to implement changes that move you closer to the long-term goal. First we focused on developing authentic problems. However, in our first attempt, few of the problems genuinely required the content and issues to emerge. Thus, as we continued our process we took further care to clearly identify the concepts and issues that needed to emerge so the learning outcomes of the course could be met. Then we structured the authentic problems to capture those issues by considering the process through which the problems may typically be solved. Although our problems were ill-structured, allowing for a variety of solutions, we found it necessary to define the specifications for the assignments in detail. This allowed students to turn their questions to the content rather than the product they were creating and also provided a means to covertly specify an authentic process for solving problems in this field. Finally, group time in class was increased so that we could identify the questions and problems with which the students struggled, providing whole group information as needed. This also communicated the importance of the problems as the primary vehicle for interacting with the concepts and content of the course. These incremental small-scale changes benefited the students as well (judging from feedback and course evaluations) and allowed us a means to gradually move a course towards problem-based learning.

References

Albanese, M. A., and S. Mitchell. 1993. Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine* 68 (1):52-81.

Arambula-Greenfield, T. 1996. Implementing problem-based learning in a college science class. *Journal of College Science Teaching* 26 (1):26-30.

Ausubel, D. P. 1963. *The psychology of meaningful verbal learning: An introduction to school learning*. New York: Grune & Stratton.

Barrows, H. S., and A. C. Myers. 1993. Problem-based learning in secondary schools. Springfield, IL: Problem-Based Learning Institute, Lanphier High School and Southern Illinois Medical School.

Duch, B. J. 1996. Problem-based learning in physics: The power of students teaching students. *Journal of College Science Teaching* 25 (5):326-329.

Duffy, T. M., and D. J. Cunningham. 1996. Constructivism: Implications for the design and delivery of instruction. In *Handbook of research for educational communications and technology*, edited by D. H. Jonassen. New York: MacMillan.

Hmelo, C. E. 1998. Problem-based learning: Effects on the early acquisition of cognitive skill in medicine. *Journal of the Learning Sciences* 7:173-208.

Hmelo, C. E., G. S. Gotterer, and J. D. Bransford. 1997. A theory-driven approach to assessing the cognitive effects of PBL. *Instructional Science* 25:387-408.

Honebein, P., T. M. Duffy, and B. Fishman. 1993. Constructivism and the design of learning environments. In *Designing environments for constructivist learning*, edited by T. M. Duffy, J. Lowyck and D. Jonassen. Heidelberg: Springer-Verlag.

Jonassen, D. H. 1997. Instructional design models for well-structured and ill-structured problem-solving learning outcomes. *Educational Technology, Research, and Development* 45 (1):65-94.

Lebow, D. G., and W. W. Wager. 1994. Authentic activity as a model for appropriate learning activity: Implications for emerging instructional technologies. *Canadian Journal of Educational Communication* 23 (3):231-244.

Meirson, S. 1998. A problem-based learning course in physiology for undergraduate and graduate basic science students. *Advances in Physiology Education* 20(1):16-27.

Meyers, S. A. 1997. Increasing student participation and productivity in small-group activities for psychology classes. *Teaching of Psychology* 24 (2):105-115.

Percac, S. and E. G. Armstrong. 1998. Introducing a problem-based anatomy course in a traditional curriculum: A Croatian experience. *Medical Teacher* 20 (2):114-117.

Roth, W. 1992. Bridging the gap between school and real life: Toward an integration of science, mathematics, and technology in the context of authentic practice. *School Science and Mathematics* 92 (6):307-317.

Savery, J. R., and T. M. Duffy. 1996. Problem based learning: An instructional model and its constructivist framework. In *Constructivist learning environments: Cases studies in instructional design*, edited by B. G. Wilson. Englewood Cliffs, NJ: Educational Technology Publications.

Siegl, J. and M. F. Shaughnessy. 1994. An interview with Howard Gardner: Educating for understanding. *Phi Delta Kappan* 75 (7):563-566.

Verhoeven, B. H., G. M. Verwijnen, A. Scherpbier. R. S. G. Holdrinet, B. Oeseburg, J. A. Bulte, and C. P. M. Van der Vleuten. 1998.

An analysis of progress test results of PBL and non-PBL students. *Medical Teacher* 20 (4):310-316.

Woolfolk, A. E. 1998. *Educational Psychology, Seventh Edition*. Boston, MA: Allyn and Bacon.

Table 1

Grading Criteria: Counseling an Epileptic Patient

Section	Possible Points	Your Points
Introduction State goals clearly and concisely, the follow them.	± 1	
Choice of task Previous evidence that your task might be performed in part by neurons in the left temporal cortex.	± 1	
Choice of experiment and equipment Experimental design isolates the particular task Cognitive neuroscience equipment is appropriate for answering question and advising patient	± 1	
Data Analysis Clearly state how the results will be used to advise the patient	± 1	
Reliability Identification of potential design flaws or difficulties with current cognitive neuroscience techniques	± 1	
Presentation Design and analysis clearly communicated in the Research Symposium	± 2	
Team Contribution Do your teammates feel that you contributed appropriately?	± 1	
Final grade: 40 ± _____ = _____		

Within this rubric is an explicit expectation that students will perform at a passing level (for this course were designated that as a “B”). In our case, the total point value for each project was 40 points, although this is obviously an arbitrary decision. If a student or group of students produce a document that shows proficiency, they neither receive nor lose points for that area. Points were added or subtracted based upon deviation from that proficiency level.

Table 2

Summary of course evaluation results for four questions over a five-year period.

Year	N [a]	Quality of course [b]	Subject learning [c]	Quantity of learning [d]	Problems solving [e]
1995	5	2.8	2.2	3.2	2.5
1996	11	3.27	3.00	3.00	2.27
1997	7	3.43	3.29	3.71	3.14
1998	13	3.15	3.31	3.31	3.08
1999	17	3.53	3.41	3.47	3.24

Response ranges were from 0 to 4 (with 4 being strongly agreeing with a positive statement).
a. Number of students completing course evaluation, total students in the course varied.
b “Overall, I would rate the quality of the course as outstanding.”
c “Course assignments help in learning the subject matter.”
d “I learned a lot in this course.”
e “I developed the ability to solve actual problems in the field.”

Table 3

Suggested problems for abstraction in a variety of domains. Note that these suggestions that we have developed as users of PBL, not as experts in the specific domain, and thus these should be viewed as starting points by instructors in different domains.

Domain	Possible Abstracted Problem
Chemistry	Students propose a novel application based on electrical or chemical properties for a company that produces carbon-based nanotubes.
Political Science	A political candidate for a national office is interested in the impact of vote-by-mail on voter participation in Western States. The students are asked to study this issue as part of the candidate's campaign plan and also the impact that it may have on the outcome of the election.
Computer Science	Students modify an existing web-based search engine to match the specific structure of an existing database such as the US Patent database or the Associated Press photo archive.
Economics	Students prepare a presentation for a town meeting that addresses the viability of moving from a property-based taxation system to an income-tax based system to pay for local schools.
Mathematics/ probability	As a casino owner, students determine the house odds on a new game of chance and set up guidelines for payoffs accordingly.
Psychology	Students consider an alleged daycare child sex abuse case and propose and evaluate methods for determining whether the children are accurately describing the events that may have occurred.
Anthropology	Students write and produce a documentary on the social behaviors of the Neanderthal's given artifacts from a recent Neanderthal archeological dig.
Business	Students evaluate the possibility of taking an existing company public.
Law	Following the lead of the Chicago cases, students are asked to present a defense for particular death penalty cases where there exists alleged racial bias.
Cognitive Science	Students develop a simple system of rules to explain the behavior of a complex system (e.g. birds flying, fish schooling, ideas spreading through a culture) that will be well understood at an interdisciplinary symposium.