A Problem-Based Learning Approach to Teaching Introductory Soil Science

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ABSTRACT

At most land-grant universities in the USA, Introduction to Soil Science is traditionally taught using a combination of lecture and laboratory formats. To promote engagement, improve comprehension, and enhance retention of content by students, we developed a problem-based learning (PBL) introductory soil science course. Students work in groups to solve five real-life problems during the semester for approximately five class periods each. Every problem is contained within a study unit that has learning objectives, relevant resources, as well as a description of the problem. As students work through problems, they go through a PBL cycle of: (i) understanding the question, (ii) identifying what they know and do not know, (iii) finding the information they need, (iv) sharing new information, and (v) identifying new questions. Each group produces a synthesis paper describing their approach and solution to the problem. Tests are based on the learning objectives and students can recapture points by explaining wrong answers. They can also revise synthesis papers. Most students reported improvement in verbal and written communication skills, ability to interact in groups, and problem solving skills. They identified writing and revising synthesis papers, and preparing for, taking, and revising exams as very helpful in learning course content. More than three quarters of students indicated a positive response to the PBL format for Introduction to Soil Science. Exam scores for students taught using PBL were 1 to 8 percentage points higher than those taught earlier by the same instructor using traditional methods.

INTRODUCTORY SOIL SCIENCE is traditionally taught using a combination of lecture and laboratory sections. Lecturing offers a number of advantages (Little and Sauer, 1997): it is a time-honored teaching approach (thus enjoying automatic legitimacy), the content and structure of lectures are easily derived from published curricula and textbooks, and it allows optimization of numbers of students taught relative to resource needs. The effectiveness of lecturing as an educational approach has, however, been called into question for at least a century (Osler, 1913). A number of studies indicate that lecturing is not a particularly effective teaching format: it encourages passive learning, results in poor information retention, and does not develop higher-order inquiry and thinking skills (Lord, 1994; Ahern-Rindell, 1999; Crowther, 1999).

Our lecturing experience to more than 1000 introductory soil science students over the course of 9 years at the University of Rhode Island supports the observation of others, that there is limited learning in lecture courses. Students listened quietly, most took notes diligently, completed problem sets, and took tests. The instructor received high marks for the course. Learning appeared to be taking place. However, subsequent interaction with students in other courses and reports from other faculty members indicated that students' knowledge, understanding, and retention of course content was limited. Their ability to integrate newly acquired facts into what they already knew was poor, as was their ability to apply this knowledge to new situations. This became painfully obvious when junior and senior students who had excelled in Introduction to Soil Science worked on undergraduate research projects under our supervision. These students had difficulty in remembering and applying basic concepts of soil science to address research questions or solve practical problems.

Frustration with the ineffectiveness of lectures as an educational vehicle led us to restructure the Introduction to Soil Science course using a problem-based learning (PBL) approach in the spring of 2002. Problem-based learning involves small groups of students working in permanent groups to learn the course content within the framework of a realistic problem. The process involves (Boud and Feletti, 1997) the following:

1. Present students with a problem. Students assess the problem and identify what they know in relation to the problem.
2. Determine what aspects of the problem they do not understand. These "learning issues" serve to focus group discussion.
3. Rank learning issues in order of importance. The group decides which issues will be considered by the whole group or by individuals. In the case of individual follow-up, that student is then responsible for informing the rest of the group about his/her findings.
4. Explore previous learning issues and integrate new knowledge in the context of the problem. Students summarize their progress, make connections between previous and newly acquired knowledge, and develop new learning issues.

These steps are repeated until the group is satisfied that they have developed a satisfactory solution to the problem.

The modern PBL approach has its origins in reforms to medical education at McMaster University in Canada more than 40 years ago (Neufeld and Barrows, 1974), although the constructivist approach to education has its roots in ancient Greece (Crowther, 1999). The success of PBL in medical education made this approach appealing for application to teaching soil science for a number of reasons. First, medicine and soil science are both integrative scientific disciplines. In soil science, students need to draw from their knowledge of physics, chemistry, biology, ecology, and geology to understand the properties of soils and the processes that take place within them. Second, like problem solving in medicine, authentic soil science problems are invariably complex, ill-de-

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Abbreviations: PBL, problem-based learning.

fined, and require that the individual develop the ability to apply knowledge in the proper context. Third, and again similar to medical science, problems related to soils are more often than not addressed by teams of individuals with different professional training, so that success requires not only technical knowledge but the ability to communicate this knowledge both to colleagues and to the nonexpert public.

The PBL approach has been used successfully in undergraduate courses in natural resources (Arthur and Thompson, 1998). Thus, after lecturing *at* introductory soil science students for 9 years, we restructured the course using a PBL approach. In this paper we describe the structure of the PBL approach, student performance, their reaction to the course, as well as pitfalls and positive aspects of the course from the instructor's perspective.

COURSE STRUCTURE

Overview

At the University of Rhode Island, Introduction to Soil Science (NRS 212) is taught in the Department of Natural Resources Science and is a required course for students majoring in environmental science and management, environmental economics and management, wildlife biology and conservation, water and soil science, landscape architecture, and urban horticulture and turf management. The course has no prerequisites, and most students take it during their sophomore or junior year.

Traditionally the course was taught once a year as a large (>100 students) lecture-only course in a fixed-seat auditorium. Assessment consisted of problem sets, which accounted for 10 to 20% of the final grade, and three to four multiple-choice exams, which accounted for the rest of the grade.

The PBL version of NRS 212 is taught every semester, with an average enrollment of 45 students, of which 5.6% are freshmen, 44.0% are sophomores, 46.1% juniors, 2.2% are seniors, and 2.2% are nonmatriculating students. The course meets twice a week for 75 minutes per period. The physical setting involves either movable desks or tables and chairs, depending on classroom availability. Attendance is recorded and students are penalized for unexcused absences (see Assessment, below). During the course of the semester, students work on solving a total of five different problems in permanent groups of four or five students. Brady and Weil (2002) is the required textbook. Groups are assigned randomly on the first class meeting. Class time is used exclusively for group work or to administer tests. Groups typically work on a problem for four to six class periods (2 to 3 weeks). Groups share the breakthroughs and difficulties they encounter in open discussion with other groups approximately every 20 minutes during the class period. This provides the students and the instructor with an opportunity to identify important issues as well as misconceptions. Students are assessed via synthesis papers (group assessment) and tests (individual assessment). Group performance is assessed through peer evaluations. In addition to striving to improve content learning and problem-solving skills, the assessment structure encourages students to develop professional standards in communications, quantitative estimation, the use of evidence in support of conclusions, and team management.

Study Units

The course is divided into five different study units: (I) Genesis and Classification, (II) Physical Properties, (III) Soil Water, (IV) Carbon and Nutrient Cycling, and (V) Contaminants and Erosion. A study unit has four sections: (i) a list of learning objectives; (ii) resources relevant to the unit; (iii) a timetable that includes a schedule of class activities, dates of tests, and due dates for original and revised papers; and (iv) the narrative for the problem. The learning objectives are drawn from the "Soil Science Competency Areas and Performance Objectives," compiled as content standards by the Council of Soil Science Examiners (2002). In addition to relevant chapters in the textbook, resources include print and recorded media and websites.

The problems are drawn from the instructor's own professional experiences, old problem sets, print media, and research articles. Problems are usually divided in three parts, with all parts delivered at the same time. We try to design problems that address contemporary issues in soil science. For example, in the spring of 2003 the problem for Unit I (Genesis and Classification) involved trying to delineate a wetland based on soil property data. Unit III (Soil Water) addressed the irrigation dilemmas of a local farmer that were featured in a local newspaper the previous summer. Problems have an introduction, in which the setting and characters are described. Each part addresses different aspects of the problem and ends with a series of questions. The issues, and the questions, become progressively more complicated as the students work through the problem. All problems have data sets that require quantitative analyses. Data sets can be incomplete and/or inaccurate, and may sometimes be irrelevant—by design, to stimulate discussion. Design of problems is done with a list of learning objectives that should be covered. In our experience, introducing humorous fictitious characters and/or situations makes the problems more accessible to students.

Companion Web Site

A companion website, developed by the instructor, has bulletin board, chat and email functions, as well as the course syllabus and class schedule. The problem for each unit is posted on the website and students are expected to print the problem and bring it to class. Required, anonymous peer evaluations are also available. Students are able to access their grades as well as old exams on the website. In addition, there are guidelines for the preparation of synthesis papers and the rubric used to grade the paper. The chat room function of the site is used to conduct online office hours the evening before tests.

Assessment

Synthesis Papers. At the end of a study unit, each group produces a written report, or synthesis paper, describing their approach and solution to the problem. Students receive a group grade on the synthesis paper. At the beginning of the semester students are provided with a set of guidelines on the structure, content, and style of the paper, and with a copy of the rubric used to grade the papers. The rubric is designed around criteria based on content, process, and professional standards. Paper structure, style, content, and grading rubric information is also found in the companion website. Papers are due 3 to 4 days after discussion of a study unit has concluded. Groups are asked to determine who will be the authors (two students) and who will be revising the paper (two students) at the beginning of a study unit. Papers are graded by the instructor, and returned to students 2 to 3 days after the due date. Grading is based on the following: quality and accuracy of ideas (20%); logical development of ideas (10%); organization of ideas (10%); wording and phrasing (10%); use of terminology, units, and equations (10%); application of concepts (30%); formatting (5%); and grammar and spelling (5%). Feedback is provided in the form of specific comments written on the manuscript, summary suggestions for improvement on the grading rubric, and scores for each section. Students typically have 2 days to turn in the revised version of the paper. The revision is graded, with the best of the two grades used to calculate grades.

Although a score is assigned to the synthesis paper produced by a group, the grade an individual student gets in a synthesis paper depends on two factors: attendance and peer evaluations. For example, consider a student called Rosa, who is part of a group that received a 90 on their Study Unit I synthesis paper. Rosa's two unexcused absences while the group worked on this unit reduces her grade to 72 (90 × 0.80, since she loses a grade for every unexcused absence). If she received a peer evaluation (see below) score of 0.90 (out of a possible 1.00), her final grade on the synthesis paper would be a 65 (90 × 0.80 × 0.90). Synthesis papers account for 40 to 50% of the course grade.

Exams. A modified version of a multiple choice exam is given at the end of each unit. Multiple choice exams are an effective learning assessment tool in medical school programs that have adopted the PBL approach (Norman, 1997; Swanson et al., 1997). The exams consist of 15 to 20 questions based on the learning objectives for that particular unit. Students know in advance that the questions on the exam will be based on the learning objectives.

Exams are given in two parts. During the first part students have 30 minutes to answer the exam questions. Students can use written notes that they have prepared, but not printed material (e.g., textbooks or photocopies, etc.). At the end of the first part, students turn in their answer sheets (this part of the exam is graded using an optical scanner) and the instructor posts the correct answers. For the second part of the exam students are given an additional 20 minutes to provide a written explanation for why an answer to a particular question is wrong. Students have full access to their textbook and notes during this time. At the end of the period exams are collected and the students' explanations are graded by the instructor. For every correct explanation (e.g., shows an understanding of the principle, process, etc.) the student is awarded half the points for the question. Exam grades account for 50 to 60% of the course grade.

Peer Evaluations. Students evaluate each other's performance in the group at the end of every unit. These peer evaluations are performed anonymously online using the Survey Utility of WebCT. The survey consists of six questions pertaining to effective participation in, and contribution to, group activities based on Kitto and Griffiths (2001). The score can range from 0.70 to 1.10. Scores lower than 0.90 or higher than 1.00 require written justification by the student doing the evaluation. The validity of an explanation is determined by the instructor. Peer evaluation scores are averaged and used to determine a student's grade in the synthesis paper.

STUDENT PERFORMANCE

The limited amount of data we have on attendance for the lecture version of the course (based on fraction of registered students that responded to student evaluation of teaching) indicates that attendance for the PBL version of the course is considerably higher (94%) than for the lecture version (70–80%). In the PBL version of the course scores on synthesis papers increased more than a letter grade, from 78.8% before revision to 87.6% after revision. Data for exams were similar to synthesis papers, with the mean score for revised exams (79.8%) being one letter grade higher than for the original exam (69.9%). Students taught earlier by the same instructor using traditional methods had average exam scores ranging from 60 to 68%. Peer evaluation scores averaged 1.02 out of a possible 1.00. Students were most generous with peer evaluations initially, with mean scores declining as the semester progressed.

STUDENT PERCEPTIONS

At the end of the semester students were asked to fill out an anonymous course evaluation. Over the course of three semesters a total of 105 students responded out of a possible 135 (78%). The respondents had the following distribution of majors: environmental science and management, 28%; wildlife management and conservation biology 24%; urban horticulture and turf management, 20%, landscape architecture, 20%; and other, 8%. This distribution of academic majors is typical for this course for the past 11 years.

Professional Skills

Communication. The majority of students (48–69%) agreed with statements on improved communications skills (Table 1). Of those who *agreed strongly* with the statements (12–35%), the majority did so with improved listening skills, followed by ability to explain own reasoning, ability to defend own point of view, providing constructive criticism, written communication skills, and verbal communication skills. The proportion of students who disagreed with statements on improved communication skills ranged from 13% ("I can explain my reasoning better") to 21% ("My ability to defend my point of view has improved").

Group Interactions. Most students reported greater confidence working in groups after taking the course (Table 1). Similarly, 39% of students agreed strongly with the statement "I am a better contributor to group activities," with 47% reporting that they agreed somewhat with the statement.

Personal Management. Thirty-four percent of students indicated that they *disagreed somewhat* or *disagreed strongly* with the statement, "My ability to manage time has improved" (Table 1). Students were somewhat more favorable with respect to the statement, "I am better at prioritizing," with 77% expressing agreement. More than 80% of students agreed with the statements related to criticism, with over a third agreeing strongly with the statements, "I am better at using

Table 1. **Student response to statements on how taking the problem-based learning (PBL) version of the Introduction to Soil Science course affected their written, verbal, and interpersonal communication; problem-solving; and personal management skills, and their view of soil science (*n* = 105).**

Statement	Percent responding that they: Agree strongly	Agree somewhat	Disagree somewhat	Disagree strongly	χ^2
Communication					
My verbal communication skills have improved.	12	69	15	4	45.15***
I can explain my reasoning better.	30	56	12	1	40.91***
I am a better listener.	35	48	15	2	32.45***
I am better at providing constructive criticism.	24	61	14	1	42.16***
My ability to defend my point of view has improved.	27	52	18	3	29.78***
My written communication skills have improved.	24	56	18	2	34.49***
Group interactions					
I am more confident working in a group.	40	39	15	6	22.00***
I am a better contributor to group activities.	39	47	13	1	37.16***
Personal management					
My ability to manage time has improved.	11	55	29	5	31.86***
I am better at prioritizing.	21	56	19	0	30.06***
I am better at using criticism to improve my performance.	34	55	12	0	44.10***
I am more critical of my own ideas.	35	50	14	0	40.10***
Problem-solving					
I am better at identifying what is important in a problem.	36	55	8	1	44.63***
My problem-solving skills have improved.	41	55	3	1	36.95***
My ability to solve complex word problems has improved.	36	45	17	2	30.31***
I am more confident in my ability to solve real-world problems.	45	45	10	0	44.16***
My ability to determine the relevance of information has improved.	41	50	10	0	45.46***
My ability to synthesize knowledge from different areas has improved.	38	53	9	0	48.20***
I can discriminate between useful and useless information better.	31	58	9	2	42.58***
My ability to use math to solve problems has improved.	14	54	27	5	28.83***
I am more confident about making assumptions and estimating when solving problems.	32	54	10	3	36.96***
Relevance of soil science					
I have a better idea of how soil science fits within my major.	59	32	5	5	44.23***

*** Significant at $P = 0.001$

criticism to improve my performance" and "I am more critical of my own ideas."

Problem Solving. Students reported a high level of improvement in their problem-solving skills (Table 1). Ninety-six percent agreed with the statement, "My problem-solving skills have improved," and 68% agreed with the statement, "My ability to use math to solve problems has improved." An equal proportion of students (45%) expressed strong or somewhat strong agreement with the statement, "I am more confident in my ability to solve real-life problems."

Relevance of Soil Science. More than 90% of students agreed with the statement, "I have a better idea of how soil science fits within my major," with 59% agreeing strongly.

Contribution of Course Activities to Learning

Survey items were divided into three categories with respect to contribution of course activities to learning: (i) group, (ii) writing, and (iii) exams. The overwhelming majority of students reported that class activities were *very helpful* or *somewhat helpful* to learning (Table 2). Typical of the written feed-

Table 2. Student response to statements on how effective course activities in the problem-based learning (PBL) version of the Introduction to Soil Science course were in helping them learn in the course (*n* = 105).

Activity	Percent responding that activity was: Very	Somewhat	Not helpful	χ^2
Group				
Working in a group to solve a problem	55	39	6	26.67***
Discussing what you know and didn't know as you worked through a problem	61	34	6	29.02***
Summarizing your approach to a problem	51	46	3	33.04***
Feedback during group discussions from your instructor/teaching assistant	70	25	5	37.78***
Feedback during group discussions from your peers	56	38	6	26.97***
Looking for information outside of class time	48	44	8	29.09***
Explaining the information you found to other group members	48	42	10	16.19***
Papers				
Writing synthesis papers	52	46	2	35.91***
Revising synthesis papers	62	31	7	27.73***
Instructor feedback on synthesis papers	77	20	3	48.69***
Group member's feedback on synthesis papers	40	43	16	9.13*
Exams				
Studying for tests	41	50	9	19.87***
Preparing written notes to use on tests	73	23	4	42.44***
Explaining incorrect answers on tests	77	22	1	52.84***
Reading the textbook	52	37	12	14.73***

* Significant at $P = 0.05$.
** Significant at $P = 0.01$.
*** Significant at $P = 0.001$.

Table 3. **Effort level, satisfaction with group interaction, and course format preference reported by students taking the problem-based learning (PBL) version of the Introduction to Soil Science course (*n* = 105).**

Question	Percent that chose:			χ^2
Effort level				
On average, how much time did you spend on work for this course outside of class time?	less than 3 hours/week: 36	between 3 and 6 hours/week: 53	more than 6 hours/week: 11	16.22***
On average, how much time do you spend on work for similar courses (200-level, 3 credits) outside of class time?	less than 3 hours/week: 43	between 3 and 6 hours/week: 47	more than 6 hours/week: 10	16.11***
How do you rate the workload for this course?	too much work:11	just enough work: 89	too little work: 0	72.54***
Group interaction				
How well did your group work together?	very well: 46	well: 43	poorly: 12	13.37 ***
Course Format Preference				
Which class format do you find most effective for learning?	lecture: 24	PBL: 70	neither: 7	34.28***
Which class format do you prefer?	lecture:32	PBL: 61	neither: 8	25.51***
Would you take another course using a problem-based learning format?	yes: 55	maybe: 32	no: 13	14.70***
What did you think of the problem-based learning format before taking this course?	not for me: 26	I may like it: 64	it will work for me: 12	21.45***
What is your opinion of the problem-based learning format now?	not for me: 17	liked it some:43	worked for me: 40	7. 34*

* Significant at $P = 0.05$.
** Significant at $P = 0.01$.
*** Significant at $P = 0.001$.

back provided by the students on this aspect of the course were statements such as the following:

> *I found that the papers and group work reinforced much of the knowledge I came across…*
>
> *If I did not understand something, members of my group and the class gave me a better understanding.*
>
> *Even though I was not thrilled with working in groups and this problem-based learning, it was actually helpful to a certain extent. Being able to work with people helped a lot in being able to understand.*
>
> *Revising tests helped me learn from my mistakes.*

Group Activities. Seventy percent of students found "Feedback during group discussions from your instructor/teaching assistant" as very helpful, followed by "Discussing what you knew and did not know as you worked through a problem" (61%), "Feedback during group discussion from your peers" (56%), and "Working in a group to solve a problem" (55%). Forty-eight percent of students rated "Looking for information outside of class time" and "Explaining the information you found to other group members" as very helpful to learning.

Writing. "Instructor feedback on synthesis paper" was found *very helpful* to learning by 77% of students, followed by "Revising synthesis papers" (62%), and "Writing synthesis papers" (52%). "Group member's feedback on synthesis papers" had the greatest proportion of students indicating that the activity was *not helpful* (16%) in this part of the survey.

Exams. More than three-quarters of the students identified "Explaining incorrect answers on tests" as *very helpful* to learning, followed by "Preparing written notes to use on tests" (73%), "Reading the textbook" (52%), and "Studying for tests" (41%).

Effort Level, Group Interactions, and Format Preference

Fifty-three percent of students reported that they spent between 3 and 6 hours per week on work for the course outside of class time, with 36% spending less than 3 hours per week, and 11% spending more than 6 hours per week (Table 3). By contrast, 47% of students indicated they spent between 3 and 6 hours per week on work for similar courses outside of class time, with 43% spending less than 3 hours per week, and 10% more than 6 hours per week. The overwhelming majority of students (89%) rated the workload for the course as "just enough work," with 11% indicating that it was "too much work." No students indicated that they thought the course was "too little work."

Forty-six percent of students reported that their group worked *very well* together, with 43% reporting their group worked *well* and 12% indicating that their group worked *poorly* together (Table 3).

Initial perceptions of the PBL course format were ambivalent, with 26% indicating that the at the beginning of the semester they thought the PBL format was "Not for me," 64% indicating "I may like it," and 12% indicating "It will work for me." Students' perceptions of the format became more favorable after taking the course, with 40% indicating that "It worked for me," 43% choosing "I like it some," and 17% of the students selecting "Not for me." When asked which course format they preferred, 61% of students chose PBL, with 24% indicating they preferred "Lecture," and 8% "Neither" (Table 3). Fifty-five percent of students indicated that they would take another course using PBL, with 32% choosing "Maybe," and 13% "No."

Written feedback was generally positive with regard to the course:

> *I feel that I have actually learned something (not always the case with classes) that I will* RETAIN*…*
>
> *The time seemed to fly by. It was fast paced and kind of stressful, but in the good way.*
>
> *I felt accomplished and productive in this course.*
>
> *I liked how we had to figure out most of the material ourselves. It was much better than sitting in a lecture listening to a teacher lecture for a whole class period.*
>
> *I enjoyed this class even though at times it gave me an ulcer.*
>
> *I felt like I accomplished so much in the end after doing all the hard work. I also felt like I learned every concept very thoroughly, which I do not necessarily get from other classes I liked.*

A number of students expressed a need for more structure and reassurance:

> *(I would like) more input from the teacher. I found we could head off in the wrong direction and a few times wasted an entire class making calculations that were totally irrelevant.*
>
> *I would like to have a lecture before each unit that would give a general overview.*
>
> *I needed confirmation that I was headed in the correct direction.*
>
> *(I would have liked) more definitive input from the instructor. Providing answers for questions when confusion is high as opposed to answering questions with more questions.*
>
> *I personally need more structure.*

LESSONS LEARNED

Issues

Our experiences teaching Introduction to Soil Science using a PBL approach, and those of the students that have taken it, have been generally positive. However, as with any teaching approach, there are issues that must be addressed by those planning to use PBL.

Initial Resistance to the Problem-Based Learning Approach. We observed resistance to the approach for the first four class meetings during the first semester the PBL version of the course was taught. The resistance involved four or five students and took a number of forms, including open refusal to participate in group discussions, frequent public queries as to when the instructor was going to start lecturing, and an informal delegation indicating that they simply could not learn using this approach. We addressed this issue by reiterating the importance of group work to individual success in the course, indicating that lecturing was not part of the course structure, and that the PBL approach is used to teach a wide variety of subjects, including medicine, successfully. Resistance generally subsided when the first study unit was completed. We observed considerably less initial resistance in subsequent semesters, probably for two reasons: (i) by then it was clear that the instructor was not willing to bargain on the structure of the course, and (ii) the majority of students who were part of the initial PBL class clearly had a positive experience. This information was no doubt passed on by students who had taken the course previously.

Time. Teaching using PBL involves a greater time commitment than lecturing. Writing soil science problems that are sufficiently—but not overly—challenging, that maintain the attention of students with a wide variety of academic and professional interests, and cover the necessary content areas is initially time-consuming; however, it becomes easier with practice. Grading and providing feedback on exams and papers also require more time than for a lecture-format course.

Shifting Gears. Significant time is needed for the instructor to shift from being the "sage on the stage" to become the "guide on the side." After years of lecturing, the switch from answering questions by providing a full explanation to answering them in a manner that will help students find the answers themselves can be difficult. This change is especially challenging at the beginning of the semester, when students have not yet become accustomed to this style of teaching. Watching a student group pursue an approach that the instructor knows is unlikely to yield positive results and not intervening can be difficult. However, allowing students to make mistakes is very important. In most instances mistakes are identified and corrected by group members, or by members of other groups during open class discussion. Furthermore, students may learn more from such mistakes than when a successful approach is followed from the beginning. Avoiding direct intervention by the instructor and teaching assistants is critical, except in cases where errors of fact or faulty reasoning are not identified through other mechanisms.

Positive Aspects

Teaching soil science using a PBL approach has provided the instructors with a high level of professional satisfaction. Class assessments clearly show that the students are interested in what is going on in class, engaged, and learning. The level of discussion and interaction at the group and class levels is usually high. A number of students come to class early to get a head start on the day's work, and often class discussion continues past the allotted time without students noticing. In addition, many students explore and incorporate information from sources other than those provided by the instructor, including class notes from other courses, textbooks, research articles, and the web. There is also a great deal of satisfaction in observing improvement in student's writing, debating, and problem-solving skills as the semester progresses. For their part, students recognize that what they learn in the course is largely the result of their efforts, and most express a feeling of personal accomplishment at the end of the semester.

We have found that PBL is a viable alternative to the lecture format to teach Introduction to Soil Science. Acceptance by students is high while they see this class as rigorous. The approach successfully integrates content learning with problem-solving skills. In addition, PBL establishes a climate of accountability for both the instructor and the learner by communicating the content standards and process criteria with rubrics on criteria for professional conduct. Instructors in subsequent soil and plant science courses have indicated that students taught using PBL have a more solid knowledge of the principles of soil science and their applications relative to students that were taught by the same instructor using traditional methods in previous years.

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