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Reinvigorating the Undergraduate Experience:

Successful Models Supported by NSF's AIRE/RAIRE Program

Scaling Up Research-Based Education for Undergraduates: Problem-Based Learning

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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 it’s best,” instructors and institutions across the country have systematically begun to lower the barriers to students’ active engagement in learning 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 in 1992 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, in particular the impact of lectures on the large majority of undergraduates who do not engage in direct research collaborations with faculty, and whose experience of science is thus limited to course work. 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 changed the way we taught and tested and the way we thought about learning. It led to 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 even in courses beyond the sciences ranging from international relations, art history, and business to nursing and agricultural biotechnology. The faculty using PBL in their courses established a community of educators who collaborated 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 questions, share their research findings, and formulate and evaluate possible solutions. PBL 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 that is packaged and presented by the instructor, memorized by the students and later applied to problems. When presented with the problem, students begin by organizing their ideas and previous knowledge to define the problem's broad nature. Inevitably they reach a point at which they realize they are missing essential information or do not understand aspects of the problem. Students assign responsibility to one another to research these questions (called learning issues). They teach one another the results of their research during the next class session, and summarize these presentations in a way that allows for their integration into the problem context. The students continue to define where additional learning is needed as they dig progressively deeper into the underlying content and assumptions. Working in this way, the problem and progress towards its resolution unfolds in stages through progressive disclosure (Barrows and Tamblyn, 1980; Engle, 1998). Thus, in many respects, the PBL process has the essential features of scholarly inquiry.

Although the reasons for adopting PBL strategies into undergraduate courses were unique to each course, many faculty members 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 and 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, rather than to cover up their lack of knowledge. In moving from what they know to what they do not know, we expected that students who did not engage in research collaborations with faculty would nevertheless get to experience the process of constructing knowledge and discover the origins of abstract principles encountered in textbooks or lectures.

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 emphasizing 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 and Feletti, 1998). In short, the processes and objectives essential to PBL align in many fundamental respects with those of the undergraduate research experience, making these learning opportunities accessible to a broader population of students.

In addition, the group format could help students 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 can result in enhanced student motivation, retention in the major and in college, and academic achievement (Johnson et al, 1991; Springer et al, 1999). We hoped that more women and minorities might be attracted to enter and stay in a science, math or engineering curriculum if the competitiveness and isolation typical of these courses were removed (Project Kaleidoscope, 1991; Tobias, 1990). 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).

As faculty members in the basic sciences, we thought that the inquiry-driven nature of PBL, like the undergraduate research experience, was ideally suited to a research university. 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 that the original medical school model for PBL (Barrows and Tamblyn, 1980) would have to be adapted to fit the greater class sizes (and therefore greater demands on faculty resources) and less intellectually mature population of learners in the undergraduate setting. 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. Nevertheless, the challenges of implementing PBL in an undergraduate setting are numerous. In the process of implementing PBL, we discovered many different strategies that could be used 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

The layout and furnishings of existing classrooms were an obvious barrier to implementation of the group learning aspect of PBL. Fortunately, the University of Delaware's administration responded readily to faculty requests by funding and expediting the renovation of PBL classrooms as the need for them grew. 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 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 and Duch, 2001). Groups are typically four students, so a group can use two adjacent rows by having 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, problems must be able to engage active, cooperative learning activities within student groups for up to a week or more. End-of-chapter textbook problems in general do not have the contextual richness, nor do they require the analytical, synthetic, and evaluative thinking needed for PBL (Duch, 1996). Consequently, a major hurdle for adapting PBL was the necessity to write problems appropriate to the instructional goals. While that hurdle 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 turn their creative energies towards writing and disseminating college level course materials.

PBL problem writers seek inspiration from a variety of sources, including fictionalized composites of events in a typical person's life (for example, *A Bad Day for Sandy Dayton*; Duch, 2000; *Riverside's Dilemma*; Groh, 2001; *Rice-a-Roni: A San Francisco Treat*; Watson, 2001), articles from the popular press about inventions and discoveries (example: *Who Owns the Geritol Solution*; Allen, 2002), science and society interactions (example: *To Spray or Not to Spray*; Dinan and Bieron, 2001), or landmark experiments (example: *Dating Eve*; White, 1995).

Harold White (Chemistry and Biochemistry) and David Sheppard (Biological Sciences) at the University of Delaware use problems that provide explicit models for research. In White's Introduction to Biochemistry course, students build their understanding of what biochemists have learned about a specific area of biochemistry by reading a carefully selected series of articles that document the history of the seminal experiments in the field. In a course required for biology majors, Sheppard asks students to mine research quality nucleic acid and protein databases to resolve problems about important recent experiments in the field of genetics. In both cases, students discuss and resolve these research-oriented problems, using the PBL process.

Although the sources of problems and the contexts for their classroom use may vary, PBL problems have common features (Duch, 1996). To be appropriate, problems should engage students' interest and motivate learning, require students to develop a line of reasoning that is backed up by evidence, be complex enough to motivate participation of a group of students rather than just a single individual, be open-ended enough at the outset to allow participation by all students, incorporate the learning objectives of the course and allow for many legitimate resolutions or many paths to a single resolution. These objectives are embedded in the problem, rather than posed separately or otherwise set apart by the instructor.

The problem “Riverside's Dilemma” (Groh, 2001) exemplifies the PBL process as it unfolds in a chemistry context. The problem, written for use in general chemistry courses, presents students with the dilemma faced by a town council that must decide on allowable limits for wastes flowing into a local river. In working on this problem, students encounter concepts related to the chemistry of weak and strong acids and bases, neutralization reactions and related equilibrium calculations. In Stage One, Riverside's town council receives a proposal from a multinational chemical corporation (Chemex) to buy several old, closed-down factories. The dilemma is that the old design of the factories would result in discharge of wastes directly into the river; retrofitting of the factories seems prohibitively expensive. Placed in the role of a consultant to the town council, students must consider the impact of these potential waste streams on the health of the river. Knowing the amount and types of emissions projected for each plant (various strong and weak acids and bases), students first determine what level of dilution of each waste stream would be needed to bring it to an acceptable pH value, then decide whether dilution would be an effective strategy. In doing so they are introduced to the concept of neutralization and its relationship to dissociation equilibria. In order to refresh students' memories of high school chemistry, the students complete a quiz - first as individuals, then within groups – on the basic terminology of acid-base chemistry.

In Stage Two of “Riverside's Dilemma,” students realize that dilution is not a reasonable solution because of the very large volume of water that would be required. They now must consider the feasibility of neutralizing the waste streams to achieve an acceptable pH range in the river. Students, still in the role of consultants, must consider the use of two relatively inexpensive neutralization agents and determine how much of the appropriate agent would be required. This stage helps students discover the relationship between neutralization and dissociation reactions. Stage Two, like Stage One, typically requires one 50 minute class period for resolution.

The third and final stage of the problem is the most difficult and open-ended. Students must pull together the material dealt with in the previous two stages to consider a more complex situation. The town council has requested that the student consultants evaluate the feasibility of combining some of the waste streams before they are released into the river in order to bring pH into the acceptable range. In addressing this problem, students must recognize which combinations of waste streams are possible, decide which combinations constitute neutralization processes and of these, which have equilibrium constants appropriate for the desired results.

A stage-by-stage account of how a biological problem (*Who Owns the Geritol Solution*) is worked out in the PBL classroom can be found in the University of Delaware's PBL Clearinghouse (Allen, 2002). This problem centers around John Martin's novel scheme to cure global warming by seeding the oceans with iron to harness the latent primary productivity of marine phytoplankton. The problem motivates students to research major concepts related to cellular energy transformations, biogeochemical cycles, global climate change, and marine ecosystems. "A Bad Day for Sandy Dayton" (Duch, 2000) provides an example for how an introductory physics problem is constructed and unfolds in the classroom. This problem is designed to help nonscience majors understand forces, motion and mechanical energy by reconstructing a rear-end auto collision that occurs outside their classroom. In doing so, they explore the relationship between speed and stopping distance, reaction time and stopping distance, and the design and safety features of seatbelts and airbags.

Several collections of problems (cited in a resource list at the end of this chapter) are available on-line for instructors who would like to use PBL. These include the University of Delaware's PBL Clearinghouse, which contains problems and teaching notes for the sciences and disciplines outside the sciences, Life Lines On-Line, a collection of introductory life sciences problems produced through collaboration between Southeast Missouri University and the BioQUEST Curriculum Consortium, The National Center for Case Study Teaching in Science's (State University of New York at Buffalo) collection of case studies which includes some appropriate for PBL instruction, a library of several hundred engineering case studies available through Carleton University, and a set of pharmacology problems written by P. K. Rangachari at McMaster University.

Books containing PBL problems are not common but a collection of problems with teaching notes for general biology (Allen and Duch, 1998) is available. There are also several books of case studies that provide ideas that can be adapted for use in PBL (see resources list). To be appropriate for PBL, the cases would need to be written in a format of progressive disclosure, and the content would have to be reduced so that students would be motivated to do independent research.

Monitoring Multiple Groups

The most daunting challenge is how faculty can 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). The facilitator should also prompt the group to dig deeper into content, ensure that students make connections and tie information together, keep students on track during discussions, help to locate resources, examine evidence that can be used to support conclusions, ensure that all students are involved in the process, model the process of giving and receiving feedback, and help the group learn to plot its own course. Clearly, few undergraduate classes are small enough that the instructor can be a dedicated facilitator of a single small group of students in this intensive fashion.

A roving facilitator strategy that is used in many cooperative learning settings, also works well in PBL classrooms. In this model the instructor walks around the classroom to observe groups in action, looking for signs of engagement with the problem and for the participation of all students in their group discussions. Typically the roving instructor poses questions that encourage students to dig more deeply into essential content or get beyond a conceptual impasse. The instructor looks for signs of behaviors that seem counterproductive to good group function and may enter into discussions when appropriate. This roving facilitator strategy works well with use of PBL problems constructed to provide natural break points that allow for insertion of instructor-led discussions. Whole class discussions at key intervals in the problem-solving process allow the instructor to provide feedback and model the process of evaluating resources, and analyzing and summarizing information. Groups that are moving at a substantially slower pace can benefit from hearing about their peers' progress, but care must be taken to prevent groups from intentionally piggy-backing on other groups' efforts. During these whole-class discussions, the instructor can provide, in a more structured and formal way, some of what the classic PBL facilitator contributes when s/he guides a single group.

Assigned roles of responsibility and drafting of group guidelines - strategies commonly used in cooperative learning classrooms - can also work effectively in PBL. The roles of discussion leader, reporter (for group products and class discussions), recorder, and accuracy coach (the "skeptic") may rotate among group members on a regular schedule or with each new problem. Students draft ground rules for effective group work that typically include their notions of acceptable attendance and preparedness, and include penalties for non-adherence that escalate with each incident.

Peer facilitators can also be effective as group monitors (Allen and White, 2001). Students who have successfully taken the course return to guide student groups as either a roving or dedicated facilitator, working alongside 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 in large classes 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 progress through the problem. The instructors typically choose to implement closely defined 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. Students are asked to make suggestions for policies and penalties for group guidelines. Group evaluations often include ratings of each other's contributions to assignments and products. Highly streamlined versions of the written and verbal feedback strategies used in smaller-class PBL (Barrows and Tamblyn, 1980) can be used.

PBL instructors of large enrollment classes also intersperse other classroom activities between the PBL problems. While the PBL problem often serves as the central focus, lectures, discussions, and short active learning activities associated with the problem are used to help students build conceptual frameworks. In "Who Owns the Geritol Solution Problem" a concept mapping exercise has been used. 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" for which the student group constructs a concept map. This helps provide timely feedback to both students and instructor about whether the major concepts evoked by the problem have been understood and synthesized.

PBL strategies for large classes include use of hybrid models in which, for example, four to six shorter problems are presented for each major content unit (Donham et al, 2001). In these hybrid models, traditional methods such as lecture are used to support the PBL instruction but do not supplant it. In these large classes, the problems typically are used in association with clearly defined final products, such as whole class debates, position papers, and mock town meetings, trials or congressional hearings, that are naturally embedded in the context of the problem. For instructors reluctant to commit to using PBL throughout the entire semester, even use of a single problem of several weeks duration can be effective (Hans, 2001). For instructors of large enrollment course who find the management of large numbers of classroom groups to be a daunting prospect, discussion, recitation or laboratory sections of the same course can provide the requisite smaller class setting for PBL. If using this strategy in conjunction with teaching assistants, however, care must be taken to select individuals who support the underlying goals and assumptions of PBL (Shipman and Duch, 2001).

Is there a limit to how large a PBL class can be? Shipman and Duch (2001) compared selected outcomes in a class of 120 with those in a class of 240 students. Their preliminary findings suggest that PBL can work in the class with the larger enrollment. Students reported that problem solving and group work enhanced their learning and helped 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 greater 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.

Assessment of PBL Outcomes

Faculty who use PBL instruction want students to develop skills such as the ability to find and analyze information from a multitude of sources, to engage effectively in self-directed study, to communicate well using diverse media, and to work productively with a group of peers. These goals are often assessed by comparing student performance several times during the semester at such tasks as giving oral presentations, writing reports, or answering exam questions. Classroom observations and peer evaluations of group performance are helpful in assessment of students' contributions to their groups.

Development of other skills, such as the ability to reason critically and creatively, and to make reasoned decisions in unfamiliar situations is not so easily assessed. Documentation of student attainment is hampered by the lack of instruments that have the sensitivity needed to detect changes in critical thinking (as defined by particular instructors or within particular disciplines) over the course of a semester.

PBL was not designed as a way to enhance content understanding alone, but the constructivist nature of its approach often invokes concerns about whether students are learning essential course content. Specific experiences with PBL (Kaufman et al, 1989), and meta-analyses of outcomes (Albanese and Mitchell, 1993) from PBL curricula in the medical school context have shown that content learning in PBL matches that in a traditional curriculum. Additional outcomes in PBL include greater retention of knowledge and greater satisfaction with the educational experience.

Data comparing traditional and PBL classrooms can be more difficult to obtain in the undergraduate setting, with its diversity of majors and tracks. Disciplines such as physics, for which national standardized surveys of content learning outcomes exist, provide some comparison data. Williams (2001) reports gains in force concepts inventory scores for a PBL course in introductory physics that are nearly twice those found in courses using traditional methods. This is a common finding for physics courses that use active learning methods (Hake, 1998). However, care must be taken in interpreting the outcomes of these scores or those from any multiple choice pre- and post-test, since they capture only one of the goals (content understanding) of PBL instruction, and because students in PBL courses typically do not encounter multiple choice tests in the course of the semester. Conversely, it would be inappropriate to evaluate students in lecture-based courses with instruments that assessed PBL's additional goals if these students had had little opportunity to practice these skills in their courses.

The University of Delaware recently completed a broad study on PBL outcomes that was funded by the Pew Charitable Trusts. This study sought to document the instructional use and impact of PBL at the undergraduate level. Preliminary results include the following findings (Bauer et al, 2002). Exposure to PBL positively and significantly affected the number and/or quality of student-faculty interactions, as well as the number of diversity-related experiences in which students participated. Exposure to PBL was defined as a composite measure of the number of PBL courses completed by each students and students' report of participation in several activities that collectively represent PBL activities in the classroom.

Discussion with students in structured focus groups offered further insights into students' learning experiences. Students indicated that the collaborative nature of PBL increased their level of comfort and inclusion in the class. In addition, students believed that their learning was enhanced because PBL increased their ability to consider, evaluate, and respect different points of view. They discovered that there might be more than one good answer to a problem or an issue developed within the context of a problem. The PBL setting helped students to apply theory to real world issues, made course content more interesting, and helped them to learn course content more thoroughly. Students also believed that their communication and interpersonal skills had improved as a result of participation in PBL courses.

While gains in critical thinking skills were measured (using standard instruments such as the Watson-Glaser Critical Thinking Appraisal), it was not possible to conclude that these changes were due to PBL, or to other aspects of the students' undergraduate experiences. Interpretation of findings was hampered by the presence of many different models of PBL instruction, including hybrid ones, on the University of Delaware campus, as well as the lack of a uniquely PBL curriculum track that could be compared to a more traditional track, as is the case in some medical school settings.

Institutional Costs of PBL Instruction

Transformation of courses to incorporate PBL strategies has some costs associated with it. Classrooms were refurbished 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. Other costs resulted from the additional demands placed on faculty time in the early phases of PBL adoption, when materials and activities were planned and developed. 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 members formed a PBL institute 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; 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, PBL allows more students and student hours to be engaged in educational activities that resemble those of a faculty-directed undergraduate research experience without the associated costs of such one-on-one faculty-student interactions. Nearly 100% of the science and engineering faculty at the University of Delaware already take undergraduate collaborators into their research and they are now serving as many undergraduate researchers as they can handle. Therefore, this classroom-based mode of student engagement in the discovery process effectively scales up research-based learning so that all undergraduates can benefit.

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 on a different model. Ideally in the PBL classroom, the instructor guides, probes, and support students' initiatives rather than lectures, directs, or provides 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 classroom authority to their students. Giving up the safety and authority of the podium 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 courses 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.

The '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 (http://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 with the support, resources and training needed to encourage them to transform their courses to incorporate PBL and related active learning strategies (Watson, and Groh, 2001). At last count (Watson, and Groh, 2001) over 200 faculty (65 in the SMET disciplines) from all colleges at the University of Delaware have participated as institute fellows. Over 30% of the faculty at the University have 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.

Elements that were crucial to the development of UD’s PBL program include a critical mass of individuals who were attracted to PBL’s underlying philosophies and committed to moving the program forward, our success at attracting external funding that helped to leverage support and validate the effort, a mechanism for preparing and mentoring other faculty in the new pedagogy and administrative support to help remove potential barriers to innovation and to make adequate resources available. Because these key elements were in place, PBL is now a byword on the University of Delaware campus. In fact, the PBL effort was cited in the summer 2001 alumni magazine as one of the university's top accomplishments of the past 10 years. What began as an effort 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 involving a community of learners in the essence of what scholarship entails.

The Institution

The University of Delaware is a mid-sized, research-intensive institution with approximately 15,000 full-time undergraduates, who are taught by about 1000 faculty members in 122 degree programs. Of the undergraduate students receiving degrees each year, 1671 received degrees from the College of Arts and Science, the largest college, 204 from the College of Engineering, 178 from the College of Agriculture and Natural Resources, and 380 from the College of Health and Nursing Sciences. Campus wide, approximately 10 percent of the student body participates in faculty-mentored research, although this number rises to 30 percent and greater in the basic and applied sciences.

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