STUDENTS' PERSPECTIVE: DOES PROBLEM-BASED LEARNING INCREASE OWNERSHIP OF ONE'S EDUCATION?

Roza Vaez Ghaemi^{1,2} and Gabriel Potvin¹

¹Department of Chemical and Biological Engineering, University of British Columbia

²School of Biomedical Engineering, University of British Columbia

ghaemi@chbe.ubc.ca, gabriel.potvin@ubc.ca

Abstract – Students in the 4th year laboratory course in the Department of Chemical and Biological Engineering (CHBE) at UBC perform multi-week problem-based laboratories (PBL). Open-ended industrially-relevant problem statements are provided as context, but teams are not bound by them and can choose alternative problems according to their interests. Operating instructions for equipment are provided, but students must develop their own experimental designs and data collection and analysis protocols. TA involvement is greatly reduced compared to previous courses to promote independence and self-reliance. In previous work, students indicated that this approach helped them develop their critical thinking and problem-solving skills, and increased their confidence in their engineering abilities. Anecdotal evidence and an analysis of the survey data in that study suggest that one possible reason for the benefits outlined above stem from students' imposed self-reliance and ownership of their work, coupled with a freedom to experiment with no consequences for failure.

To explore this question, a questionnaire was sent to the current cohort of students, asking them to qualify their enjoyment of the course (level of enjoyment, workload, perceived relevance), the effectiveness of the course (perceived knowledge and skill development), as well as their perceived level of agency in the course (perceived freedom and autonomy regarding content and research direction). Students were then invited to a focus group to further elaborate on the course and reflect on their overall experience during the undergraduate studies, whether they felt they had agency or ownership during their studies, and whether they believe problem-based learning should be implemented in other courses earlier on in the program. Responses were thematically analyzed, and are presented in this paper.

Keywords: Problem-based Learning, Agency, Motivation, Engineering Skill Development

1. INTRODUCTION

Problem-based learning is an educational practice that focuses on the creative application of technical skills to open-ended problems [1]. In recent years many have implemented problem-based learning as part of their engineering curricula and have reported a significant improvement of students' critical reasoning capabilities [2]–[4]. While these studies focused on improvement of engineering competencies such as problem-solving and design; several other indicated problem-based learning as an instructional model that also helps to develop transferrable skills including teamwork and communication skills, flexibility, initiative and management skills, while providing students with a self-determined pace and increased self-awareness (through decision making opportunities) [5]. In previous work [6], we described an application of problem-based learning pedagogy to a laboratory course, in which experiments were referred to as Problem-Based Labs (PBL).

Problem-based learning is driven by the problem that is encountered by the students and focuses on research and inquiry [7], making it amenable to integration in a lab context. One of the primary objectives of PBL approaches is to transform the labs to be student-centered where the outcomes and objectives are largely determined by the students, to create an environment of self-directed learning. The solution, therefore, is partly dependent on the acquisition and comprehension of facts, but also based on an ability to think critically and to make decisions and judgement calls. Throughout these labs, the process becomes more important than the product. This pedagogy tests students' ability to generate problem-solving strategies or to find and create information, and by encouraging them to demonstrate their capabilities, increases their motivation to tackle the problem. The majority of the learning process takes place in the teams, where students get a chance to observe their teammates approaching the same problem with different strategies and discuss the cases and justify their approaches, which mirrors what takes place in professional engineering

settings, allowing students to experience the process as a practitioner [7]–[10].

The benefits measured in the implemented PBL course format warrant further investigation. One explanation for students finding this approach to laboratory education so valuable and their perception that they are developing valuable engineering skills may lie in the increased level of autonomy and responsibility given to them, as well as the sense of agency and control that comes with this. This study seeks to further elucidate students' perception of the value of this pedagogical approach, evaluate their experience while taking it to explore this idea of agency and its impact on the student experience of the course, and identify key factors contributing to its success.

2. COURSE DESCRIPTION

The course is described in greater detail in previous work [6]. Briefly, CHBE 464 - *Chemical and Biological Engineering Laboratory* is a four-credit course composed of wet and dry lab compartments focusing on experimental design, data analysis, and engineering decision-making, offered as part of the chemical engineering curriculum at UBC. Student teams receive open-ended problems aligned with industrial operations and as much as possible with their declared interests. Problems are designed to mimic questions or challenges engineers would encounter in practice. Students are expected to self-direct their investigations (with some guidance from the instructor) by setting specific experimental goals, developing data collection and analysis methods, and making engineering decisions based on obtained results. Students are assigned a particular topic based on their interests from a list of eleven experimental setups spanning a wide range of industrially-relevant areas of interest in chemical engineering (see Table 1). The course spans two terms, with each team performing a single, 9 to 12-week lab each term. The overall course design, described below, aims to provide an opportunity to apply technical engineering skills to unique open-ended problems, and allow them to develop lifelong learning and other transferrable skills (e.g. critical thinking, teamwork, leadership, communication skills) and technical data analysis and interpretation skills.

Table 1: Available experimental setups

1. Biodiesel production
2. CO ₂ absorption in packed towers
3. CO ₂ capture through gas hydrate formation
4. Hydrocyclone separations
5. Electrosynthesis of hydrogen peroxide
6. Reactor design
7. Plate Distillation
8. Yeast fermentation
9. Three-phase catalytic reactor operation
10. Microalgae production
11. Genetic engineering and culture of bacteria

2.1. Description of the problem-based labs

Self-selected groups of 4-6 students are assigned to one of the 11 experimental apparatuses listed in Table 1 based on their ranked preferences. Each group develops an experimental plan allowing for the collection of data necessary to inform the selection of a solution to their assigned problem statement, or one of their own choosing. Students are provided with operating manuals for the equipment, but no instructions on experimental protocols or data collection. After familiarizing themselves with the equipment during a supervised session, teams prepare proposals that include a management plan, a budget and cost breakdown, and safety and environmental impact analyses, and defend them as an oral presentation. Upon review and approval of their plan, they proceed with the experimental work over 4-6 weeks, submitting updated work plans at the beginning of each session that outline any changes to the experimental work presented in the proposal. To encourage self-reliance and the development of students' confidence in their engineering skills, TAs are present only for the first hour of each lab session, with a primary responsibility of ensuring students are organized and able to proceed safely, with lab oversight maintained by the instructor. At the end of the experimental sessions, students present their findings and recommendations in an oral presentation, before submitting an extensive final written report. The course is designed in such a way as to provide as much autonomy and agency to the students as possible in terms of research direction and troubleshooting.

3. METHODOLOGY

At the end of the latest iteration of the course, students were asked to complete an anonymous survey, on a voluntary basis, asking about their overall experience compared to previous lab courses, and perceived level of autonomy and control they had on their learning. The survey was composed of two sections. The first was composed of fifteen 5-point Likert-scale questions (1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree) asking participants to qualify their enjoyment of the course (level of enjoyment, workload, perceived relevance), the effectiveness of the course (perceived knowledge and skill development), as well as their perceived level of agency in the course (perceived freedom and autonomy regarding content and research direction compared to previous courses). The second section of the survey contained seven optional open-ended text questions, asking students to elaborate on different elements from the first section, and to delve more deeply into perceptions of control and autonomy within this course design. The full list of questions is found in Table 2. Survey results were thematically analyzed. Students were then, again on a voluntary basis, invited to participate in a focus group where they were asked to elaborate on the possible

causality of trends in the survey results. Focus group questions were framed around autonomy, career goals and overall educational experience in their engineering studies.

Table 2: Survey questions

<u>Section 1 – Likert-Scale Questions</u>	
Please indicate your level of agreement with the following statements:	
1.	I have learned a lot in this course.
2.	I developed useful skills in this course.
3.	The subject matter of the labs I performed was interesting.
4.	Overall the lab (in PBL format) was a positive experience.
5.	This course is useful in the pursuit of my career goals.
6.	This course is useful in developing “real-world” skills such as critical thinking and problem-solving.
7.	I understand what is expected of me in order to succeed in this course.
8.	I find this course challenging.
9.	After taking this course, I feel more confident in my engineering skills.
10.	I had control over the direction of my experiments in this course.
11.	I had control over/into my overall learning in this course.
12.	I had control/input into my learning during my undergraduate degree.
13.	I prefer this format of lab course (PBL) to conventional lab courses.
14.	My interactions with my teammates were positive.
15.	The instructor cared about my learning.
<u>Section 2 – Open Text Questions</u>	
16.	This course gave you more autonomy and control over your work than other lab courses. Is this a good thing, bad thing, or had no effect? Why?
17.	Which aspects of the labs do you feel you were able to control or influence?
18.	Which aspect(s) of the course were controlled or dictated by the course instructor?
19.	Over which aspect(s) of the course, if any, would you wish to have more control?
20.	Over which aspect(s) of the course, if any, would you wish the instructor took more control?
21.	Do you feel you had control and/or input over your overall education during your undergraduate studies? Explain your answer.
22.	How was your experience in this format of lab course (problem-based labs) compared to conventional labs (like your earlier courses)?

4. RESULTS AND DISCUSSION

45 students responded to the survey, out of a class of 120 students. Only relevant data is presented here, but the full data can be shared with interested readers.

4.1. Likert-Scale Questions

The results of the Likert-scale questions are shown in Figure 1. More than 85% of students strongly agreed with statements about learning a lot, developing useful skills, being interested in the subject matter as well as this course being relevant/useful in the pursuit of their careers, which highlights the perceived value of this approach. Almost everyone (93%) indicated they had control over their overall learning in this course while only half of them indicating having input into their learning during their undergraduate degree. This underscores the deviation of this instructional approach from the majority of other courses, which is further discussed in subsequent sections. General experience indicators (expectations, interactions with instructor and peers) are overall very positive, setting context for participants’ experiences and eliminating extraneous contextual elements that may negatively affect student perceptions.

4.2. Open-Ended Questions on PBL experience

Responses to the open-ended questions were analyzed and coded to identify emerging themes. Despite the large variety of projects, the identified positive aspects of the course were very similar, focusing primarily on autonomy (words like *freedom*, *choice*, *responsibility*, *independence*), and opportunities for self-improvement (comments with phrases like *valuable feedback*, *low risk grading*, and *opportunities for discussions*). The very few negative comments were mostly concerned with time constraints and equipment restrictions, all of which is related to logistics of course delivery.

When asked about the overall experience of autonomy and control in the course, 42.5% of the responses mentioned key words related to professional prospects like *engineering job*, *real world problems*, and *research skills*, and indicated the importance of this kind of lab experience for the development of industrially-relevant skills. Some comments on the value of autonomy for student development and participation are included below.

“The autonomy and control over our course work that this course provided is a good thing because it required the students to think critically about what kind of results would be obtained, how to obtain these results, and what conclusions could be made from these results. The limited help that was provided to us during the labs caused the students to have to utilise their problem-solving skills to solve issues that arose.”

Figure 1. Summary of responses to Likert-scale questions.

“It is a good thing so students are more challenged to formulate their own lab objective and procedure which are important for their future career.”

“Having more autonomy made me more engaged and invested in the lab. I found it much more enjoyable and learned a lot more.”

Approximately 1/3 of the respondents listed the development of engineering competencies such as *critical and creative thinking, troubleshooting, and problem-solving* as the main advantages of this course format. 18 responses compared the structure and learning in this lab with previous courses and considered this format as most effective in terms of providing a thorough understanding of relevant material and making connection between theory and practice, while being suitable in terms of level of difficulty for a 4th year engineering course. Despite responses focusing on professional relevance, very few mentioned teamwork or collaborations as positive aspects of the course. Given that Likert-scale responses suggested overall very positive team experiences, this may suggest either an undervaluing of teamwork skills as they relate to professional environments, that the overall curriculum already contains sufficient opportunities to develop those skills and that this course did not bring anything new in that respect, or simply that no significant conflicts arose and therefore the opportunities to develop tangible teamwork skills were fewer in number.

The students were then asked to identify the aspects of the course they were able to control as well as aspects on which they would have liked to have more influence. 40% (15/37) of the respondents felt they had control over every

aspect of the course. 43% (16) indicated experimental design as the most controlled part by their team; while 32% (12) felt they had a lot more control over the actual procedure of the experiment. Time available to do the labs and the resources allocated to each team were the top elements on which participants would like to have more control, while at the same time acknowledging the intrinsic limitations in terms of budget, experimental apparatus and scheduling of these labs. Given that lab sessions are already 6-8 hours in length each week, this may be a good indicator of student’s involvement in the process. Some responses also indicated a desire for more control over the topic of investigation to which they were assigned, while again acknowledging understandable logistical constraints. Some relevant examples of students’ comments include:

“We were able to control pretty much everything in the lab, except for some issues arising due to physical limitations of the equipment we used.”

“I feel like I had a large degree of control over how experiments were conducted and how data was analysed and processed. But, I do wish we had more control over the exact equipment we got to use, but I understand that our selection is limited.”

“I feel like I was able to control almost all of the lab myself. As long as the experiment was feasible and not terribly expensive, we had free reign over the lab and got to figure it out ourselves. I would have liked to have more options for scheduling for the lab (e.g. several sessions in one week) but I understand this may not work well for everyone due to course conflict and lab use.”

Next, we asked students to identify the aspects they saw as being dictated by the instructor and aspects they wish the instructor had more control over. 66% of responses indicated the instructor being in control of course structure in terms of deliverable and deadline/schedule, and interestingly only 38% considered the instructor to be in charge of the resource and equipment throughout the course. When asked about the area where the instructor could possibly have more control to improve students experience in the course over 90% of respondents indicated they did not want anything being dictated by the instructor, suggesting an ownership of the process at the course's conclusion (when the survey was administered). The minority of critical comments mentioned a desire for more lab time to be made available, again suggesting an enthusiasm for the process, and some requests for additional guidance or clarification, and course structure. Examples of suggested improvements include:

"I cant find any aspect with this regard. The instructor was very helpful. But it would have been great if in the orientation there would be an example of a demo lab to show how the instructors approach towards the analysis and a problem based lab would be. I feel this would help students to develop their standards of lab analysis up to a level."

"The timing of experiments is controlled by the instructor because the lab is used by other courses, though we were given some flexibility in term 2 with Saturday labs. I think it would be nice if the instructor went over our experimental procedure early on to help us figure out if what we're doing is going to cause any problems later on in the experiment, but I get that's part of the learning experience to figure it out ourselves."

4.3. Focus Group

Five students accepted an invitation to participate in the focus group where they were asked some follow up questions regarding the observed trends from the survey. Overall, students agreed it was a very positive experience.

In the open-ended survey questions, many comments focused on "real-world" skills and readiness for future careers. During the focus group, although some of these same themes emerged during discussions on the benefits of having to design their own experiments, emphasis was also largely placed on improving their confidence dealing with uncertainties and failures, as well as their capacity to troubleshoot their processes and establish some quality control measures. They indicated that overall the PBL was a great experience for them whether they were interested in their specific topic or not. For some groups, the freedom and flexibility in this course made it enjoyable experience,

as they were able to manipulate and modify the topic toward areas that were more interesting/exciting for them:

"Our group changed our topic and area of investigation to get to the points we hate the least."

"With the flexibility of the open-ended labs, we were able to change our experimental design several times throughout the semester and we were able to investigate different aspects according to our interests."

Meanwhile other participants thought the ability to modify the process in an ongoing manner turned the labs into a personal project for some members, which in turn affected their investment in the course and increased the share of the work they took on themselves.

They identified confidence, accountability, quality control and troubleshooting as well as decision making, as some of the major tangible outcomes of the course.

"This course made me more ready for real-world problems at large."

"464 didn't feel like I am just working another assignment or deliverable."

"Compared to conventional labs, where the focus was more learning the calculations, error analysis and report writing, in this course more than the data, the approach was important"

"This lab was not about how to operate the lab, but about understanding why something happens"

"It is not about the investigation itself it is about the approach"

Students were also asked what they thought about the level of autonomy provided to them in this course. They indicated that the level of autonomy and agency in this format was a great motivator for them. However, being thrown into almost full autonomy in the 4th year with this lab and their Capstone project, some might find it difficult to deal with this freedom. The question of variable motivation or buy-in was also raised. They indicated the transition between the conventional system and full autonomy in their 4th year could be made a bit smoother by having a bridging experience in earlier years where they are taught how to deal with the freedom while receiving in-depth guidance and feedback on their work.

"This autonomy/control is like a double edge sword: A motivated person who is interested in the topic might get the most out of this as they are able

to come up with meaningful objectives and investigations; while an unmotivated student, won't be doing anything"

"It all depends on the attitude you go in with, if going with the mindset of personal growth and development, you can really dive deep and learn a lot; but if you go in thinking I just want this to be done, then there is not much to be learned on top of the 3rd year experiments."

Another positive aspect brought up multiple times in the focus group was the real time constructive feedback provided on an ongoing basis:

"This course has a unique aspect, and it is the coaching/mentorship that did not exist in any other labs"

Although the survey results suggested overall positive team experiences, during the focus group all respondents indicated that tension between team members did arise when some students were not as motivated as others, or not interested in the topic, resulting in unfair distributions of the workload. One of the very interesting aspects in the conversation was about the team formation, team dynamics and interpersonal chemistry. The flexibility to choose groups as opposed to having them assigned like in previous lab courses was perceived as a positive aspect of this course. However, given the number of new factors the students were introduced to, it was difficult for them to predict what would make an effective team member at the onset of the project. Having the groups assigned by the instructor or picked by the students was discussed from different viewpoints. The general agreement was, however, that the level of general interest and personal investment of each group members to be the key considerations to assemble effective teams in this setting.

"Unproductive lab groups members often get by when there is always someone who is ready to take charge and who is ready to pull everyone else in and get things done. You don't always have to be super onboard and you won't get much out of it because you are not sure how to deal with all this control, and you can still get your degree and there is always other people who are ready to pull your weight because they do care about the grade. There is usually enough people to cover it."

"Having the groups assigned is not usually pleasant but as long as they are at least willing to put the effort to make it work it is not a big deal."

"Picking people that are like-minded and would reduce [the unfair work distribution-related] stress"

Although the experience was generally positive, participants suggested that group assignments could be made based on interest in a particular topic or lab, as opposed to set before lab selection, which would maintain some level of self-selection and flexibility, but may improve collaboration, distribution of work, and team dynamics.

Finally, participants also suggested that instead of performing one lab per term, interested teams should be allowed to do a single experiment over two terms, to allow for a more in-depth exploration of the subject matter. There were also suggestions related to establishing concrete consequences for team members that didn't pull their weight in terms of contributions to the work, which were not present in this iteration of the course.

5. CONCLUSION

The data collected here and in previous work [6] suggest that this problem-based lab approach is effective, and students see value in terms of its challenge, relevant knowledge acquisition, professional skill development, and development of confidence in their engineering skills. Though very time consuming, for both instructor and students, this approach has significant pedagogical benefits.

Based on the results presented here, the benefits above seem to emerge, at least in part, from the autonomy and agency provided to students. Student responses in both the survey and focus group indicate that although students were initially apprehensive and unsure about open-endedness of the process and the responsibility given to them, responses seem to focus on the benefit of the opportunities provided to explore topics of interest and of being responsible for their own work. The identified areas of improvement, though valid, seem to arise from a desire for even more freedom to explore a topic, and from discrepancies in the level of buy-in of all members of a particular group. This suggests that the students that participated in the survey perceive autonomy and having agency as a good thing and a great opportunity for skill development and growth, and therefore become quite invested in the process, but with differences in the desired level of participating being an issue.

It should be noted that participation in the various elements of this study was entirely voluntary, and participation levels were relatively low. Some level of self-selection bias is almost certain to limit the applicability of the data collected to the broader context of the course. Though the information collected over several years does provide some justification for the further expansion of this approach in other academic settings, it does also pose some interesting questions about student intrinsic motivation and desire to participate in their education. It seems like those who do take the opportunity to take advantage from a measure of autonomy do get a lot out of it. In future

iterations of the course, it would be interesting to look at specific motivation factors that may impact the benefits that would be obtained by different students while going through this course design, and how to maximize those benefits for all students.

References

- [1] J. Uziak, "A project-based learning approach in an engineering curriculum," vol. 18, no. 2, pp. 119–123, 2016.
- [2] S. Hirata, "Co-design of service innovation through problem-based learning" vol. 10, pp. 40–47, 2019.
- [3] R. V. Ghaemi and V. G. Yadav, "Implementation of project-based learning in a second-year cellular biophysics course and students' perception of the value of the practice" in *Proc. 2019 Canadian Education Association Conference*, paper 202, 2019.
- [4] D. Tanah and E. Theodora, "The integration of PBL and cooperative script to empower critical thinking skills of biology students," *JPBI*, vol. 5, no. 2, pp. 217–228, 2019.
- [5] I. V. I. Tynja, "Project-based learning in post-secondary education – theory , practice and rubber sling shots" *Higher Education* vol 51. pp. 287–314, 2006.
- [6] G. Potvin, "Integrating elements of team-based learning and increasing independence in a 4th-year lab course to promote the development of critical thinking, problem-solving and troubleshooting skills" *Proc. 2017 Canadian Education Association Conference*, paper 10, 2017.
- [7] J. M. Baseya and C. D. Francis, "Design of inquiry-oriented science labs : impacts on students ' attitudes," *Research in Science & Technological Education*, vol. 5143, 2011.
- [8] M. S. Matijevi and N. D. Jovi, "Remote Labs and Problem Oriented Engineering Education," *Proc. IEEE Xplore*, April, pp. 1391–1396, 2017.
- [9] N. Mora, B. An, A. M. Gonza, J. M. N. Rrez, and B. D. Jones, "Motivational Factors to Consider when Introducing Problem-Based Learning in Engineering Education Courses * Model of Motivation," *International Journal of Engineering Education* vol. 33, no. 3, pp. 1000–1017, 2017.
- [10] A. Kohnle, C. T. A. Brown, and C. F. Rae, B.D. Sinclair. "Problem-based labs and group projects in an introductory university physics course" *Physica Education*, vol 47, no 4, 2012.