

# **Problem-Based Learning Laboratories Involving Chemicals From Biorenewables**

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## **Abstract**

At Iowa State University, we have developed a unique and valuable experience for our students by giving them an opportunity to work in multidisciplinary teams on cutting-edge problems involving biorenewables, while using novel problem-based learning approaches. The focus of four new 1-credit laboratory classes is to bring important emergent areas from the development of biorenewable sources of chemicals into new and existing courses in the Chemical Engineering curriculum. The laboratory components are being offered in parallel with four lecture courses. These new classes are open to undergraduates as well as graduate students. New engineers entering the work force need to combine knowledge of appropriate technologies with the ability to work in multidisciplinary teams, continue to learn as new possibilities evolve, realize the societal impacts of these technologies, and communicate their solutions and the benefits and risks that come with implementation. That collection of attributes suggests that problem-based learning is an excellent context in which to learn. The four laboratory modules we have developed address topics at the top of the priority research needs lists published recently by the National Research Council and industry roadmap groups studying the emergence of a chemical industry based on biorenewables. Under the direction of faculty members active in each area, the modules address bioinformatics for enzyme engineering, metabolic engineering for product yield, processing of plant materials for product recovery, and utilization of biobased polymers for tissue engineering. In these courses, students directed their own learning in multidisciplinary teams under the guidance of a faculty member trained in using problem-based learning. The common core training elements of the four laboratory classes included an orientation to research ethics, design of experiments, analysis of data, teamwork, communication, and self-assessment of learning. Novel problem-solving, teamwork, oral and written report rubrics were developed and used to assess and evaluate knowledge acquisition, problem-solving skill development, attitude toward lifelong learning, and improvements in metacognition. These rubrics have broad impact and are also currently being implemented in the graduate program to assess students' research performance.

## **Introduction**

Chemical engineers are being increasingly expected to use their process and design skills in the manufacture of bio-based industrial products. There is a strong need for new course materials that reflect this trend, although many chemical engineering curricula today include a senior-level

biochemical engineering course. Our central theme is to involve students in solving laboratory-based problems related to the conversion of chemicals into biorenewables. We used a problem-based learning (PBL) approach, i.e., the students recognize the relevant knowledge they already possess, identify what must be learned, acquire that knowledge and work towards a solution. We created multidisciplinary student teams, assigned them an industrially relevant problem, and guided them through the steps of the problem-solving process.

PBL originated four decades ago in the medical field when educators tried to find a better means of preparing physicians for practice<sup>[1]</sup>. They incorporated a practice of life-long learning and team skills by having students solve typical problems encountered in professional practice. PBL is now widely practiced in medical schools and we believe that PBL can be effectively implemented in engineering curricula. One of the Accreditation Board for Engineering and Technology (ABET) required outcomes attained by engineering graduates<sup>[2]</sup> is: ability to engage in life-long learning; ability to work in multidisciplinary teams; ability to identify, formulate and solve engineering problems; and ability to consider the ethical and social dimensions of engineering solutions. PBL facilitates the achievement of these outcomes in the standard curriculum. Our approach couples the learning of critical technologies for producing value-added products from biorenewables with improvement in these ABET-related process skills.

In PBL<sup>[3]</sup>, the learning is student-centered and is carried out in small groups with the teacher as guide. Problems provide a focus and motivation for learning, developing problem-solving skills is a desired component, and students identify the need for new information and then obtain it. In addition to the technical knowledge acquired by motivated learners, the outcomes include skills for problem solving, teamwork and life-long learning. PBL helps students know when and how to use knowledge, offers students the opportunity to demonstrate unique abilities, and allows students to work in teams<sup>[4]</sup>. According to Allen et al.<sup>[5]</sup> students need to acquaint themselves with the learning resources available to them ahead of time and explicitly identify attributes for successful teamwork. Others<sup>[6]</sup> have pointed out the need for students to be involved in developing desired process skills. The benefits of the course beyond factual knowledge need to be made clear to the students. They should also know how learning will occur so that they can develop the metacognitive ability to assess their own progress<sup>[7]</sup>. Self-assessment results from reflecting on questions such as, "What am I going to do?" "How do I do it?" and "Did it work?" (Additional references are available at <http://chemeng.mcmaster.ca>, [http://www2.ncsu.edu/effective\\_teaching/](http://www2.ncsu.edu/effective_teaching/), and<sup>[8]</sup>).

The learning journal is an example of an assessment tool that can be useful in assessing the important outcomes of PBL. A learning journal is a tool in which students respond to a series of questions and maintain a journal of their responses. These learning journals assist students by offering clear criteria that can guide students in the learning process, and is particularly useful when solving open-ended problems in the PBL environment. In this paper, we describe how we developed learning journals as means of consciously challenging students to think about the learning process.

We have developed four laboratory-linked modules. These laboratories were 1-credit classes that met for one afternoon each week. Each has a list of desired scientific/technical outcomes that should result from the solution of the problem, as well as a set of process-related outcomes.

The instructors do not initially share the technical outcomes with the students. Rather, the instructor uses them to develop questions that can be raised with students during the problem solving process, guiding them in new directions as they develop and test solutions. The process outcomes are shared with students at the outset, along with metrics describing the essential components of each of the outcomes. There were no out-of-class assignments per se, but the students were expected to perform activities such as literature surveys. The following results section first describes the desired subject-related outcomes for each individual laboratory course. Next, we describe the development of learning journals and the results of implementing these learning journals in one specific laboratory course (ChE 543L – Polymeric Biomaterials Laboratory).

### **Results: Subject-related student accomplishments**

All of the four laboratory modules have now been taught. The subject of each is described briefly.

**The metabolic engineering module** combined experimentation with mathematical analysis of the metabolism of the ethanol fermentation. Extracellular measurements of product and substrate levels of the fermentation broth are the inputs to a metabolic model that consisted of stoichiometric equations. The outputs of the analysis are the calculated metabolic fluxes. Students in this course will be able to perform a yeast fermentation, model the network for ethanol formation, determine and carry out the measurements needed, analyze the flux distribution, assess areas of reaction network for genetic modification, and determine whether more tools are needed for future characterization.

**The plant protein recovery module** allowed for exploration of alternative separation sequences for recovery of a recombinant protein from transgenic corn. The research aspect was enlivened by the result being sent to a company planning to commercialize the process. The resulting student-selected experimental effort included selective extraction, precipitation, ultrafiltration, ion exchange and hydrophobic interaction chromatography for purification of the protein product from the corn extract. The project provides opportunities to consider both process (column operation) and product development (resin selection) questions. Students in this course will be able to collect and store samples, prepare and standardize solutions, be able to perform the procedures listed above, interpret and report results, and draw appropriate conclusions regarding procedures and results.

**The tissue engineering module** exposed students to biotechnology-related product development through an experiment involving skin tissue culture on porous biodegradable polymer scaffolds. The students explored the use of various polymer substrates for skin culture in bioreactors. This enabled them to use chemical engineering principles to determine the appropriate media flowrates and control the heat and mass transfer rates to provide the right environment for the cells. The extended application was to design an appropriate bioreactor to sustain the growth of the cells on the polymer substrates for a period of two to three weeks to form artificial skin with good transport of nutrients and wastes to and from the cells. Students in this course will obtain an overview of polymer science and engineering, be able to identify the criteria to be satisfied before choosing a polymeric biomaterial, know necessary tests to assess biocompatibility, be

able to recognize important properties of polymers with respect to biocompatibility, and understand bioethical issues associated with the use of biomaterials.

**The bioinformatics module** is composed of four sub-modules, each of equal length: 1) An experimental investigation of the properties (optimal temperature and pH, effect of substrate concentration on activity) of a hydrolytic enzyme; 2) computation-based multi-sequence alignment of the amino acid sequences of the different forms of the enzyme produced by different organisms; 3) construction of a phylogenetic tree of the different enzyme forms by computation; and 4) computational automated docking of different substrates in the enzyme active site. The student teams in the course studied either  $\beta$ -glucosidase or glucoamylase.

### Results: Learning Journals

Each of the three modules shared common problem-solving course learning outcomes. Through these courses, students develop problem solutions using information from several information sources, function effectively on multidisciplinary teams, express ideas effectively orally and in writing, plan and monitor progress, improve self-knowledge of how they learn, and self-assess their role in developing an effective solution.

**PBL development and implementation.** The term began with an orientation session that helped students learn about or review topics such as problem-based learning, research methods, statistical analysis, research ethics, literature searching, and lab safety. We also familiarized them with two key elements of the module: (1) the metrics we would be using to assess each process outcome (written and oral communication, weekly reports, teamwork, and problem-solving) and (2) the web-based tools we would employ to deliver materials, administer surveys, and communicate with the class.

The learning journals were implemented via the web and consisted of the following six exercises, which were given to the students over the course of the semester. Exercise 1 was given immediately after the orientation session and Exercise 6 was given at the end of the semester.

Exercise 1:

1. What questions do you have about PBL? Which areas need additional clarification?
2. How can the professor and the graduate assistant facilitate your learning?
3. Throughout the course you will work with other students as a team. Describe your previous experiences in group learning. What have you liked/disliked about group projects?
4. Write one personal goal that could help to make the experience positive.

Exercise 2:

1. You are in the middle of problem solving and getting ready to do experiments. Describe your sense of confidence in your team's ability to solve problems. Feel free to use the following questions as guides for your thinking: How do you feel about the team's efforts? How well is your team able to identify issues, set goals, and define problems?; Would you recommend any changes to the team's approach?

Exercise 3:

1. Provide an example of a time when the team was effective or ineffective.
2. How has working on a team influenced your learning? How has working on a team influenced your thinking about your role on a team?

Exercise 4:

1. One of the objectives of the course is to improve your knowledge about how you learn. Describe how your experiences thus far have influenced your thinking about problem solving and how you best learn.

Exercise 5:

1. Describe the ways in which this course affected your learning in each of the following areas: Knowledge of the content of the discipline, Critical thinking, Written and oral communication, Teamwork, Problem solving, Other.

Exercise 6:

1. Describe how you have integrated your understanding of various concepts to enhance your learning and develop problem solutions.
2. How has your approach to problem solving changed throughout the course?
3. What aspects of the course helped you develop your problem solving skills?
4. What aspects of the course could be improved? How can these areas be improved?
5. As a result of the course, how prepared do you feel to address new problems?

## Discussion

**Evaluation of PBL and Learning Journals.** The use of learning journals for student evaluation of learning is different from traditional assessment methods. The implementation of the PBL format is a shift to a learner-centered approach that requires changes in the traditional laboratory structure and format. Huba and Freed<sup>[4]</sup> explain that one strategy to support students through these changes is making evaluation standards public through tools such as rubrics in order to facilitate a trusting relationship between faculty and students. Another strategy is to ask students for feedback that faculty can use to improve the learning environment. We sought this type of feedback by asking students throughout the term to provide reactions to various aspects of the course through the written journals and focus groups. Analysis of these comments provided information regarding the benefits and challenges of the PBL learning environment in general.

The next sections provide a summary of benefits and challenges of the PBL process that emerge from student comments. This document summarizes students' initial reactions to PBL, teamwork experiences, perceptions of student learning, and overall reactions to the course.

**Initial Student Reactions to PBL.** In early journal reflections, students indicated that they were confident in their understanding of problem-based learning. One student explained, "I no longer have any questions about this style of teaching. All of it seems very clear to me." Another student commented, "PBL is an open-ended process very similar to the real world." Students also indicated that they liked working in teams and enjoyed previous group projects. Students

appreciated the positive aspects of teamwork explaining, Good groups have shown that the result is more than a sum of the parts, but a synergy or skills.”

Although students were comfortable with the concept of PBL, they noted several aspects of the course that were unclear. One student stated, “The only question that I have is concerning how the instructors monitor our process and relay advice to students. I have a feeling that the instructors might not be conveying what they truly think when they observe the team talking about the project.” A different student mentioned, “The grading scheme is still a little fuzzy, but the rubric helped.”

Overall, students seemed to have few questions about PBL and did not need clarification regarding the concepts. They did ask some questions about how PBL would be used in practice. In particular, student comments indicated the need to explain how instructors would relay information to students and the need to clarify the grading process. The student’s concern about “how the instructors monitor our progress and relay advice to students” indicates that students have expectations regarding the faculty member’s role. Although the PBL process allows students to direct their own learning, students still want instructors to monitor their progress, provide advice, and redirect efforts when necessary. It may be helpful to talk about the teacher’s role throughout the semester to provide students with the support that they need.

Students explained that the instructor and teaching assistant can be helpful with the PBL process through being available to answer questions, providing technical consulting, and ensuring that the groups remain on track to solve the problem. It appears that students have the expectation that the instructor and teaching assistant will continue to fulfill important roles in the problem-solving process. Students’ initial expectations indicate the need to explicitly examine with students the role of the instructor and teaching assistant. This dialogue could assist both students and the instructor in developing clear and effective communication throughout the project.

Students offered several initial personal goals that they believed would help to make the PBL experience positive. Students’ goals reflected their disposition to be critical thinkers and their willingness to consider alternatives and to suspend judgment. For example one student’s goal was to “keep an open mind of others’ opinions because it is a group effort and not the effort of just one person.” Another person wanted to “not let differing opinions and slow progress perturb me.” A third student expressed the goal, “To be persuaded by one of my partners to change my opinion on a crucial topic because their viewpoint is better than mine. The debate and discussion in such situations is the true definition of learning a new topic.”

**Teamwork.** In early reflections, students expressed confidence in the team’s ability to solve the problem. The team worked together to gather information about the problem and then divided up basic tasks. The team relied on one student’s expertise in project management to identify issues, set goals, and define the problem. One team member expressed concerns regarding the group’s efforts, “Our team is pretty adept at identifying issues and setting goals. Defining problems is also a strength, but I feel like we don’t map a path to get to the goals very well. I think I would like a little more structure to our approach at this point, but I don’t have a very good idea on how to implement this.” It seems that with time, it becomes increasingly difficult for the team to achieve its designated goals. While the teams are successful in defining the problem, identifying

issues, and setting goals, they would appreciate some additional structure to the problem solving approach.

Students expressed various levels of effectiveness depending upon whether the team was working together or individually. One student stated that the team was most ineffective when the group was working together, because some of the individual tasks (e.g., bioreactor design) were not relevant to the initial preparations (i.e., cell growth). In contrast, one student thought that the team was most effective when the team worked together to discuss the requirements of the bioreactor, saying, "Nobody on the team could have come up with the requirements alone, but we gathered around the table and each added blocks to a schematic to fill in things based on our individual experience." One student recommended a balance between individual and group work stating that the team was most effective when, "We all presented our information and shared the new developments and left the meeting with new tasks to do. I felt really good about the project at that point." The exercise when students discussed the bioreactor design represents a possible discussion cue that instructors can use to elicit this type of interaction with team members.

In general, the students did not want to alternate roles within the teams. For example, one student thought that the team was most ineffective when the student became the next group leader. In response to this reaction, it might be helpful to provide student teams with feedback regarding the skills that they have developed through changing roles within the team.

Working on a team had a positive influence on students' learning. Students explained that they learned things from other students like project management or how to conduct literature searches. One student explained the benefit of working in a team, "I like working in a team because I can rely on others to fill the holes in my own knowledge. It is a lot easier to solve a problem when there are other people to bounce ideas off of." Another student wrote, "My learning is much more ... organic, because it seems to come more naturally than when I am just being lectured to."

**Student Learning.** Students provided several comments that described how their experiences in the laboratory course influenced their thinking about problem solving. The student comment below provides an illustration of how the PBL format influenced the way one student thinks about solving problems.

My experience so far has been more objective thinking, more "outside the box" per se. I like it a lot because it makes me question things a lot more and it makes me question group members more to make sure they are on track and to gain the necessary knowledge that I need for these types of projects. This was not the original way I learned. I was used to having it all handed to me, but now I feel more apt to go seek out a problem and tackle it on my own which is probably more helpful in many situations rather than waiting for a task to be assigned to me and just doing it then.

Other student comments explained that the process of reviewing literature and the opportunity to engage in hands-on experiences helped them to increase their knowledge about the problem and to remember the information.

Students' journal comments also provided reactions to the PBL format. Several comments indicated that the PBL format helped to enhance student learning. Students indicated that they

appreciated the “challenge of having students essentially make their own assignments” and “the more intimate relationship between professor and student.” Other comments provided suggestions for ways to improve learning. One student explained that the grading criteria were not clear, “I wish I had a bit more idea of the grading. Since part of the point of the course is the learning process, and I am working hard, I think I’m doing all right but I really have no idea.” The same student indicated that it might be helpful to provide more feedback so that students are aware of their progress.

Students offered several comments regarding how the course affected their learning. Selected examples of these comments are included below.

It has made me realize how important research is on the area to find relevant information on the topic.

I have learned the places to find up to the minute information in order to research a topic. This course has taught me where to look for my own information.

The course has taught me how to critique the work of others working on similar topics. [The course has] taught me about roles in a group, leadership, and gave me more experiences in these roles.

I learned how to find information to create a plan, test the plan, use alternative methods when the primary plan didn’t work, and to use creativity in solving problems when background information could not be found.

The course has completely opened up a new world to me. I have had no previous experience in life sciences and feel now that I can understand some of the overall technical issues involved in tissue engineering and the economic considerations to be made.

The need to research technical literature forced me to discern whether I was collecting reliable information or not.

I have seen how important it is to thoroughly explain my ideas because I am working with people of a different background and major than me. Many of my assumptions are things that they have never considered before, and vice versa.

This course has taught me that it is good to have a team made up of various backgrounds. The proposed solutions are far more broad reaching and innovative than what would be suggested if everyone were from the same major.

I am better able to see the big picture, and how each individual topic fits in.

At first I wondered where to start with such a big project. Going through the process of literature reviews helped me get a handle on where to begin, and the process of breaking down a big task into many small tasks made the project more do-able.

**Overall Reactions.** Students provided several comments in the last journal exercise that offer insights into students overall reactions to the PBL format. Students explained that several aspects of the course helped them to develop their problem-solving skills. One student cited the nature of the open-ended problem as an important aspect of the course that helped students develop problem-solving skills. The same student also mentioned that the requirement to review the literature and look at various techniques to accomplish a task were helpful aspects of the course. Other students explained that the teamwork aspect – “working more cohesively as a group toward a goal” allowed students to “draw from other people’s knowledge...to bring things together more easily.”



Students recommended adding more structure to the class schedule within the PBL framework in an effort to ensure that teams are moving forward with their projects. One student explained, “Unfortunately, too late in the semester we began to realize that one key aspect of our project was not being handled adequately, and we are at a position where there is not much we can do about it now....if a suggested or example timeline was given, it could give groups a realistic idea of how long things like experiments take, which we did not have.”

Overall, both times this class was taught, the students indicated that the experience contributed to their problem-solving skills. The students provided the following comments:

I feel reassured that some of my notions of solving a problem are appropriate. Yet I also feel that I have to spend more time keeping my teammates motivated and supported so that crucial tasks aren't ignored for long periods.

I feel that I have a much better way of tackling new problems presented to me, with an open mind, instead of a structured plan.

More prepared than before. Confident, even. :)

I don't think it was life changing but it helped some.

## Summary

PBL represents an atypical learning environment that offers challenges to both students and faculty as they engage in different ways of learning. We designed the learning journals to assist both students and faculty in making the transition to the new environment, and we found that the journals were generally useful and favorably received by the students. Nevertheless, some students described several challenges of using these journals in the courses, and struggled with the open-ended nature of the PBL format. Students' concerns suggest that we need to build upon our successes and continue to explore ways to incorporate the use of journals even more deliberately into the course environment. We point out that the journal questions presented here are appropriate for other course settings that require team assignments or written and oral reports.

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