Julie Tan
Professor of Chemistry
CHEM 491
Cumberland College
Williamsburg, KY
jtan@cumberlandcollege.edu

Part I. Introductory Information

A. Institutional

Name of College:	Cumberland College
Total Enrollment:	1800
Institution – Public or Private	Private
Carnegie Classification:	Baccalaureate College – Liberal Arts

B. Individual

School:	Natural Science
Department/Division:	Chemistry
Faculty Rank:	Professor
Highest Degree Earned	Ph.D.
Number of years teaching at the college level:	11
Awards Received for excellence in teaching:	Excellence in Teaching Award, Cumberland College, 2002 Honored Faculty Award, Cumberland College, 1998

C. Course

Course Name:	Introduction to Environmental Chemistry
Course Abbreviation and Number:	CHEM 491
Number of Semester Credit Hours	3
Catalog Description:	A study of selected topics in chemistry of current interest in a specified field of chemistry such as advanced organic, polymer chemistry, spectroscopy, environmental chemistry, medicinal chemistry, organometalic chemistry, or chemical literature usage.
Number of Students you typically teach in this course	5-15
In what year do students typically enroll in this course?	Juniors and Seniors
This course is best described as:	Elective course for chemistry majors and minors

D. Problem-Based Learning

What percent of this course uses PBL?	100%
How long have you been teaching the course using PBL?	This is the second time. The first time 20% of PBL was incorporated.
Is the course designated as PBL in any official way?	No

Part II. Course Design

Rationale

Even though the traditional lecture method has certain advantages such as teaching specific facts and basic skills in a direct and logical manner or clarifying facts that are confusing in nature, there are questions regarding the effectiveness of the traditional lecture approach. Traditional lecturing is a one-way communication that puts students in a passive role rather than students becoming more active participants in the learning process (McIntosh, 1996).

It is recognized that there is a need to move from the passive learning style to a more dynamic style because the latter promotes greater student participation and students assume greater responsibility in their own learning (Tobias 1992). But how do we develop a teaching style that will facilitate a paradigm shift from teacher-centered teaching to student-centered learning?

As I continue to refine and improve the way I teach my students, I look for methods that will facilitate successful teaching and student-centered or active learning (Project Kaleidoscope, 1991). The rationale for active learning is that students learn more when they explore a topic rather than when they passively watch and listen to a teacher (Huba & Freed, 2000). My focus on promoting student-centered learning has led me to explore alternative approaches to traditional classroom instruction. Problem-Based Learning (PBL) holds great promise in creating an environment that will nurture student-centered learning (Barrow & Tamblyn, 1980).

I chose to 'try' the PBL approach in my Introduction to Environmental Chemistry because it is a one-semester elective chemistry course. I understand that 'teaching experiments' may sometimes not turn out as expected, but I feel confident to take this calculated risk in hopes that better learning will result.

Reflection Essay on Content of Course

My role is to create an environment that promotes learning and to provide appropriate stimuli for students to master skills, attitudes and an appropriate set of chemistry concepts (Delisle, 1977). The ultimate goal is to equip students to become their own lifelong teachers and to develop educated citizens.

The more immediate learning goals for this course will be to promote my students' ability to:

1. Gather and evaluate new information and use appropriate learning resources.
2. Develop self-directed learning skills to identify what needs to be learned based on what they already know.
3. Think critically, analyze, reason effectively and solve complex, real world problems that extend beyond the classroom.
4. Communicate clearly, drawing upon evidence to provide a basis for argumentation.
5. Demonstrate collaborative and communication skills necessary to work respectfully, productively and effectively as a team.
6. Demonstrate effective verbal and written communicative skills.
7. What can be done to create a student-centered environment so that students learn the course materials in a way that promotes deep understanding? As a professor, what is the best way to act as a coach and facilitator to promote effective student-centered learning?
8. What are the hallmarks of critical thinking and how do I emphasize critical thinking and problem-solving in this course (Paul & Elder, 2001)?
9. How can I design assignments that will integrate the skills and perspectives they learn in general education with the content of this course?
10. How do I help students to shift from their traditional teacher-centered 'comfort zone' to a more learner-centered paradigm?

The first step involved in developing the course was to design the course syllabus. Since the PBL principles and processes seemed a promising strategy to promote the learning outcomes I advocate, the majority of the project assignments are PBL by design. The course syllabus was a guide that kept the students and the instructor on the same path throughout the course of instruction. The syllabus clearly communicated course objectives, assignments, due dates, required readings, and grading policies. The syllabus was used to reflect my philosophy of teaching, introducing the students to PBL and to emphasize student-centered learning. Pertinent educational objectives (e.g., knowledge, comprehension, application, analysis, synthesis and evaluation) that I hoped to accomplish were explained to the students using the much heralded Bloom's Taxonomy of Learning. A statement of intended learning outcomes that defined my expectations were introduced to the students by the use of project outcome rubrics. Students appreciated the rubrics as it gave them a better sense of what they were expected to learn, and it also helped them know the direction they were going. A grading scale showed how their overall grade would be computed. An explanation of assignments, due dates and policy on work submitted late, attendance policy, tardiness, and participation in class were provided.

For each assignment, students were given a self-directed guideline. The guideline was designed using the following parameters:

1. Instructional objectives are given to the students when they receive their assignments.
2. As a team, they select their own path to search, gather, evaluate new information and use appropriate learning resources (with suggestions introduced as they are needed).
3. Frequent student brainstorming sessions requiring high level cognitive involvement as they think critically, analyze, reason effectively, and solve problems.
4. Informal in-class discussions with peers and the professor for evaluation of the process and resources that were gathered, value of the information, success of the endeavor, and other possibilities for solving the assigned problem.
5. Final evaluation of the students' structured feedback sessions.
6. Each team communicates (oral and written) their completed work to the professor and their peers at which time further questioning takes place and additional feedback is provided.

Each assignment was developed using these questions:

1. What should this assignment accomplish?
2. How can the assignment be designed in order to help the students make new discoveries while encouraging them to think independently and creatively?
3. What questions can be asked to accompany the assignment that applies the set of educational objectives provided by Benjamin Bloom (1956)?
4. How can critical thinking and problem-solving be incorporated and emphasized in this assignment?
5. How in this assignment can be created an opportunity to help students integrate the skills and perspectives they learn in general education?
6. What hypothetical situations or real-life problems can be created to help students think and behave like members of the chemistry discipline?
7. How are the qualities revealed to the students that make their final product excellent?
8. What activities can be incorporated into the assignment that will make the students feel a sense of pride in their work and accomplishments?

Reflective Essay on Instructional Practice

The structure of the course and expectations of the students' performance were introduced and established at the very beginning of the first class meeting. Criteria for judging the students' assignments (e.g., timeliness and quality of completed work, ability to respond to questions during discussion sessions, effectiveness of written and oral communications) were shared with students before assignments were given.

Students were asked to complete a student profile form after a student-teacher informal conversation to get to know the students better and get insights into the students' minds in order to help me better improve their motivation, attention levels, and understanding of the transition from their teacher-centered teaching to the student-centered learning approach.

Since the students were expected to collaborate as teams throughout this course, they were given some guidelines on group effectiveness covering topics like how to call and facilitate a meeting and how to keep on task. A collaboration/teamwork expectation rubric was revealed to help students have a better sense of the criteria behind excellent collaboration. At the end of each assignment, a questionnaire was used to survey the effectiveness of each group and their satisfaction with learning using this approach. A summary of students' responses was discussed and appropriate steps were taken to help improve their future assignments. I made continual modifications throughout the semester in organization and implementation of the groups based on students' feedback. Over time, I observed a steady increase in student satisfaction with the collaborative approach.

The problem-based nature of the assignments the students worked on as a team, required them to search, organize, analyze, and use new information. For example, students were given a brief introduction to green chemistry through 'well-structured' assignments to ensure they acquired the basic concept needed to handle follow-up assignments that contained 'ill-structured' problems (Stepien & Gallagher, 1993). In attempting the ill-structured, more authentic assignment, students had to explore and research, make choices, and explain. This process helped them develop an understanding of the chemistry discipline that is practiced in the real world. For example, in the assignment on green chemistry, they worked as a consulting team of chemists to evaluate existing chemical reactions and processes to develop greener alternatives. They first analyzed the existing process, identified the starting materials used in the transformation (starting materials, reagents, solvents), the products and by-products produced by the transformation and the reaction conditions such as temperature and catalysis. They then identified any potential hazards posed by these materials.

In teams of three, students assigned tasks to each other, discussed findings, brainstormed recommendations, and reacted to each other's ideas. Through the process of inquiry, idea generation and discussion; each student developed a deeper understanding of various aspects of the field of chemistry as practiced by the professionals in the discipline of chemistry.

Feedback was provided when students reacted to each other's ideas during arranged structured feedback sessions. The two teams presented their proposals and their rationale to each other with one team defending and the other questioning their proposals. The same format was used again in the final evaluation of the assignment. My role during these structured feedback sessions was to provide prompt, thoughtful reflections by questioning each teams' suggestions (Rowe, 1978). Their understanding of good and practical real world practices increased when the students realized from the feedback that their proposals violated certain regulations or standards. Upon completion of the assignment, students showed a clearer understanding of how to effectively evaluate and develop greener alternatives. Students learned that real-world problems are complex and often times may not be solved with one simple 'correct' answer. Over time, the students' ability to identify problems, apply logic and reasoning to solve the problems, participate in sound argument, and appreciate the value of applying these skills improved. The positive experience from this class confirms my belief that active student participation helped them develop a deeper understanding of their course materials than they would if they passively listened to a lecture.

Throughout the semester, students were reminded that as they explore the information resources from the Internet and from the library, they must employ the attributes of a critical thinker. In order to develop better critical thinking skills, criteria for critical thinking were provided to help students (Paul & Elder, 2001):

1. Determine which sources found over the Internet are reputable and which are not.

2. Differentiate between fact and opinion from the information they gather.
3. Examine the assumptions made by the authors of the sources they find and then include the students' own assumptions.
4. Be flexible and open minded while looking for explanations, causes, and solutions to problems.
5. Be aware of fallacious arguments, ambiguity, and manipulative reasoning.

Over time, the students automatically used all the criteria that were given as guidelines for solving other projects, and also used the criteria to assess what they were doing well and where they needed to improve. At the conclusion of each assignment, students reflected on how well they worked as a team, how well they contributed individually to the team's success and how they might work better as a team in the future. As time went by, I observed that rather than shouldering the responsibility for the success of the students, the course was becoming the students' course. Students were taking an active role in their own learning. In-class participation improved because the students now knew their peers personally and felt comfortable asking questions more freely.

PBL Content and Application

A conscious effort was taken to ensure that the topics and activities used were of interest to my students. This was critical in promoting their curiosity and motivating their learning. At the same time, I tried to develop problems that were of current concern to practitioners in their discipline (e.g. evaluating the greenness of a given synthetic method) so that the students felt they were doing important things and they were not acquiring knowledge for knowledge's sake. Assignments were designed around real-world problems so they would experience the compelling challenges typically faced by professionals in their discipline. The problems were ill-defined, that is they had no single right answer and their structure was not always apparent. The ill-defined nature allowed students to make errors and learn from them and develop a deeper understanding of their discipline as it is practiced in the real world.

Each assignment started with 'well-defined' homework followed by using 'ill-defined' assignments so the student could apply the 'known' to solve the 'unknown.' The purpose of the well-defined problems was to develop skills that will be needed in solving the 'ill-defined' problems.

A representation of the activities for this course is summarized as follows:
1. Pre-class reading and preparation guided by a Pre-class Learning Guide
2. Structured homework assignments
3. Discussion sessions of homework assignments
4. Ill-structured PBL assignments
5. Formal discussion of ill-structured assignments
6. Oral/written presentation of completed assignments

A typical learning cycle for this course looks like this:

Before class

Students were required to read and interpret assigned materials before coming to class. The pre-class assignment is guided by a Pre-class Learning Guide; a document specifying materials to be covered in the next class. The guide was distributed two weeks in advance of a new assignment. Each assignment was followed by a structured homework question to acquire the minimum knowledge needed before the next meeting.

In class

Beginning of class (20 minutes)

Each class began with a three question multiple choice quiz (open notes and open book) which took five minutes. This was to promote careful reading and thorough preparation for the class. This was followed

by a discussion session (15 minutes) to discuss the quiz they had just taken and the assigned homework questions.

Middle of Class (45 minutes)
The class was split into groups to work on the ill-structured PBL assignment where students solved problems and answered questions related to materials specified in that day's pre-class learning Guide. The cycle of PBL discussion sessions was repeated in each class meeting. During the 45 minute problem-solving session, I circulated among the teams and provided guidance as needed. After 45 minutes, the problem-solving session was called to a halt.

End of Class (10 minutes)
The last ten minutes of the class was used to respond to any questions and to review key issues and concepts. A new pre-class learning guide was provided and another PBL learning cycle continued.

Structured Discussion/Feedback Session
Students presented their proposals and their rationale to each other and constructive feedback was provided by the professor and their peers.

Verbal/Poster Presentation
Upon completion of their assignment, a written paper on the case was turned in by each individual student for assessment by the professor and peer reviewed by their fellow classmates. Students then presented their work orally in teams of their peers using a poster presentation that was assessed by the professor and their fellow classmates.

Part III. Student Understanding

Evidence of Students Meeting the Learning Objectives
The students' oral presentations and written assignments were useful in assessing if the students had attained the learning objectives of this course. I was pleased with the work generated by the students. Their presentations and assignments were interesting, informative, and showed evidence of thoughtful analysis and fair minded reasoning. The quality of the work they had generated showed over time, they had become more sophisticated learners. By their final assignment, the students showed they had improved in the way they gathered, evaluated and used new information. They showed improvement in the way they reason and think critically, communicated more effectively, and worked more effectively as a team than they did in their first assignment. They developed qualities, such as persistence and time management that will help them reach long-term goals.

The students' response to the PBL approach used in this course was evaluated by free-written responses and informal interviews with individual students. In addition, the students were given Samford University's 'End of Course Evaluation' survey (http://www.samford.edu/pbl). Table 1 gives the questionnaire statements and the mean student response based on a scale of one to five (strongly disagree to strongly agree). The students' response was favorable for each of the statements.

Student interviews made it clear that they perceived that they had developed effective communication skills, better thinking and problem-solving skills, and enhanced their skills in self-directed learning. These remarks are encouraging because the ability to think, problem solve and communicate are essential tools that will benefit them throughout their life.

The students also stated that the need to let go of their habit of passivity allowed them the opportunity to exercise their decision-making skills. The feedback sessions harnessed the students' creative energy and revealed each students unique way of approaching problem-solving and communication. Less frequently mentioned by the students, were comments on the heavy workload and the amount of time required for each assignment and initial problems in working together. The learning outcomes,

performance rubrics, and characteristics of excellent work that were given with each assignment made the additional time and effort students put into acquiring the learning goals worthwhile.

The richness found in their free-written responses gave valuable insights to the students' feelings. Sample comments that best represent the students' perceptions and feelings by the learning outcome of the PBL approach are given in Table 2. The students were motivated by the opportunity to work on assignments that resembled the problems that were more representative of real life. The realization of the opportunity to develop valuable skills such as the ability to think critically, communicate effectively, work collaboratively and manage time, motivated students to accept the PBL approach graciously at the cost of an increased workload and the demand of working cooperatively.

Table 1. Student Responses to Questionnaire Statements of End of Course Evaluation[1]

Questionnaire statement	Mean Score[2]
This course increased by ability to solve real-world problems	4.7
This course encouraged me to consider alternatives when solving problems	4.7
This course improved my ability to identify appropriate resources	4.8
This course increased my ability to work effectively on a team	4.5
This course encouraged me to take an active role in my learning	4.7
I have used knowledge and methods drawn from outside this course to complete my course assignments	4.8

[1]Samford University's PBL Assessment, 1999

[2]The means for the score are shown with a grading scale of 1 to 5 representing strongly disagree to strongly agree.

Table 2. Free-Written Responses from Students' Evaluation of PBL Outcome

1. The PBL approach puts the emphasis on the students to acquire the knowledge needed to solve problems effectively. Because we worked as a team, I must make sure that I have the needed background knowledge before I meet and discuss with my classmates during discussion sessions.

2. I was forced to put my personal views aside and look at concepts/ideas from many different angles so that I could determine the best solution to the task that was presented in an unbiased manner.

3. Working as a team, I learned that there may always be another possible solution proposed by teammates. I learned to weigh my opinion and proposed answers more thoroughly, and try to approach a problem from multiple angles because someone in my team might have a differing view.

4. The need to 'think' for every assignment has helped me to think 'deeper.' In this course, I actually had to think of a solution instead of looking for a correct answer in my textbook. It has also helped me become a better problem solver.

5. The need to search for information so frequently in this course helped me to judge and evaluate the validity and reliability of the information given. I also learned the importance of using multiple sources to get a more complete view on a subject matter instead of using one or two sources.

6. With the PBL method, the focus was on the students solving the task rather than the professor providing the question and the answer.

7. Every task in this class required some form of communication. We needed interpersonal skills when working as a team. We needed verbal and written skills when communicating our findings or ideas.

8. I learned to be more flexible to adapt to my teammates' styles and work ethics.

9. I have definitely learned to allow enough time for preparing a professional looking Power Point presentation.

10. I was able to apply my knowledge from other classes such as English for the writing assignments. Public speaking for the verbal presentation and Application Software for the Power Point and Excel assignments.

Reflection on the Evidence of Student Learning

The PBL approach seemed to be successful in moving students from their passive comfort zone to becoming responsible for their learning (Tobias, 1990). This approach allows for the opportunity to develop problem-solving and decision-making skills, learning how to communicate (verbal and written) effectively, and working cooperatively with others.

Due to their packed schedule, students were often 'stretched' in trying to meet the demands of this course. Despite the heavy workload and the time required for this course, students welcomed the opportunity to work hard to develop and attain the characteristics of successful learners. Adjustments could be made in the future to lighten the assignments to a more manageable workload. In addition, guidelines may be given to the students to help them gauge the time they are expected to spend on a given assignment.

The strength of PBL lies in the real life problem-solving opportunity. PBL not only increases the understanding of the course material, but also adds to the enjoyment of working with problems that exercises student creativity.

Part IV. Reflective Summary of the Course

There is a growing trend for practicing quality pedagogy in higher education that calls for classes that are more focused on learning than teaching, and faculty members that involve students so that students take ownership of their learning. Viewing the changes in higher education today, I was looking for ways to achieve successful learning outcomes as I continue to refine and improve the way I teach. In viewing the principles and processes of PBL, this learning strategy seemed a worthwhile approach to explore. In PBL, the catalyst for learning is focused on the problem to capture the students' attention. As students 'explore' their way through collaborative problem-solving, information gathering, communicating and decision-making processes, the students become responsible for their own learning and capable of thinking for themselves.

As students worked together as a team in addressing real-world problems, they developed their own ideas through sharing them with others and listening to their feedback. This helped develop their collaborative skills that will benefit them throughout life. The interdisciplinary nature of PBL allowed the opportunity for students to use the general skills learned through their college years effectively in this course. The project outcome rubrics presented to the students so they would know the objectives and goals for each project were valuable tools for motivation. Early introduction to the PBL process to ensure sound understanding and better orientation to the PBL approach was vital for a less intimidating transition from their passive learning mentality. Most importantly, as students searched and read articles, integrated and applied information, and solved challenging problems, students were developing and using skills of scientific inquiry.

The encouraging experience of this course has inspired me to incorporate the problem-based approach into other courses that I teach. This method is effective in shifting students from their traditionally passive role to being an active participant, and being responsible for their learning. The nature of this course allowed amply opportunity for me to assume the role of a coach and facilitator in a learning environment that is conducive to motivating active student participation and increased learning.

In the beginning, the students were not comfortable in collaborating as a team and sharing their opinion openly and being solely responsible for their own learning. However, over time, they developed and became more sophisticated learners, better team players, and more effective communicators.

References

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

Bloom, B. (1965). Learning Domains or Bloom's Taxonomy. Available online. http://www.nwlink.com/~donclark/hrd/bloom.html

Delislie, R. (1997). *How to use problem-based learning in the classroom.* Association for Supervision and Curriculum Development. Alexandria, Virginia, USA.

Freed and Klugman (1997). *A culture for academic excellence: Implementing the quality principles In higher education.* ERIC Clearinghouse on Higher Education, Washington, D.C.

Huba, M.E. and Freed, J.E. (2000). *Learner-centered assessment on college campuses: Shifting the focus from teaching and learning.* Allyn and Bacon, Boston.

McIntosh, N. (1996). *Why do we lecture?* JHPIEGO Strategy Paper #2. JHPIEGO Corporation, Baltimore, Maryland.

McKeachie, Wilbert (1980). *Improving lectures by understanding student's information Processing in McKeachie, W.J. (Ed), Learning, cognition and college teaching.* New Directions For Teaching and Learning, No. 2. Jossey-Bass, San Francisco.

Paul, R. & Elder, L. (2001). *Miniature guide to critical thinking, concepts & tools.* The Foundation For Critical Thinking.

Rowe, M.B. (1978). *Teaching science as continuous inquiry.* McGraw Hill, New York.

Samford University (1999). End of course evaluation. Samford PBL Initiative, Available online http://www.samford.edu/pbl.

Stepien, W., & Gallaher, S. (1993, April). *Problem-based learning: As authentic as it gets.* Educational Leadership, pp. 25-28.

Tobias, S. (1992). *Revitalizing undergraduate science.* Research Corporation, Tucson, Arizona, Research Corporation.

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