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Work in Progress: Design and Implementation of Collaborative Problem-Based Learning Laboratory Modules for Engineering and Non-Engineering Students

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Motivation and Background

Problem-based learning (PBL), which originated in the 1960s for professional training of physicians for medical practice, is now extensively practiced in various science, technology, engineering, and mathematics (STEM)-related fields.[1, 2] PBL can provide opportunities for students to solve complex and open-ended, real-life problems encountered in professional practice. It is often carried out in small groups under the guidance of an instructor with varying degree of structures or scaffolds embedded in the course. Its main goal is to equip students with the knowledge, skills, and experience required to be competitive forces in their future careers. PBL has been proven to foster lifelong learning, teamwork skills, and critical thinking.[3]

While it is not a "silver bullet" to solve every challenge in engineering education, it is generally agreed that PBL can be an effective strategy for teaching difficult engineering concepts and improving learning outcomes when applied correctly.[4, 5, 6] Its implementation and effect on students' learning outcomes have been studied and demonstrated in courses in various disciplines of engineering, educational settings, and student populations. However, there is a dearth of research on PBL application and its assessment for engineering courses offered to a mixed group of students from engineering and non-engineering STEM disciplines. In addition, according to the author's knowledge, there is a limited number of studies on PBL application in food process engineering courses, while dozens of studies on the implementation of PBL in other food-related courses such as food science, food safety, chemical engineering, and biotechnology are available.[7, 8, 9, 10, 11]

This work-in-progress paper describes the collaborative PBL laboratory modules developed for one of the food and process engineering courses offered at the University of Wisconsin-River Falls. Food and Process Engineering I (AGEN 352) is a required course for multiple majors within the college. The course is taken by engineering and non-engineering STEM majors (Ag Engineering Technology, Ag Engineering, and Food Science and Technology) in their junior and senior years. The fact that the enrolled students vary in their majors, background knowledge in engineering, and experiences in solving engineering problems poses a unique challenge for this course. The course must provide a rigorous and applied educational experience for engineering students to meet the criteria set by Accreditation Board for Engineering and Technology (ABET) while ensuring that the non-engineering STEM students (in Ag Engineering Technology and Food Science and Technology) in the class learn and apply core engineering concepts and technology to solve food engineering problems in a team setting. In the past, the non-engineering STEM students enrolled in this course often expressed that they felt daunted and overwhelmed by the rigorous engineering-focused coursework involved in this course. This challenge led to the need to redesign the course, especially the laboratory (lab) portion, to help all students – regardless of their background knowledge in food process engineering – acquire problem-solving skills and preserve conceptual knowledge through multiple problem-solving experiences.

The PBL labs as described in this paper were implemented for the first time in fall of 2019. This work-in-progress paper mainly focuses on the details of the PBL labs developed, their implementation, and the challenges identified from the observations and the students' course feedback collected at the end of the semester. The qualitative information described in this paper is based on the student feedback that was collected as a pilot study to determine the feasibility of this research and to investigate the initial implementation outcomes. The author is currently in the process of developing detailed assessment and survey tools to evaluate the effectiveness of the PBL implementation that will be reviewed by Institutional Review Board (IRB). The feedback and observations described in this work are expected to help the instructor refine data collection procedures and instruments to develop a systematic research design for this study.

The overall goal of this study, which will span the next three to five years, is to assess the impact of PBL on students' problem-solving ability and learning attitude in an engineering course taken by a mixed group of students from engineering and non-engineering STEM disciplines. The challenges identified by this preliminary study provide insight into how to guide a mixed group of engineering and non-engineering STEM students to solve complex problems and how to equip them with the necessary technical skills while strengthening their teamwork skills.

Course Description

The Ag Engineering Technology department at the University of Wisconsin-River Falls currently offers three sequential food process engineering courses – Food and Process Engineering I, Food and Process Engineering II, and Food Bioprocess Technology – for students interested in food engineering as a career track. Food and Process Engineering I (AGEN 352) is one of the core engineering courses that all Ag Engineering Technology (AET), Ag Engineering (AE), and Food Science and Technology (FS&T) majors are required to take regardless of each student's option or emphasis within the major.

Food and Process Engineering I (AGEN 352) aims to teach the common engineering concepts that are essential in the design and operation of food processing systems. Among the various engineering concepts and unit operations in food processing, the course mainly focuses on material and energy balances, liquid and solid mass flow systems (pumps, pipes, fittings), and heat transfer and preservation processes (pasteurization, canning, dehydration), which are ubiquitous in various industrial food and bio-processing operations. Subsequently, the students interested in food processing as a career track are advised to take Food and Process Engineering II and Food Bioprocess Technology to broaden their knowledge base concerning other unit operations in food processing systems. The topics taught in AGEN 352 and the course outline are summarized in Table 1.

Table 1. Course outline of Food and Process Engineering I (AGEN 352) before and after lab-redesign

<table>
<tr><th>Week</th><th>Subject</th><th>Lab activity topic before lab modification</th><th>PBL-based lab activity after lab modification</th></tr>
<tr><td>Wk 1</td><td>• Introduction
• Units</td><td>Units</td><td>Units, lab safety, introduction to PBL concept map exercise</td></tr>
<tr><td>Wk 2</td><td>• Material balance</td><td>Material balance</td><td rowspan="5">Lab Module 1:
Osmotic Dehydration of Pineapple

Exam I</td></tr>
<tr><td>Wk 3</td><td>• Thermal energy concepts
• Steam energy
• Steam table</td><td>UWRF central heating plant tour</td></tr>
<tr><td>Wk 4</td><td>• Energy balance</td><td>Energy balance</td></tr>
<tr><td>Wk 5</td><td>• Fluid mechanics concepts
• Liquid properties
• Continuity equation
• Reynolds number</td><td>Friction losses in pipes</td></tr>
<tr><td>Wk 6</td><td>• Fluid flow in a pipe
• Pump energy equation
• Pump curve
• System curve</td><td>No lab (Exam I)</td></tr>
<tr><td>Wk 7</td><td>• Multiple pumps
• NPSH
• Pump affinity law
• Pump selection</td><td>Pump characteristics (pump curve, system curve)</td><td rowspan="4">Lab Module 2:
What Pump Will Work?

Exam II</td></tr>
<tr><td>Wk 8</td><td>• Heat transfer and heat exchanger overview
• Steady state conductive HT</td><td>Pump selection</td></tr>
<tr><td>Wk 9</td><td>• Steady state convective HT (forced, free convection)</td><td>Plate heat exchanger configuration</td></tr>
<tr><td>Wk 10</td><td>• Overall HT coefficient
• Heat exchanger design</td><td>Heat exchanger performance</td></tr>
<tr><td>Wk 11</td><td>• Transient heat transfer</td><td>No lab (Exam II)</td><td rowspan="4">Lab Module 3:
How Long Should I Cook Meat in the Oven?</td></tr>
<tr><td>Wk 12</td><td>• Transient heat transfer</td><td>No lab (Thanksgiving)</td></tr>
<tr><td>Wk 13</td><td>• Preservation processes
• Dehydration</td><td>Transient heat transfer measurement</td></tr>
<tr><td>Wk 14</td><td>• Preservation processes
• Dehydration</td><td>UWRF dairy pilot plant heat tour</td></tr>
<tr><td>Wk 15</td><td>• Psychrometrics</td><td>Psychrometrics</td><td>Psychrometrics</td></tr>
</table>

Table 2 summarizes the student counts by academic standing and major for the past three fall semesters AGEN 352 was offered. Typical class size is 20 to 25 students. As indicated in Table 2, the majority of the students are AET majors. Both FS&T and AE programs are new programs offered the first time within the past three years. While AE majors typically take the course in their junior years, AET and FS&T majors take the course in their senior years.

Table 2. Student counts by academic standing and major

	Fall 2019	Fall 2018	Fall 2017
Number of students enrolled in AGEN 352	25	21	23
Majors			
AET	17	12	21
AE	3	8	2
FS&T	5	1	0
Academic standing			
Juniors	9	9	7

AGEN 352 comprises two one-hour lectures and a two-hour laboratory session each week. The lectures focus on introducing engineering concepts, systems, and components in food-processing systems and explaining techniques and methods relevant to such systems through a combination of PowerPoint slides and lecture handouts. The subsequent two-hour lab session focuses on reinforcing the students' learning by providing them with an opportunity to apply, test, and evaluate the key concepts discussed in the lecture materials.

In the past, each lab assignment was designed to focus on a specific topic aligning with the course outline. The weekly two-hour lab was based on a simple and well-defined task in which students followed step-by-step procedures to solve a hypothetical food-processing problem or to test, measure, and analyze data. These lab tasks had limited complexity to allow students to finish the lab task within the assigned two hours of each lab. For example, in the material balance lab, students were provided with a hypothetical food-processing scenario and asked to solve mass-relevant parameters by applying material balances such as moisture contents, amount of moisture removed or added, amount of materials required, or compositions of streams within the process including that of the final product. In the case of the pump curve lab in Week 7 (Table 1), a detailed procedure on how to obtain data of flow rates versus heads of pump arrangements was provided. The instructor set up the pump apparatus and its arrangement. The range of flow rates to be measured for pressure drops and all relevant equations for calculating pump heads were also provided by the instructor. Students simply followed the steps to record the data and prepare a pump curve from the measured data.

While these lab activities provide students with tangible experiences to learn a specific concept or skill and allow them to be more involved and engaged with the course materials, they are inadequately designed to prepare the students to solve real engineering problems, which are often open-ended, complex, and ill-defined with many unknowns and variables. For example, students may learn how to measure certain parameters or engineering properties related to a flow or heat exchanger system from these lab activities, but they do not necessarily understand how those measurements are used in the design of flow or heat exchanger systems in food processing, what other variables to consider, and how those variables are interrelated and can affect the design and operation of such systems.

The department curriculum includes a senior-level capstone design course for AE majors and a multi-semester project course for AET majors. In these senior-level project-based courses, students are tasked with applying their knowledge and skills to solve complex and ill-structured engineering problems. The level of knowledge and competence required to successfully work on such design and problem-solving projects cannot be realized unless the preceding core courses expose the students to problem-solving experiences with a proper level of complexity and uncertainty. In addition, FS&T majors who typically take this course in their senior years need to exercise an advanced level of problem-solving skills to improve their knowledge and gain confidence in solving complex workplace problems they are likely to encounter in their future careers.

To provide students with an opportunity to experience the complexity of engineering problems and the interdependence of different conceptual knowledge and skills required to solve such problems, the lab portion of AGEN 352 was redesigned by incorporating PBL-based collaborative activities. The implemented changes were expected to achieve the following outcomes required by ABET, which are especially challenging to achieve in a traditional lecture-based learning environment:

- An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
- An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
- An ability to acquire and apply new knowledge as needed using appropriate learning strategies

While these learning outcomes are set by ABET to ensure that engineering students are adequately prepared to enter the profession with the necessary skills and experiences, non-engineering majors in STEM disciplines can also greatly benefit from acquiring these skills since the complexity and challenges associated with the problems society faces today require a collaborative interdisciplinary effort. The following section describes the details of the changes made and the modified lab structure.

Methodology

Lectures: The two-hour lecture portion of the course remained unchanged in terms of content, topics covered, and schedules. Lecture hours were spent explaining engineering concepts and approaches, working out example problems, and introducing new technologies relevant to the topic covered. Lecture materials (PowerPoint slides, relevant journal articles and learning resources) were distributed prior to the labs to ensure the students understand the key concepts required to work on the lab assignments. In addition, lecture packets were provided to students prior to each lecture. The lecture packets were basically printout copies of lecture notes with example problems and blanks left for students to fill in during the lectures. These lecture packets helped students be more attentive and focused during the lectures.

Lab Modules: The labs were restructured to adopt a PBL approach by creating a student-centered, collaborative learning environment. The main goal was to provide students with problem-solving experiences with a proper level of complexity and uncertainty. Since teamwork is a critical component of PBL learning, the class was divided into five to seven teams, with each team comprising three to four students depending on the size of the class. Teams were formed based on the Comprehensive Assessment for Team-Member Effectiveness (CATME) team-maker survey. The relative importance of the new PBL-based lab activities for the final grades increased from 25% to 40% considering the increased level of time commitment and teamwork demanded to complete each lab module. The following description summarizes the changes and the main components of the PBL-based labs.

The weekly lab session was modified into three separate multi-week lab modules (see Table 1). The lab modules contained realistic engineering problems that emulate real-life situations. According to Jamaludin et al.,[12] effective engineering problems should be authentic, realistic, constructive, and integrated with suitable complexity and should promote self-directed learning and critical thinking. Thus, the lab module problems were designed to stimulate thinking skills and to broaden students' experiences and confidence in solving workplace engineering problems, which are open-ended, not limited to one correct solution, and require decision-making, troubleshooting and diagnosis, and design skills to solve. Integration of prior knowledge and making decisions or judgments based on facts and assumptions are the key elements of solving these problems. The size and complexity of each problem were challenging enough to require three to four weeks of focused and organized teamwork to complete each lab module. Each of the modules focuses on the following subject in accordance with the topics taught in this course. The focus topics, title, and problem statement of each lab module are described in the following sections.

A. *Lab Module 1* *(Weeks 2 to 6)*

Topics: Mass and energy balances in food processing, preservation processes (dehydration)
Title: Osmotic Dehydration of Pineapple
Problem statement: Fruits and vegetables are essential to a healthy diet. However, they can be easily contaminated and spoiled without proper preservation. Osmotic dehydration is considered a simple yet effective preservation technique for increasing shelf life by removing water while preserving the sensory and nutritional characteristics of fruits and vegetables. It is often applied as a pre-drying step prior to a conventional hot air-drying process to reduce the moisture to a level needed for long-term storage. In this lab module, your team must develop an osmotic dehydration process to achieve dried pineapple with $a_w < 0.7$ within 12 hours of oven drying at 50°C.
Final report: Based on your measurements and data analysis, determine and discuss the following in your final report:

(a) The amount of fresh pineapple, sucrose, and water needed to produce 1 ton of osmo-hot air-dried pineapple wedges
(b) Composition of the dried pineapple wedges (moisture content, solids content)
(c) Thermal energy needed to produce 1 ton of osmo-hot air-dried pineapple wedges (for energy required, consider osmotic dehydration and oven-drying steps only)
(d) Sensory evaluation test results (taste, texture, moisture, color, flavor, etc.)
(e) Provide a process flow diagram of the osmo-dehydration process to produce 1 ton of osmo-hot air-dried pineapple wedges and an Excel spreadsheet summarizing your calculations

B. *Lab Module 2* *(Weeks 7 to 10)*

Topics: Pump characteristics, pump performance and selection

Title: What Pump Will Work?

Problem statement: Suppose you work in a small wine production facility that is currently undergoing a major renovation. The process will include a new, upgraded filtration system larger in capacity than the previous one. As a production engineer, you must replace a very old pump that had been used in the wine transport system. The pump to be replaced is missing all the information related to it. Its technical specification sheet, operating manual, and pump performance curve are nowhere to be found. Its manufacturer has been out of business for a couple of years already, so you cannot get the information from the manufacturer. Your main goal is to find a new pump that will work for this new system.

Final report: The Lab Module 2 report should outline your team's detailed procedure of how you have determined which pump will work for the wine transport system described in this lab module and the rationale behind your decision. Based on your analysis of the system, suggest a commercially available pump that will be suitable for the system. Include the name of manufacturer, model name, pump performance curve, and other technical specifications. Additionally, recommend a necessary brake power to run the pump motor. Be sure to include the following items in your report:

(a) A table that summarizes all the necessary parameters for constructing a system curve

(b) A list of all equations used for constructing system heads versus flow rates (provide the definition of each parameter in the equations with its unit)

(c) A table that summarizes the calculated system heads (m) at various flow rates (liter/min)

(d) A plot of system curve (system head in m vs. flow rate in L/min)

(e) The manufacturer name and model of the pump of your choice with its full technical specifications

(f) The pump performance curve of the pump as provided by the manufacturer

(g) The $NPSH_A$ calculated for the system and the $NPSH_R$ of the pump you have selected

(h) A one-page summary and discussion of how you have determined that the pump of your choice would work for the system and an Excel spreadsheet that shows the calculations of the system heads at various flow rates and $NPSH_A$

C. *Lab Module 3* *(Weeks 11 to 14)*

Topic: Unsteady state (transient) heat transfer, heat transfer measurement, and heat exchanger design

Title: How Long Should I Cook Meat in the Oven?

Problem statement: Required cooking duration can be easily estimated using a cooking thermometer in a small-batch operation (such as cooking at home). However, such measurements are not possible in a large-scale operation where the amount of meat cooked (or cooled) in one operation is significantly larger than typical meat cooking done at home. Additionally, the meat to be cooked and processed comes in all different shapes and sizes, making the direct measurement of internal temperatures during the heating or cooling process an impractical option to apply in an industrial-scale operation.

Suppose you, as a food process engineer, work in a food processing company that produces various types of fully cooked, ready-to-eat meat products such as cooked sausages, ham, chicken breasts, and hamburger patties. The plant uses a linear continuous oven.

You must determine the surface convective heat transfer coefficient (h) inside an industrial-scale linear oven. The h value can be used to estimate the cooking time required for any meat of any size to reach its target safe minimum internal temperature in the oven without having to measure it directly.

Final report: Based on your measurements and data analysis, determine and discuss the following in the results and discussion section of your final report:
(a) Describe all the assumptions made
(b) Briefly discuss the limitations of the method applied
(c) Based on the measured surface heat transfer coefficient (h), estimate how long it takes for the center of pork loin to reach the target safe internal temperature; use Heisler charts
(d) Discuss how the estimated duration compares to the actual measured data
(e) Discuss the sources of errors and suggest ways to improve the method of determining the convective heat transfer coefficient of pork loin
(f) Provide a printout of an Excel spreadsheet showing your calculations and the list of all equations used with a definition of each parameter within the equations

Structure of the Lab Module: Each lab module involved the following sequence:

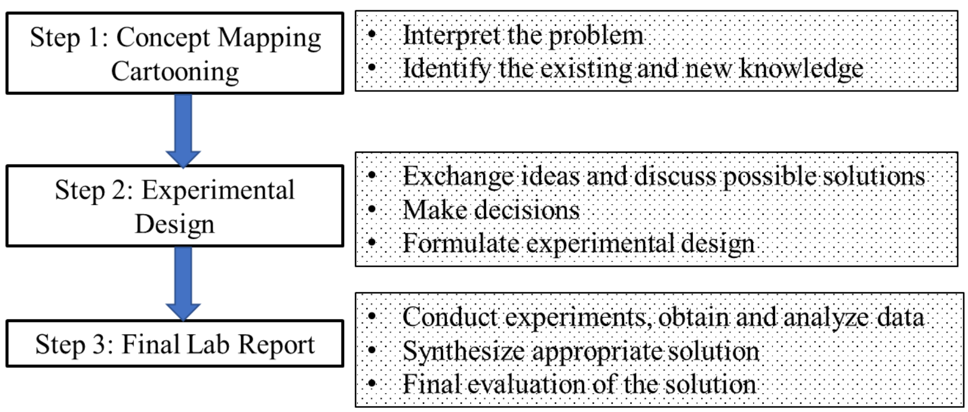

Figure 1. Lab module sequence and detailed tasks of each step

Each lab module consisted of the following assignments with slight variations among the modules. Some of the assignments (concept mapping, cartooning) were adapted from the consider, read, elucidate the hypotheses, analyze and interpret the data, and think of the next experiment (C.R.E.A.T.E.) method.[13]The instructor provided the students with feedback and comments at various stages of this problem-solving process to provide guidance as a facilitator rather than as a didactic instructor or source of knowledge.

A. *Concept Mapping*

A concept map is a visualization tool used to display the relationships among a set of connected concepts and ideas. It has wide applications in various fields, including engineering education.[14, 15] Concept mapping can be an effective active-learning technique that helps students identify what they do and do not know, see how different concepts are related to each other, and communicate their understanding of the topic to others.

For each lab module, students were provided with one or two research or technical article(s) relevant to the topic of the given lab module. Students were asked to read the assigned paper(s) outside of class prior to each lab module. During the first lab session of each lab module, they were tasked to develop a “consensus concept map” as a team using Cmap software (IHMC). The main goals of the concept mapping were to allow students to identify what knowledge they do and do not have, actively look up the meanings of any unknown terms, communicate and discuss what they have learned, and finally organize concepts in a meaningful way to represent the topic in a team setting. This approach was chosen to stimulate and reinforce the students’ self-learning activity and enhance teamwork at the early stage of each lab module.

For Lab Module 1, students were also asked to prepare a cartoon describing the experiments and the results associated with each experiment in the article(s) they read for the concept-mapping activity. The C.R.E.A.T.E. method indicates that the cartooning activity facilitates active learning and engagement by circumventing students’ tendency to read scientific articles superficially and allowing them to visualize and teach themselves what experiments were done and how they were conducted. Through this activity, students were expected to make connections between the concepts and experimental data and understand the design of an experiment and the hypothesis that underlies it as well as the tools and methods used in each experiment.

B. Experimental Design

In the subsequent lab session, students discussed how to design experiments to measure and test the parameters, material properties, or processes necessary for constructing a solution to the given problem. Each team prepared a scientific experimental proposal containing the following items:

1) Define the goals and objectives of the experiment
    a. Goals: may be general
    b. Objectives: must be specific and directly or indirectly measurable
2) Research
    a. Relevant theory (including relevant equations)
    b. Previously published data from similar experiments
3) Constraints and variables
    a. Define constraints (parameters that are fixed and cannot be changed)
    b. Select dependent and independent variable(s) to be measured
4) Materials and methods
    a. Select appropriate materials and methods for measuring these variables
    b. Select appropriate equipment and instrumentation
    c. Select proper range of the independent variable(s)
    d. Determine appropriate number of data points needed for each type of measurement
    e. Determine the data analysis and statistical methods to be applied

The instructor provided comments on the proposed experimental design before the students conduct the experiments.

C. Final Lab Report

For the remaining lab sessions of each lab module, which are typically one to two weeks of lab, students conducted experiments and collected and analyzed data as planned. Based on the data obtained, each team summarized its proposed solution to the problem, discussed limitations, and provided the rationale, assumptions made, and sources of information used in their solution. Each lab module required a different set of specific questions to be discussed in detail in the final lab report.

Student Feedback and Challenges

This section describes students' behaviors observed throughout the semester and the feedback received at the end of the semester through the following open-ended questions: 1) what did you like best about the course? and 2) how could your experience have been improved?

Feedback and responses received after the semester indicated that in general, the students perceived the PBL-based labs as more challenging and time consuming than typical labs. This was expected due to the nature of PBL, which is very different from the traditional didactic setting the students are used to. In a traditional lab, students are asked to simply read and follow the recipe in the lab manual and are given most of the information needed to solve a well-defined, tightly constrained problem that is often aimed at verifying a specific concept or theory. On the other hand, the PBL labs as described above required students to communicate their ideas, design and conduct their own experiments, and draw conclusions from the evidence. In addition, most of the students in the class indicated little or no previous exposure to PBL-based labs, which also contributed to this perception. However, the open-ended responses regarding what the students did or did not like about the labs reflected a consistent theme that students felt PBL provided a highly engaging, hands-on experience and that the lab activities were more relevant to real-life problems. In terms of the time commitment required to complete each lab module, some students stated that they preferred the modified lab structure (a multi-week lab task) to a weekly lab, because it provided them with a greater degree of flexibility in scheduling with other team members to complete the lab assignments. The following are quotations from the student feedback related to these aspects.

"*Hands-on is very helpful in learning and the labs were great and connected with lecture."*

"I actually enjoyed the longer labs. It provided more time and enough data and procedure to be able to write a thorough lab report."

"I liked the fact the instructor restructured the lab part. Not having a lab report every week was nice especially with my schedule."

"I enjoyed thoroughly working through a lab and developing experimental designs. In-class packets were extremely helpful and allowed students to engage more and worry about writing down all the notes less."

"I like that we had hands-on labs and it wasn't just all calculations for every lab."

"It was challenging, and I liked the collaborative labs."

"The labs were brutal but did teach me how to use most of the equations."

"The labs were very in depth and challenging but could be applicable."

"The labs made our team really try and struggle. At points I thought it was too hard, but we would eventually figure it out by using people around us. Even though I would like to say it would be easier the old way of labs, this way is more applicable to my future."

While the students enjoyed the hands-on aspect of the PBL labs, they also shared their perspectives on the challenges and potential improvements. The students reported that they feel more comfortable with the traditional weekly assigned labs with clearly identified tasks, detailed steps to follow, and all the necessary information provided to them. The students reported that the most challenging aspects of the PBL labs were 1) the lack of well-defined, constrained objectives and uncertainty associated with the problems; 2) the time commitment required to complete the assignments; and 3) having to work in a diverse group of students with different knowledge backgrounds and skills. The students especially felt uncomfortable dealing with a broad and under-defined problem to which they had little or no prior exposure. Many comments indicated that the students would have liked more instruction and direction in the labs with clearly defined goals and aims. One student reported,

"I wish the labs had more defined objectives. There were too many uncertain variables to the point that all other group members more or less gave up, placing the load of the point-rich labs on a few students."

Another student commented the he or she would prefer having *"slightly more constrained lab goals that cannot be interpreted as broadly as they often were."*

Some students felt overwhelmed with the fact that the labs did not tell them what to do and how to do it. One student commented,

"I understand having the student figure out on their own what needs to be measured and recorded for the lab reports, but for some labs I felt like most of the class didn't have a clue where to start. I think a little guidance or a simple briefing of what needs to be accomplished would help."

Another common theme of challenges the students expressed was the amount of work required and the insufficient time given to complete each lab module. While most students liked the freedom to design and conduct their own experiments, they often felt the time provided to complete each lab module was insufficient and thus felt rushed to complete each assignment. This was especially challenging for the students who had other commitments outside of study, such as part-time jobs. They had a difficult time scheduling work with other team members, especially to conduct experiments, record and analyze data, and contribute to the final report.

Regarding the workload, one comment said, "*The amount of work expected for this class exceeded all my other classes combined by a lot, it should be more than 3 credits!"*

Finally, it was interesting to see comments regarding the team composition and challenges related to having to work with team members from other disciplines. The instructor used the CATME survey to form diverse teams in terms of students' areas of study, gender, and college year standing. The five FS&T majors enrolled in the class were all dispersed into different groups, and no team was comprised of all juniors or seniors, all males or females, or all engineering or non-engineering majors. Unlike the majority of AE and AET students, FS&T majors have been exposed to different subjects of food science and processing through the previous courses they have taken for their major. Despite the fact that AGEN 352 does not focus on "science" aspects of foods but rather on the processing and engineering side of food production, the FS&T majors in general appeared to be more familiar with food-related topics, including processing and production, than AE and AET majors. For the majority of the AE and AET majors, AGEN 352 was the first food-related course they had taken. In addition, FS&T students were more familiar with the type of experiments and testing described in the reading assignments and were thus able to design experiments with a greater level of confidence than AE and AET majors.

The FS&T students indicated that they often felt pressured to lead lab activities and were held more responsible to complete various tasks, because they were perceived to have a broader and deeper knowledge background than the AE or AET majors within the same team. The comments related to this issue are as follows:

"I felt the labs really put a lot of pressure on the food science major students because of how the labs are structured now. AET students and AE students have zero prior knowledge about food processing which makes it 95% our responsibility to teach ourselves, but the labs are weighted so heavily, it is hard to feel like you can make mistakes and learn. So, a lot of the work gets put on the food science students to do the work. The old structure of walking students through the lab helped ensure students had a firm understanding of the material and made it much more likely for all group members to participate in reports."

"I would have liked to be in a group with students with similar schedule and background as I. For example, I had to explain dehydration too many times and I was only free when my other group members had class."

This observation reflects a unique challenge of implementing a PBL approach in a class comprised of students from both engineering and non-engineering STEM disciplines. While the preliminary data is insufficient to provide a comprehensive understanding of the issues that arose, it indicates that in addition to the engineering background knowledge, the subject matter of an engineering course and the familiarity with the subject might be important factors to consider when assessing the effectiveness of PBL in an engineering course offered to a mixed group of engineering and non-engineering students. These identified challenges indicate the need to construct a systematic research design and evaluation methodology for this study to evaluate the effectiveness of PBL more accurately.

Future Directions

Although the student feedback was largely positive, challenges arose, and improvements are planned for the next offering of this course. While some of the challenges described above are commonly observed and reported in other PBL studies, the author found a challenge unique to the course described in this study. Unlike an engineering course that comprises a relatively homogenous group of students of the same discipline, AGEN 352 is required for three different areas of study (AE, AET, and FS&T majors). The author found the knowledge background and level of prior exposure to designing and conducting experiments related to food process engineering to vary significantly among the students depending on their majors. While students can view having to work with a diverse group of students with varying degrees of background knowledge as another hurdle or impediment, the author believes this can be a positive aspect of the course presented in this study. Students need to be more frequently exposed to students from different disciplines and given opportunities to work closely with them. Working with a diverse group of people better reflects the real teamwork situations students will encounter in their future careers.

To address the issues and challenges described above, the author plans to spend more time explaining the proven effects of PBL on improving students' learning and the benefits of diverse teams and lay out the lab format more clearly and thoroughly in an early phase of the course. While the students were provided with a brief overview of the modified lab structure and the rationale behind the modification during the first lab session, they still struggled to adopt the new approach and expressed varying degrees of resistance throughout the semester, wondering why the labs could not be taught in a traditional way. Students were often very focused on completing assignments by due dates and failed to see beyond the rigorousness and complexity of the lab activities to what they were learning and how they can be used in their future careers. The author believes that the benefits of PBL cannot be realized unless the students understand the rationale behind the PBL approach and its goals.

The instructor plans to develop a comprehensive PBL evaluation plan to apply the next time the course is offered. The instructor plans to improve the grading rubrics to apply them as tools to assess the learning outcomes. Additional assessment and survey tools will also be developed and implemented in the future to assess learning outcomes more systematically and comprehensively.

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