Professional Development of University Professors:
Case Study from the University of Delaware

By D. E. Allen[1], B. J. Duch[4], S. E. Groh[2], G. B. Watson[3], and H. B. White, III[2]
Department of Biological Sciences[1], Department of Chemistry & Biochemistry[2], College of Arts & Sciences[3], and Mathematics and Science Education Resource Center[4]
University of Delaware
Newark, DE

Introduction: A Brief History of Problem-Based Learning at the University of Delaware

In answering the call of the American Association for the Advancement of Science (1990) that "science should be taught as science is practiced at is best," instructors and institutions across the country have systematically begun to lower the barriers to students' active engagement in their learning of science by introducing new strategies into their classrooms. For a nucleus of science faculty at the University of Delaware, problem-based learning (PBL) allowed us to join in this reform by directing our skills as scientists to finding solutions for our dissatisfaction with "business as usual" in our classrooms.

Problem-based learning (PBL) arrived at the University of Delaware more than twelve years ago when the University's Center for Teaching Effectiveness sponsored a workshop featuring a medical school model of PBL (Kaufman et al, 1989) for faculty about to teach in a new Medical Scholars Program. Sophomore and junior students worked through a graduate-level biology problem in fishbowl fashion, demonstrating the process and their reactions to it for workshop participants.

This first workshop identified for many participants the source of our growing dissatisfaction with our lecture approach to teaching science. Our lectures clearly covered the content material efficiently, but they seemed to be doing little to stretch our students beyond memorization and superficial understanding. The combination of lectures and assigned textbook readings seemed to reinforce our students' perception of science as a static collection of incontrovertible facts with little relevance to their daily lives. In direct contrast, the PBL workshop gave us a window on a learning environment that was alive with discussion, debate, and controversy, and in which intellectual curiosity seemed to be the driving force for student learning.

For many of the workshop participants, the experience was transforming, changing the way we taught and tested and the way we thought about learning. It led to the funding of a proposal to the National Science Foundation (NSF) involving faculty from several basic science departments. Through annual workshops and campus conferences (many of these organized and led by faculty) PBL was soon adopted in courses ranging from international relations, art history, and business to nursing and agricultural biotechnology. Together, these faculty using PBL in their courses established a community of educators who have began to collaborate across departmental boundaries to write problems, consult with one another about effective teaching methods, increase skills development through workshops, and create an environment that nourishes both faculty and students (Groh et al, 1997).

Essential Features of the Problem-Based Learning Approach

In PBL instruction, complex problems rooted in real world situations are used to motivate students to discover important concepts and their interconnections. Working in groups, students learn to analyze problems, identify and find needed information (by posing and answering their own and peers' questions), share their research findings, and formulate and evaluate possible solutions. In essence, it has the potential to give all undergraduates a substantive foundation in the processes of discovery and scholarship, not just those who have a one-on-one research experience with a faculty sponsor.

The basic premise of PBL is that learning begins with a problem (Woods, 1985) presented in the same context as it would be encountered in real life. This is in direct contrast to traditional teaching, which often begins with abstract, disciplinary knowledge, packaged and presented by the instructor, to be memorized and later applied to problems. When first presented with the problem students begin by organizing their ideas and previous knowledge related to it, and by attempting to define the problem's broad nature. They then pose questions on aspects of the problem that they do not understand, and decide which questions should be followed up by the whole group and which can be assigned to individual students to research independently. When the students reconvene, they teach one another the results of their research on the questions posed in the previous session, integrating their new knowledge and skills into the context of the problem. The students continue to define new areas of needed learning (digging progressively deeper into the underlying content and assumptions) as they work through the problem, which typically enfolds in several stages through progressive disclosure (Barrows & Tamblyn, 1980; Engle, 1998).

Although the reasons for adopting PBL strategies into undergraduate courses were unique to each adopter, many faculty instructors at the University of Delaware saw it as a way to incorporate instructional goals that had been difficult to capture using our traditional approaches. For example, we expected that by working through carefully constructed, open-ended problems, students would encounter concepts in contextually rich situations that would impart meaning to those ideas and enhance their retention (Coles, 1998; Dunkbase & Pennick, 1990). In contrast to typical science lecture classroom instruction, in the PBL method students are continually encouraged to define what they do not know, as well as what they know, rather than to cover up their lack of knowledge. We thought that by encouraging students to assess their own knowledge, to recognize deficiencies, and to remedy those shortcomings through their own investigations, PBL would model an authentic process of learning that could be used beyond the boundaries of the college experience. That is, rather than emphasize assimilation of all the knowledge currently deemed essential for majoring in a particular discipline, PBL would help students develop the skill to cope with the rapid expansion and change in the knowledge base that pervades all disciplines (Engle, 1998). The use of problems to introduce concepts would also provide us with a natural mechanism to highlight the interconnections among disciplines. Knowledge transcends artificial boundaries; the PBL approach strives to make obvious the underlying integration of concepts. From the faculty perspective, PBL was additionally attractive because it supported our view of how our field of activity operates far better than did the curriculum we were exposed to as undergraduate novices (Boud & Feletti, 1998).

In addition, the group format could help students to learn the power of working cooperatively, fostering not only valuable communication and interpersonal skills, but the ability to harness the power of diverse thinking and learning styles. We were aware that use of cooperative working groups (whether in a PBL setting or elsewhere) can result in enhanced student motivation, retention in the major and in college, and academic achievement (Johnson et al, 1991; Springer et al, 1999). In addition, more women and minorities might be attracted to enter and/or stay in a science, math or engineering curriculum if the typical high competitiveness and isolation of these courses were removed (Project Kaleidoscope, 1991; Tobias, 1990), as we hoped would be the case in our PBL courses. For women students, entrance into this community of learners is particularly critical in introductory courses; in the first and second years of college, a disproportionate number abandon the pathway leading to a career in science, math or engineering (Petersen, 1996).

From a final perspective as faculty members in the basic sciences, the inquiry-driven nature of PBL seemed to make it ideally suited for a research university environment, with the multiple resources for investigation and independent learning such a setting enjoys. The underlying philosophy of PBL resonates with these comments from the recent Boyer Commission Report (1998) on undergraduate education at research universities:

"The research university must facilitate inquiry in such contexts as the library, the laboratory, the computer, and the studio, with the expectation that senior learners, that is, professors, will be students' companions and guides....The research university's ability to create such an integrated education will produce a particular kind of individual, one equipped with a spirit of inquiry and a zest for problem solving; one possessed of the skill in communication that is the hallmark of clear thinking as well as mastery of language; one informed by a rich and diverse experience. It is that kind of individual that will provide the scientific, technological, academic, political, and creative leadership for the next century."

Adapting Problem-Based Learning to the Undergraduate Setting

It was clear from the outset of its arrival at the University of Delaware that the original medical school model for PBL (Barrows & Tamblyn, 1980) would have to be adapted to the undergraduate setting, with its greater class sizes (and therefore greater demands on faculty resources) and less intellectually mature population of learners. Fortunately, PBL is not a single strategy, but rather a collection of strategies that can be assembled in many combinations, and thus lends itself to adaptation without necessarily comprising its essential nature. But nevertheless, the challenges presented to implementation of PBL in an undergraduate setting are numerous. The sections that follow describe how some of these challenges were addressed at the University of Delaware, and in doing so provide additional insights into the particular permutations of strategies chosen in the design of PBL activities for courses with different enrollment sizes, learning objectives, and populations of learners, and by faculty with varying perspectives and time constraints.

Classrooms

A first and obvious barrier to implementation of the group learning aspect of PBL was the existing classroom layout and furnishings. Fortunately, the University of Delaware's administration responded readily to faculty requests, funding and expediting the renovation of PBL classrooms as the need for them has grown. These classroom renovations were designed to maximize blackboard space (for student groups to use when reporting on their research), include tables for group work, and provide cabinets for storing resource materials between classes.

Nevertheless, some faculty using PBL in large classes (in which enrollment exceeds 80 students, the capacity of the University's largest PBL classroom) are still challenged by less than ideal classrooms where seating is fixed. When possible, instructors in these classrooms typically under enroll them, so that the seating plan can include vacant rows for greater ease of instructor access to student groups (Shipman & Duch, 2001). Groups are typically sized to four students per group, so that a group can span two adjacent rows (the two students in the front row turn in their seats to more immediately face the remaining two students in the row behind).

Sources of problems

A major roadblock when PBL was first implemented in undergraduate courses, particularly in the introductory basic sciences, was the absence of suitable problems. To meet the goals of PBL instruction, these problems must be able to engage active, cooperative learning activities within student groups for up to a week or more. Typical end-of-chapter textbook problems in general do not require the analytical, synthetic, and evaluative thinking needed for PBL, nor the contextual richness (Duch, 1996; White, 1996). Consequently, a major "problem" for adapting PBL was the necessity to write problems appropriate to the instructional goals. While that ensured that only fully committed instructors became involved, it undoubtedly discouraged others from trying. Fortunately, this barrier is being lowered as more and more faculty drawn to PBL are willing to turn their creative energies towards writing and disseminating course materials for use at the college level.

Faculty who write problems turn to a variety of sources for inspiration - landmark experiments (for example, *Dating Eve*, White, 1995); popular press articles about recent discoveries, inventions, or ethical dilemmas (examples: *Who Owns the Geritol Solution*, Allen, 2002; *To Spray or Not to Spray*; Dinan & Bieron, 2001), or even "factual fiction" accounts of ways in which central concepts of a particular discipline might impact the average person's life (examples: *A Bad Day for Sandy Dayton*; Duch, 2000; *The Brominator*, Groh, 2001; *Rice-a-Roni: A San Francisco Treat*, Watson, 2001).

Two science faculty members at the University of Delaware use problems that provide students with an explicit model for scientific research: Harold White (Department of Chemistry and Biochemistry) uses a carefully selected series of primary research articles around the theme of hemoglobin as PBL problems in an introductory biochemistry course (1996). David Sheppard (Department of Biological Sciences) has constructed a series of problems around important areas of recent discovery in the field of genetics in a course required for all biology majors. The problems allow students to develop their ability to access research quality (nucleic acid and protein) databases, analyze and make sense of their findings, and apply them to resolution of the problems.

Although the sources of problems and the contexts for their classroom use may vary, they share the following common features (Duch, 1996): 1) they engage student interest and motivate learning; 2) they require students to develop a line of reasoning that is backed up by evidence; 3) they are complex enough to motivate participation of a group of students, rather than just a single individual; 4) they are ill-structured and open-ended enough to allow participation by all students, and to allow for many legitimate resolutions or many paths to a single resolution; and 5) they incorporate the learning objectives of the course. These objectives are embedded in the problem, rather than posed separately or otherwise set apart by the instructor.

Monitoring Multiple Groups

A third and perhaps most daunting challenge for many faculty contemplating use of PBL or other forms of active learning is how to facilitate the PBL efforts of many classroom groups simultaneously. In the earliest model of PBL, an expert facilitator guides the group process by observing, asking questions, and intervening when appropriate (Mayo et al, 1995) to (among other roles) 1) prompt the group to dig deeper into content, 2) to see connections and tie together information, 3) to stay on track during discussions, to locate resources, 4) to examine evidence for conclusions, 5) to involve all students in the process, 6) to model the process of giving and receiving feedback, and 7) to help the group learn to plot its own course. Clearly, few undergraduate classes are small enough for an instructor to become a dedicated facilitator of a single small group of students in this intensive fashion.

One strategy for monitoring multiple groups in the PBL classroom (for courses of all sizes and levels) has general features that work for collaborative learning settings in general. The instructor walks around the classroom, looking and listening for signs that the groups are engaged and on track, and that all members are participants in the group discussion. The "roving" instructor may also enter into discussions, pose questions, look for overt signs of behaviors that undermine group function, or otherwise focus on a particular group for a short period of time.

This roving facilitator strategy is particularly effective if the PBL problems are constructed so that instructor-led, whole-class discussions can be inserted at key intervals in the problem-resolving process. Groups can then compare notes on each other's progress and the instructor can simultaneously give all groups essential feedback or guidance. This can include tips on finding important resources, helping students beyond conceptual impasses, and encouraging students to dig more deeply into topics whose understanding will enrich their passage through the problem. In essence, faculty members using this model are striving to supply for the whole class in a structured way the guidance supplied by the classic PBL facilitator more informally and extemporaneously.

Additional procedures that help to monitor group process include the drafting of group guidelines or ground rules, and the assigning of rotating roles of responsibility for group members. In the case of group ground rules, student groups draft their own at the start of the semester, and refer to them as needed. Typical ground rules drafted by students incorporate policies on attendance and preparedness, plus an escalating sequence of penalties for each failure to adhere to the guidelines. Roles of responsibility, which rotate amongst group members on a regular time schedule or with each new problem, typically include a discussion leader, a reporter (for group products and class discussions), a recorder, and an accuracy coach (the "skeptic").

Another model, growing in popularity, has been to enlist the help of other undergraduates to serve as peer or near-peer facilitators (Allen and White, 1999). That is, students, who have completed a course and done well return to work in the PBL classroom as group facilitators. They can serve as a "dedicated" facilitator for a single classroom group, or as a "roving" facilitator along with the faculty instructor. The use of peer facilitators has proved to be an excellent model for enhancing the effectiveness of classroom groups, and is a model that can be extended to active learning activities other than problem-based learning.

The Large Class

Instructors using PBL in this setting use many of the previous mentioned strategies, but the need for them intensifies. They enlist the help of undergraduate and graduate TAs to have more individuals to monitor groups. They use carefully staged problems that allow the instructor to intervene at roughly 15-20 min intervals to help guide students progress through the problem. The instructors typically choose to provide more input into group monitoring strategies such as rotating roles and ground rules. They ask students to record their roles each week or with each problem (to verify that roles have actually rotated among group members), or make suggestions for policies and penalties that are essential to well-crafted group guidelines. Group evaluations are often based on students' comments and ratings of each other's contributions to assignments and products, or are highly streamlined versions of the written and verbal feedback strategies used in smaller-class PBL (Barrows & Tamblyn, 1980).

PBL instructors of large enrollment classes also intersperse other classroom activities between and within the course of PBL problems. In these hybrid models, a PBL problem often serves as the central focus of a unit of instruction, but lectures, discussions, and short active learning activities associated with the problem help students to build conceptual frameworks. In the example of the "Who Owns the Geritol Solution Problem," one of these activities has been a concept mapping exercise. Between the first two stages of the problem, students are given map titles such as "the light-independent reactions of photosynthesis," "the carbon cycle," "the Geritol solution," or "the flow of energy through the biosphere." Each student group constructs a concept map with one of these titles, providing timely feedback to both students and instructor about whether they have understood and synthesized major concepts evoked by study of the problem.

Instructors teaching large classes have found that use of either one longer problem (Hans, 2001) in which a clearly delineated final product is embedded (for example, a position paper that serves as a prelude to a whole class debate, mock trial, town meeting, or congressional hearing), or 4 to 6 short problems, one for each major content unit (Donham et al, 2001) are both manageable strategies. Others conduct the PBL elements of the course in laboratory, discussion or recitation sections in which the class meets in smaller subunits - however, if these sections are taught by teaching assistants who are not familiar with PBL or its underlying goals and assumptions, this becomes a less than optimal strategy (Shipman & Duch, 2001).

Is there a limit to how large a PBL class can be? The preliminary findings of Shipman & Duch (2001), in which selected outcomes were compared in a class of 120 and a class of 240 students, suggest that PBL can work in the larger enrollment class - students reported that problem-solving and group work helped their learning and to prepare them for their working lives, and these perceptions were backed up by independent assessments of classroom performance. From the perspective of both students and faculty, the PBL experience was better in the smaller class - students reported more positive attitudes towards, and interest in learning the subject in the smaller class, and instructors were not enamored of the sheer magnitude of the management task involved in monitoring up to 60 classroom groups.

Institutional Costs of PBL Instruction

For consideration by faculty and administrators considering adoption of PBL, transformation of courses to incorporate PBL strategies has some costs associated with it. On the University of Delaware campus these costs included the additional demands placed on faculty time in the early phases of PBL adoption in a course, when materials and activities were planned and developed. Classrooms were refurbished (as described more fully in the section above) to include new furnishings and seating arrangements more conducive to group work (while these classrooms are ideal, they are not essential to successful use of PBL strategies). Outside consultants were brought in the first few years of PBL adoption on our campus to assist with faculty development in PBL instruction, but in later years, University of Delaware faculty took over this role. These faculty formed a PBL institute (see section below), supported in part by an extramural grant to provide the training and mentoring often needed by faculty attempting to redefine their teaching. Faculty incentives to attend the institute and to transform their courses were provided by a match of institutional funds to funds from extramural sources, including the National Science Foundation, the Pew Charitable Trusts, and for biomedical sciences faculty, the Howard Hughes Medical Institute. These incentives have taken the form of professional development accounts through which faculty can purchase materials, hire technology assistants for aspects of course design, or attend and present at education-related conferences in their scholarly disciplines. At the University of Delaware, there was no reduction in class size with adoption of PBL, so no additional faculty time was needed to accommodate greater numbers of course sections - that is, faculty adopted PBL strategies that would work within existing class sizes. Although having additional graduate teaching assistants (TA) to help facilitate student groups might have been ideal, reallocation of TAs towards PBL courses or creation of new TA lines did not occur. It is important to point out that these costs are mitigated by the way in which PBL contributes to a unique definition of instructional productivity. That is, it can lead to more student time spent on educational activities that resemble those of a faculty-directed undergraduate research experience without the associated costs of such one-on-one faculty-student interactions.

Conclusions - Breaking the Cycle of Teaching as We Were Taught

Despite the advantages for improving the undergraduate experience that PBL offers, the adoption of PBL as a mode of instruction is a change not undertaken lightly for faculty whose formative educational experiences were based largely on a different model. Ideally in the PBL classroom, the instructor guides, probes, and support students' initiatives, rather than lectures, directs, or provides easy solutions. When faculty incorporate PBL in their courses, they empower their students to take a responsible role in their learning - and as a result, faculty must be ready to yield some of their own authority in the classroom to their students. Giving up the safety and authority of the podium, however, can be unsettling for faculty accustomed only to a traditional teacher-centered lecture format (Uno, 1997). Attempts to adopt PBL at a level beyond a small collection of course and committed faculty, therefore, must be accompanied by broader efforts to change the campus culture to one more accepting of active, student-centered, and inquiry-based learning.

As mentioned above, a "faculty mentoring faculty" model has been effective in moving the initial grass-roots effort to improve undergraduate courses through use of PBL into a thriving reform of the undergraduate experience at the University of Delaware. With support from NSF's Institution-Wide Reform Initiative, faculty who had adapted PBL for courses in the basic sciences established a campus-wide teaching and learning institute. This institute (www.udel.edu/inst) sponsors weeklong, "hands on" workshops twice yearly (plus follow-up activities) that are led by faculty who have transformed their own teaching. The institute and the workshops it sponsors provide institute fellows the support, resources, and training needed to encourage them to (in turn) transform their courses to incorporate PBL and related active learning strategies (Watson, & Groh, 2001). At last count (Watson, & Groh, 2001) over 270 faculty and staff members (90 in the SMET disciplines) from all colleges at the University of Delaware have participated as institute fellows. Over 25% of the faculty at the University has participated either in institute activities or shorter PBL workshop sessions (held before the institute was founded), for a total impact on more than 150 courses.

In short, PBL is now a "byword" on the University of Delaware campus - in fact, the PBL effort was recently (summer, 2001) cited in the alumni magazine as one of the top accomplishments of the University in the past 10 years. What began as a search on the part of a few science faculty to find a better way to teach, has cascaded into a broader community of educators committed to capturing the essence of what scholarship entails to a broader community of learners.

Acknowledgments

A longer version of this article by the same authors first appeared in Kauffman, Linda R, and Janet E. Stocks, eds., "Reinvigorating the Undergraduate Experience: Successful Models Supported by NSF's AIRE/RAIRE Program," Council on Undergraduate Research, 2004.

References

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

Allen, D. E. (2002). Who owns the Geritol solution? *University of Delaware PBL Clearinghouse*. Retrieved July 31, 2002 from https://www.mis4.udel.edu/Pbl/index.jsp

Allen, D.E. and B. J. Duch, Eds. (1998). *Thinking towards solutions: Problem-based learning activities for general biology*. Philadelphia: Saunders College Publishing

Allen, D.E., Duch, B. J., & Groh, S. E. (1996). The power of problem-based learning in teaching introductory science courses. In L.A. Wilkerson, & W.Gisjalaers (Eds), *Bringing problem-based learning to higher education: Theory and practice*. (*New Directions in Teaching and Learning 68*) (pp. 43-52). San Francisco: Jossey-Bass.

Allen, D. E., & White, H. B. III. (1999). A few steps ahead on the same path: Using peer tutors in the cooperative learning classroom - a multilayered approach to teaching. *J. College Science Teaching 28*, 299-302.

American Association for the Advancement of Science (1990). The liberal art of science: agenda for action. In *Report of the project on liberal education and the sciences*. Washington, D. C.: American Association for the Advancement of Science.

Barrows, H. S., & Tamblyn R. N. (1980). *Problem-based learning: An approach to medical education*. New York: Springer.

Bauer, K., Bauer, G., Revelt, J. & Kight, K. (2002). A Framework for Assessing Problem-Based Learning at the University of Delaware. Presented at PBL 2002: A Pathway to Better Learning conference, June 20, Baltimore, MD.

Boud, D., & Feletti, G. (1998). Changing problem-based learning: Introduction to the second edition. In D. Boud, & G. Feletti. (Eds.), *The challenge of problem-based learning* (pp. 1-14). London: Kogan Page.

Boyer Commission on Educating Undergraduates in the Research University. (1998). Reinventing undergraduate education: A blueprint for America's research universities (pp. 21 of pdf version). Stony Brook, NY: State University of New York at Stony Brook: Retrieved September 9, 2001 from http://naples.cc.sunysb.edu/Pres/boyer.nsf/

Coles, C. (1998). Is problem-based learning the only way? In D. Boud, & G. Feletti (Eds.), *The challenge of problem-based learning* (pp. 313-325). London: Kogan Page.

Dinan, F. J., & Bieron, J. F. (2001). To spray or not to spray: A debate over DDT. *J. College Science Teaching 31(1)*, 32-36.

Donham, R. S., Schmieg, F. I., & Allen, D. E. (2001). The large and the small of it: A case study of introductory biology courses. In, Duch, B. J., S. E. Groh, & D. E. Allen (Eds.), *The power of problem-based learning: A practical 'how to' for teaching courses in any discipline* (pp. 179-192). Sterling: Stylus.

Duch, B. J. (1996). Problems: A key factor in PBL. *About Teaching 50 (Spring)*, 7-8.

Duch, B. J. (2000). A bad day for Sandy Dayton: The physics of accident reconstruction. *J. College Science Teaching 30(1)*, 17-21.

Dunkbase, J.A., & Penick, E. (1990). Problem-solving in the real world. *J. College Science Teaching 19*, 367-370.

Groh, S. E. (2001). The brominator. *University of Delaware PBL Clearinghouse*. Retrieved August 2, 2002 from https://www.mis4.udel.edu/Pbl/index.jsp

Groh, S. E., Williams, B. A., Allen, D. E., Duch, B. J., Mierson, S., &White, H. B. III. (1997). Institutional change in science education: A case study. In C. D'Avanzo, & A.P. McNeal (Eds.), *Student-active science: Models of innovation in college science teaching* (pp. 83-94). Philadelphia: Saunders College Publishing.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand student survey of mechanics test data for introductory physics course. *Amer. J. Phys. 66*, 64-74.

Hans, V. P. (2001). Integrating active learning and the use of technology in legal studies courses. In, Duch, B. J., S. E. Groh, & D. E. Allen (Eds), *The power of problem-based learning: A practical 'how to' for teaching courses in any discipline* (pp. 141-148). Sterling: Stylus.

Johnson, D.W., Johnson, R. T., & Smith, K. A. (1991). Cooperative learning: Increasing college faculty instructional productivity. *ERIC-ASHE Higher Education Report No. 4*. Washington, D.C.:George Washington University.

Kaufman, A., Mennin, S., Waterman, R., Duban, S., Hansbarger, C., Silverblatt, H., Obenshain, S. S., Kantrowitz, M. Becker, T., Samet, J, &Wiese, W. (1989). The New Mexico experiment: educational innovation and institutional change. *Academic Medicine 64*, 285-294.

Mayo, W.P., Donnelly, M. B., & Schwartz, R.W. (1995). Characteristics of the ideal problem-based learning tutor in clinical medicine. *Evaluation and the Health Professions 18(2)*, 124-136.

Petersen, A. C. (1996).Women in science: Beyond the false summit. *ASM News 62*, 120-121.

Project Kaleidoscope (1991) *What works: building natural science communities*. *Volume One.* Washington, D.C.: Stamats Communications.

Shipman, H. L., & B. J. Duch (2001). Problem-based learning in large and very large classes. In, Duch, B. J., S. E. Groh, & D. E. Allen (Eds), *The power of problem-based learning: A practical 'how to' for teaching courses in any discipline* (pp. 149-163). Sterling, VA: Stylus.

Springer, L., Stanne, M. E. & Donovan, S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Education Research 69*, 21-52.
Tobias, S. (1990). *They're not dumb, they're different: Stalking the second tier*. Tuscon, AZ: Research Corporation.

Uno, G. E. (1997). Learning about learning through teaching about inquiry. In C. D'Avanzo & A.P. McNeal (Eds.), *Student-active science: models of innovation in college science teaching* (pp. 189-200). Philadelphia: Saunders College Publishing.

Watson, G. B. (2001). Rice-a-roni: A San Francisco treat. Newark, DE: University of Delaware Problem-Based Learning Clearinghouse. Retrieved July 27, 2001 from: https://www.mis4.udel.edu/Pbl/index.jsp

Watson, G.H., and Groh, S. E. (2001). Faculty mentoring faculty: The Institute for Transforming Undergraduate Education. In, Duch, B. J., S. E. Groh, & D. E. Allen (Eds), *The power of problem-based learning: A practical 'how to' for teaching courses in any discipline* (pp. 13-25). Sterling: Stylus.

White, H. B., III (1996) "Addressing content in problem-based courses: The learning issue matrix." *Biochemical Education 24(1)*, 41-45

White, H. B., III (1995). Dating Eve. *University of Delaware Problem-Based Learning*. Retrieved August 2, 2002 from: http://www.udel.edu/pbl/curric/chem647prob.html

Williams, B. A. (2001). Introductory physics: A problem-based model. In, Duch, B. J., S. E. Groh, & D. E. Allen, Eds, *The power of problem-based learning: A practical 'how to' for teaching courses in any discipline* (pp. 265). Sterling, VA: Stylus.

Woods, D. (1985). Problem-based learning and problem-solving. In D. Boud (Ed.), *Problem-based learning for the professions* (pp. 19-42). Sydney: HERDSA.

Sources of PBL Problems or Cases

Allen, D.E. and B. J. Duch, Eds. (1998). *Thinking towards solutions: Problem-based learning activities for general biology*. Philadelphia: Saunders College Publishing. (25 problems with teachings notes available in instructors' edition)

Center for Case Studies in Engineering, Carleton University, Rose-Hulman Institute of Technology (1997). Retrieved August 2, 2002 at http://www.civeng.carleton.ca/ECL/cat-f93.html. (A library of several hundred engineering cases, some of which are available from the Internet)

J. College Science Teaching. (2000 and 2001). Volumes 30(no.1) and 31 (no. 1) (These issues are dedicated to case study teaching in the sciences, and provide sample cases and teaching notes.)

National Center for Case Study Teaching in Science. Case study collection.

Rangachari, P. K. (2002). *Problem writing: A personal casebook*. P. K. Rangachari, Department of Pharmacology, McMaster Universityhttp://www.fhs.mcmaster.ca/pbls/writing/contents.htm (From PBL courses in pharmacology and an arts and sciences inquiry course, written by an expert practitioner.)

Simmons, S. University of Minnesota. The Clearinghouse for Decision Case Education. (1999). Retrieved August 1, 2002 from http://www.decisioncase.edu/catalog.htm. (A catalog of decision cases in agriculture, food, natural resources and the environment)

Underwood, L., S. (2000). *Case studies in environmental science*. Pacific Grove, CA: Brooks Cole.

University of Delaware. (2002). PBL Clearinghouse. Retrieved July 15, 2002 from https://www.udel.edu/pblc. (Problems plus teaching notes for the humanities, basic and applied sciences, and the social sciences, protected from student access).