

A PROBLEM-BASED LEARNING COURSE IN PHYSIOLOGY FOR UNDERGRADUATE AND GRADUATE BASIC SCIENCE STUDENTS

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In small-group problem-based learning (PBL), students work cooperatively to solve complex, real-world problems. The problems *lead* the students to learn basic concepts rather than being presented as applications of concepts they have already learned. The goals are for students to learn and be able to apply the disciplinary content, develop critical thinking abilities, and acquire skills of life-long learning, communication, and team building. PBL has been widely used in recent years in medical and related areas of professional education. In those settings each small group typically has its own faculty facilitator. PBL can be successfully adapted for teaching undergraduate and graduate basic science students, in part by having multiple groups meet in one room with a roving facilitator. This report describes a two-semester PBL sequence in organ-systems physiology. To keep the interest of a diverse group of seniors and graduate students, several types of problems were used: clinical, laboratory research-based, real-life scenarios, and published research articles. The majority of students have responded enthusiastically.

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Problem-based learning (PBL) has been widely used in recent years in medical and related areas of professional education (1, 4, 8, 13). It is also well-suited to teaching basic science students in their undergraduate and graduate years. Before adopting this new teaching strategy, I had often wanted to engage students more in class discussion, challenge them to pose their own scientific questions, and create a community of learners. In short, I wanted to give them a taste of the scientific process and the culture of science. PBL gave me a way to do all that.

In PBL (5, 7, 12), students work cooperatively to solve complex (deliberately ill-defined or open-ended) real-

world problems. The problems engage the students' curiosity and drive their learning. Students learn to ask critical questions, to identify what they need to know to answer their questions, and where to find answers. They then perform the needed research and bring the results back to the group. The faculty member facilitates the problem-solving process, functioning as coach and role model for the students' efforts and skill development. The problems *lead* the students to learn basic concepts rather than being presented as applications of concepts they have already learned. Compared with traditional lecture-based science courses, the learning that occurs in a PBL science course is more learner centered and less teacher centered.

The goals of this method of instruction are for students to learn and apply science content, develop critical thinking abilities, and acquire skills of life-long learning, communication, and team building. Life-long learning skills include, as a minimum, 1) identifying what one knows and does not know, 2) locating sources of information, and 3) organizing bodies of information. Whereas instructors usually engage in the last two in preparing a lecture, students have little experience in doing them. In addition, students who have spent much of their education sitting in lectures have little practice in *talking* about science. Numerous recent studies (9, 19, 20, 29) have identified a common set of skills and abilities as critical to almost any profession. This set includes the abilities to think critically and analyze complex problems; to find, evaluate, and use appropriate resources; to work in teams; and to communicate effectively both orally and in writing. PBL helps students develop all these abilities. In addition, it can transform a classroom into a place of lively activity, human interaction, and even, on occasion, joy.

In medical and other professional schools at which small-group PBL is used, each group (typically 5–8 students) meets with its own facilitator in a separate room or even at a separate time from other groups. Because undergraduate and graduate science programs cannot usually provide that kind of resource, a different format has been adopted (2, 14). Multiple groups (usually 4–6 students per group) meet in one large room with one or more roving facilitators, and small-group work is interspersed with whole class discussion.

This paper describes a two-semester PBL sequence in mammalian physiology, taught using both formats at different times. There are advantages to each format, as will be described later. A preliminary report of this course appeared previously (18).

ORGANIZATION OF COURSE

Advanced Mammalian Physiology is a two-semester graduate-level sequence. It is a survey of organ-systems physiology taught to seniors and graduate students; it has a prerequisite of a one-semester undergraduate course in mammalian physiology. Beginning in 1992 the course was taught using a small-group, student-centered PBL approach. From 1992 to

1995, each small group of eight students had its own “dedicated” faculty facilitator, and the two groups met simultaneously in different rooms. Subsequently, student enrollment increased with no increase in the number of available faculty facilitators, necessitating modifications in the format. Hence, beginning in the fall of 1995, six groups of five students each met in one specially designed PBL classroom, with two “roving” facilitators. [There are now several classrooms at the University of Delaware appropriate for teaching with small groups. These rooms have small tables, comfortable mobile chairs, blackboards on as many walls as possible, and storage cabinets for resource materials (14).]

The students served by this course were from three main groups: 1) graduate students in physiology and related fields, 2) seniors in the Medical Scholars Program (see below), and 3) senior biology majors, commonly those with an interest in clinical and/or research careers. Most of the students in the class have been seniors. Development of the course using PBL was motivated in part by an article in *Advances in Physiology Education* (24) and by development of the Medical Scholars Program (7), a joint program between the University of Delaware and Jefferson Medical College. When the program was planned, PBL was to be incorporated at both universities, in part, to foster independent thinking and improved communication skills between physicians and patients.

Class met twice a week for 2.5 hours each session. The students remained in the same group the first semester (14–15 weeks), with new groups formed the second semester. There were three content units per semester, with different facilitators for each unit. This meant that each faculty member facilitated for ~5 weeks. Students were assigned to the groups so that each group was as heterogeneous as possible with respect to gender, age, educational level, career interest, and racial or ethnic background.

The role of the faculty member in small-group, student-centered PBL is to facilitate group members' interactions and inquiries. The facilitators were drawn from a pool of basic scientists and clinicians at the University of Delaware, Jefferson Medical College, the Medical Center of Delaware, and occasionally nearby industry. Whenever possible, a basic scientist and a clinician

were paired for a unit. The facilitators participated in a 3-day tutor-training workshop offered by the Center for Teaching Effectiveness at the University of Delaware (14). In addition to content knowledge of the discipline, PBL facilitators in general need a set of skills different from those required of a lecturer, and therefore the training makes a big difference in the success of the course. Skills and qualities required to facilitate a group include the ability to listen, restraint in *not* giving the answers so that students can engage in their own learning process, monitoring the group dynamics and knowing when to intervene and when not to intervene, challenging students' understanding of scientific concepts without dominating the tutorial group, a willingness to acknowledge one's own ignorance, giving feedback, managing conflicts, and empowering students rather than always holding the reins of control (3, 4, 17, 27, 28). The facilitators and course director usually met once a week. At those meetings a content expert coached the others through the problem being covered (as needed) and answered questions on the related physiology. Facilitators discussed their groups' approaches to a problem with respect to both the science content and the group dynamics.

THE TUTORIAL SESSION

For those unfamiliar with the tutorial process, I will describe a tutorial session as practiced in this PBL physiology course. The students were assigned to relatively permanent heterogeneous groups. At the beginning of a new problem, the students in their small groups read through the first page of the problem in class. They brainstormed what they needed to learn in order to understand the problem, come up with a diagnosis, or answer any questions posed in the problem. These topics were written on the blackboard as a list of "learning issues." At this stage little or no judgments or priorities were attached to the topics. Students defined terms, reviewed what they already knew about the subject, and posed hypotheses. Particularly at the beginning of a new topic, and if the students had not done any preparatory reading, this session tended to be a combination of insight and ignorance and could appear chaotic. However, this session played a key role in helping students remember what they *already* knew about a topic so that they had a context for new learning (21). At this stage, restraint on the part of the facilitator was required to

not correct all the students' errors; the students usually corrected their own mistakes in the next session or two. The problems were designed to be used as springboards for discussion of basic normal physiology; students were encouraged *not* to focus solely on a diagnosis or on one "right" answer to a specific question posed in the problem.

The PBL faculty member, called either a tutor or a facilitator in the literature, plays a variety of roles. Most faculty think of themselves as content experts but not necessarily as guides or facilitators. Hence, in this paper I use the term facilitator to remind ourselves of that function. Mayo et al. (17) distinguish between *facilitator* and *activator*. My use of the term facilitator is not meant to connote passivity. However, without training in facilitation skills and group dynamics, and without occasional reminders, some PBL instructors tend to use a method of questioning in which the instructor becomes the primary focus of attention in the group. When used as the primary mode over long periods of time, this more familiar questioning method can take control of the agenda away from the students and thus may not be conducive to learner-centered learning.

Near the end of the class period, the students examined their list of learning issues. Some items had been answered or seemed less significant in light of the ensuing discussion. The students then prioritized and decided how to deal with the issues they kept. In some cases each student learned about every issue; at other times students distributed the topics among themselves. They also discussed where to go to find the information, whether to textbooks, monographs, articles, or experts in the field. The facilitator guided the students through the process of assessing and assigning learning issues, although less guidance was usually needed as the semester progressed. The students were learning how to organize a body of information, a major skill that develops only with time and practice.

Between classes the students studied from textbooks or from other sources. At the next tutorial session, they discussed with each other what they learned and integrated the new information into their understanding of the problem. When they and the facilitator were satisfied with the level of understanding, the group

turned to the next part of the problem, and the cycle began again. The process was indeed cyclical because when students discussed what they had learned from their reading, they found that some points were confusing or contradictory and led to further learning issues. Reading was not "assigned," because one of the goals is for the students to learn how to identify appropriate resources. Usually the source of apparent contradiction was different interpretations by different students. However, sometimes there was conflicting information among references. These instances presented opportunities to discuss how to assess the reliability of sources.

The role of the facilitator in this stage was to ask questions that helped students probe their knowledge or that pointed out contradictions, and to monitor the group dynamics to ensure that everyone had a chance to participate. Although the best learning tended to occur when the learning issues were specific and focused, students often read more than the minimum required for their assigned learning issue(s). The problem often pulled them in and students kept reading. Students sometimes reported that they studied more for this course because they were interested in the subject and wanted to be prepared for questions from their peers. I deem those motivations more relevant to establishing the habits of life-long learning than simply studying to pass an exam.

At the end of each class meeting or of every few meetings, the students discussed how they were functioning as a team and gave each other feedback. This will be described in the section on evaluation.

The last page of each problem usually listed the learning objectives for that problem. The students and facilitator decided how close their list of learning issues was to the list given in the problem and whether any further study or discussion was warranted to fill in gaps. The given list of learning issues was not meant to be all encompassing; groups could and often did pursue relevant topics that interested them beyond the minimal learning objectives included there. When the group (in the case of the dedicated facilitator format) or class (in the case of the roving facilitator format) and the facilitator(s) were satisfied that they had completed a problem, they proceeded to the next problem. Both students and

facilitators knew how many problems were to be covered in a given time period and could manage their time accordingly.

THE PROBLEMS

For guidance in writing the problems, authors generally found it useful to start with a list of learning objectives to be covered on that topic. To keep the interest of a diverse group of students and to provide different contexts for thinking about physiology, several types of problems were used: 1) clinical case studies, in which students learned the underlying normal physiology while arriving at a diagnosis; 2) laboratory research-based problems, in which students were presented with experimental findings and asked to design hypotheses and experiments to test them (24); 3) scenarios, for which students were required to explain the relevant physiology; and 4) published articles (26) from physiology journals. Table 1 lists the problems.

For a clinical problem, the most common type for this course, the patient's symptoms would typically be given on the first page. Subsequent pages would give medical, social, and family history, results of a physical exam, laboratory tests, and possibly exhibits (X-rays, micrographs, etc.). At each step, students formulated or prioritized hypotheses, proposed questions for the patient or tests to be conducted, and assessed hypotheses in the light of new data. When a published article was used as the basis for a problem, the students were given the article ahead of time with several questions to answer based on the article and possibly some historical background. Within their group they made a list of topics they needed to know more about to answer the questions and understand the article. This list constituted the learning issues. The students might also critique the article or propose further experiments. Using published articles as problems gave the undergraduates in the class experience working with the primary literature.

The problems were critiqued each year in two ways. 1) At the end of a problem, each group jointly filled out a brief questionnaire on what the students liked about the problem and recommendations for revision. 2) An end-of-semester evaluation form asked students which problem they liked most, which they liked least, and why. Preferences varied from one student to

TABLE 1
PBL problems for Advanced Mammalian Physiology

Problems were selected from this list. Not every problem was used every year.

Only very general content objectives are given here so as not to spoil the challenge of PBL for anyone who tries these problems.

1) David Haskins
A 61-year-old man has aches in his neck, back, thighs and calves, and numbness and tingling sensations in his fingers and toes, following a low grade infection. Today he is having trouble walking.
(Written by S. Mierson; nerve conduction)

2) Xeno-Neuroscientist
You have obtained a fictitious creature from Venus and set out to design experiments to characterize the determinants of the creature's nerve resting potentials.
(Written by S. Mierson and S. Grant; membrane transport)

3) Synaptic Transmission
Students read and discuss a classic paper on the role of calcium in neuromuscular transmission.
(Written by S. Mierson; neuromuscular junction)

4) The Caveman and the Bear
A caveman is attacked by a bear, is injured, fights, and escapes. Students are required to explain the underlying neurophysiology.
(Written by S. Siegel; autonomic nervous system)

5) Natalie Gradinkov
A 22-year-old ballerina has increased hair growth on her lip and chin, high blood pressure, and restlessness during sleep. She recently has trouble making some of the dance jumps she used to make routinely.
(Written by G. S. DeCherney; hormonal feedback loops)

6) Mr. Balatinsky
A 67-year-old retired factory worker is getting up 3 or 4 times in the middle of the night to urinate. He is thirsty and hungry all the time and is overweight.
(Written by G. S. DeCherney; more hormonal feedback loops, molecular mechanism of action of hormones)

7) Tom and the Dairy Farm
Your brother-in-law Tom has just come into a large inheritance. He decides to fulfill a life-long dream of dairy farming but runs into one difficulty after another thanks to his ignorance about mammalian reproduction. He calls you in as a consultant.
(Written by M. Watson-Whitmyre; male and female reproductive physiology)

8) NMS Pharmaceuticals
When he retires after 30 years as a family practice physician, Dr. Thomas T. Tubule establishes a biotechnology company specializing in the discovery of novel treatments for skeletal muscle diseases. The students either assess or take part in formulating the research plans.
(Written by B. S. Brown; skeletal muscle physiology)

9) Vernon James Acosta
A 27-year-old male waiter has trouble swallowing, pain in his lower chest, and occasional regurgitation. The symptoms are getting worse, and now he is losing weight.
(Written by W. R. Galey, for the Primary Care Curriculum at the University of New Mexico School of Medicine; smooth muscle contraction, physiology of swallowing)

10) Dwayne Mackler
A 45-year-old attorney has chronic epigastric pain and diarrhea with bulky, smelly stools. He is losing weight despite eating well and frequently, even though he used to be overweight.

TABLE 1
(Continued)

10) Dwayne Mackler (cont.)
(Written by W. R. Galey and S. Mierson; revised from a problem written for the Primary Care Curriculum at the University of New Mexico School of Medicine; gastric acid secretion, intestinal absorption and digestion)

11) Intestinal Absorption
Students discuss a laboratory experiment using intestinal loops from a rat. They predict and then interpret data testing for absorption or secretion of various substances by the small intestine.
(Written by S. Mierson; adapted from a laboratory experiment in the M-I Physiology course at the Medical College of Virginia, Virginia Commonwealth University, written by John A. DeSimone and Jack Grider; osmotic pressure, intestinal absorption)

12) Cardiac Blood Flow and Electrical Activity
A 63-year-old commercial airline pilot has a myocardial infarction. After she recovers, she admits that her diet is a bit rich from eating out frequently and her exercise irregular; she blames this on her travel schedule.
(Written by R. E. Waterman, S. Obenshain, and G. Stephens; revised from a problem written for the Primary Care Curriculum at the University of New Mexico School of Medicine; title describes topic)

13) Cardiac Hemodynamics
A 3-month-old baby boy has been eating poorly, breathing rapidly, and sweating a lot for the last few weeks. He seems tired and sleepy all the time.
(Written by M. Bhat; title describes topic)

14) Blood Pressure Regulation
A 45-year-old male corporate executive has hypertension.
(Written by T. Spalding, B. Woodside, and D. E. Allen; revised from a problem written for the Primary Care Curriculum at the University of New Mexico School of Medicine; title describes topic)

15) Daniel Carter
A newborn infant born by C-section has trouble breathing.
(Written by R. Vidal; alveolar ventilation and pulmonary mechanics)

16) Effect of Salt Water on Lung
Students read and discuss a paper on the subject to learn both physiology concepts and analysis and assessment of a published study.
(Written by V. G. Vernier; osmosis)

17) Erica Johnson
A 20-year-old woman is diagnosed with cystic fibrosis.
(Written by R. Vidal, based on a case written by J. J. Goodill; membrane transport and cystic fibrosis)

18) Mark Johnson
The school nurse notices a pink coloration and frothy appearance in the urine sample of a 12-year-old boy in a routine in-school health screening.
(Written by G. Lavery; renal glomerular filtration)

19) Concentrating Engines in the Desert
Students are asked to solve an apparent paradox about the comparative physiology of renal function.
(Written by G. Lavery; concentrating mechanism in the kidney)

20) Tiny Tim
A few years ago the press reported on a paper written by a pediatrician, who attempted to construct a hypothesis for the underlying pathological condition of Charles Dickens' "Tiny" Tim Cratchit. The physician concluded that Tim suffered from a form of metabolic acidosis.
(Written by G. Lavery; acid-base balance)

Course director: S. Mierson.

another. Often the same problem was one student's most favorite and another's least favorite. Some students preferred problems that were more well defined because the learning issues were clear; others preferred problems that were more open ended because it gave them a chance to read extensively about topics that interested them. Our strategy was to preserve a mix of problems. Periodically, some of the problems were revised or replaced on the basis of students' and facilitators' assessments.

COMPARISON OF FORMATS

The PBL format using small groups with dedicated facilitators, as is most common in medical schools, has been well documented in the literature. The use of roving facilitators is less common, so a brief description is in order (2, 11, 16). The students have roles that rotate on a regular basis. These roles can include discussion leader, scribe, and group reporter as necessary functions, plus any combination of skeptic, summarizer, accuracy coach, participation coach, and/or process consultant. (Students can assume these roles under the dedicated facilitator format as well, but the structure is more important when a facilitator is not always present.) Class time was divided between small-group work and whole class activities. On some days for whole class activities, we collected and discussed questions the groups were unable to answer or we compiled everyone's learning issues. Usually the facilitators identified a couple of general learning issues for all the students to study. On other days we had the groups compare answers to particular questions in the current problem, or we posed a question to help all the groups organize or place in context the material related to the problem. On still other days we had the groups draw concept maps (6, 22), or we discussed some aspect of small-group skills.

I found it useful to have each group select a group liaison for the semester. In my role as course director I met with all the liaisons approximately once a month during the lunch hour. The official job of the liaison was to bring any problems or concerns of the group to the course director or to one of the facilitators. The unofficial job was to help their individual groups function better. At our meetings the liaisons exchanged information about strengths and difficulties of their groups and gained ideas from each other

about the group dynamics. The meetings gave me information I needed to be of more assistance to the groups as well as a source of advice for making decisions about the course.

Because I now have several years of experience with small-group PBL using each format, dedicated facilitator and roving facilitator, I can compare the two. Each format has advantages. This was a surprise to me; I did not anticipate that the roving facilitator format would make some aspects of the course easier or more effective. Here are some of the advantages of each format.

Dedicated Facilitator

- 1) I got to know the students well in the group I was facilitating. Because as course director I took a turn facilitating each group, I eventually got to know all the students.
- 2) I was more likely to be aware of the group dynamics of the particular group I was facilitating.
- 3) There were more opportunities to model the types of questions that would help a group probe for a deeper level of knowledge.
- 4) I could more easily challenge the group I was facilitating to deepen their understanding of a particular topic.
- 5) I had many opportunities to become alert to conceptual errors a group was making about the content.
- 6) I could reinforce desirable behavior in the group.

Roving Facilitator

- 1) I came to know all the students in the class much sooner, although not in the same depth as when I was a dedicated facilitator.
- 2) The student groups became self-sufficient much earlier. The students took more responsibility for their own group dynamics.

3) The logistics were simpler. The small seminar rooms we used for the dedicated facilitator format were often in different buildings, and announcements or distribution of printed materials often involved trips across campus. With all the groups in one room, coordination of groups and materials was more straightforward.

4) There were opportunities for short mini-lectures on topics that were confusing to all the groups and for end-of-problem wrap-up discussions involving all the groups.

5) There was more opportunity for formal exchange of ideas about the content among groups. This exchange was often rich and productive.

6) There was also the opportunity for exchange of ideas about group process among the groups.

7) If one of the facilitators was a content expert in a particular area, all the groups had some access to that person.

Here is an illustration of one of the differences between the two structures, i.e., how self-sufficient the groups became. At the end of the *second* week of the first term, in a semester with roving facilitators, one group discussed the role the facilitator played. They noticed that the facilitator frequently asked questions such as "How?" and "How does that work?" and "Can you explain that?" and "How do we know that?" One student said that although they wanted a facilitator present all the time, they had come to realize that there might be advantages to *not* always having one there. They had to ask each other those types of questions, and indeed they were beginning to do so. My observation was that this transition to asking their own questions took longer with a dedicated facilitator.

EVALUATION

Evaluation of Students

To reflect the diversity of skills emphasized in the course, and to give students with different strengths a chance to demonstrate their skills and knowledge, grading was based on several forms of assessment.

These included 1) exams, 2) problem summaries, 3) papers, and 4) participation in the tutorial groups. The assessment methods were modified from those described by Rangachari (24) for an undergraduate course in pharmacology.

Exams. Various types of exams were used at different times. We used several versions of the triple jump exercise (10, 15, 23, 24), which was designed to assess *how* students approached a problem in addition to *what* they knew. In one version, students provided hypotheses for a given set of experimental observations, designed an experimental test for one of their hypotheses, and then reassessed their initial hypotheses and experimental tests in light of new information. In another version, the students were given a new clinical problem or a scenario; each student was asked to write two main learning issues. The faculty then wrote questions on those learning issues. The students had from several days to one week to prepare outside of class, during which time they could work with their peers. They then took an individual in-class written exam on the questions the faculty had prepared; not all students answered the same questions. In one modification we made of this triple jump, several main learning issues were chosen from those compiled from student responses and were assigned to all the students, and all the students then individually answered the same set of questions. Alternatively, we assigned the learning issues with the initial problem; this was more teacher centered but made the faculty time more manageable.

We have also used an exam with more traditional short-answer and essay questions. In some cases the students were given essay questions 1 week ahead of time. Only some of the questions were actually used, but the students did not know in advance which ones. They then wrote their answers individually in class on the selected questions. In response to student requests, there was opportunity in all these exam types for the students to work with their groups, either in preparation for the exam or during part of the exam itself. In the first semester of teaching this course, the first exam was entirely individual. The students pointed out that this was inconsistent with the emphasis on collaborative skills in the course, so, in keeping with

course objectives, we modified the exam format to have both individual and collaborative components.

Summaries. The students prepared short written summaries of the physiology they learned from each problem. The summaries were two pages single-spaced in length, covering three to four learning issues and a discussion of the relationship of those topics to the problem. This assignment was designed to give the students experience in writing about scientific content and to assist them in integrating the information they learned. In some semesters the summaries were done individually. Other times they were done as a group, in which case the writer rotated among group members.

Papers. Several types of papers were assigned in different years. The first was a written critical analysis of a published paper (25). The second was a new problem that could be used for a similar PBL course, complete with teaching notes containing background information about the science content. The third was an update of a topic related to one of the problems covered in the course (suggested by D. E. Allen), accompanied by an annotated bibliography on the topic.

Participation. Participation in tutorial groups was evaluated both orally and in writing. The students and facilitator usually discussed their functioning as a group for the last 10 min of each meeting; once each unit they had a longer in-depth oral evaluation led by a facilitator. The students evaluated each other and themselves numerically in writing at the end of each unit ($\frac{1}{3}$ of a semester); each student's scores from the other group members were averaged. Written comments were collated anonymously and given to the student. Because giving feedback in a manner likely to be useful to the person evaluated is a new skill for most students, they were taught this skill during the course. Because it is also new for most faculty, delivering feedback was a topic included in the facilitator training workshop. Although most students were initially uncomfortable with both giving and receiving feedback, most became more comfortable and more skilled at it as the year progressed. A number of students commented in end-of-course evaluations on the helpfulness of this feedback in improving their

performance in their group. The skills of evaluating their own and their peers' performance are valuable for any professional and are not likely to develop to the same extent when the main evaluation tool is a grade from the professor.

Evaluation of Facilitators and Course

Students evaluated the facilitators verbally throughout the unit and in writing at the end of the unit. Ongoing feedback usually proved helpful to improve the facilitators' functioning. The immediate feedback provided in the small groups was generally more useful and satisfying to the facilitators than the end-of-course written forms common to university courses, although this ongoing feedback could also be frustrating at times. Most facilitators were evaluated positively by the students in the written evaluation forms. Students let us know when we reverted to lecturing, thereby negating the active and learner-centered aspects of the course. We expected the students to value the learner-centered aspect over the "convenience" of faculty lectures by the end of the first semester or in the second term, but in fact it occurred very early in the first semester.

The end-of-course evaluation form was modified from the standard departmental form. Because the students had several facilitators over the course of the semester, the end-of-semester form focused on the course as a whole rather than on the individual facilitators. Course evaluations were always positive. Table 2 lists student responses for the dedicated facilitator format, compiled for a three-year period (1992–1995). The responses to some of the items showed improvements in ratings between *term 1* and *term 2*; however, these changes were not statistically significant. In addition to the items listed in Table 2, items were included on the evaluation form of the type "I have a good understanding of the basic principles of [blank]," where the blank was filled in with "membrane transport," "endocrine physiology," etc., for each organ system covered during that term. With two exceptions, all items elicited an average response between 1 and 2 on a scale of 5, where 1 is the most positive. The exceptions were the items about exams and about the grading scheme (*items 12 and 13* in Table 2). We modified both the type of exams and the grading scheme from one semester to another. However, the

TABLE 2
Student evaluations of the course

Item*	Term 1 (n=38)†			Term 2 (n=28)		
	Mean	±SD	Range	Mean	SD	Range
1 The course helped me learn to obtain information from a variety of sources.	1.3	0.6	1–3	1.3	0.6	1–3
2 I feel that I can apply the general principles I learned to other physiology problems.	1.4	0.8	1–5	1.2	0.5	1–3
3 I am comfortable with working in groups.	1.6	1.0	1–5	1.3	0.7	1–4
4 I do not feel reluctant to confess my ignorance on specific issues.	1.6	0.8	1–4	1.6	0.9	1–5
5 I am confident that I can analyze a physiology problem.	1.7	0.7	1–4	1.5	0.5	1–2
6 I am confident that I can set appropriate learning objectives.	1.7	0.7	1–4	1.4	0.6	1–3
7 I feel comfortable sharing information with others.	1.3	0.6	1–3	1.4	0.6	1–3
8 I feel comfortable in asking for help from others.	1.7	0.8	1–3	1.6	0.8	1–3
9 I can assess my own performance adequately.	1.8	0.7	1–3	1.6	0.7	1–3
10 I can assess the performance of my peers adequately.	1.8	0.6	1–3	1.9	0.7	1–4
11 I can evaluate new information and reassess my knowledge.	1.7	0.6	1–3	1.6	0.5	1–2
12 I think that the exams were an appropriate way to measure the skills that I developed in the class.	2.4	1.1	1–5	3.4	1.4	1–5
13 I think that the grading scheme in this class fairly reflects the objectives of the course.	2.0	1.0	1–5	2.5	1.2	1–5
14 The written problem summary helped me relate the concepts covered in that problem.	1.7	(n=36)	1–4	1.7	1.0	1–5
15 Compared to other courses in my major, I learned: 1=much more than usual, to 5=much less than usual.	1.7	1.0	1–5	1.3	0.6	1–3
16 On the whole, the amount of effort required in the course was: 1=greater than usual, to 5=less than usual.	1.4	0.6	1–3	1.3	0.5	1–3
17 Overall, I would rate this course: 1=excellent to 5=poor.	1.7	1.0	1–4	1.4	0.5	1–2
18 If given an opportunity, I would like to take another PBL class.	1.8	1.0	1–5	1.5	0.7	1–3
		(n=37)				

Students responded using a 5-point scale. Except where noted otherwise, the scale was from 1 = strongly agree to 5 = strongly disagree. These values were compiled for a 3-yr period using the dedicated facilitator format. *Items 1–11 were modified from Ref. 24. †The total number of students enrolled over a 3-yr period (1992–1995) was 44 in term 1 and 31 in term 2; 38 students in term 1 and 28 students in term 2 responded to the items, except where noted otherwise.

resulting ratings on those two items did not vary much over time.

For the subsequent two years (1995–1997), using the roving facilitator format, the ratings on end-of-course evaluations were similar to those in Table 2. The term 1 values were compared between the two formats, and the same was done for term 2 values. Table 3 shows only the items for which there was a statistically significant difference between the two formats. The values for all three of these items favored the dedicated facilitator format; however, all the values for both formats were better than the midpoint for the scale used. Note that these were self-reports from the students, not external measures of student achievement. Because exam format differed significantly from

one year to another, comparison of exam scores was not deemed valid.

The course evaluation form always included open-ended questions. Both positive and negative samples from students' answers are in Table 4. The negative comments stimulated us to refine and improve the course. They also stimulated us to support the students better to make the course a successful learning experience for them. The positive comments helped confirm that we were meeting the course objectives. The comments also reminded us of why we are teaching, and they inspired us to continue. Enough of these sorts of positive comments appeared each year on course evaluations to assure us that many of the students appreciated both the skills they

TABLE 3
Differences in student evaluations between dedicated facilitator format and roving facilitator format

Item*	Dedicated Facilitator Format (1992–95)			Roving Facilitator Format (1995–97)			Two-tailed P Value
	Mean	±SD	Range	Mean	SD	Range	
18 If given an opportunity, I would like to take another PBL class.†	1.5	0.7 (n=28)	1–3	2.2	1.1 (n=36)	1–5	0.003‡
19 I have a good understanding of the basic principles of membrane transport.	1.5	0.6 (n=38)	1–3	1.8	0.6 (n=44)	1–3	0.04§
20 I have a good understanding of the basic principles of acid-base balance.	1.6	0.6 (n=28)	1–3	2.0	0.7 (n=36)	1–3	0.01§

Students responded using a 5-point scale from 1 = strongly agree to 5 = strongly disagree. Only items with statistically significant differences between the 2 formats are included. *Items 19 and 20 were modified from Ref. 24. †The comparison for item 18 was for term 2 only. The difference in scores between the 2 formats for term 1 (item 18) was not statistically significant (dedicated facilitator format: 1.8 ± 1.0 , $n=37$, range 1–5; roving facilitator format: 2.0 ± 1.0 , $n=44$, range 1–4). The comparisons for items 19 and 20 were for the term that included the unit on that topic (term 1 and term 2, respectively). ‡Welch's *t*-test. §Student's *t*-test.

learned in PBL and the access to faculty in their small groups.

SOME FINAL COMMENTS

Participating in a learning group, when the group is functioning at its best, can be rewarding and even exhilarating for the facilitator and for the student. The facilitator watches the students struggle with information and observes how they think. Some of the learning that is invisible in a lecture class becomes visible in watching a PBL group at work. There is nothing quite like listening to an animated scientific discussion among students or observing their pleasure in their own and each other's growing skills. It is not uncommon to see a gleam in the eye of a student who previously used the library only for assigned reading and now comes to class with a half-dozen primary references on a topic that piqued his or her curiosity, or to walk into a classroom a few minutes late and find the entire class already in session. However, others have issued a warning here, and it bears repeating: "Self-directed problem-based learning is not a panacea.... Students (and facilitators) must be flexible enough to realize that there will be good days and bad days, and a stimulating dynamic tutorial may be quickly followed by a dreary one.... This intense involvement can be quite draining, and there are times when even the most ardent devotee of problem-based learning longs for a return to a simpler style" (24). Part of what can make PBL groups both so exhilarating and so draining is precisely that they are *groups*, subject to all the joys and difficulties inherent in group dynamics.

With that caveat in mind, I believe that the rewards of facilitating learner-centered active learning can be immense.

I include a note about faculty development workshops. Barrows (4) writes, "Teachers have to see problem-based learning in action, talk to students, and—most important—try it themselves." Before I saw PBL for myself the first time, I had talked to people about it and read about it. It was not until I *experienced* it that I understood what generated all the excitement. In introductory PBL workshops, participants either observe real students in a tutorial group or act as students in a tutorial group to experience the process themselves. Analogous to the process of active learning, solely reading *about* PBL is not a substitute. Similarly, there is no short-cut to the hands-on learning and practice provided by a workshop for developing a new set of skills. The process of learning in a group and of experiencing it for themselves, as students have in a PBL classroom, can also benefit the faculty by making them more self-aware and more effective with the students (28).

I have found, as have many of my colleagues, marvelous intellectual and personal satisfaction from PBL, and I would be loathe to return to traditional ways of teaching. The collaborations among students, between students and faculty, and among faculty represent the kind of learning community that I first sought in an academic career.

TABLE 4
Sample student comments on the course

Most of these comments, collected from 1992–1997, were in response to open-ended questions on end-of-course evaluation forms. A few were oral or other written comments given either at that time or later.

General

1. The class was one of the most enjoyable and useful classes I have ever taken. PBL changed the way I approach my research projects. I learned to be a more effective and efficient worker. Consequently, I am more productive and have more free time than I had in the past.
2. I am doing a co-op job this semester, where I spend one day a week with a primary care physician. Each week he assigns me a topic related to the condition of one of the patients I have met, and I am to prepare a 1- to 2-page report. It's just like B605. I would have been lost without the PBL course.

What aspects of this course contributed most to your learning?

1. Being able to talk and ask questions about material I read helped me learn.
2. I liked the fact that we had to find the answers for ourselves as opposed to having them found for us.
3. I learned how to use resources and teach myself. Also I learned how to question what I hear, not blindly accept.
4. Having to explain information to others. Being able to do this either showed I really understood the concept or exposed a flaw in my thinking and corrected it then and there.
5. Gained self-esteem. Learned to communicate with different individuals. How to study and go about learning the material.
6. Taking personal responsibility for learning material.

What aspects of this course should be changed to make the course better for you?

1. I think that a lecture component would be useful. Either as an introduction to a system or as a wrap-up of a problem.
2. Demand that everyone be in the course for the right reasons or else their lack of enthusiasm for PBL affects the entire group.
3. Less evaluation of each other.
4. I wish the exams were a little different. I feel they were not as representative of what I learned as they could have been.
5. Better training of tutors, some of them were excellent, yet others didn't seem to grasp the concept of PBL or over-dominated group discussion.
6. Plan adequate time for all problems throughout the semester.

What special issues, concerns or questions do we need to know about to plan this course in the future?

1. Grading seems a little ambiguous—a large percentage of it is highly subjective.
2. More help in finding resources; clear-cut expectations of studying and research.
3. At times I felt as though, even though I learned more detail than I may otherwise have, I was still at somewhat of a loss for the basics of a system.

TABLE 4
(Continued)

4. I think the smaller the group, and thus, the more pressure put on each individual, leads to better learning and group dynamics.
5. Some people are very intimidated working in groups and expressing what they know. Especially when the first time you've learned something was when you just read about it in the textbook.

Have the skills learned in this class made a difference in your other academic or social situations? If so, please give examples

1. I learned to say "I don't know." I had never heard a professor say that before, and it was an eye-opener.
2. I had never thought before taking this course about the importance of giving praise. I now use praise working with children in a clinical setting, and I can see the difference.
3. I have become more confident in working as well as speaking in groups. I learned how to attack a problem and apply the necessary research to find a possible answer or solution. I feel the skills learned in this class will benefit me greatly in graduate school.
4. I now feel more willing to ask questions in a class and more comfortable using primary sources.
5. I am looking to other sources for more information in other classes. I am starting to get less defensive when confronted by another student who challenges me.
6. I have learned how to include others and encourage them to work at maximum capacity.... This class encouraged me as well as others to work together in other classes.
7. Keeping quiet and listening to what others have to say.
8. Yes, the use of databases made it much easier for me to go in and use them for a political science project. I also feel I've gotten a lot closer to my classmates, this is great.

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