RE-ENGINEERING SUCCESS: YEAR TWO OF A CROSS-COURSE ASSIGNMENT TO DEVELOP CRITICAL THINKING AND COMMUNICATION SKILLS IN A LAB SETTING

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Abstract – Last year we reported on a new initiative designed to help students develop their ability to communicate to a client while applying technical lab skills in a joint, end-of-term problem-based learning exercise that we incorporated into our second-year Chemical Engineering curriculum at University of Toronto. The project asked students to research and develop a lab-based approach to a real-world problem and to communicate their solution to a client through various deliverables. A student survey, as well as our own observations and student performance have led to revisions in year two, specifically in our feedback schedule, the composition of our grading team, and the nature of a related term two project. This paper discusses the implementation of these changes, and their success using new student survey data and performance. We conclude that these changes have improved student experience and technical performance; communication performance can be further improved by more consistent training of the instructional and grading team, and additional project support in term two.

Keywords: Problem-based learning, project-based learning, laboratory courses, engineering communication, cross-course integration, cross-course collaboration

1. INTRODUCTION

In order to create effective solutions to some of the most complex problems, engineers need the technical competencies that go beyond a simple understanding of the theories and principles governing them: they must understand how these concepts are applied in practice. They must also be able to discuss these problems and communicate their solutions to engineering and non-engineering colleagues. Problem-based learning (PBL) can help support the development of these skills, as students are required to use critical thinking, problem solving and analysis

skills to solve complex problems [1]. Assessing the outcome of these projects for both technical feasibility and communication can further simulate the types of challenging scenarios our students will encounter post-graduation.

Last year we reported on a new initiative designed to help students develop their ability to communicate to a client while applying technical lab skills in a joint, end-of-term problem-based learning exercise that we incorporated into our second-year chemical engineering curriculum at University of Toronto [2]. As is typical in a PBL environment, students were not presented with straightforward facts or concepts, but instead asked to solve a problem by drawing on research, organizing new information and applying previous knowledge [3]. The project was comprised of individual deliverables instructed and assessed in CHE299: Communication and CHE204: Chemical Engineering and Applied Chemistry - Laboratory I, as well as a joint final project. In this way, the project-lab also encouraged students to be aware of the integrative nature of engineering projects, and the need to apply learning from multiple areas—research, teamwork, communication, project management—to successfully solve problems. As an activity that asked students to identify and apply transdisciplinary skills from multiple subject-areas, the project lab supports the type of lifelong learning, critical thinking and collaboration that is valued in the workplace [4-8].

CHE299 is an activity-based tutorial class, with two one-hour classes taught by a team of TA instructors and a course coordinator; CHE204 is a laboratory practical course that focuses on chemical engineering laboratory techniques in the area of analytical and inorganic chemistry. The course is taught by one course instructor and is supported by a

team of 8 TAs. It has two sections, each with one hour of lecture (referred to as the dry lab) followed by 5 hours of lab per week.

In its first year, the project asked students to analyze two copper samples from two different mine sites to make a recommendation based not only on copper yield but additional factors such as social and environmental impact as well as long-term economics. The project encouraged students to learn how to research and develop lab-based approaches to real world problems and how to effectively communicate their solution to their client. Project deliverables were scaffolded throughout the term and between two courses. The initial distribution of project deliverables is summarized in Table 1.

Table 1. Distribution of deliverables 2017/2018.

Date	Course	Deliverable	Weight
Oct 8	CHE299	Introduction for peer review	
Oct 13	CHE299	Introduction due	10%
Oct 30	CHE299	Visual abstract for review	
Nov 1/2	CHE204	Protocol for peer review	
Nov 3	CHE299	Visual abstract due	10%
Nov 8/9	CHE204	Protocol due	5%
Dec 1	CHE204/CHE299	Final proposal due	10% (299) 7% (204)

Students were guided through the project with e-Learning modules, in-class active learning exercises, and written feedback. The integrative nature of the project ensured that learning outcomes were achieved across the curriculum as students practiced critical thinking, problem analysis, independent research, lab skills, technical writing, and visual design. In their second term students were expected to apply their learning from this experience to another project lab in Chemical Engineering and Applied Chemistry Laboratory II (CHE205); this project involved less scaffolded support and required more self-directed learning.

A student survey completed at the end of CHE205, as well as our own observations and student performance have led to revisions that we are currently tracking in year two. This paper will discuss the motivation for these changes and their

implementation. We will analyze new data from the survey and student performance in this second iteration to determine whether our changes effectively supported student performance while facilitating more accurate data collection.

2. INTEGRATING CHANGE

In our 2017/2018 study we noted that while students self-reported that they applied learning from the term-one project lab to a new context in the term-two assignment, overall grades did not improve. Students suggested that we revise the feedback schedule outlined in Table 1 to allow more time to review and incorporate input on scaffolded assignment components, which led us to redesign the deliverable and grading schedule. The revised deliverable and feedback schedule is summarized in Table 2.

Table 2. Distribution of deliverables 2018/2019.

Deliverable	Instruction	Due	Feedback
Project Plan 10% (204)	CHE299: Sept 21 st	CHE204: Oct 5 th	Returned Oct 15 th
Introduction 10% (299)	CHE299: Sept 25 th - Oct 12 th	CHE299: Oct 14 th	Peer review Oct 12 th ; Returned Oct 26 th
Methodology (procedure + visual abstract) both 10%	CHE299: Oct 12 th - 23 rd	CHE204/299: Oct 28 th	Peer review Oct 24 th /25 th ; Returned Nov 12 th
Technical Report 10% (299) 10% (204)	CHE204: Nov 28 th , 29 th	CHE204/299: Dec 5 th	Returned Jan. 16/17 2019

Students questioned grading consistency between the iterative assignments, and we realized the opportunity afforded by a more consistent grading team in our data collection: we hired a team of teaching assistants to grade all project lab deliverables between the two courses (including the second-term assignment). We distributed grading responsibilities so that graders were assigned the same students between terms one and two. This change supported the type of consistency between terms that we were hoping to achieve but presented new challenges for training and benchmarking. Previously, two assessors had graded each report, one

focusing on the technical material and the other on communication; these assessors were instructional TAs from the lab course and communication course respectively, and highly familiar with the instructional content of the course and assignment instructions. This year, the implementation of some CHE204/205 dry lab lectures to review assignment requirements and expectations, helped to train this team of graders while also building more project instruction into the lab course. These project-focused dry labs, which were co-led by the CHE204 and CHE299 instructors, also underscored the connection between these two courses.

Differences between the two projects made data tracking a challenge in year one. While students in CHE204 could apply protocols from the literature to solve a challenge, CHE205 asked students to optimize a chemical process (nitration of an aromatic compound) for a fictional manufacturing plant, requiring students to engage in less straightforward research with respect to their background and introduction while at the same time grappling with more data. Taking these differences into consideration, the CHE205 project was revised to create better consistency between the two projects. First, the case was designed around a real-world company to help facilitate the same type of research students would have done for their fall term project. Second, the chemical process itself was revised to a more common transformation (Fischer esterification) allowing students to apply protocols from the literature more easily. Lastly, while the end goal (a recommendation to the manufacturing plant) did not change, students were explicitly asked to consider environmental and economic factors in their selection of a process, which aligned with the assignment instructions from term-one.

3. MEASURING SUCCESS

The effectiveness of the project lab integration in helping students to develop and apply particular competencies was measured via student surveys and student performance in the course. Student survey responses provided insight into their experience, and the perceived connections between instruction in CHE299 and its application within the project lab. Given the lack of direct instruction in CHE205, student performance in the project lab was intended to measure their retention and application of skills

developed in term-one to the minimally supervised work in term-two.

3.1 Student Response

The optional online survey was distributed early in term two during the CHE205 dry lab lecture, and completed anonymously by 61 of 104 students. It was scheduled to encourage student reflection on their first project lab experience before commencing the CHE205 project lab; at this point in the term students had been given the term-two assignment and should have started planning, but would not have done any lab work or writing. Because the survey was designed as a teaching mechanism, it asked students to consider some topics that are not directly connected to the relationship between CHE204/299/205. The questions gauging student learning in the course and the application of this learning between the project labs are discussed here.

The first survey question asked students to select the skills they felt they developed through the project lab experiences. These skills aligned with our intended outcomes for the project lab.

Figure 1. Responses to "Please check the skills you developed through the overall project lab experiences."

Survey responses, which are displayed in Figure 1, indicate that the majority of students felt they developed research, written and visual communication, teamwork and time management through the project lab experience, with a smaller number of students indicating that they developed creativity or oral communication skills.

Students' perceived learning loosely aligns with the amount of instruction in each of these areas. Almost 90% of students felt they developed research skills through the project lab sequence, which reflects its importance within the project. Conducting and integrating research was key to drafting the

introduction and background section, and to selecting an appropriate procedure to build their methodology. This first section was scaffolded by a five-class sequence in CHE299, covering problem definition, search strategies, integrating evidence and argument design. In CHE204, students were provided with a library guide to searching protocols and were given one class to work on the development of their procedure. While students study and perform the various techniques that could be used for their project, the experiments involve the analysis of other chemical systems resulting in students having to research how to adapt these procedures for the analysis of their copper samples.

Multiple CHE299 classes focused on written and visual communication using project lab deliverables as a vehicle for instruction. Four CHE299 classes were spent on visual communication in advance of the project lab visual abstract, covering diagramming, figure captioning and using quantitative visuals. This short sequence concluded with a peer review of the visual abstract for the CHE204 lab. Written communication is central to CHE299, and was linked to the project lab in classes on analyzing and structuring consulting reports, as well as designing arguments.

Creativity and oral communication, along with teamwork and time management were not directly instructed in either CHE204 or CHE299, but were viewed as a corollary of assignment requirements: students created and conducted their original lab procedure in a small team; while assignment deliverables were individual, their lab activities required team coordination, in-person communication, and time management. Students were also asked to develop a project plan early on in the term, which included a timeline for completing different assignment deliverables, and a distribution of individual and team work.

Two questions asked students to gauge their application of learning from the two courses to the project lab. These responses, summarized in Figures 2 and 3, indicate some variation between the application of learning from CHE204 and CHE299. While 87% of students reported applying their CHE204 theory and skills mostly or a great deal, only 49% of students selected these responses for the application of their CHE299 knowledge and skills. Despite this unevenness, students were more likely to comment on the application of communication skills in response to a short answer prompt. When asked:

“How do you see yourself applying the skills you developed through this assignment in the future?” most student responses focused on generating technical documents and reports, with only 10 of 48 students commenting on their use in designing future protocols and lab procedures, or in industry.

Students may have been confused about the application of CHE299 instruction to the project-lab because of perceived inconsistencies in instruction between the two courses, which is reflected in responses to the question: “What recommendations do you have for improving this sequence of assignments and their integration across the two courses?” Approximately one-third of responses asked for more consistent instruction between the two courses, with some students pointing out the challenge of receiving most of their CHE299 instruction from tutorial TAs who were not responsible for assignment design or assessment. Students may have been skeptical about the value of lessons delivered by these instructors or their familiarity with these assignments.

Figure 2. Responses to “Overall did the project lab assignment help you apply theory and skills developed in CHE204?”

Figure 3. Responses to “Overall, did the project lab assignment help you apply knowledge and skills instructed in CHE299?”

Another question asked students to consider how they'll apply their learning from their first project lab to the second, with the question: "How (if at all) has your performance on the CHE204 project lab impacted your approach to the CHE205 project lab? How do you plan to approach this assignment differently?" A few themes emerged in response to this question. Fifteen of 51 respondents indicated that they will work on improving their time management for the second project lab, with one student explaining:

I believe that my performance in the project lab was decent, however, I would benefit from revising my document for a longer period of time. Therefore, I will try to plan out my project plan more effectively and follow it to ensure I have adequate time.

Requesting and using feedback was another common theme, with one student observing that better time management would help them to budget time to integrate feedback, explaining:

The CHE204 assignment went well because most things were done ahead of time. This resulted in getting lots of feedback to improve the final report. I plan to do the same this time. Since this time we are not getting feedback throughout the assignment, I still plan to finish sections early in order to manage time well and talk to professors for possible feedback so the project lab is successful.

Approximately one-fifth of respondents indicated that they planned to improve their research skills in the project lab, by allotting more time to this task or making better use of available resources.

3.2 Student Performance

Project lab reports were evaluated for both technical content (objective, background information/theory, methodology and data analysis) and communication (structure and organization, paragraphs and sentence structure, and visuals). To ensure internal consistency in course grading we compared TA averages across the team and between the two projects. We observed no major discrepancies in the grading team, as the TAs were within $\pm 5\%$ of one another. TAs were also consistent between the two assignments; while there were some differences they were within an acceptable range of $< \pm 6\%$.

In total 103 students completed both assignments. Overall, we saw no significant change to the class

average (81.9% for CHE204/299 and 81.4% for CHE205). However, analyzing the percentage change in student grades between the two assignments for both technical content and communication yields some interesting findings.

Between the CHE204 and CHE205 project lab reports the class average increased by 1.4% for the technical component and decreased by 2.1% for communication. Figure 4 shows the percentage change for the technical component. There appears to be a 50:50 split, with 52 student grades increasing and 51 student grades decreasing. A majority of the class appears to be clustered between -6% and +13%, with fewer students seeing increases or decreases larger than $\pm 14\%$.

Figure 4. Percentage Change in Technical Score.

Figure 5 shows the percentage change for the written component. In total, approximately 40% of the class's grades improved, with the most common increase at +3% (18 students), while the rest of the class saw a decrease. A majority of the decreases ranged from -15% to -3% (46 students), with only 7 students seeing a decrease larger than -15%, the largest being -24% (1 student). Only a quarter of the class saw an increase higher than +3%, with the highest being +20% (1 student). Figure 5 also shows a slightly smaller range with respect to increases compared to Figure 4; both show the same level of decrease in scores.

Figure 5. Percentage Change in Communication Score.

The results suggest that students were more successful at applying their technical knowledge to the CHE205 project than they were the communication principles instructed and practiced in the CHE204 project and through CHE299. If we think about most Engineering programs, the core courses, which they receive in years one and two, focus on building skills around problem solving, critical thinking and data analysis. Specifically, in CHE204 and CHE205, students receive continuous feedback on all three of these skills throughout the term through pre- and post-laboratory assignments. For post-laboratory assignments (i.e., lab reports), while there is a communication element, emphasis is generally placed on critical thinking, problem solving, calculations, and data analysis. In this way, students are given an opportunity to consistently practice these skills in a variety of similar activities over multiple terms.

Students' inconsistent application of communication knowledge may be due to a lack of similar scaffolding around communication in the CHE205 course. While earlier CHE205 deliverables—three memo style reports—included a writing component grade of 20%, students did not receive explicit communication instruction in this course. At the same time, students were spending the second term of CHE299 learning about a new communication genre through an environmental consulting project that required students to produce a proposal.

Without the type of formal scaffolded instruction provided by the CHE204/299 partnership, students may have been challenged to retain and apply their learning from the previous course. Confusion around

differing requirements for different genres may also have contributed to their inconsistent performance. Within CHE205, students had most recently produced the memo style report, the requirements of which differ from the requirements of the project lab. Our TAs for the project report were encouraged to focus on the navigability of the reports, and how effectively students used signposting and organizational constructs to direct their reader through their logic to arrive at a substantiated recommendation for their client. Lab TAs were less likely to look for these elements of effective communication in a short reporting memo. Similarly, while written assignments in other courses require students to communicate their findings, the criteria and expectations of other professors may vary. As a result, students may be less confident about the communication principles that should be applied for a particular project in a particular context.

4. NEXT STEPS

With the changes made in the second iteration of this project we were able to address some of the challenges faced in year one.

- 1) **Feedback and turnaround time:** Based on survey feedback we have observed a decrease in the number of students asking for more timely feedback, with only one student asking that we turnaround graded assignments even more rapidly. Many students reported that they valued the iterative nature of this project and the multiple opportunities for feedback, but suggested additional minor improvements, for example one-on-one feedback sessions for all students. These requests were framed around consistency of grading and feedback, addressed below.
- 2) **Differences between projects:** Revisions made to the CHE205 project helped address some of the inconsistencies observed in student performance in year one. When reviewing content presented in the introduction and background of these reports, students were better able to select appropriate information for inclusion. For example, a majority of students provided sufficient background information about the company and were able to connect relevant information, such as environment and safety mandates to the design of their process and overall project objectives. Rubrics used for

both projects were also revised to include the same elements of evaluation, which allowed us to better track student performance.

- 3) **Consistency in grading:** While hiring a team of TAs seemed to create better consistency in grading between the two courses (CHE204 and CHE299) as well as the two terms, student comments continue to suggest a lack of consistent instruction between the two courses (CHE204 and CHE299). From observations and informal discussion with students, team-taught classes not only helped emphasize the collaborative nature of the assignment but also helped address a majority of questions regarding the final technical report. Inconsistency arose from other classes as both CHE299 TAs and CHE204 lab TAs who were not directly connected to the assignment may not have been able to address student questions accurately or consistently between sections. In order to address this, we will work to bring those TAs into the planning and instruction of the assignment through team meetings with those TAs responsible for grading the assignments. We will also ensure that all TAs (grading and instructional) attend the dry lab lectures related to the project.
- 4) **Assignment design:** Many students also requested a comprehensive assignment outline to be shared between both courses. Presently, each deliverable is described in a different course assignment, with the assignments posted on the course website in which they will be submitted and graded. Students seemed to be confused about where to look for which assignment, and this may have been a challenge for scheduling deliverables and designing the project plan. One complete outline for the sequence of project lab assignments will work to alleviate this confusion, and further contribute to the consistency in messaging and instruction that will be our focus this year.

5. CONCLUSION

We developed the CHE204/205/299 joint project sequence as a vehicle to teach problem-solving, critical thinking and communication within a lab-based environment. Student feedback indicates that the project-lab sequence is helping students to

develop and apply their knowledge in these areas. Implementing recommendations for improving consistency in instruction and feedback will help to effectively scaffold these skills.

Student performance in the course, specifically the discrepancy between improvements in technical and communication components, exposes a less easily resolved challenge in the way that communication instruction is delivered across the curriculum. The nature of our second-year curriculum and the need to develop engineers who are proficient in multiple communication genres, constrained the time dedicated to this project in CHE299 to term one, meaning the project was not scaffolded in this course in term two when students were taking CHE205. Student performance on the CHE205 project underscores the value of continued iterative practice when mastering multiple communication genres. One of our survey responses even articulates the anxiety students feel when moving on to a new genre, and their preference for continued feedback on familiar genres. One student writes: "I wish [the] project lab was with CHE299 again. Since [Environmental Chemistry] is a new topic for us, it takes time [to] learn concepts." Here the student is referring to CHE299's second-term focus on the environmental consulting proposal, and expressing a desire to continue work in the project lab genre before moving on to new communication requirements and technical content.

Based on student performance and feedback, it seems valuable to provide more consistent communication instruction in support of the CHE205 project lab. More broadly though, this phenomenon speaks to the value of iterative communication instruction across multiple courses, and consistent assessment criteria. The centralized nature of communication instruction in the University of Toronto's Engineering Communication Program makes possible this type of departmental consistency, and devising and managing consistent principles for effective communication across four-year degree programs remains a top priority.

References

- [1] B. J. Duch, S. E. Groh, D. E. Allen. *The Power of Problem-Based Learning*, Sterling, VA: Stylus Publishing, 2001, pp. 274.
- [2] Jennifer Farmer and Lydia Wilkinson, "Engineering Success: Using Problem-based Learning to Develop

- Critical Thinking and Communication Skills,” *Proceedings of the Canadian Engineering Education Association*, 2018.
- [3] M. Z. Jamaludin, K. M. Yusof, N. F. Harun, S. A. H. S. Hassan. “Crafting Engineering Problems for Problem-Based Learning Curriculum”. *Procedia – Social and Behavioural Sciences*, vol. 56, pp. 377-387, 2012.
- [4] M. Eraut, “Transfer of Knowledge between Education and Workplace Settings” in *Knowledge Values and Educational Policy: a Critical Perspective*, H. Daniels, H. Lauder & J. Porter, Eds. Abingdon, Oxon: Routledge, 2009.
- [5] P. Tynjala, “Perspectives into Learning at the Workplace,” *Educational Research Review*, vol 3, no. 2, 2008.
- [6] P. Tynjala, V. Slotte, J. Nieminen, K. Lonka, E. Olkinuora, “From University to Working Life: Graduates’ Workplace Skills in Practice” in *Higher Education and Working Life – Collaboration, Confrontation and Challenges*, Elsevier Ltd., 2006.
- [7] J. Trevelyan, “Engineering Education Requires a Better Model of Engineering Practice” *Proceedings of the Research in Engineering Education Symposium 2009*, Palm Cove, QLD.
- [8] J.W. Pellegrino, M.L. Hilton, M.L. *Education for life and work: Developing transferable Knowledge and Skills in the 21st Century*. National Research Council. National Academic Press: Washington DC, 2012.