FLUID MECHANICS PROJECT-BASED LEARNING KITS: AN ANALYSIS OF IMPLEMENTATION RESULTS IN A BLENDED CLASSROOM

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ABSTRACT

Fluid Mechanics is a foundational course in civil, chemical, and mechanical engineering that is often offered as a combination of lectures, tutorials, and laboratories. In the laboratories, students typically perform experiments using commercial flow benches, following scripted laboratory procedures to conduct experiments. Without a detailed understanding for how these experiments are designed or operate, students often rely on laboratory reports written by students from previous years to guide their analysis and documentation process. From the Bloom's Taxonomy cognitive domain perspective, this represents a lost learning opportunity as analysis is one of the highest levels of knowledge activation that students can experience in a foundational course like Fluid Mechanics. The work reported here seeks to address this lost learning opportunity by increasing active student engagement using inquiry-based learning. In the Summer of 2017, 61 students participated in a flipped-delivery Fluid Mechanics course and conducted five experiments using custom-designed project-based learning kits. The benefits of adopting a project-based approach to learning are numerous, but appear specifically promising in the areas of self-efficacy and professional skills development. Through this approach, students become co-creators of their learning journey rather than passive observers using traditional "black box" commercial flow benches. This paper examines student performance and self-assessed professional skills development through quantitative and qualitative analysis of student results on a variety of assessments and surveys measuring professional skills development. Paired t-tests and hierarchical modelling were used to conduct statistical analyses of a variety of demographic factors influencing student performance on assessment. A qualitative reflection of these results is also conducted. Findings indicate that students reported statistically significant growth in most graduate attributes on two different surveys. Technically-focused attributes (1,2,3,5) ranked highest in terms of growth on both surveys, while attributes 9, 11, and 12, impact of technology on society and the environment, economics and project management, and lifelong learning also saw large improvements. Fourth year students performed significantly worse than their counterparts on the project-based laboratories, likely reflecting a lack of motivation associated with taking a second or third year course later on in their academic careers.

KEYWORDS

PjBL, PBL, Student-centered learning, CDIO approach, Blended learning
Standards: 2, 3, 5, 7, 8

INTRODUCTION

Educators, employers and regulators have spent a great deal of time creating pedagogies, frameworks, and policies in an effort to close the professional skills gap in engineering graduates (Crawley et al., 2014). In Canada, the Canadian Engineering Accreditation Board (CEAB) created a list of graduate attributes which act as a vetted set of desirable characteristics for engineering graduates. Of the twelve attributes, seven are considered to be professional in nature; the list with professional skills highlighted is presented in Table 1.

Table 1. CEAB Graduate Attributes (Canadian Engineering Accreditation Board Accreditation Criteria and Procedures, 2017)

Graduate Attribute	
1 – Knowledge base for engineering	7 – Communication skills
2 – Problem Analysis	8 – Professionalism
3 – Investigation	9 – Impact of Engineering on Society and Environment
4 – Design	10 – Ethics and Equity
5 – Use of Engineering Tools	11 – Economics and Project Management
6 – Individual and Team work	12 – Lifelong learning

Previous work has demonstrated how these twelve attributes map directly to the CDIO syllabus, indicating that Canadian regulators are closely in alignment with international initiatives in their effort to develop well-rounded engineers (Cloutier, Hugo, & Sellens, 2012). While there appears to be broad consensus on the importance of professional skills in the engineering curriculum, there is still a great deal of work to be done on establishing the best ways to achieve this goal. Project-based learning offers promise in the enhancement of professional skills in engineering education (Crawley et al., 2014a). A brief search of the terms “project-based learning”, “engineering”, and “professional” in the academic database Scopus will return results from 1996 onwards, with publications increasing in frequency every year to present. These trends indicate that researchers are increasingly interested in the relationship between these topics.

Project-based learning appears to be a promising approach for the development of professional skills as it is inherently student-centered. By emphasizing knowledge co-creation rather than memorization, project-based learning requires that students, peers and instructors engage in a dialogue that more closely approximates real-world experiences than the traditional lecture approach. Project-based learning appears to naturally facilitate channels of informal feedback which can support the practice of formative assessment and self-regulated learning (Butler & Winne, 1995). Many Canadian schools offer project-type courses for design-oriented classes, for example, in the form of a final-year capstone project. Less popular, however, are project-based deliveries in technical, core engineering courses. An explanation for this may be that core engineering courses center around “declarative”-type knowledge (Ambrose, 2010). Mastering technical material for many students can be difficult enough, with students spending the majority of their effort remembering or understanding, the first two cognitive classifications in the revised version of Bloom’s Taxonomy (Anderson, Krathwohl, & Bloom, 2001). As many of these courses function as pre-requisites and form the basis of engineering fundamentals, it can be challenging to meaningfully integrate professional skills development into an already tight technical curriculum.

Blended learning and PjBL appear to address some gaps but it is important to document and better understand its benefits and drawbacks. As a result this study was designed to better understand what the pitfalls are and illuminate key findings that may enhance the way that others engage with it in the future. In the next section we discuss research questions and then follow with the methodology, results, discussion and conclusions.

RESEARCH QUESTIONS

This paper will discuss the experience of implementing project-based learning in a technical fluid mechanics undergraduate course. A description of the course setup, motivation, and findings are presented. The questions being investigated in this paper are:

- Can project-based learning in a technical course significantly increase self-reported professional skills as measured by two sets of paired surveys?
- What are the factors in the context of technical project-based learning that influence professional skills development?
- Is there a student demographic that performed significantly better or worse on assessment types in this particular class?

Findings from this experience are shared here to encourage dialogue on project-based learning practices. Locally, further findings from this research will be used to influence continuous improvement efforts within the authors' university.

METHOD

To answer the research questions, a blended, project-based delivery course was created and offered to 61 University of Calgary students in July and August 2017. As the course was offered in a blended delivery format, all lectures were made into videos curated into modules on a free and open YouTube channel. All links to the open videos were placed on the online learning management system, D2L. A more detailed description of the course activities and the methods of analysis follows.

Course Design

Learning Activities

The lab activities were designed to reinforce technical learning outcomes covered in YouTube video lectures and reviewed in active learning tutorials. Students were also given access to additional problem sets which were not graded but promoted self-directed mastery of technical concepts. Weekly quizzes were used to validate uptake of technical learning outcomes from the sum of the previous week's activities. At least one quarter of weekly quiz questions were based off technical learning outcomes from the active learning laboratories, with additional questions geared towards concepts from the online lectures. Active learning laboratories were used to scaffold professional skills development with technical learning, and weekly quizzes served as checkpoints to validate synthesis of technical concepts. Table 2 summarizes the course activities and how each were assessed.

Table 2. Course Activities and Assessment Items

Course Activities	Type of Outcome	Assessed by
YouTube Lectures	Technical	Cornell Notes, Quizzes, Final Exam
Active Tutorials	Technical and Professional	Clicker responses, self- and peer- formative assessment
Active Learning Laboratory (Design-Build, Experiment)	Technical and Professional	Report, Poster or system map, Quizzes and Exam

Problem Sets	Technical	Self-assessment (no grade)
Cornell Notes	Technical	Cornell Notes Rubric

Figure 1 depicts the constructive alignment of learning outcomes and activities conducted in this course.

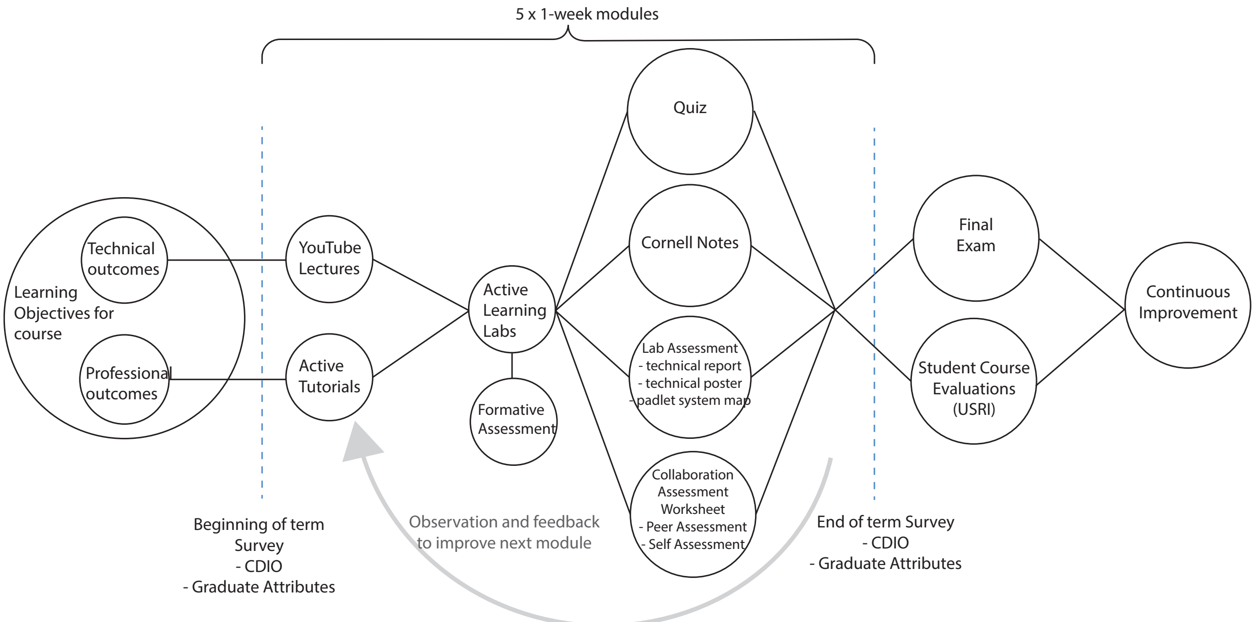

Figure 1. Visualization of constructive alignment of outcomes, activities and assessment of the course.

The course was run in five modules which covered technical and professional learning, with some aspects scaffolded from week to week. It is important to note that while lab assessment appeared to be independent of exams, there was overlap between the assessments in terms of the learning outcomes that were assessed.

Active Learning Labs

Five laboratories were offered using project-based delivery, a more detailed description of the laboratories can be found in the Appendix. The major themes for each of the five experiments were: calibration of a flowmeter and measuring volumetric flow rates, hydrostatic pressure, momentum transfer and nozzle design, pump performance and dimensional analysis, and head loss in a pipe network. For each lab, students were provided a set of objectives and high-level instructions that would guide discovery. This was meant to encourage self-regulated learning within a technical course which has historically been taught using step-by-step scripted laboratory experiments performed on commercial laboratory bench systems. Student teams were required to design, build and operate their own experimental apparatuses using a standardized kit of supplies that was assembled by the authors. For example, instructions on pump and power supply setup were provided, however explicit dimensions for pipe assemblies were not. This resulted in 15 (the number of teams in the class) unique setups for each of the five labs, all constructed from the same standard set of materials and basic instructions. Students were asked to formulate their own hypotheses and base their experimental approach and analysis in theory, while instructors were available to provide feedback on this process. The supplies included ½" PVC piping and fittings, pumps and power supplies and a number of experiment-specific items, such as calipers and balloons.

Figure 2. Standardized kit and additional lab-specific materials.

Active Learning Lab Assessment

Each week lab teams submitted a summary of the lab and their results for assessment. A technical memo was assigned for lab 1 and 3, while a technical poster was assigned for lab 2 and 4. Lab 5, head loss in pipes was designed to scaffold on previous experiments, particularly experiment 1, therefore students were asked to create a system map on the online tool Padlet.com. This tool was utilized because it allows collaborative work (more than one student can work on the application at the same time), and can store text, images, videos and voice memos.

Exams

One quiz was administered each week, for a total of five quizzes throughout the summer semester. Students were given one hour to complete the quiz, and directly after finishing, were placed in teams according to their rank on the previous exam. The grouping for the first exam was done randomly. Each team was assigned a top, middle, and low-ranking student. The teams were then given one blank copy of the same exam and had 30 minutes to complete it together. This was to encourage student dialogue and formative assessment practice among peers. A final summative exam was administered at the end of the term, and students did not repeat the final exam in teams. The five quizzes comprised 40% and the final exam 25% of the semester mark.

Peer and Self-Assessment

At the end of each lab module (after lab reports were submitted) students were asked to fill out assessments of their team members. A copy of the peer assessment form can be found in the Appendix. Outcomes assessed on the form were: participation, leadership, listening, feedback, co-operation, and time management. Students were also required to self-evaluate on these skills. Peer and self-assessment comprised 10% of the students' course mark. Formal and informal discussions on the importance of professional skills development were conducted throughout the semester usually in the active learning tutorials.

Cornell Notes

One half-page of Cornell Notes per lecture video (5-10 minutes) were implemented to encourage early student engagement with the material. This was initiated to mitigate a finding from when the same course was offered in 2015 that video watch minutes peaked the evening before quizzes.

Data Collection

The bulk of this paper will concentrate on the statistical analysis of the results from survey and assessment data gathered in this class, further quantitative and qualitative analysis are presented in a companion paper, Meikleham et al. (2018).

Graduate Attributes Survey

A survey comprised of 38 questions was administered in the first and last lectures of the semester. Students were asked to identify on a scale of 0-1: “How confident are you in your current ability to…?” A response of “0” indicated having no confidence and “1” indicated having total confidence, with responses distributed in 0.25 increments between these two values. A detailed description of the survey and similar analysis on responses from a different group of students can be found in Brennan & Hugo (2016).

CDIO Survey

The CDIO Syllabus at the third level of detail (Crawley et al., 2014b) was used as a survey to verify self-reported competencies on each syllabus item and was also administered at the first and last lecture of the semester. The students ranked their abilities with respect to the syllabus from 0-1 according to the following scale: “0 - To have experienced or been exposed to”, “0.25 - to be able to participate in and contribute to”, “0.5 - to be able to understand and explain”, “0.75 - to be skilled in the practice or implementation of”, and “1 - to be able to lead or innovate in”. These questions loosely translate to Bloom’s taxonomy increasing from Remember (a rating of 0), to Understand, Apply, Analyse, Evaluate, and ending with Create (a rating of 1) (Anderson et al., 2001).

Data Analysis

Statistical testing including general and hierarchical linear modelling and paired t-tests were used to investigate factors related to student performance on assessment and two professional skills surveys, described below. This was to support a holistic discussion on our experiences in project-based learning. The statistics provide valuable insights to this discussion but are only one part of a much bigger picture. These methods are mainly used to help support the qualitative discussion of the statistically significant factors in our experience offering project-based learning. A drawback to this approach is that it is limited only to the factors which were gathered under research ethics approval, for example, student GPA was not included due to limitations on internal ethics approval. Another important point to note is that modeling for responses to the professional skills survey assumed that the scale between the points was continuous and linear. It is important to recognize that while this may not be completely accurate and can add error to the model, ratings between 0 and 1 on all questions for both surveys indicated directional (increasing) and incremental development of skills, which was deemed to be sufficient to use linear modeling to investigate important factors. A similar approach was described in Knight & Novoselich, (2017) where linear modeling was used to investigate factors influencing self-reported leadership skills on a national student survey.

All results from the statistical analysis are reported at the 95% confidence level, or when $p<0.05$. Each of the three research questions were explored through the statistical tests reported in Table 3.

Table 3. Tabulation of statistical tests aligned with research questions.

Research Question	Statistical Test
Can project-based learning in a technical course significantly increase self-reported professional skills as measured by two surveys?	One tailed t-test for pre- and post- survey data
What are the factors in the context of technical project-based learning that influence professional skills development?	General linear model (GLM)
Is there a student demographic that performed significantly better or worse on assessment types in this particular class?	Two-tailed t-test, GLM, HLM

Limitations

The use of a case study has benefits and drawbacks. While it can be a useful tool to share practical experience, it is important to note that there are many factors which could limit repeatability in new contexts. Another important factor is that multiple interventions were conducted simultaneously in comparison to traditional course design, for example the course made use of blended delivery and technological mediated learning, active tutorials and project-based learning; it is therefore difficult to ascertain whether the effects observed are as a result of any one specific intervention. Another limitation to this study is that self-assessment methods have been shown to be biased in some cases. For example, Mabe & West (1982) have shown that there are several factors which can influence the validity of self-assessment, including user belief that anonymity will be violated. We have attempted to circumvent this perception via the ethics approval process to administer the surveys within our institution. Before the surveys were administered, a presentation clarifying how the survey results would be used was made for the students. Students were given a handout clarifying that survey results would be kept confidential, anonymous (except to pair pre- and post- surveys), and that the surveys would be placed in a sealed envelope and not be opened until after final grades were submitted for the course.

A further limitation in the study design is that this course was offered in a condensed format during the summer months. As a result, there may be some selection bias with respect to the students that were involved. Often students taking summer courses are either repeating the course or are attempting to get ahead in their sequence, which may have resulted in a sample that is unrepresentative of the population. Students who must repeat courses with lab sections are often given credit if they have previously passed the labs, however due to the nature of the course it was not possible to make this arrangement, which may have influenced student attitudes.

RESULTS

Description of the Sample

There were 48 (of 53) students who consented to be included in the study, ten females and 38 males. Each student was assigned randomly to a lab team for the semester (all five labs). There were 37 students in mechanical engineering and nine in civil engineering (two students did not report department). A subset of 38 students completed the Graduate Attributes survey, while a subset of 37 students completed the CDIO survey; some students who completed the Graduate Attribute survey did not complete the CDIO survey and vice versa. Data for all 48 students were used to analyse differences in assessment performance, while data from the 37 or 38 students were used for the analyses relating to factors associated with professional skills development as indicated by survey responses. Descriptive statistics are tabulated for each factor in Table 4.

Table 4. Descriptive statistics for each factor.

	Gender		Year of Study				Program*	
	Female	Male	1	2	3	4	Civil	Mechanical
Assessment Results	10	38	2	14	28	4	9	37
Graduate Attribute Survey	6	32	2	11	21	4	7	29
CDIO Survey	7	30	2	12	20	3	7	28

*Program information was not available for two students.

Professional Skills Development

The graduate attribute survey was previously tested with another group of students for reliability on the twelve CEAB graduate attributes in Brennan & Hugo (2016). The CDIO survey has been administered to measure professional skills development and is currently being analysed for reliability over ten years of data (thesis is in progress). In previous work (Cloutier et al., 2012) the syllabus has been correlated to CEAB graduate attributes 2-12. A Cronbach alpha analysis revealed that all mappings were “adequate” (Milliken, 2010) attaining an alpha of at least 0.7.

t-Test for Paired Means on Both Surveys

A paired sample t-test for all attributes was performed on responses to the CDIO and Graduate Attributes survey (this formed a total of 23 tests as the CDIO survey only included questions associated to graduate attributes 2-12). The alternate hypothesis for this test was that the difference in post and pre-responses was statistically significantly greater than zero (i.e. that there was a statistically significant increase in this skill); results are tabulated in Table 5**Error! Reference source not found.**. All results were found to meet the Shapiro-Wilks test for normality.

Table 5. Graduate attributes by survey, p-value for normality test, mean, standard deviation, sample size and paired sample t-test p-value. Highlighted values did not increase significantly.

Survey, Attribute	S-W normality	Paired Mean	Standard Deviation	N	p-value
CDIO GA2 - Problem Analysis	p>0.100	0.072	0.12	37	0.000
CDIO GA3 - Investigation	p>0.100	0.096	0.15	37	0.000
CDIO GA4 - Design	p>0.100	0.065	0.16	37	0.008
CDIO GA5 - Use of Engineering Tools	p>0.100	0.092	0.20	37	0.004
CDIO GA6 - Individual and Team work	p>0.100	0.044	0.15	37	0.037
CDIO GA7 - Communication skills	p>0.100	0.041	0.13	37	0.033
CDIO GA8 - Professionalism	p>0.100	0.016	0.15	37	0.260
CDIO GA9 - Impact of Engineering on Society and Environment	p>0.100	0.060	0.15	37	0.009
CDIO GA10 - Ethics and Equity	p>0.100	-0.015	0.15	35*	0.666
CDIO GA11 - Economics and Project Management	p>0.100	0.055	0.18	37	0.033
CDIO GA12 - Lifelong learning	p>0.100	0.032	0.14	37	0.094
GA1 - Knowledge base for engineering	p>0.100	0.16	0.18	38	0.000
GA2 - Problem Analysis	p>0.100	0.15	0.21	38	0.000
GA3 - Investigation	p>0.100	0.13	0.20	38	0.000
GA4 - Design	p>0.100	0.11	0.23	38	0.004

GA5 - Use of Engineering Tools	p>0.100	0.13	0.17	38	0.000
GA6 - Individual and Team work	p>0.100	0.060	0.16	38	0.015
GA7 - Communication skills	p=0.092	0.10	0.17	38	0.001
GA8 - Professionalism	p=0.070	0.00	0.20	38	0.500
GA9 - Impact of Engineering on Society and Environment	p>0.100	0.026	0.19	38	0.199
GA10 - Ethics and Equity	p>0.100	0.035	0.16	38	0.088
GA11 - Economics and Project Management	p>0.100	0.079	0.17	38	0.003
GA12 - Lifelong learning	p>0.100	0.11	0.16	38	0.000

* Two outliers were removed from this analysis after attaining a significant p-value in Grubb's test. One outlier was abnormally high, and one abnormally low. The finding of significance was not affected by this change

There were two attributes which did not increase significantly across both surveys. The first was *Attribute 8 – Professionalism*. Further examination of the questions associated with this attribute reveals that this finding is not completely surprising as most of the questions mention themes which were not dealt with explicitly in this course. The finding for *Attribute 10 – Ethics and Equity*, however, is a bit more surprising, as the CDIO survey actually indicated a decrease in this attribute. This was the only attribute of all 23 tests that indicated a decrease. Looking more closely, this decrease was accounted for from responses to CDIO questions 2.5.5 Equity and Diversity and 2.5.2 Professional Behaviour and Responsibility (highlighted in Table 6Table *6*). Question 18 on the Graduate Attributes survey was found to have a negative response as well but did not contribute enough weight to cause negative growth in the attribute overall. The questions for this attribute are tabulated in Table 6 for convenience.

Table 6. Questions associated with Attribute 10 – Ethics and equity. Highlighted questions contributed the most to lack of growth in this attribute.

Survey	**Questions associated with Attribute 10 – Ethics and Equity**
GA Survey	Q18. Admit when you have made a mistake.
	Q37. Analyse opposing positions on an issue and make a judgment based on the evidence.
CDIO Survey	4.1.5 Contemporary issues and values
	2.5.5 Equity and Diversity
	2.5.2 Professional behaviour and responsibility

An investigation of a box plots indicates that the second-year students account for the majority of the negative response (though this difference was not statistically significant).

Students indicated they were less confident in their ability to admit when they made a mistake after the course, possibly due to conflicts that arose in the team activities. Conflict resolution was not explicitly dealt with in this course but could indicate an area of growth for future professional development in such classes.

Attribute 9 – Impact of engineering on society and the environment was found to increase significantly according to the CDIO survey, while the Graduate Attributes survey showed no significant increase. This is not surprising as the questions appear to capture slightly different themes related to this attribute. The questions for Attribute 9 are tabulated in Table 7 for convenience, with Q4 contributing most to the insignificant growth of this attribute.

Table 7. Questions associated with Attribute 9 – Impact of engineering on society and the environment for Graduate Attributes and CDIO Survey. Highlighted question contributed the most to lack of growth in this attribute.

Survey	**Questions associated with Attribute 9 – Impact of engineering on society and the environment**
GA Survey	Q4. Identify the interactions that an engineering project has with the economic, social, health, safety, legal, & cultural aspects of society.
	Q27. Apply technical, social, and environmental criteria to guide trade-offs between design alternatives.
	Q34. Incorporate sustainability considerations in project decision-making.
CDIO Survey	2.4.1 Initiative and willingness to make decisions in the face of uncertainty
	4.1.2 The impact of engineering on society and the environment
	4.1.7 Sustainability and the need for sustainable development
	4.1.4 The historical and cultural context
	4.4.6 Design for sustainability, safety, operability, aesthetics and other objectives
	4.5.1 Designing a sustainable implementation process
	4.6.1 Designing and optimizing sustainable and safe operations
	4.6.3 Supporting the system lifecycle

Further inspection of a boxplot for Attribute 9 demonstrated responses from fourth year students contributed the most negative result, with second and third years having the most gain in this area, though the differences are not statistically significant. This may be because fourth years enrolled in this course are more likely to be taking it as a repeat due to previous failed attempts.

Attribute 12 – Lifelong Learning was found to increase significantly on the Graduate Attributes survey, but not on the CDIO Survey. The questions are tabulated in Table 8 for convenience with question 2.4.6 *Lifelong learning and educating others* highlighted in the table as this is the question that had the least growth in this attribute. It is a possibility that students were confused by the term "lifelong learning" which can take on many meanings, or they were unable to link the current project-based learning activity to the development of lifelong learning skills. This could indicate a lost learning opportunity and should be considered for future discussion within the course.

Table 8. Questions associated with Attribute 12 – lifelong learning from both surveys. Highlighted question contributed the most to lack of growth in this attribute.

	Questions associated with Attribute 12 – Lifelong Learning
GA Survey	Q5. Recognize your strengths and weaknesses when working on a specific problem.
	Q23. Identify the best approach that is suited to your learning style.
	Q32. Use technical literature or other information sources to fill a gap in your knowledge.
	2.4.5 Self-awareness, meta-cognition, and knowledge integration

CDIO Surveys	2.4.6 Lifelong learning and educating others
	2.5.3 Proactively planning for one's career
	2.5.4 Staying current on the world of engineering
	2.5.7 Vision and intention in life
	4.1.6 Developing a global perspective

General Linear Model for Survey Responses on Both Surveys

A general linear model was then generated for responses to survey questions on the Graduate Attribute and CDIO survey. Factors which were examined were lab group, gender, department, and year in program. Lab group was examined to better understand whether a student being placed in a particular group impacted their perception of professional skills development – for example students on a "strong team" may have felt more positively about their professional skills development than those having a negative team experience. Gender was examined to verify whether there were any differences in the groups' perception of professional skills, and where those gaps were. Department was examined to verify whether mechanical and civil students perceived their experiences in a similar way, and year in program (1-4) was used to distinguish whether this impacted students' perceived development of professional skills.

Lab group, year in program, and gender were not found to be significant factors for graduate attribute development in the CDIO survey. Only two of the twelve attributes on the Graduate Attributes Survey were found to have significant factors: *Attribute 1 – Knowledge base for engineering* and *11 – Economics and project management.* In a Cronbach's alpha analysis both of these factors were found to be questionable to acceptable (alpha value 60-70), which contradicts findings from a previous study where these attributes were found to have acceptable alphas >0.7 (Brennan & Hugo, 2016). Given that all other factors were found to be insignificant across the other attributes, these factors warranted further discussion, with the significant attributes and associated factors tabulated in Table 9:

Table 9. Tabulation of R-square and p-value for factors: lab group, gender, department, year in program, lack of fit, on general linear model. Highlighted values were significant.

	Lab Group p-value	Gender p-value	Department p-value	Year in Program p-value	Lack of Fit p-value	R-squared value
GA1 - Knowledge base for engineering	0.400	0.524	0.041	0.062	0.062	58.93%
GA11 - Economics and Project Management	0.555	0.013	0.295	0.014	0.475	61.79%

Department was found to be a statistically significant factor for *Attribute 1 - a knowledge base for engineering*. Closer inspection of the model indicated that civil engineering students rated themselves significantly lower in growth of this attribute. This may reflect a difference in students' comfort level with the technical material covered in this course, which may put a higher emphasis on dynamics than civil students are accustomed to. For responses to Graduate Attribute survey questions on *Attribute 11 –Economics and Project Management*, students' year in program and gender were both factors in their responses. Women rated themselves significantly higher than their male counterparts, with fourth and first years ranking themselves significantly lower than third years (there was no significant difference between second years and the others) in a fisher test for mean differences.

General Linear Model Relating High and Low Rank on Project-Based Learning Lab Assessment and Professional Skills Development

Students were grouped by their overall rank on assessment of the project-based learning labs into two groups (high and low). A general linear model was performed for responses to surveys on professional skills development. It was found that there was no significant difference between the groups in self-evaluated performance on any skills measured by the Graduate Attributes survey, however on the CDIO survey groups performed significantly differently on six of the eleven measured attributes, tabulated in Table 10.

Table 10. Attributes with significant performance differences between high and low-ranking students on PjBL lab assessments.

Survey - Attribute	Coefficient of Higher Ranked Group	p-value	R-squared value
CDIO4 - Design	0.15	0.003	22.64%
CDIO6 - Individual and Team work	0.13	0.004	20.92%
CDIO7 - Communication skills	0.12	0.007	19.01%
CDIO8 - Professionalism	0.10	0.043	11.18%
CDIO9 - Impact of Engineering on Society and Environment	0.11	0.019	14.78%
CDIO12 – Lifelong learning	0.094	0.047	10.81%

This finding confirms that students who ranked well on labs reported significantly higher increases on these attributes, however the claim cannot be reversed (because students developed more in these attributes it cannot be claimed that this is the reason they performed significantly better on laboratories). It is logical, however, that there is some relationship between these two. Further inspection of the R-squared value for each of the attributes indicates that the effect size can be classified as medium to large. Cohen, (1988) previously reported that an r-squared value of between 9%-25% be classified as medium, and anything larger than 25% be classified as large, while a more recent empirical study by Hemphill, (2003) has suggested that values greater than 9% can be classified as large.

For all reported significant factors, the higher performing group coefficient was reported. In the models, the lower performing coefficient was zero, therefore each factor's coefficient gives a direct indication of how much higher the skills were reported over the lower performing group.

General Linear Model Relating High and Low Rank on Peer Assessment and Significant Professional Skills Development

Peer assessments were performed at the end of each of the five PjBL activities for each of the students in their assigned group. To get an indication of whether students being grouped into the same teams throughout the semester biased their results on peer assessments, a hierarchical linear model was performed nesting student grades on peer assessments within their teams (ie. Did teams mark themselves significantly differently than others). In this model teams were not found to be a significant factor (p=0.624). This meant that there was no confounding of student peer assessment grades based on the team they were in, and this factor was removed from further analysis.

Students were then grouped according to how they ranked with respect to their peers on peer assessments. Top students were placed in group 1 and all below average ranked students were placed in group 2. Their survey results were compared for significant differences between these two groups. P-value and r-squared values for the significant attributes are tabulated in Table 11.

Table 11. Attributes with significantly different performance between high and low-ranking students on peer assessments.

Survey-Attribute	Coefficient of Higher Ranked Group	p-value	R-squared value
CDIO4 - Design	0.10	0.056*	10.07%
CDIO5 - Use of Engineering Tools	0.15	0.028	13.02%
CDIO6 - Individual and Team work	0.12	0.019	14.80%
CDIO7 - Communication skills	0.088	0.049*	10.59%
CDIO9 - Impact of Engineering on Society and Environment	0.12	0.015	15.86%
CDIO11 - Economics and Project Management	0.14	0.018	15.05%

*Reported although at the cusp of significance.

A similar statement to the relationship previously made between ranking on lab assessment and attribute development can be made here – students who performed significantly better on the peer assessments tended to develop better in the above areas. Again, it cannot be claimed that because students developed these attributes they performed better on their peer assessments. Qualitatively it stands to reason that there is some relationship between them.

For all reported significant factors, the higher performing group coefficient was reported. In the models, the lower performing coefficient was zero, therefore each factor's coefficient gives a direct indication of how much higher the skills were reported over the lower performing group.

This finding also helps to support the validity of self-assessment responses to the CDIO survey. The above table demonstrates for these particular attributes that students who were ranked higher by their peers on peer assessment during the course (participation, leadership, listening, feedback cooperation and time management) rated themselves significantly higher on related attributes 6, 7, and 11. It is an interesting result that the graduate attributes survey did not show any significant differences between the two groups. This may reveal differences in the ability of the surveys to measure these skills accurately.

Rank of Overall Professional Skills Growth

Placing the attributes in rank order reveals that the top five growth areas were mainly in the more technically-oriented skills (Attributes 1-5). Attribute 2, 3, and 5 were the only three professional skills making the top five ranking across both surveys, tabulated in Table 12.

Table 12. Ranking of top five skills by growth and significance by survey.

Graduate Attributes Survey	CDIO Survey
1 – Knowledge base for engineering	2 – Problem Analysis
2 – Problem Analysis	3 – Investigation
3 – Investigation	5 – Use of Engineering Tools
5 – Use of Engineering Tools	9 – Impact of Engineering on Society and Environment
12 – Lifelong learning	11 – Economics and Project Management

These findings indicate that project-based learning can be a useful tool for professional skills development in a technical course without sacrificing the development of technically-oriented engineering acumen (referred to as dual-impact learning experiences in CDIO).

Assessment Performance Comparison

t-test Comparing Individual vs. Group Quiz Grades

A paired t-test was performed for quiz grades between student individual attempt and their combined grade for the same exam (a weighted average of: 90% individual quiz grade and 10% team's grade). There was a significant increase between the two grades for all exams (p=0.000 for all five exams), n=48. This does not necessarily indicate that the lower-ranked students learned more due to this practice. What it does appear to indicate is that there was no harm for the higher-ranked students (their grades were not reduced). An increase in student grades may not be the only externality of such a practice. Students must practice communicating as they articulate their approach and convince their team why their solution made sense. Students also gained experience in offering and receiving feedback: students articulated how their approaches could be improved. Time-management was also practiced, as students implemented techniques to complete the one-hour quiz as a team in 30-minutes or less. The statistically significant increase in communication and teamwork attributes observed in the previous section may be partially explained by this experience.

Factors Influencing Performance on Assessment Types

To discover whether there was a student demographic who performed significantly differently on assessment type in this course, general linear models were created relating lab group, gender, department of study, and year in program to grades on various assessment types. The only factor found to be significant at the 95% confidence level was gender and performance on exams, with women performing significantly worse than their male counterparts. Findings from the model are tabulated in Table 13.

Table 13. Summary of results from general linear model relating gender to performance on assessment types.

Assessment Type	Coefficient for Female	P-value	R-squared value
PjBL Labs	-0.017	0.262	2.73%
Exams	-0.15	0.000	27.15%
Cornell Notes	0.21	0.069	7.02%
Peer Review	-0.0023	0.909	0.03%

Coefficient for the female term in the model was reported (with males taken as the reference level), which gives an indication of the magnitude of contribution by the female term to the model (normalized).

These findings indicate that there was no demographic of student favoured or challenged by this type of course delivery, with the exception of the statistically significant lower performance by females on quizzes and exams. It is unclear why females performed significantly lower on these assessment types. Taken with the finding from the professional skills survey that females performed significantly better in the area of economics and project management (the only attribute in which there was a statistically significant difference between the genders), it is possible that the female students concentrated more of their time supporting their groups on the projects while sacrificing time to study for their exams. This finding may also indicate a bias by teaching assistants in marking, however it is not possible to verify this claim for this course. Yet another explanation may come from the finding that females performed better than males on the Cornell Notes (though not statistically significantly better). This may indicate that the female students spent more time perfecting their Cornell Notes, which did not translate into performance on exams. This finding may indicate that students who sacrificed performance on Cornell Notes by jumping to practicing technical problems performed better in general, however there is no statistically significant evidence to substantiate this finding.

A general linear model was created relating lab group, gender, program of study and year in program to performance on PjBL assessments. Lab group and year in program where both found to be statistically significant ($p<0.05$). Lack of fit was significant ($p<0.05$), however R-squared was also quite high at 84.41%. A hierarchical model was therefore created nesting year in program within lab groups, and was found to be significant ($p=0.001$). This finding indicates that there was a significant difference on performance between students in different program years when their lab groups were accounted for. This model had no lack of fit and had an R-squared value of 95.61% indicating that these two factors explained almost all variance in this model. Further inspection of a boxplot of lab grades and a fisher difference of means test revealed that fourth year students performed significantly lower than the other students in the labs. As there were only four fourth years in this course it is likely that their performance is an inaccurate representation of what fourth year performance may look like in general for this class. It should be noted, however, that this course is traditionally offered in the second year of the program, so it is possible that students in fourth year are taking this course for the second or third time and are either not motivated to the level the other students are or perform lower in experiential learning for some other reason. The finding that lab group was a factor in lab performance is also an important one as it may indicate that group dynamics played a role in student success in the labs.

Reflections

While the findings in this paper present a departing point for future discussion on blended and project-based learning, it is important to recognize that we cannot make a claim about which intervention led to the development of professional skills in the offering of this course. While it is clear from the findings that the mix of active PjBL learning and technology-mediated blended delivery, increased many professional skills, the findings here do not say anything about whether the same depth of development could have been achieved with less or different intervention. A recommendation for future studies would be to conduct smaller-scale experiences where the effect of one variable could be more easily isolated and the response to that variable measured.

CONCLUSION

In general it can be concluded that the vast majority of students performed as well as their peers in the demanding and complex environment of open-ended project-based learning. Females performed significantly worse than males on quizzes and exams only. This finding is inconsistent with the theory and requires further investigation. Fourth year students performed significantly worse than students from all other years on assessments in the project-based learning laboratories. This may be because of a lack of motivation on the part of the fourth-year students in taking this second or third year course later on in their program or because of having to repeat the class due to failure in previous terms. Students repeating the course were not given credit for previous attempts in the course due to the addition of project-based labs in this offering, which may have negatively biased them.

All except six of the 23 attributes measured were found to increase significantly in a paired t-test for the two surveys indicating that there was a significant improvement in graduate attributes development. *Attribute 8 – Professionalism* and *Attribute 10 – Ethics and Equity* did not improve significantly on either survey, which is not surprising as these themes were not dealt with explicitly in the course. *Attribute 9 – Impact of engineering on society and the environment* increased significantly only on the CDIO survey, with no increase found on the graduate attributes survey, and *Attribute 12 – Lifelong learning* only increasing significantly on the Graduate Attributes survey. These contradictions were likely due to the nuanced thematic differences between the questions on the two surveys. An analysis of the findings from the survey responses indicates that technical skills and professional skills can both be developed in tandem in a project-based learning course; however, there are limits to which all of the attributes can be developed simultaneously, as expected.

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BIOGRAPHICAL INFORMATION

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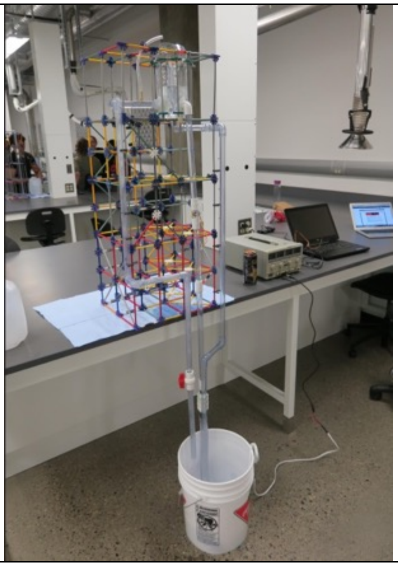
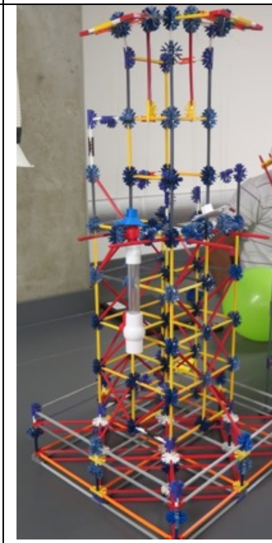
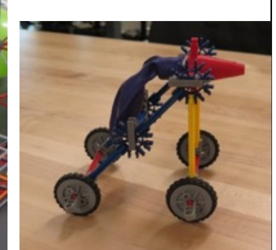
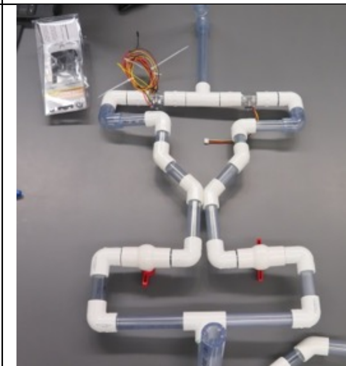
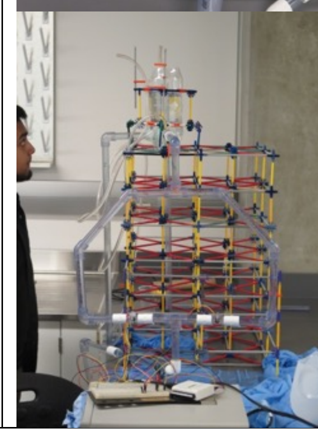
APPENDIX

Lab	Topic	Description	Objectives	Picture
1	Constant head tank and calibration of a flow meter	Students designed and built a constant head tank apparatus using a 12V DC power supply, submersible pump, ½” clear pvc piping and connectors, Knex structure, and data acquisition device.	To use a constant head tank to plan and perform the calibration of a turbine flow meter using a USB-6009 data acquisition device; Understand averaging techniques to achieve statistically-converged flow meter data; To quantify the volumetric flow rate of an electrically driven submersible pump as a function of input voltage when operating under steady state conditions; Clearly communicate the process and findings of the experiment in a technical memo.	
2	U-tube manometer	Students used their K’nex structures to assemble a U-tube water manometer using tygon tubing, barbed couplers and valves to measure the pressure in a balloon.	To design and assemble a support structure that is stable and able to support a vertical U-tube manometer of Tygon tubing; To specify the design length of Tygon tubing and required dimensions of the structure to support a U-tube manometer, given expected pressure inside a vessel (balloon); Demonstrate the relationship between volume of air and pressure of a balloon; Utilize averaging and sampling techniques to achieve consistent results;	

			Clearly communicate the design and experimental procedure and findings in a technical poster.	
3	Momentum Transfer	Quantify momentum transfer on a curved and a flat plate of air flow through a 3D printed nozzle. Utilize the best performing nozzle to compete in an balloon car race.	Design and prototype (3D print) two nozzles, test and compare performance in terms of produced thrust; Research, understand and articulate the factors of nozzle design that affect performance, discuss tradeoffs that exist in the design process; Utilize control volume analysis to verify experiments against theory; Build a calibration unit and quantify thrust from a balloon/nozzle assembly using experimental data; Design and build a car for a balloon / nozzle combination for maximum performance; Demonstrate performance of top nozzle in a K'NEX car race (covering a fixed distance of 20' in the shortest amount of time).	  

4	Dimensional Analysis and Pump Performance	Students built a small holding tank with a plastic container, submersible pump and 2m of tygon tubing. Hall effects sensor data was used to verify RPMs.	To investigate non-dimensional parameters for a submersible pump; Utilize hall effects sensor to measure RPM of a brushless motor; Conduct experiments to determine the pump performance curve, system curve and efficiency of a pump and determine the operating point for the system**.**	
5	Head loss in Pipes	Students utilized their constant head tanks from experiment 1 to quantify the head loss as measured from a series of pressure taps and velocity using flow meters across a variety of pipe networks.	To determine the roughness factor of a length of ½" clear PVC pipe To determine the energy loss due to a variety of standard pipe components as a function of Reynolds number: Flow meter, Ball valve (at a variety of openings angles), Two parallel, symmetric circuits of a variety of pipe components, Two parallel, asymmetric circuits of a variety of pipe components.	 

CDIO survey

Name: _________________ Age: _________ Date: _________________

Please indicate which of the five levels of proficiency that <u>you feel you are at</u>:

Scale:

1 To have experienced or been <u>exposed</u> to
2 To be able to <u>participate</u> in and contribute to
3 To be able to <u>understand</u> and explain
4 To be <u>skilled in the practice</u> or implementation of
5 To be able to lead or <u>innovate</u> in

	Proficiency Level (1-5)
2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES	
2.1 ANALYTICAL REASONING AND PROBLEM SOLVING	
2.1.1 Problem Identification and Formulation	_____
2.1.2 Modeling	_____
2.1.3 Estimation and Qualitative Analysis	_____
2.1.4 Analysis With Uncertainty	_____
2.1.5 Solution and Recommendation	_____
2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY	
2.2.1 Hypothesis Formulation	_____
2.2.2 Survey of Print and Electronic Literature	_____
2.2.3 Experimental Inquiry	_____
2.2.4 Hypothesis, Test, and Defense	_____
2.3 SYSTEM THINKING	
2.3.1 Thinking Holistically	_____
2.3.2 Emergence and Interactions in Systems	_____
2.3.3 Prioritization and Focus	_____
2.3.4 Trade-offs, Judgment and Balance in Resolution	_____
2.4 ATTITUDES, THOUGHT AND LEARNING	
2.4.1 Initiative and the Willingness to Make Decisions in the Face of Uncertainty	_____
2.4.2 Perseverance, resourcefulness, flexibility, responsibility, and will and urgency to deliver	_____
2.4.3 Creative Thinking	_____
2.4.4 Critical Thinking	_____
2.4.5 Self-awareness, Meta-cognition and Knowledge Integration	_____
2.4.6 Lifelong Learning and Educating Others	_____
2.4.7 Time and Resource Management	_____
2.5 ETHICS, RESPONSIBILITY, EQUITY, AND CORE PERSONAL VALUES	
2.5.1 Ethics, Integrity and Social Responsibility	_____
2.5.2 Professional Behavior and Responsibility	_____
2.5.3 Proactively Planning for One's Career	_____
2.5.4 Staying Current on the World of Engineering	_____
2.5.5 Equity and Diversity	_____
2.5.6 Trust and Loyalty	_____
2.5.7 Vision and Intention in Life	_____
3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION	
3.1 TEAMWORK	
3.1.1 Forming Effective Teams	_____
3.1.2 Team Operation	_____
3.1.3 Team Growth and Evolution	_____
3.1.4 Team Leadership	_____
3.1.5 Technical and Multi-disciplinary Teaming	_____
3.2 COMMUNICATIONS	
3.2.1 Communications Strategy	_____
3.2.2 Communications Structure	_____
3.2.3 Written Communication	_____
3.2.4 Electronic/Multimedia Communication	_____
3.2.5 Graphical Communication	_____

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Name: ________________ Age: ________ Date: ________________

3.2.6 Oral Presentation . . . . ____
3.2.7 Inquiry, Listening and Dialog . . . . . . ____
3.2.8 Negotiation, Compromise and Conflict Resolution . . . ____
3.2.9 Advocacy . . . . ____
3.2.10 Establishing Diverse Connections, networking . . . ____

3.3 COMMUNICATIONS IN A FOREIGN LANGUAGE
3.3.1 Communications in English . . . . . . ____
3.3.2 Communications in languages of regional industrial nations . . . ____
3.3.3 Communications in other languages . . . . . ____

4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – INNOVATION

4.1 EXTERNAL, SOCIETAL, ECONOMIC AND ENVIRONMENTAL CONTEXT
4.1.1 Roles and Responsibility of Engineers . . . . . ____
4.1.2 The Impact of Engineering on Society and the Environment . . . ____
4.1.3 Society's Regulation of Engineering . . . . . ____
4.1.4 The Historical and Cultural Context . . . . . ____
4.1.5 Contemporary Issues and Values . . . . . . ____
4.1.6 Developing a Global Perspective . . . . . . ____
4.1.7 Sustainability and the need for sustainable development . . . ____

4.2 ENTERPRISE AND BUSINESS CONTEXT
4.2.1 Appreciating Different Enterprise Cultures . . . . ____
4.2.2 Enterprise Stakeholders, Strategy and Goals . . . . ____
4.2.3 Technical Entrepreneurship . . . . . . ____
4.2.4 Working in Organizations . . . . . . ____
4.2.5 Engineering Project Finance and Economics . . . . ____
4.2.6 New Technology Development, Assessment and Infusion . . . ____
4.2.7 Working in international organizations . . . . . ____

4.3 CONCEIVING, SYSTEMS ENGINEERING AND MANAGEMENT
4.3.1 Understanding Needs and Setting Goals . . . . . ____
4.3.2 Defining Function, Concept and Architecture . . . . ____
4.3.3 Modeling of System and Insuring Goals Can Be Met . . . . ____
4.3.4 System Engineering and Development Project Management . . . ____

4.4 DESIGNING
4.4.1 The Design Process . . . . ____
4.4.2 The Design Process Phasing and Approaches . . . . ____
4.4.3 Utilization of Knowledge in Design . . . . . . ____
4.4.4 Disciplinary Design . . . . ____
4.4.5 Multidisciplinary Design . . . . ____
4.4.6 Design for Sustainability, Safety, Operability, Aesthetics and other Objectives . ____

4.5 IMPLEMENTING
4.5.1 Designing a Sustainable Implementation Process . . . . ____
4.5.2 Hardware Manufacturing Process . . . . . . ____
4.5.3 Software Implementing Process . . . . . . ____
4.5.4 Hardware Software Integration . . . . . . ____
4.5.5 Test, Verification, Validation, and Certification . . . . ____
4.5.6 Implementation Management . . . . . . ____

4.6 OPERATING
4.6.1 Designing and Optimizing Sustainable and Safe Operations . . . ____
4.6.2 Training and Operations . . . . ____
4.6.3 Supporting the System Lifecycle . . . . . . ____
4.6.4 System Improvement and Evolution . . . . . ____
4.6.5 Disposal and Life-End Issues . . . . . . ____
4.6.6 Operations Management . . . . ____

4.7 LEADING ENGINEERING ENDEAVORS
4.7.1 Thinking Creatively and Imagining Possibilities . . . . ____
4.7.2 Defining the Solution . . . . ____
4.7.3 Creating New Solution Concepts . . . . . . ____
4.7.4 Building and Leading and Organization and .Extended Organization . . ____

Name: _______________ Age: ________ Date: _______________

4.7.5 Planning and Managing a Project to Completion . . . . . _____
4.7.6 Exercising Project/Solution Judgment . . . . . . _____
4.7.7 Innovation – the conception, design and introduction of new goods and services _____
4.7.8 Invention – the development of new devices, materials or processes that enable new goods and services . . . . _____
4.7.9 Implementation and Operation – the creation and operation of the goods and services that will deliver value . . . . _____

4.8 ENGINEERING ENTREPRENEURSHIP
4.8.1 Company Founding, Formulation and Organization . . . . . _____
4.8.2 Business Plan Development . . . . . . _____
4.8.3 Company Capitalization and Finances . . . . . _____
4.8.4 Innovative Product Marketing . . . . . . _____
4.8.5 Conceiving products and services around new technologies . . . _____
4.8.6 The Innovation System, Networks, Infrastructure and Services . . _____
4.8.7 Building the Team and Initiating Engineering Processes (conceiving, designing, implementing and operating) . . . . _____
4.8.8 Managing Intellectual Property . . . . . . _____

Peer Assessment Rubric

Peer Assessment Collaboration Rubric – Exp #1 / Constant Head Tank

(Weight: 2% of final grade) Team #: ______ Date: ____________________

	4	3	2	1
Participation	Group member participated fully and was always on task in the lab activity.	Group member participated most of the time and was on task most of the time.	Group member participated but wasted time regularly or was rarely on task.	Group member did not participate, wasted time, or worked on unrelated material.
Leadership	Group member assumed leadership in an appropriate way when necessary by helping the group stay on track, encouraging group participation, posing solutions to problems, and having a positive attitude.	Group member sometimes assumed leadership in an appropriate way.	Group member usually allowed others to assume leadership or often dominated the group.	Group member did not assume leadership or assumed it in a nonproductive manner.
Listening	Group member listened carefully to others' ideas.	Group member usually listened to others' ideas.	Group member sometimes did not listen to others' ideas.	Group member did not listen to others and often interrupted them.
Feedback	Group member offered detailed, constructive feedback when appropriate.	Group member offered constructive feedback when appropriate.	Group member occasionally offered constructive feedback, but sometimes the comments were inappropriate or not useful.	Group member did not offer constructive or useful feedback.
Cooperation	Group member treated others respectfully and shared the workload fairly.	Group member usually treated others respectfully and shared the workload fairly.	Group member sometimes treated others disrespectfully or did not share the workload fairly.	Group member often treated others disrespectfully or did not share the workload fairly.
Time Management	Group member completed assigned tasks on time.	Group member usually completed assigned tasks on time and did not hold up progress on the projects because of incomplete work.	Group member often did not complete assigned tasks on time, and held up completion of project work.	Group member did not complete most of the assigned tasks on time and often forced the group to make last-minute adjustments and changes to accommodate missing work.

ENME 341: Experiment #1 – Constant Head Tank
Source: Intel Corporation - Intel Teach Program – Designing Effective Projects

Peer Assessment Collaboration Rubric – Exp #1 / Constant Head Tank

(Weight: 2% of final grade) Team #: ______ Date: ____________________

Write the proficiency level (1 to 4) from the rubric that fits each group members' participation in the box under the collaboration skill. <u>Include your own name at the end of the list.</u>

Group Member	Participation	Leadership	Listening	Feedback	Cooperation	Time Management
Your name (self eval.):						

Note: Be honest in your assessment. If a score of 4 is entered for every team member, all scores will be set to zero. This helps to prevent collusion within the group.

ENME 341: Experiment #1 – Constant Head Tank
Source: Intel Corporation - Intel Teach Program – Designing Effective Projects