University of Alberta

Application of Blended and Active Learning to Chemical Engineering Design Instruction

by

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Abstract

The Capstone Design Course instructional team was selected to participate in the digital learning initiative at the University of Alberta. The goals of this initiative are to increase student engagement and promote flexible, independent learning. The objectives of the instructional team were to enhance the interactions between instructors and student design teams in the face of increasing enrolment and to align the course strategically with attributes expected for graduating engineers set out by the University and elaborated in the Canadian Engineering Accreditation Board (CEAB) Guidelines. Existing course materials were redeveloped to an asynchronous online format for individual student engagement. Related activities were completed in class. Course delivery effectiveness is being evaluated by comparison with previous cohorts, pre - post course student skill self-assessment, student engagement and satisfaction, and will include post course interview and survey data.

This thesis contributes to the development of a continuous improvement process for teaching and learning for Chemical Engineering students, by creating a blended course design based on constructive alignment with program objectives, learning activities and performance based assessment consistent with the Canadian Engineering Accreditation Board Graduate Attribute Assessment. Examination of factors that impact the quality of the learning experience for students and instructors, studying the impacts of changes, tool development and technology applications, especially blended learning, to determine significant factors in improving learning, performance, and satisfaction are key elements of this work

The key research questions investigated in this work are:

- Does flipped learning lead to equivalent or better outcomes for Design II students?
- Is CEAB Graduate Attribute development demonstrated from data collected?
- Is student effort and quality of the final report equivalent or better for flipped learning students?
- Does a flipped learning structure produce equivalent or better academic performance?
- Is the co-op program a predictor or factor in student outcomes in design?
- Is the co-op program a predictor or factor for student results in a flipped structure?

While studying the data to answer these questions potential confounding variables were identified. These variables were examined to determine the potential impact (bias) on the measurement of student performance and comparison of the traditional and blended course design outcomes. Confounding variables included student to instructor ratio, course design model (mentorship or internship), program of study (co-op or regular), and student intellectual development bias within the co-op and regular program cohorts.

The principle findings of this study are that blended learning in the context of a flipped design course structure resulted in equivalent aggregate student performance and individual outcomes when compared with historical traditional results for both co-op and regular program students. Graduate Attribute development was demonstrated from the data collected. Student effort and quality of final report produced is found to be equivalent regardless of the course structure. A flipped learning structure produced equivalent academic performance when compared to historical performance. The co-op program was found to be a predictor of higher academic performance in the design course historically when student instructor ratios were high. It is less of a factor in the internship model and when student instructor ratios are lower. Co-op students are more likely to achieve a grade of A+ in capstone design than regular program students, most other grades are equally likely between the two programs when comparing historically and between the blended and traditional delivery methods. Ongoing course developments linked to the second iteration of the pilot project are described and discussed.

Dedication

To

my parents, Frank and Irene Vegesi;

my husband, Mark Jamieson;

our children, Melanie, Nathan, Matthew, Brandon, Mary and Megan

and

my teachers and my students throughout my life

- as both have taught me.

This work is dedicated to the achievement of professional knowledge in the context of lifelong learning:

"Many teachers and educators prize knowledge to some extent because of the simplicity with which it can be taught or learned. Mass methods, such as lectures, audiovisual methods, printed material and the like can be readily used for the acquisition of information." (p. 34)

Although information or knowledge is recognized as an important outcome of education, very few teachers would be satisfied to regard this as the primary or sole outcome of instruction. What is needed is some **evidence that the students can do something with their knowledge**, that is, they can apply the information to new situations and problems. It is also expected that students will acquire generalized techniques for dealing with new problems and materials. Thus it is expected that when a student encounters a new problem or situation, he will select an appropriate technique for attacking it and will bring to bear the necessary information, both facts and principles. This has been labeled "critical thinking" by some, "reflective thinking" by Dewey and others, and "problem solving" by still others. In the taxonomy we have used the term "Intellectual abilities and skills." *The most general operational definition of these abilities and skills is that the individual can find appropriate information and techniques in his previous experience to bring to bear on new problems and situations.* This requires some analysis or understanding of the new situation; it requires a background of knowledge or methods, which can be readily utilized; **it also requires some facility in discerning the appropriate relations between previous experience and the new situation**. (p. 38)"

Excerpted from the "**Taxonomy of Educational Objectives, the Classification of Educational Goals, Handbook I: Cognitive Domain**" - Benjamin Bloom et al. (1956) Sourced June 25, 2015

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Additional support was provided by CTL: Roger Graves, Heather Graves; CME: John Nychka, Amin Pourmohamadbagher, Linda Kaert, Fraser Forbes, Arno DeKlerk, Sirish Shaw, and Suzanne Kresta; IST: Dave Laurie; Faculty of Engineering Dean's Office: Raymond Matthias, Grace Jiang; Alumni Office: Jonathan Durynek.

Preface

This thesis is an original work by Marnie V. Jamieson. The CTL blended learning research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, No. *Pro00048272*.

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Nomenclature

Abbreviation	Units	Description
ADDIE		An Instructional Design Framework based on Analysis, Design, Development, Implementation, and Evaluation phases
AES		Automatic Essay Scoring
AGKO		Acid Gas Knock Out Drum (Plant equipment)
AvgMR		Average Moving Range
BM		Bare Module (cost estimation unit)
CCID		Campus Computing Identification (ID)
CEAB		Canadian Engineering Accreditation Board
eClass		The Moodle eClass Learning Management System
EPC		Engineering Procurement and Construction
F_{BM}		Bare module factor
GAA		Graduate Attribute Assessment
GPA	4.0 pt GPA	Grade Point Average: either based on or converted to the 4.0 scale
GPA Gap	4.0 pt GPA	Difference between the co-op and regular cohort average for a particular graduating class. Note: the graduating class does not start together.
GPA Range	4.0 pt GPA	Range of the GPA for specified cohorts (Top and Lowest Noted)
GPA Variance	4.0 pt GPA	Standard deviation of the GPA for analyzed cohort
HX		Heat Exchanger (plant equipment)
ISD		Instructional System Design
LMS		Learning Management System
LNPLx	4.0 pt GPA	The lower control limit (Wheeler and Chambers, 1992)
μ	4.0 pt GPA	Mean of the Study population indicated from 2004-2015
MR		Moving Range
MS		Microsoft (i.e. MS-Project – scheduling software)

MVSPC		Multivariate Statistical Process Control
NLP		Natural Language Processing
OR		Odds Ratio (Defined in Table 7.1)
PDF		Portable Document Format
PFD		Process Flow Diagram
P&ID		Piping and Instrument Diagram
pt		point
RCT		Randomized Control Trials
σ	4.0 pt GPA	Standard Deviation of the population indicated from 2004-2015
SAM		Successive Approximation Method an ISD method based on a modification of ADDIE. Iterations of design are used prior to implementation
SI Ratio		Student to Instructor Ratio
SOM		Screen Cast-O-Matic software for recording learning elements
SPC		Statistical Process Control
STDev	4.0 pt GPA	The standard deviation of a specified cohort
UNPLx	4.0 pt GPA	The upper control limit (Wheeler and Chambers, 1992)
URL		Uniform Resource Locator
VLE		Video Learning Elements
VMG Sim		Virtual Materials Group Simulator: A process simulator
Xbar	4.0 pt GPA	The average of a specified cohort grouping of interest
Xbar shift	4.0 pt GPA	The change in Xbar for the 2004-2009 cohorts to the 2010 – 2015 cohorts. Used to examine changes between Mentorship and Internship course models
XmR	4.0 pt GPA	Average of the Moving Range (Wheeler and Chambers, 1992)

1. Introduction

This work continues the tradition of continual improvement in design instruction (curriculum, teaching methodologies, and assessment) that has been practiced at the University of Alberta from the inception of the Chemical Engineering undergraduate program. With the establishment of web based teaching, increased use of eLearning resources, potential assessment applications and an increasingly proscriptive and ambitious undergraduate program evaluation environment, a systematic study to examine the scholarship of engineering process design teaching and the application of problem based learning in the context of project based teaching was initiated. The study focuses on an evaluation of the teaching and learning impacts of the decision to employ blended learning techniques in the capstone project course. Examination of the application of learning management system (LMS) technology to course delivery methods including the recent flipped instruction pilot is also included in the study. A holistic approach was taken to data gathering and analysis. Historical student performance data (program admission averages and design course performance data for the co-op and regular streams) were made available to the study. Blind student survey data (written and interview data) related to student experience and instructional impact, anecdotal survey data from instructors, and automated data mining techniques were all used in the assessment of student performance, student learning, student experience, instructor satisfaction, and instruction effectiveness. A brief history of the chemical engineering design courses at the University of Alberta, presented in Chapter 2, outlining the pedagogical decisions and student outcomes over time, provides both a background and a context for the present study.

1.1. Motivation

The goals of the University of Alberta digital learning initiative (to promote flexible, independent learning and increase student engagement) were combined with the capstone design course instructional objectives (to enhance quality interactions between design instructors and student design teams). The Capstone Design Course in Chemical Engineering is a project course where approximately 25 teams of 5-6 students each complete a unique industry sponsored design project. Students must research the project, identify and compare competing options using sustainable design criteria, develop a team structure, a project plan and schedule and then complete the design project. Four capstone design instructors teach as a team in the same section. Projected enrolment increases demand a solution that preserves student learning and performance outcomes while maintaining instructor time commitments to course delivery.

1.2. Student/Instructor Study Group

The study group includes student and instructor cohorts from 2004-2015 for CHE 435/465 (Design II). From 2004-2015 the student cohort is the University of Alberta Chemical Engineering graduating class and includes both the co-op and regular program cohorts. From 2004 to 2009 the instructor cohort is the same. From 2010 to 2015 the instructional team increased from three to five instructors and the number of instructors per year varied. However the core instructor team was the same and most of the instructors had some involvement with the course during this period. The historical data includes: instructor interviews spanning 1966-2015 concerning teaching practices, former/current student interviews encompassing experiences from 1955-2015, Design II student final course marks and program entry marks from 2004-2015, student pre-post course skill perception survey data from 2015, student experience post course survey data, and student access to the learning management system for 2014-2015.

1.3. Measurement and Comparison of Student Performance

The grading procedures for the capstone course have changed over time. For example, while the final report grading is completed using the same criteria and mark allocation for all study years, the grading procedure has evolved from 2 instructors marking half the reports each with the highest and lowest being remarked for calibration (2004-2009) to a system where the majority of the reports are double marked independently. Following discussion with the instructional team, and possible review by a third instructor, a final mark is assigned. It is not known in advance which reports will be double marked and typically the marks agree within 1-5 points out of 80. This procedure is detailed in Appendix A. This evolution in grading practices means results from 2004-2009 are more comparable and results from 2010-2015 are more comparable from an evaluation perspective. Procedures used for 2014 and 2015 were identical with grading done by the same instructors, hence final grades are comparable between the traditional and blended classroom.

Measures of student performance include the quality of the final project report as evaluated in the course context against a marking rubric and report specification guidelines and criterion. These data are the basis for the 2004-2014 retrospective study of student cohort performance in the design course presented in Chapter 2, the 2004-2015 ecological and retrospective cohort studies, and the 2014-2015 comparative case study. Faculty and program admission aggregate performance data is examined to quantify program cohort bias as part of the ecological study. A pre and post blended course student skill perception comparison study based on indicators related to the Graduate Attribute Assessment, observed student behaviors, comparison of traditional lecture and blended cohorts with respect to handing in assignments, downloading software, timing of questions and types of questions asked was also performed. Each of these studies has the specific objective of comparing the traditional and blended delivery on student outcomes while accounting for the impact of confounding variables. Students in the 2015 cohort were monitored closely by examining student learning, performance and satisfaction for comparison with previous student performance to determine overall impact of moving to a blended learning environment. As student cohorts change from year to year, assessment of blended learning impacts on individual student needs is challenging. An ecological study was chosen to compare program effects on aggregate student performance under various pedagogical models implemented from 2004-2015. The retrospective cohort analysis attempts to further this by investigating program and model effects on individuals. Case study comparison methods are used to compare the 2014 and 2015 cohort LMS access and lecture delivery time. A case study was chosen to review student self assessed skill competency perceptions pre and post course for a portion of the 2015 cohort.

1.4. Terminology Conventions

Blended learning is defined as an instructional program thoughtfully fusing and connecting online learning for a portion of the student/instructor interaction and face-to-face (in class) learning for the balance so that the educational experience is enhanced. (Garrison & Vaughn, 2008)

The **Canadian Engineering Accreditation Board** or CEAB is the board established by Engineers Canada to accredit Canadian undergraduate engineering programs to ensure that they meet or exceed minimum educational standards acceptable for professional engineering registration in Canada. The CEAB is also responsible for auditing and assessing programs, at a minimum once every six years.

CEAB Graduate Attribute Assessment (GAA) is one of the measures used by the CEAB to evaluate engineering programs. The Graduate attributes consist of qualities under the following headings: a knowledge base for engineering, problem analysis, investigation, design, use of engineering tools, individual and team work, use of communication skills, professionalism, impact of engineering on society and the environment, ethics and equity, economics and project management, and life long learning. (CEAB, 2014)

The **Center for Teaching and Learning** or CTL at the University of Alberta is a central entity that supports the development of digital learning environments . . . "to create and sustain a vibrant and supportive learning environment that discovers, disseminates, and applies new knowledge through teaching and learning, research, creative activity, community involvement, and partnerships" (UofA Mission, 2015). CTL is a key partner in the Provost's Digital Learning Initiative (PDLI), which funded this project, and an essential resource for this project and others funded under the PDLI.

Criterion referenced assessment (CRA) is a performance measurement method where the criteria for obtaining a certain mark are set and provided to students prior to any teaching. The assessment of the final product is done according to the criteria. (Biggs, 2003) For the purpose of the design course, students may only attempt to produce a final report once.

A **Continual Improvement Process** (CIP) is defined, in this context, as a process demonstrating that capstone design course outcomes are being assessed and results applied to further the development and improvement of the course. Assessment includes student and instructor feedback on course effectiveness in the context of the CEAB graduate attributes. (CEAB, 2014; Hattie, 2009)

Course objectives are defined as instructional goals. These may be general, such as: *integrate all prior knowledge from the undergraduate curriculum…* or specific, such as: *Design process layouts, which reflect an appreciation for relevant fire and explosion codes, and standards for access and insurability*. Ideally, course objectives are mapped to CEAB Graduate Attribute Assessment criteria. A course objective typically has multiple learning objectives related to achieving a terminal goal and is used to develop curriculum content. (Biggs, 2003; Hattie, 2009; Sosniak, 1999)

Course plan is defined as a time-based strategy linking course objectives to learning objectives used to guide development of learning resources, activities, assignments and assessment. (Garrison & Vaughn, 2008)

Design I (CH E 464) refers to the first design course taken in term 7 of the undergraduate Chemical Engineering program. In the current format the first half of the course is lecture based and the second half comprises an industry sponsored design project. The course has a mid term and final exam. This is a face-to-face course with lecture, laboratory, and project components. (Pick and Rajendran, 2015)

Design II (CH E 435/465) is the Capstone Chemical Engineering Design Course taken in term 8. In the current format (2015) this course has an online learning based component, an in class active learning component and a major industry sponsored 13 week team design project to apply learning and further develop CEAB Graduate Attributes (GAs). (Jamieson and Shaw, 2015)

Learning objectives are defined as the ability of the student to perform a specified task under certain conditions and can be used as indicators or measurements of the development of individual students. An example: *After completing a PFD students will complete a P&ID for a single piece of simple equipment.* Bloom's taxonomy and or the SOLO taxonomy can be of assistance in writing course and learning objectives to target specific cognitive development (Airasian, 1999) and knowledge application levels (Biggs; 1996, 2003).

A **flipped classroom** is defined in this work, as a subset of blended learning where asynchronous online instruction is provided to students prior to in class time where active learning connected to online instruction is guided and facilitated by instructors (Watson, 2008). In the blended learning implementation for the capstone design course, post class asynchronous applications directed toward individual project completion were also included. It is noted that a classroom may be flipped and not blended.

Functional knowledge is based on the idea of performance understanding. It encompasses conditional knowledge subsets of declarative and procedural knowledge. Professional knowledge is functioning, specific and pragmatic. (Biggs, 2003)

Internship course model is the 2010 – 2015 course model where instructors assume the role of an Engineering supervisor or project manager. They meet with the same teams weekly to provide advice, monitor progress and understand individual contributions to the team. The course operates in a similar manner to an EPC office and students are treated as accountable interns in a work experience environment. Students are expected to monitor their progress and project schedule weekly.

Mentorship course model is the 2004 – 2009 course model where instructors assume the role of a mentor. They meet with teams weekly to provide advice, answer questions and discuss concerns while monitoring individual contributions to the team. Students completed projects and could ask for advice from either mentor as required.

Student cognitive task level is defined according to Bloom's taxonomy (Bloom, 1956) and discussed in Chapter 4. Learning objectives for the chemical engineering capstone design course tend to be concentrated at the top of the pyramid: analysis, synthesis, evaluation and creativity.

Student engagement is defined in the context of teaching a large technical class and employs active learning techniques as a basis for team activity development and accountability. (Jacobson, 2002)

Student intellectual development is defined as a qualitative observation and classification of students according to Perry's schema. (Perry, 1970) A modified version of the schema describes the student's worldview, view of the instructor's role and the student's role (Knefelkamp, 1979). These perspective categories are expanded and Perry's original nine stages are simplified to four: dualism, multiplicity, relativism and commitment as described in Chapter 4. It is recognized individual student intellectual development is complex and may vary between stages for various perspective categories and is not quantitatively measured in this work. Observational trends are applied.

Student learning is examined through instructor observations, conversations and student self-assessment. The student or instructor perception of the student's functional knowledge and the level of skill mastery perceived typically measure learning. Performance is not necessarily an equivalent measure of learning. The degree of student learning is dependent on student ability at the beginning of the course and the change during the course. "Learning is best conceived as a process and not in terms of outcomes" (Avis, Fisher, Thompson; 2010).

Student performance is defined as the final course grade and includes term work. Performance is a result of student ability to perform a set task meeting specific criterion by the end of the course. In the case of the CH E 435/465 final report, the performance assessment is a criterion referenced assessment (CRA) and can be found in Appendix A. The final report quality is a significant determinant of course performance. At times, student performance components are examined using text analytics, task completion relative to deadlines and work completion quality. Performance is typically measured by what students produced and when relative to deadlines.

Student programs options are co-op and regular. The regular program is the traditional method of educating engineers at the University of Alberta. This program of study includes a common first year, discipline selection after first year and three years of discipline specific study grouped into fall and winter terms with the summer term available for student obtained work experience. The co-op program includes all course elements and the first year experience of the regular program. In addition, twenty months of engineering related work experience supported by the University of Alberta Co-op Office start in second year. There are several patterns of academic and work terms offered. The co-op program takes an additional calendar year to complete. In this study, sub specialties, such as computer and process control, oil sands, etc., are lumped and examined as part of the co-op or regular groups.

Student satisfaction is defined as how much the student enjoyed the learning processes. It can include enjoyment with setting schedules, goals, activities, selecting teammates and accomplishments. Student satisfaction is typically measured using anonymous student comments and survey results.

A **traditional classroom** is defined in this work, as the in person lecture method of providing information to students in a classroom. In the case of the traditional implementation for the capstone design course, power point presentations were delivered in two consecutive one-hour time slots twice per week. Limited interaction with students was possible due to the large section (~120 students). An online component was present, but no in class restructuring had occurred.

1.5. Global Objectives of the Thesis

The over all objective of the Blended Learning Award, described in Chapter 3, is to improve student learning in chemical engineering design by implementing relevant aspects of globally identified best practices for teaching and performance evaluation. To this end, redesign of the capstone design course from a lecture based project course to a blended learning course with an asynchronous individual on line learning space and connected group face to face learning space flowing to team project applications was undertaken. Specific issues addressed in the blended course design include: the broad range of student learning needs, discussed in Chapter 4; adapting to and adopting valuable new technologies and teaching methods, discussed in Chapter 5; meeting CEAB requirements both from curriculum and assessment perspectives discussed in Chapter 4 and 5 respectively; engaging students in effective learning, discussed in Chapter 6.

The effectiveness of the first iteration of the redesigned course implemented in the Wi2015 pilot is measured by research questions outlined in Chapter 3. Specific research questions investigated in this thesis comprise elements of the overall research components of the Blended Learning Award. In particular, the impact of blended learning and teaching methods on chemical engineering capstone design student performance, including CEAB indicators, and student satisfaction is evaluated as the following:

- Does flipped learning lead to equivalent or better outcomes for Design II students?
- Is CEAB Graduate Attribute development demonstrated from data collected?
- Is student effort and quality of the final report equivalent or better for flipped learning students?
- Does a flipped learning structure produce equivalent or better academic performance?
- Is the co-op program a predictor or factor in student outcomes in design?
- Is the co-op program a predictor or factor for student results in a flipped structure?

In order to study these issues holistically, historical data related to student course performance, evolving baseline pedagogy, student instructor ratios, and student industrial experience (studied as co-op vs. regular program) are investigated to determine internal validity of the cohort comparisons especially sources of bias, history, and instrumentation (Campbell, 1966). Potential confounding factors impact the ability to discern the impacts of exposure to blended learning on student outcomes, student satisfaction, instructor perceptions and satisfaction.

Comparison of the traditional lecture format project course with the blended version is accomplished by first examining the complete historical graduating class cohorts final course performance during the study period. Next final performance is examined for co-op and regular program cohort natural groupings for each year of the study. The ecological study of the average cohort performance provides a basis for examining the impacts of evolving course pedagogy including the blended learning pilot and possible confounding factors. The next phase of the study using statistical process control to evaluate evolving pedagogy impacts on the *process of learning* as evidenced by the performance outcomes. Individual student performance is then examined to determine the possibility of grade prediction based on confounding factors. The results of these analyses prompted further examination of the cohorts in a retroactive study to quantify the impact of program selection vs. the pedagogical decision to design a blended course. This examination was completed using a post test only natural control group design.

Proof of student access is then examined as a case study using static group comparison of the Wi2014 and Wi2015 cohorts. Student satisfaction is assessed via a post course survey, and student perception of their skill level development in the CEAB Graduate Attributes was assessed using a pre-post test experimental set up.

Research on, creation and evaluation of learning elements during and following the first iteration of the flipped course; implementation of pedagogical tools to support course functions (team development); automation of data analysis; creation and implementation of surveys to evaluate the effectiveness of flipping, all comprise important subsidiary tasks. Chapter 7 discusses the basis for study selection and application and Chapter 8 the study results.

1.6. Thesis Outline

The starting point for this work is a University of Alberta peer reviewed Blended Learning pilot project, led by J. M. Shaw, and supported by the Centre for Teaching and Learning, and the Department of Chemical and Materials Engineering. The goal of the pilot program is to seed development/application of demonstrated best practices that support student learning by leveraging best on-line and in class teaching methods in diverse courses/undergraduate programs across campus. For this project, the focus is chemical engineering design course blended design, instruction and performance outcome evaluation. To provide context, the history of design instruction in Chemical Engineering at the University of Alberta is described in Chapter 2. The capstone design course began using an online LMS as a resource repository in 2004. The online component developed gradually as a go-to resource. The first blended learning objects were introduced during the winter 2014 term, to observe student acceptance and to provide online materials not covered in lectures. Informal positive student response to reducing in class lecture time and increasing in class time for project work and discussion encouraged further development. With the blended learning award (outlined in Chapter 3) and the assistance of CTL, an accelerated course redevelopment plan presented in Chapter 4, was researched, designed and implemented. Electronic data gathering, course development, and continual improvement tools needed to demonstrate CEAB accreditation and GAA requirements are described in Chapter 5. Creation, development and preliminary evaluation of blended learning objects using the Successive Approximation Method (SAM) to rapidly develop succedent prototypes for on line elements is discussed in Chapter 6. Instructor experiential learning in the development and implementation of learner objectives, integration of CEAB GAA, documentation needs and course planning of these teaching, learning and assessment prototypes ahead of the launch of the redeveloped course during the winter term 2015 are described using illustrative examples. A listing of learning objects prepared for the pilot is also provided. A discussion of evidence hierarchy and study design methods (Chapter 7) is followed by the study results (Chapter 8). Analysis of findings in the context of management and continual improvement of the design course including application of results and demonstration of the CEAB GAA (Chapter 9) is followed by a discussion of undergraduate program continuous improvement strategies for enhancing design student success and exploration of how CEAB performance based graduate attributes can be further developed earlier in the chemical engineering undergraduate program (Chapter 10). The conclusions from the first iteration of the blended redevelopment, using a flipped approach, of the capstone design course are presented in Chapter 11 along with recommendations for further improvements for the iteration 2016 of the course.

Summative reflections on the teaching and learning outcomes from this work are presented in Appendix B. The first, published as “Chemical Engineering Case Study” in Part II of The Flipped College Classroom: Conceptualized and Re-conceptualized, edited by Ross Perkins, Boise State University; Lucy Santos Green, Georgia Southern University; Jennifer R. Banas, Northeastern Illinois University; to appear as a book published by Springer, New York, focuses on lessons learned and the second, published as “The University of Alberta Chemical Engineering Design Course Goes Flipped” in the CEEA 2015 Conference Proceedings published online and archived on the Queens University library system at http://library.queensu.ca/ojs/index.php/PCEEA/issue/view/544, focuses on elements of course design and preliminary findings.

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2. University of Alberta Chemical Engineering Education Development

Changing cohorts, societal, professional, and pedagogical developments have led to course and curriculum design changes at the University of Alberta over time. Student cohorts have changed from a small mainly male Caucasian class with rural Alberta roots that graduated in 1955 to the large urban mixed gender, ethnically, culturally and linguistically diverse class that graduated in 2015. This shift reflects the enormous changes in Alberta over the intervening period. The numbers of Chemical Engineering graduates per year, shown in Figure 2.1, is expected to grow to 170 students in 2016 and to 200 students in 2018 (Durynek, 2015; Matthias, 2015). The design courses and the overall curriculum have adapted in response to these external pressures and the internal drive to provide the best education and best experience to students in preparation for sustainable careers in industry, design, research and business. Continual reflection and improvement has led the department on a path of applying current technological and pedagogical techniques to education for more than sixty years. Flipped learning is the latest in a long line of innovations intended to improve the Chemical Engineering educational experience and respond to the changing needs of student cohorts and societal needs more broadly. Brief biographies of instructors who contributed to the history of design education development at the University of Alberta can be found in Appendix C.

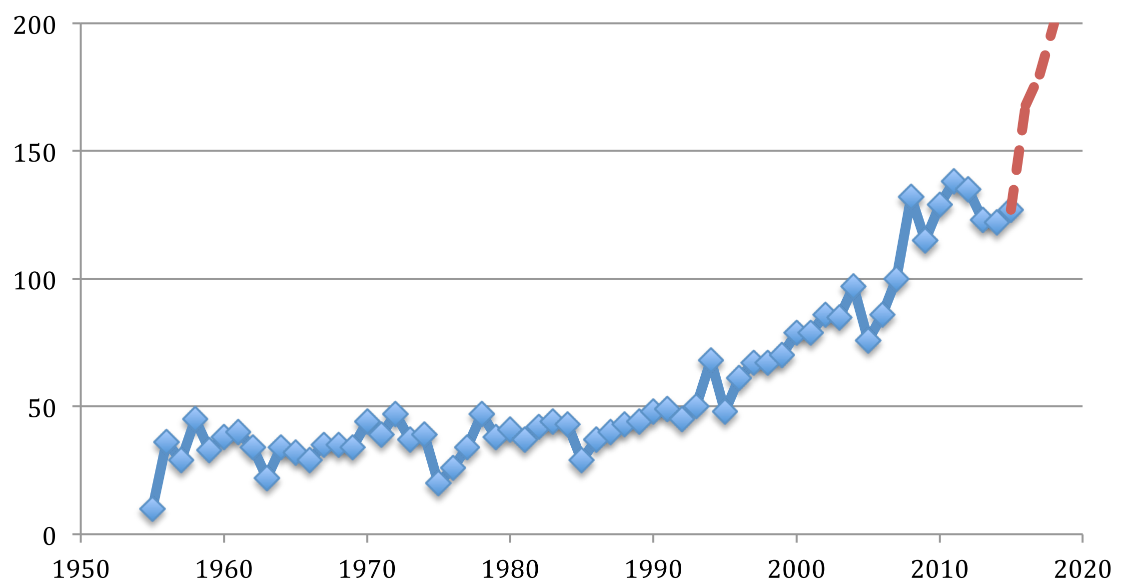

Figure 2.1. UofA Graduating Chemical Engineers 1955-2015 (Source: UofA Alumni Office) and Projected Graduates 2016-2018 (Source: Faculty of Engineering Admissions)

2.1. Design Course History

Development of the Chemical Engineering design course(s) at the University of Alberta came about as a result of the intersection of several key influences and contributors. The Department of Chemical

Engineering was founded in 1946 as part of the Faculty of Applied Science. The Faculty of Applied Science, established in 1913 was renamed the Faculty of Engineering in 1948.

This history was developed from personal and email interviews with selected former and current instructors, students, and administrators who shared their experiences, recollections and perspectives. These individuals include instructors closely involved with the University of Alberta Chemical Engineering design courses in the past and those who knew them. I am humbled by the commitment of the instructors to student transformation into practicing engineers and their long-term pursuit of the optimal strategy to achieve that transformation. I have been a part of this transformational experience as a student, as an instructor, as a researcher and as an educator. It is with gratitude that I acknowledge the contributors to this history, to students and instructors for their contributions to my own development, the development of the design course, and that of approximately 3500 Chemical Engineering Graduates. I also acknowledge those who have supported and continue to support the Chemical Engineering design courses by teaching foundational concepts of Chemical Engineering in ways that change who students are and the way they think.

2.2. 1955-1965

According to the 1955 University of Alberta Calendar, 4th year Chemical Engineering students had a choice: a Research Project, a Design Project, or a course on Industrial Chemistry. Dr. Alan Mather, who taught at the University of Alberta from 1967 to 2011, indicated that students thinking of graduate studies took the research project, some others took the design project, but most students took the industrial chemistry course. Dr. Fred Otto, a 1957 graduate who continued on to graduate studies and completed the research project, corroborates this. However, by 1959 all students had to take the design course then taught by Dr. Ivo Dalla Lana. The research project and the alternative chemistry course were no longer offered as options in the calendar. The 1959 version of the design course comprised groups of two students developing and completing different projects. Dr. Mather was one of the early participants of the design course. In the mid 1960's Dr. Don Quon, a 1944 graduate of the U of A, attended a workshop run by the Ford Foundation at the University of Michigan and returned to the University of Alberta promoting the ideas of inter departmental co-operation in engineering design education.

The Ford Foundation was established on January 15, 1936. Due to significant growth in the value of the foundation the 1949 Gaither Report recommended five key areas of support. **<u>Education in a Democracy</u>** was one of the areas proposed in the study. From that point forward the foundation has been supporting education:

…Activities to strengthen, expand and improve educational facilities and methods to enable individuals to more fully to realize their intellectual, civic, and spiritual potentialities; to promote greater equality of educational opportunity; and to conserve and increase knowledge and enrich our culture. (Page 81, Gaither Report, 1949)

In October 1960, the Ford Foundation gifted four US Universities with approximately $3 million in grants to support the development of engineering education: The North Carolina State College, which became North Carolina State University (NCSU) in 1962, The University of Florida, The Georgia Institute of Technology and the University of Texas (The Alcalde, 1960). The foundation also funded other projects during the 1960's such as the application of computers to engineering education and design education. These programs were funded at the University of Michigan and some promoted computer use in engineering under the direction of Professor Donald Katz (Hatcher, 1961). Although the Ford Foundation did not endow the University of Alberta, the pedagogical ideas from the University of Michigan found their way to the Chemical Engineering Department early on. Both Drs. Mather and Otto completed their PhDs at the University of Michigan studying with Dr. Katz and Dr. G. Parravano respectively. The University of Alberta design course continued to involve small student groups applying their knowledge to the design and evaluation of conceptual projects.

2.3. 1965-1970 Problem Based Learning and Design Foundations

Dr. Alan Mather, Dr. Reg Wood and Dr. Fred Otto recall this time frame well. In 1965 Dr. Jim T. Ryan was hired to teach the design course. He taught on his own for several years. In 1968 as a result of the promotion of interdepartmental cooperation in design, the Chemical Engineering Department decided to offer a three-course design sequence in 2nd, 3rd and 4th year. The second year course consisting of general design topics and was common to Chemical and Mechanical Engineering. Specific courses applicable to process design had not yet been taken, such as distillation, reactors and fluid mechanics so projects needed to be both general and simple. The 3rd year course was about equipment sizing and costing. The fourth year design course continued in a similar manner as the 1959 version with a unique open-ended design problem.

In 1966 Dr. Wood joined the department and was assigned CH E 365 "Industrial Stoichiometry". The second year design course had not been a success and was redeveloped into a materials and energy balance course, renamed CH E 365 "Process Analysis". Dr. Wood taught it for many years. By 1985, Dr. Wood was using Felder and Rousseau for teaching this course and he employed problem based learning and skill development in weekly seminars. Dr. Wood continued to use these methods to form the mass and energy balance foundation for the design course until he retired in 1997. Richard Felder from NCSU is a prolific writer on Chemical Engineering Education and problem based learning in the foundation of fundamental skill development. The 3rd and 4th year design courses remained the same for a number of years.

2.4. 1970-1980 Design Pre Requisites and Program Placement

By 1975 the design instruction continued as a third and a fourth year two-course sequence. The key instructors in the design courses continued to be Drs. Alan Mather, Ivo Dalla Lana, and Jim Ryan. Bill Pick studied design at the U of A in 1978. At that time the first design course was in 3rd year and had some lectures and a simple design project. In 1979 he took the fourth year design course and the course was entirely project based, with 19 (two-member) student teams. Projects were still unique and most would have been classified as open-ended complex problems. Mr. Pick's recollection of his design experience is:

"I took the CHE 464 equivalent in 1978 from Dr. Al Mather. The course was in third year. At that time, as we do today, the course was split into 2 parts: first half lectures/assignments, second half projects. Projects were done in teams of 2, and processes were taken from the literature of 'standard' processes. Ours was a sulphuric acid plant. The heart and soul of our research was Stanford Research Institute (SRI) Process Economics Program, available in Cameron Library. There were 38 students in my class, so there were about 19 projects in Design 1 that year. I marked assignments in Design I equivalent in ~ 1983 under Dr. Ivo Dalla Lana. I took Design II (the CHE 465 equivalent) in 1979 from Jim Ryan. At that time, there was no formal instruction. Projects were from Dr. Ryan and other academics, often with very little or no industrial connection. Many could be classified as "wild and woolly". Mine was district heating of a town, using waste heat from a tailings outflow. The project was based on the Shell mine and upgrader which ultimately became Albian." (Pick, 2015)

Extensive co-op placements from eastern universities in Alberta increased competition for student job opportunities. Hence in 1979, the Dean of Engineering, Dr. P.F. Adams, requested a formal proposal be developed for an optional Co-op program in Engineering at the University of Alberta. The Government of Alberta approved the proposal and during the summer of 1981 the first group of mechanical co-op students started a summer work term. The program was expanded to Chemical Engineering in 1983.

2.5. 1980-1990 Small Classes Close Knit Communities

Over this decade Drs. Ryan and Mather continued to teach the design courses in the department. Dr. Murray Gray joined the department in 1983 and he was part of the teaching team in Design II during 1984 and 1985. Dr. Fred Seyer returned to the Department in 1984 after a sabbatical at Syncrude, and joined Dr. Ryan to teach design until the late 80's. I studied design with Drs. Ryan and Seyer during the 1987 – 1988 academic year. Typically students were members of self-selected groups of 2 or 3. Each group worked on an open-ended project that had relevance to industry but the projects were not specific to or supported by an industry sponsor. Feed compositions and product specifications were developed from the literature or research data. At times this posed difficulties for design considerations. My recollection is:

"*My experience as a student entailed two design courses both taught in fourth year (term 7 & 8) similar to the way they are now, however, the teaching for both was largely inductive, individualized and project based. Sizing and costing were developed in Design I. The design projects were both full term projects, typically groups of 2 for Design I and groups of 3 for Design II, however the first project was typically better known than the second project. Use of Hysim to model the process had been recently introduced and the process simulator was not yet commonly used in industry. Our projects were a carbon dioxide pipeline design and direct coking of oil sands materials (sponsored by Dr. Gray) respectively. Teams were self selected and the class size was 40. I thrived in these classes and developed life long learning and problem solving skills that served me throughout my career. Ryan and Seyer had a rule to limit student demands on their time: "If you don't come to class don't come to our office with questions." I was in class and I asked questions - that just in time "back of the envelope" teaching was sometimes really needed to figure something out. I would describe the experience in the design course as transitional and transformational from student to engineer – but not as transformational as working in operations.* "

The methods applied at this time were in keeping with problem based learning (PBL), inductive teaching and open-ended problem classrooms. They were progressive methods that had their roots at the University of Michigan and North Carolina State University (NCSU) brought back to the University of Alberta by engineering education pioneers in the department and implemented in design and material balance courses. A design problem was given to the students and "just in time" teaching was applied. Only the final report was graded, and no formal interim reporting was required at this time. As a result some teams did much of their work near the end of the term.

This approach has a great deal of merit. However, students exploring open-ended problems don't know what it is they need to learn. The learning process can be research intensive due to unknowns. The amount of research required, possibility and plausibility of solutions to some open-ended problems can be more than what the instructor or the student thought. This can cause a great deal of frustration and time wasting - which could be argued is just like solving “wicked” problems in real life. (Conklin, 2007) Some students may have prior knowledge or experiences or seek out previous examples of what is required to bridge the gap between linear problem solving methods and iterative approaches required for more complex open-ended design problems. Some students have developed what Dewey labels “reflective thinking” skills and Bloom classifies as “intellectual abilities and skills” (Bloom, 1956) to take them from abstraction to concrete solutions rapidly and iteratively while other students may fixate on the first solution developed and attempt to use a linear problem solving method. (Moraes, 2015) This may be one of the key differences between the students who achieve higher grades and those who do not, as teaching thinking skills and design methods was not yet a formal part of the engineering curriculum. It was thought to be an *intuitive* skill.

During the 1980’s projects often came from process research and sometimes from industrial problems. The graduating classes comprised 30 to 50 students. The first cohort of chemical engineering co-op students graduated in 1986 along with a cohort of regular stream students. At this time there was not a significant difference in the co-op outlook and the regular program outlook as students in both programs had similar opportunities. Co-op students and regular students submitted applications to companies who posted jobs with the Career and Placement Services then located in the Student Union Building, of which the Engineering Employment Centre was a part. As the co-op program gained popularity, competition for engineering placements increased.

Another significant development at the close of this decade was the Chemical Engineering Department received a gift to establish a Stollery Executive in Residence program. Dr. Sieg Wanke explained the purpose of the program was to assist with developing real world problems and to provide real world data for design projects. The program was intended to be similar to one in the Faculty of Business. Over time, this program evolved into the industry project sponsor program for design projects in place at present where advisors assist in developing initial project outlines and supply the input and output stream requirements for them.

2.6. 1990-2000 Industry Partners and Engineering Growth

Fred Otto, Dean of Engineering from 1985 - 1994, was a member of the Canadian Engineering Accreditation Board (CEAB) from 1990-98 and chair from 1996-97. During this period the description of engineering design was revised and a requirement for a significant capstone design experience based on the knowledge and skills acquired in prior course work that gave students exposure to teamwork was mandated. The University of Alberta Chemical Engineering Program may have been the first to meet this criterion. In 1994 Dr. David Lynch became the Dean of the Faculty of Engineering and a period of student and faculty growth started. In 1996, Dr. Lynch became a member of the CEAB.

Bill Pick became involved with CHE 465 on a casual basis to assist students with their projects during this period. In 1991, as the first "Stollery Executive in Residence", he gave lectures in both Design I and Design II, and supported projects. This arrangement was presented at the 1994 ASEE conference as paper 1654. A copy of this work is included in Appendix C. Practicing engineers from various companies started to be a part of the undergraduate chemical engineering design program as it grew and developed. Eventually most CHE 465 projects had industry sponsors. A former student during this period, Trevor Hawkins recalls:

"About half-way through the term we were given a list of potential projects to select from. We formed teams of 2-3; we chose our own partners. We were encouraged to contact industry sponsors for our projects. I found our sponsors to be extremely helpful describing the objectives of the project as well as constraints, and they did a good job of leaving the problem solving to us. This was among my favourite courses. The content was practical, and I could see a definite use for the information Dr. Mather provided." (Hawkins, 2015)

As enrolment increased the student design group size increased from 2 or 3 to 4 students working on one design project. It was noted at this time that the student to instructor ratio was key to providing adequate support to the student teams. The course continued to be taught as a single section and group size was increased to limit the number of projects required.

Drs. Alan Mather and Murray Gray taught Design I between 1990 and 1994. Dr. Gray recalls the collaborative nature of coordinating and teaching the design courses at the University of Alberta and the impact of the pedagogical choice of maintaining two design courses:

"During the 1990s the first design course was offered twice each year, by me (Gray) one term and by Alan Mather in the other. The basic structure of the course was set by Mather, and the positive feedback from the students encouraged us to keep the same approach of a series of lectures on design to link the fundamentals to sizing and costing of equipment, then a group design project."

"The success of the course is in pushing the students to apply their knowledge to real problems, and to work as a team on a real project. The Alberta approach differs from other universities by giving students two distinct design experiences, and by giving major feedback after a brief initial project. While the two-

course approach was required by the co-op program, it has benefits in giving the students early feedback and assessment on a major group project."

From 1990 onward student experiences in the co-op and regular programs began to diverge. The co-op office took on a larger role in assisting the growing numbers of co-op students with placements. This was also true at other Canadian universities, and fewer industrial experiences were available for regular program students. In 1996, a summer co-op academic term and a Calgary-based co-op coordinator were added as the program grew. By the end of the 1990s approximately half of the 80-100 chemical engineering graduates were co-op students. Increasing enrolment put pressure on the design course format and student experience was impacted. Jeff Ceccano, a 1999 Chemical Engineering Co-op graduate, comments:

"Technically design really wasn't a taught class, as I remember it, we had time available to talk with 2-3 professors and industry representatives were scheduled for specific weeks during design class time, you could choose to talk with them or not. My co-op term at Colt Engineering was where I learned engineering design. We typically worked cooperatively and collaboratively within the team. Two of our team members had direct ties back to EPC offices, two had strong operational experience and we could leverage this experience more than that of the representatives." (Ceccano, 2015)

2.7. 2000-2009 Increased Enrolment and Course Transition

By the 2000's the class size had grown to more than 80 students and a more structured learning environment in the design courses gradually replaced the small-class tight-knit informality of smaller classes. The co-op program was fully developed and international students were becoming a significant part of the fabric of the department. The lecture role of the Executive in Residence diminished and the role evolved to that of a project sponsor after 2000. Industry ties became well established; open-ended projects with real world connections were the standard, teaching teams were established for Design I and II, and the transition from the pioneers to the next generation of instructors began.

Dr. Murray Gray returned to teaching Design I in 1999 and continued to 2010. Dr. Mather continued to teach design until 2011. Dr. Suzanne Kresta began teaching CHE 464 in 2002 joining Dr. Gray and then continuing on her own. In 2001, Dr. John M Shaw joined the department. Dr. Jim Ryan officially retired in 1995, but continued to teach the design course. Drs. Ryan and Shaw co-taught CHE 465 during 2002 and 2003 and Dr. Shaw has been responsible for the course since 2003. Shaw, Gray and Kresta began tying both courses more directly to industry. Gray's comments reveal the impact of teaching team collaboration and industry partners on student development and learning:

"The course was always structured through consultation between the instructors because it is offered twice each year, and it leads into the senior design course. For me the highlights were getting active student-industry interaction. When it worked, the students caught fire and did some amazing work. When it failed, my role was to support the students and ensure that they had a feasible assignment for the course."(Gray, 2015)

The students who struggled with completing their design projects appeared to be procrastinating and leaving it to the end of the term. Kresta and Shaw both considered course structure changes to help students get a better start on their project and began adding milestone assignments. Kresta comments:

"In 2002 data based problem solving techniques were again being applied to Design I, but this time with a more formalized approach to help students to transition from weekly problem sets to larger more open ended projects. The problem of some students putting off their project work until the end of the term was being actively addressed. Team building and assessment were being actively addressed and integrated into Design I and the problem launch and development was broken down into a step by step process." (Kresta, 2015)

Similar changes were effected independently in Design II and project milestones were added to the course structure. Processes were tested and improved based on student results and feedback.

Dr. David Lynch continued as the Dean of Engineering and a member of the CEAB (1996-2007). He served as the chair of the CEAB from 2003-2005. The goals of the CEAB are described in the Accreditation Criteria and Procedures document (2004). Ensuring engineering programs meet minimum standards for registration is the first goal and the second is to ensure that the quality and relevance of engineering education … continuously improve[s]. This continues to be true in the 2014 CEAB Accreditation and Procedures Document.

This formalization of the continuous improvement process as a goal of the CEAB has had impacts on engineering programs, students and instructors creating a need for ongoing course evaluation and redesign. Continuous improvement coupled with additional expectations that engineering programs develop communication skills along with a deeper understanding of the environmental, cultural, economic and social impacts of engineering on society, and the concept of sustainable development have impacted curriculum development and delivery. During this period design courses started to become a key measure for CEAB accreditation because of their summative academic, project and team components. Combined with the added pressures of student growth, the challenges and complexity of designing and instructing these courses began to increase.

In CHE 435/465, the move to increase industry ties accelerated with the addition of Jim Hutton as an instructor in 2004. Hutton was among the founders of the Colt and CoSyn engineering firms and a wonderful mentor and colleague. The role of Industrial advisors, in particular, was formalized during this period. Shaw and Hutton met with industrial advisors regularly. They helped frame projects, were consulted by student teams informally as projects progressed, and met with students three times during the term formally to assess progress. Weekly update meetings and interim written reports were instituted to even out student workloads and to more closely simulate real working environments. Shaw and Hutton also made the link between course performance and first professional placements clear. The impact of this approach is highlighted in Shaw's comments:

"Students began to be hired to work post graduation on the projects they'd completed during the course. Students valued the career development and mentorship approach, and both Jim Hutton and I received student led awards for our efforts. Len Church, Frank Vagi, Bill Pick and Marnie Jamieson all became industrial advisors during this period." (Shaw, 2015)

Shaw and Hutton engaged in continuous improvement and development, an ongoing feature of the design course instructional team philosophy. Following each iteration of the course, elements were improved while keeping the focus on mentorship and career development. The Blackboard LMS introduced an online component to the course structure in 2004. It was used primarily to give students access to resources whenever or wherever they needed them for project development. By 2005 the co-op class was larger than the regular program class and a separate Engineering Employment Center was opened. The co-op program was actively identifying placements. According to Dr. Ken Porteous, quoted in a 2006 Alumni article celebrating the twenty fifth anniversary of the co-op program:

"We always figure that we need at least two vacancies per available student to guarantee everyone a job in any given recruitment period. This reflects things like availability in specific disciplines, student preferences, and positions being offered at more than one school." (Strembiski, 2006)

From the inception of the co-op program co-op work term placement success has been over 90% as shown in Figure 2.2. Unfortunately data for regular program placements are not available for comparative analysis. The regular program has been retained at the University of Alberta to provide students with a choice in the amount of time spent in their program prior to graduation. Students intending to take graduate studies might prefer the regular traditional program to the co-op program. Also, international students and students transferring into engineering at the second-year level are not normally eligible for the co-op program.

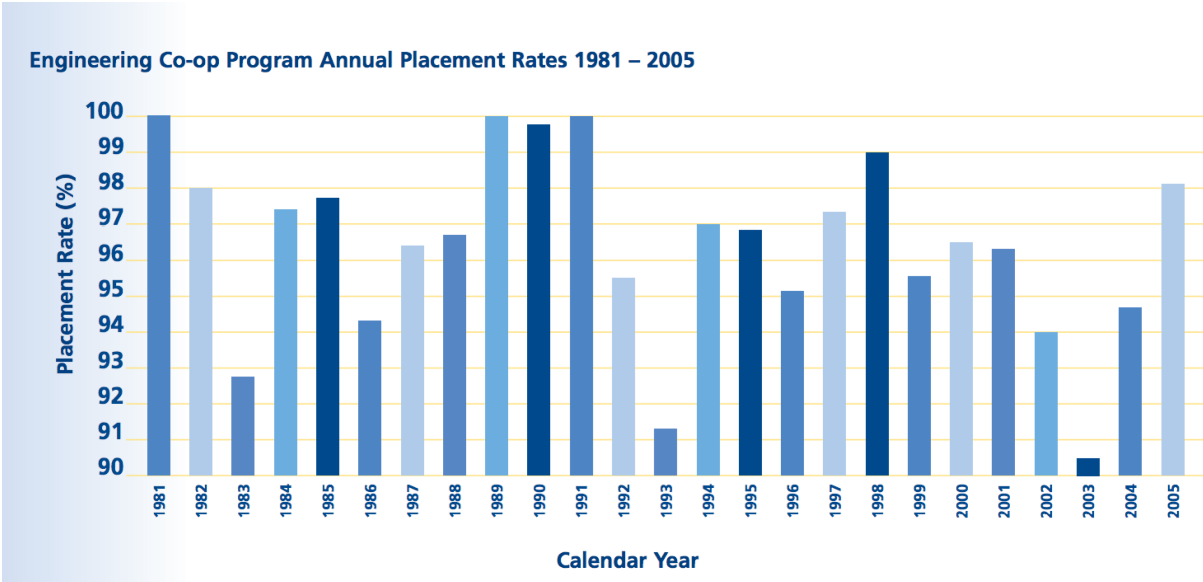

Figure 2.2. Co-op Placement Rates (source: Alumni Magazine winter 2006)

This choice between co-op and regular programs became superficial once co-op program admission became competitive based on first year engineering course performance. Students realized that the likelihood of engineering employment before and after graduation was higher for co-op students. Co-op students had advantages of more contacts and work experience in industry than regular program students. The capstone design instructors also began to notice a fluctuating grade performance gap between the regular and co-op program students during this period. This final grade gap, shown in Figure 2.3, had become large in 2008, when the class had grown again, to over 120 students. At the time this was attributed to an additional year of maturity and additional experience possessed by the co-op cohort and the provision of additional supports and resources for regular students became a priority. In retrospect, this large gap also coincided with a peak in the student to instructor ratio, Figure 2.4, which offers an alternate explanation for the grade gap observed in 2008, and raises questions such as what is the maximum number of students/projects that can be mentored effectively by one instructor in design courses that make use of unique projects? This question is examined further in Chapter 9. Clearly, with enrolment pressure, student to instructor ratio, the number of projects managed per instructor, and the importance of supplemental learning materials particularly for regular students are readily identified as areas of interest and study.

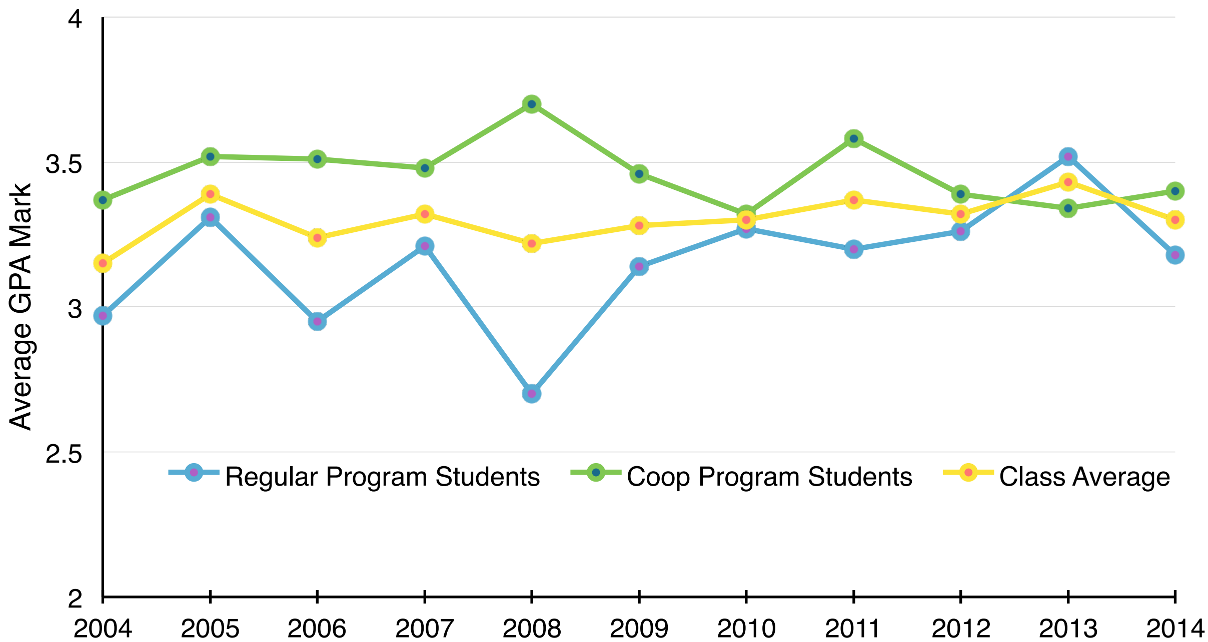

Figure 2.3 Class average combined and by program stream 2004 - 2014

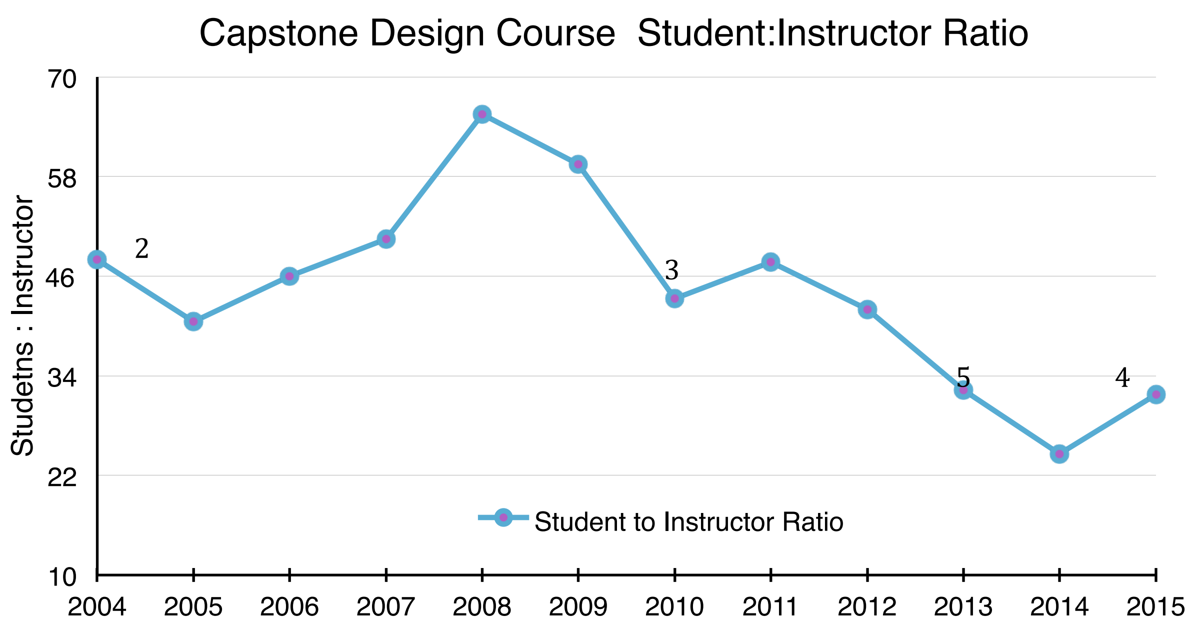

Figure 2.4. Student to Instructor Ratio (number of instructors labelled)

2.8. 2010 - 2014 Team Teaching and Team Learning

Jim Hutton retired following delivery of the 2009 course. A succession and teaching team expansion plan, and a mandate to provide additional supports for regular students were put into effect for 2010. At this point, the teaching teams for both CHE 464 and CHE 435/465 asked the question:

"How can we better support students in the design course, enhance their learning, help them transition to engineers in training, and continue to demonstrate CEAB requirements?" (Jamieson, Shaw, Pick)

For 2010, Len Church and I joined the teaching team led by John Shaw and the course instruction model shifted from a project based teaching environment with industry support to a working internship environment based on the work structure of a design office. John Shaw took a sabbatical (2012) and Frank Vagi (winter 2012) and then Bill Pick (winter 2013) also joined the teaching team. This helped control the student to instructor ratio, as the class size rose to 120-140 students. Each advisor typically worked with 5-8 teams and spent at least 30 minutes with each team per week reviewing progress and concerns. All of the instructors were accessible by email and in class to all students. Some of the instructors kept additional "office hours" by sitting in the atrium at one of the tables before class on Tuesdays and Thursdays. Students dropped by to chat and ask questions. During this period, student teams choose a project that had been solicited from industry and developed the project with ongoing input from industrial advisors in addition to specific feedback from them at three scheduled meetings, as during the prior period. The teaching team implemented weekly project meetings with teams and began developing on line materials to help students develop their teams, integrate their technical skills, track their tasks and time spent, and manage their projects. These materials provided scaffolding to support team, technical and project management skill development.

Kresta and Shaw previously noted teams needed milestone assignments to support progress. Jamieson and Church noted students needed engineering office tools and supports to improve the quality of their projects. Typically designs are not developed from first principles. More usually they are developed from an integration of research, specifications, standards, codes client expectations and field experience. Typically designs are not developed by individuals but rather by teams. Teams, in industry are typically brought together with processes, individual development plans, team goals and key result evaluations within a management structure. Students are often lacking in this background and may require support (Trivett, 2015), although co-op students have a distinct advantage in developing an awareness of the importance of this background prior to the capstone course.

Students are well adapted to the linear simple scientific method of thinking but an ability to shift from divergent to convergent thinking in an iterative design and problem solving process is still developing. Design requires iterative, lateral and reflective thinking processes supported by a team structure. Teaching materials and tutorials supporting students who:

- are unsure how to go about getting started;
- get stuck on a single idea or solution;
- are unable to generate further solutions to explore;
- are unsure of where to find helpful information;
- have difficulty in generating criteria to evaluate a solution;
- have difficulty in breaking down the task and distributing work;
- are unsure of the design process;
- think that the process is linear;
- have difficulty managing conflict in their teams;

were put in place to provide students with tools and structures to further their ability to move from a linear and individual to an iterative and collaborative process for problem solving. Figure 2.5 illustrates the process of a real designer toward a solution of a design task vs. the linear "waterfall" approach familiar to students (Conklin, 2007).

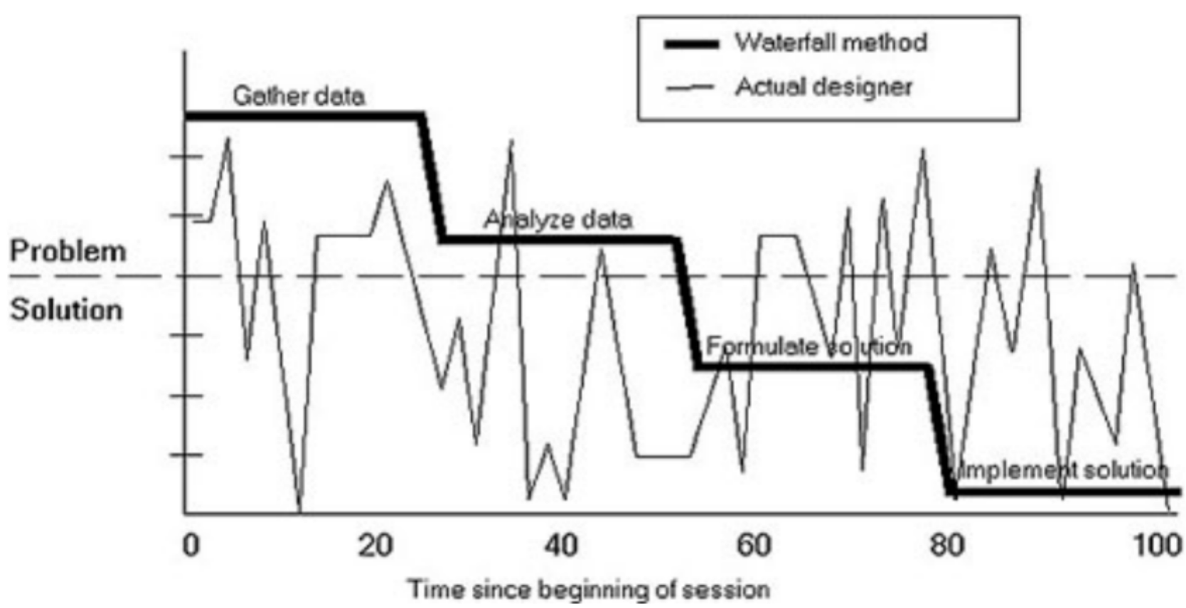

Figure 2.5. Design process of an actual designer vs. the linear waterfall process.

During this period, CH E 464 was still being team taught by Suzanne Kresta (2002-2013), Murray Gray (1999-2010) and Arno de Klerk (2009-2012). In June 2012, William Pick was appointed as the William Magee Chair in Process Design and joined the design teaching team. Design I continued to offer lectures, problem sets, mid term and final exam assessments in addition to a short design project to provide students with a transition from weekly assignments, to open ended problems (PBL), then more complex open ended project based learning. Dr. De Klerk observed the following student struggles:

"Without multicomponent separation being a prerequisite, it was very difficult to explain distillation, distillation sizing and costing, reactor design is overwhelming and the open-endedness of the course was disconcerting for many. Advance preparation of students earlier in the program may be needed."
(De Klerk, 2015)

It was clear that additional support and improvements could still be made to enhance learning from an overall program perspective and a course design perspective. The questions of *"What do students need to succeed in design?"* and *"Do they have it?"* were now being asked and actively investigated. Solutions were proposed, implemented, and evaluated based on student performance and feedback from both students and instructors.

Peer assessment was done using the teamwork rubric developed by the CATME group (Loughry, 2007; Ohland, 2012) and a "Team Play" handout was developed by Dr. Kresta and included in Appendix C. Team project launch was started with a scoping assignment to break down the steps for students. These tools reduced the number of students who delayed their project start until near the due date to zero. Ongoing formative deadlines for Design II had a similar impact after meetings with industrial advisors were implemented in 2004.

Until 2013 course development in Design I and II was done somewhat independently. However, instructors in both courses were working to improve their courses and develop team, project, research, and design skills in students using real world applications, problems and projects. The scholarship of teaching and program design came into focus when Jamieson and Pick began teaching on both teams in 2013. Dr. Arvind Rajendran joined the Design I teaching team in Fall 2013 and brought further support to application of active learning principles to problem solving and design:

"It is my strong belief that each student has the potential to achieve great things, not necessarily in engineering. This makes me respect their intelligence and treat them as fine individuals. My role as a teacher is to emphasize the mastery of fundamentals; to impart a rigorous approach to problem solving;

and to encourage them to ask the right questions at the right time. My courses are built on a strong foundation in chemical engineering fundamentals and demonstrate a logical application of these principles to solve practical problems. I encourage active learning in my lectures and as a result they are filled with questions and discussions." (Rajendran, 2015)

As with prior periods, student teams that are the most successful in both courses are the ones that are able to develop their teamwork skills, incorporate their learning from previous courses and apply higher levels of learning to their project work. Team teaching and weekly student team contact with an instructor had become key features of Design II during this period. The focus of improvement in this period was scaffolding improvements for: team selection and development, resource development to support projects, project and scope management, project evaluation techniques, and developing project execution strategies. The instructors' project management role allowed closer monitoring of work in progress, helped make scope adjustments in a timely manner, and helped to refocus the direction of design teams moving tangentially or stuck. Pick and Rajendaran adopted weekly meetings with design teams and further refined and improved Design I. Significant collaboration between the instructional teams became the norm as instructor experience with both courses increased. In 2014, Doug Colborne, an industry advisor from Design II joined the Design I teaching team. In addition Pick began the review of student preparation and where earlier design experiences might fit into the curriculum.

2.9. Historical Data Analysis

Analysis of the historical data concentrates on the 2004-2014 period. The instructors for the design courses during this time frame were available for interviews, student average GPA at program admission are available, and Design II is one of the few courses both co-op and regular program students take together making simultaneous observation of impacts on the two cohorts feasible. Changes in thinking about design team interactions, project management skills and their impacts on the final product were moving to center stage at the close of this period along with the integration of the engineering education experience. Changing expectations for accreditation and the purpose of accreditation to "reflect the need for the engineer to be adaptive, creative, resourceful and responsive to changes in society, technology and career demands" (CEAB section 2.1.3, 2004) placed pressure on engineering programs to support the formation of well rounded graduates who meet and can demonstrate these expectations. Developing a response and a plan to meet these changes became a priority and new questions were being asked. By 2008 the CEAB had developed a list of Graduate Attributes, as a measure to evaluate engineering programs. Engineering programs were going to be measured by the quality of the graduates they produced. A key question asked by Dr. Fraser Forbes, the department chair at the time, was:

"How can we teach to better support our students when they get to our design courses? And how can we demonstrate that we are meeting the new criteria?" (Forbes, 2011)

The importance of Engineering Education as a discipline began to be recognized, and measurement of graduate attributes was starting to capture the attention of many. The education *process* and the quality of the *products* of the process were going to being studied and evaluated with key result areas in mind.

As shown in Figure 2.3, the gap between regular and co-op program students closed in 2010. However with the same instructors and program the gap re-opened in 2011. The main change was the student to instructor ratio (Figure 2.4). It increased from 43 to 48. The average for co-op program entry students tended to be slightly higher for the years the gap was the widest as shown in Figure 2.6. As competition for the student engineering summer and work term positions increased, regular program students were often seen as less desirable by employers and as a consequence the co-op experience with real world problem solving during work terms was giving them an advantage in the capstone design course. Was a relatively consistent gap at the entry into the programs at second year being magnified by the differences in the quality of internship experiences available to students in both programs? Lower student instructor ratios seemed to help close the gap, but is that the only solution?

More effective teams, teams with better tools, developing clear project scopes, roles and timelines with formative milestones became the cornerstone of the chemical engineering design experience with significant effort being devoted by instructors to accomplish this during the first three weeks of term for Design II and early in the project for Design I. The development and improvement of pedagogical tools, testing various methods of teaching and communicating this to students has been key to the design courses since inception. Appropriate student to instructor ratios and continuous improvements are key features of the University of Alberta Chemical Engineering culture. Student instructor ratio between 25:1 and 30:1 were shown to be effective in first year team work at the University of Waterloo, indicating team and instructor interaction have an optimal level (Trivett, 2015). Figure 2.6 reflects the grade gap reduction resulting from post 2010 continual improvement efforts and close control of the student instructor ratio supported by the then department chair Dr. Fraser Forbes.

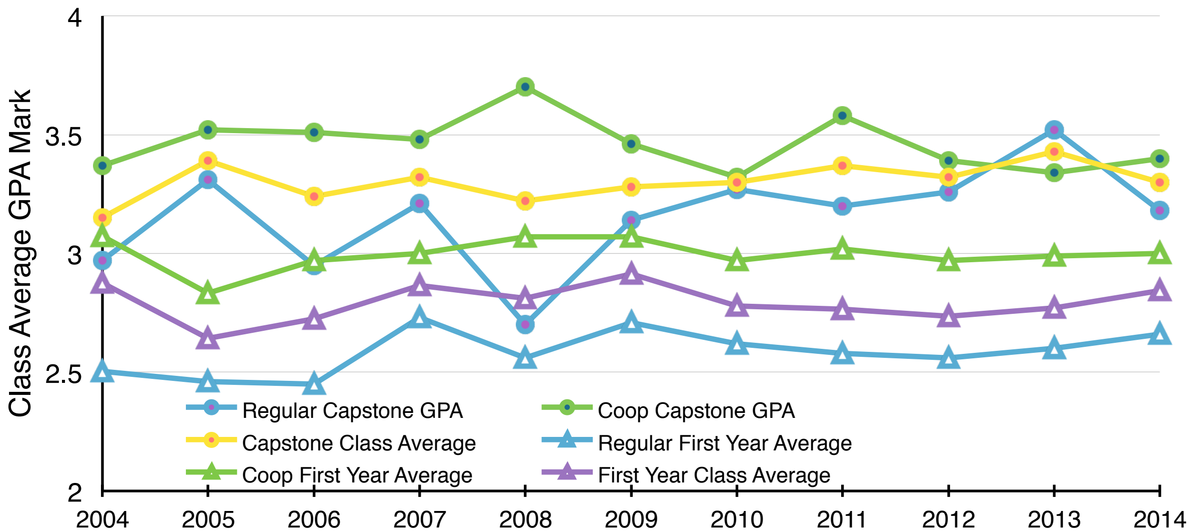

Figure 2.6. Comparison of Coop and Regular Program Entry Marks with Capstone

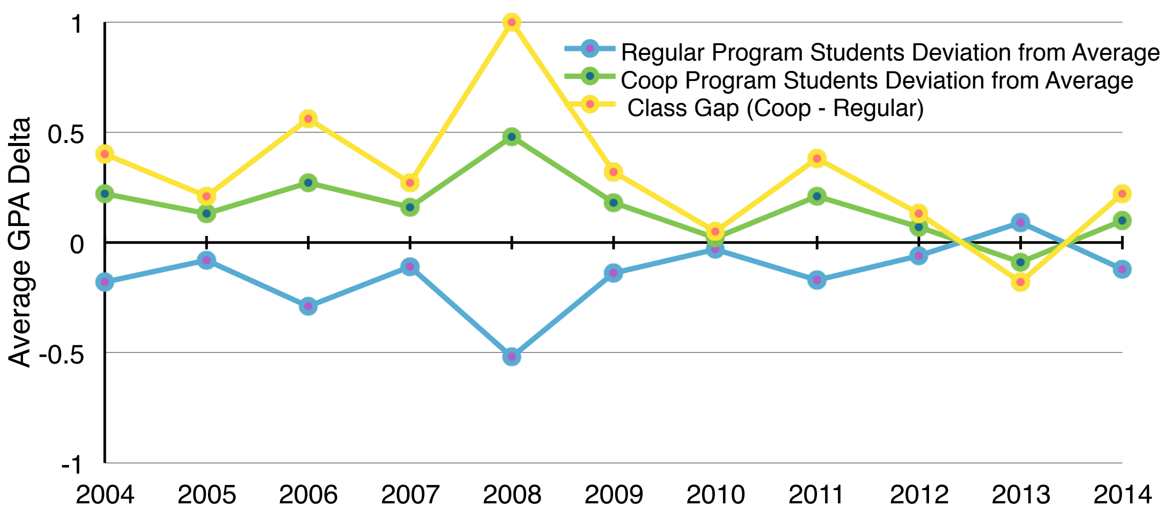

Figure 2.7. Decreasing the Coop - Regular Program Gap 2010-2015

An additional benefit of maintaining the student to instructor ratio between 30-40 is more consistent assessment of the student final reports. Available marking time is consistently bounded by the final report due date (end of term) and the mark submission deadlines. Higher student to instructor ratios reduces the ability of instructors to double mark and discuss final reports. Since 2010 a grading system had evolved in the design courses where the majority of final reports in the design courses are independently double marked and subsequently all instructors discuss grades. Figure 2.8 shows the grade distribution for the capstone design course for 2010 - 2014 course iterations. The cumulative effect of course improvements from 2010 (ongoing teaching and learning improvements, increased instructor time per team) largely eliminated low grades, defined as C or lower, in Design II.

According to the 2014 CEAB Accreditation Criteria and Procedures:

"The institution must demonstrate that the graduates of a program possess the attributes under the following headings. The attributes will be interpreted in the context of candidates at the time of graduation." (CEAB, 2014)

The evaluation of an engineering program based on the demonstration graduates possess specified attributes recognizes that engineering education is a process aimed at producing a graduate product expected by society. It suggests that the process can be designed, modified, and adjusted to produce a certain graduate product and that product can be measured in a variety of ways. Requiring the accredited institution to demonstrate a graduate possess the described attributes shifts the focus from program *content* to program *efficacy*. Much in the way that evaluation of product quality shifts the focus from the type of process to the efficiency and efficacy of the process to produce what is desired. The process can be controlled and by implication, *expected to be controlled and redesigned* in a manner of continuous improvement. The measurement of the CEAB graduate attributes for accreditation visits and measuring the success of the engineering program in producing the type and quality of graduates that society expects has become a key element in program and course design and change. In 2013 a report on Student Attributes by a committee co chaired by Steven Dew to the University of Alberta Committee on Learning Environment (CLE) defined general student attributes in the context of the University of Alberta learning environment:

"Student attributes (used interchangeably with graduate attributes in this document) generally describe the qualities, values and dispositions that students have developed by the time they have completed their university degree program. While not dissociated from disciplinary knowledge, they are fostered in each student regardless of field of study. Student attributes are broader than (but include) skills or technical competencies and are integrated throughout a higher education experience." (Dew, 2013)

According to Dew, the integration of student attributes throughout the higher education experience requires:

"Significant comprehension and proper development of attributes depend critically on the ***explicit integration of attributes into the university experience****. Once chosen, student attributes require widespread communication – through instructors, student leaders and administrators – and* ***support for curriculum updates and instructional incorporation in order to permeate the university experience****. Leaving student attributes as an implicit directive has been found to be ineffective."* (Dew, 2013 emphasis mine)

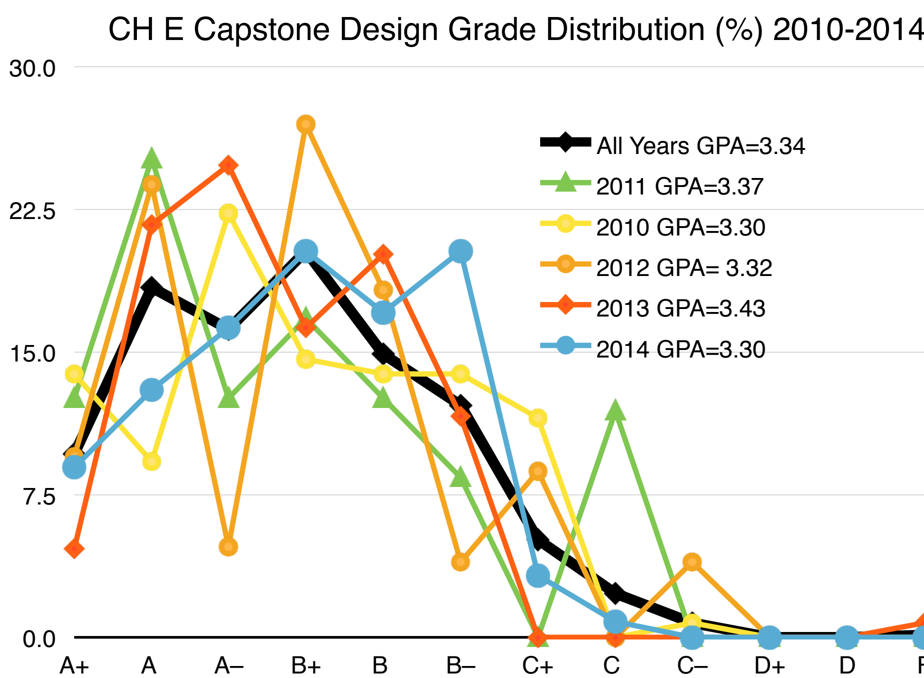

Figure 2.8. Final Grade Distribution and Class Average GPA 2013 - 2014

While Dew's report focuses on developing University of Alberta Student Attributes it recognizes the necessity of engineering programs to deliver the graduates attributes specified by the CEAB. Moving forward, consideration of how to measure the attributes and attribute and skill development in the chemical engineering capstone design course provides an additional incentive and adds an additional layer of complexity to this study.

2.10. Summary and Moving Forward

Chemical Engineering Design instructors at the University of Alberta have had a history of adopting best practices for instruction both reactively and proactively for more than 60 years.

Recent increases in enrolment and changes in the nature of the student cohorts demonstrated the need to limit student to instructor ratios and to provide supports to students for rapid start up teams, maximizing time spent on design and minimizing time "wasted" being stuck in team issues, design fixation, and poor planning decisions. With these changes, more homogenous student cohorts, measured by mean performance and a narrowing of the marks distribution were created during the 2010-2014 period from what had become clearly separate co-op and regular student populations.

During 2013, the teaching team learned that the class size would increase to 170 students for 2016 and current projections indicate further growth to over 200 students for 2018. Figure 2.1 places this additional growth into a historical perspective. Managing and maintaining the quality and intimacy of the design experience in light of significant enrolment growth presents a major challenge. Meeting the more stringent CEAB mandated criteria, implemented in 2014, for the measurement and demonstration of attainment of Graduate Attributes (listed in Appendix D) presents a second major challenge moving forward.

The CH E 435/465 teaching team had already adopted a web-based strategy in light of the steadily increasing class size and saw the benefits of enhancing this strategy given the two principal challenges of managing enrollment and maintaining quality. By the Fall of 2013 Shaw and Jamieson began detailed planning for a comprehensive redevelopment of the course, that would ensure the teaching team would continue to have adequate time and resources to meet with student teams weekly to focus on mentorship, project management and individualized teaching in light of the planned sharp increase in enrolment. The teaching team had been experimenting with on line learning elements students could access asynchronously and as-required for three years at that point with positive feedback. Many of these learning elements were not covered during class. Further, students could access all the teaching and learning materials from the previous iteration of the course from the first day of class and could access them as and when needed. As materials were updated they were made available to students on an ongoing basis. The teaching team applied for and obtained a University of Alberta blended learning award for course redevelopment during 2014. With the help of the Centre for Teaching and Learning, a research plan was developed and decisions were made on how to best apply on line education strategies to an engineering design course ahead of the 2015 iteration of CHE 435/465.

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3. CHE 435/465 Blended Learning Pilot Project Framework

3.1. Introduction

A proposal for flipping the design course to include asynchronous online instruction and replacement of lecture time with in class active learning was selected for funding in May 2014. A précis of the proposal comprising salient excerpts along with updates is presented here.

Adoption of blended learning approaches for courses offered in professional faculties presents numerous administrative challenges because assessment criteria imposed by professional accreditation bodies frequently dictate norms for teaching methods and content. This is particularly true in Engineering where the Canadian Engineering Accreditation Board does not currently recognize on-line learning in the standard calculation of accreditation units for minimum education requirements across all Engineering disciplines. Calculation of accreditation units is typically based on contact time of lectures and labs. "The Accreditation Board can give consideration to departures from this approach and these methodologies in any case in which it receives convincing documentation that well-considered innovation in engineering education is in progress." (CEAB, 2014) Further, the Accreditation Board "expects programs to achieve the same educational outcomes regardless of the delivery method(s)." (CEAB, 2014) Consequently, accreditation criteria must be considered carefully when developing and implementing innovative and effective approaches in engineering education. With online learning in particular, care must be taken to identify an equivalent outcome to the standard delivery mode. Design courses and design course performance are closely monitored during CEAB accreditation visits because aspects of the curriculum, minimum design accreditation units and required levels of performance are prescribed.

CH E 435/465 teaching staff and students (based on an oral in-class survey) were strongly supportive of moving aspects of the course to an independent e-learning format. By moving 50 % of the lecture content to verified and graded self-directed online learning, a designation change from (4-0-4) to (2-0-6) is expected. The total course hours remain unchanged but become more flexible for individual and teams. The over all hours must be maintained in order to facilitate small group meetings among students, weekly meetings between students and members of the teaching staff (a hallmark of excellent design instruction), and meetings between students and industrial advisors, in light of otherwise congested schedules, and an anticipated sharp increase in class size for the 2016 and subsequent iterations of the course.

Approximately 24 (five or six member) teams of students concurrently perform different design/feasibility studies based on negotiated scopes, as described in Chapter 2. One of the instructors meets weekly with each design team to monitor and discuss schedule progress, accomplishments, challenges, personnel issues and so forth. The industrial partners, acting as clients, meet with the students three times per term. At these meetings the students discuss their work, seek advice, and obtain tangential correction. Industrial partners value the results obtained by and interactions with the students. CH E 435/465 is the top ranked course in the Chemical Engineering undergraduate curriculum according to Engineering 400 surveys several years in a row. Student achievement is highly regarded by the CEAB (latest review, 2012).

The next CEAB review is scheduled for 2018, based on student performance and curriculum details from the 2017 academic year. The foci of the review are: demonstration of graduate attributes; continual improvement; functional student policies for quality, admission, counseling, promotion and graduation; curriculum content and quality based on the "minimum path" - defined on the basis of minimum AU in engineering science, engineering design, math, natural science, complementary studies; and program environment. Demonstration of graduate attributes is accomplished, in part, by minimum student achievement based on samples of students' work. Chemical Engineering capstone design courses, as the mandated significant design experience, comprise a key element in the CEAB review process.

In order to have a successful review in 2018, data on individual and aggregate student participation and assessment regarding online materials must be available. Time spent by individual students engaged in online learning and participation must be available to the review panel along with an assessment of student learning related to objects. Thus there is a need for automated monitoring and mostly automated marking.

Inclusion of design instruction throughout the chemical engineering curriculum systematically from the second year onward is being evaluated and cross coordination of the design courses, with these developments is in progress. It is anticipated an optimized engineering design content and delivery across both courses and beyond in the undergraduate curriculum will result. The department has a strong record for collective course development in this subject area.

The timing of the pilot is critical. With a first iteration in the Winter 2015 year, there is time for two revisions of the redeveloped course (content and delivery methods) and data tracking and analysis tools, prior to the scheduled CEAB measurements based on the 2017 academic year.

3.2. Course Redevelopment Objectives

The redevelopment of this course includes desires to:

- demonstrate blended learning leads to as good or better learning outcomes than lecture-based learning in an engineering design context.

- demonstrate CEAB GAA requirements ahead of the next CEAB review and develop data gathering methods regarding level of student effort and the quality of learning as both are measured in the review process.
- meet the needs of students related to their learning in the course. Students were surveyed in class during week 5 of the 13-week Winter 2014 term. More than 100 students were present at the time of the oral survey. Fewer than 10 students were opposed to replacing any in-class lectures with self-directed e-learning. More than three quarters were in favour of some e-learning in the course (flexibility, improved learning). Fewer than 10 were neutral. Students had experienced three optional online learning objects and one online learning exercise with an assignment prior to the survey.
- increase the frequency, quality and duration of face-to-face individual and small group interactions.

3.3. CH E 435/465 Course Redevelopment Plan

CH E 435/465 is currently web enabled within the MOODLE platform (LMS) and materials are continually updated. All course teaching/learning materials are available to students from the first class and are organized by sessions labeled "tutorial" (#1-26), or are in a resource library on the course web site. In 2014, 18 of the 26 "tutorials" included lectures and an additional three included whole class discussion of specific topics. The lecture focus is weighted toward the beginning of the course. For example, during the first five weeks of winter 2014 term, ~ 21 hours of lectures and whole group discussion were completed during 9 "tutorials" with one tutorial devoted to student/industry advisor meetings. By the end of the course there were more than 45 hours of lectures and whole class discussion.

The online portion of the course was layered on top of the in class and project components of the course. The blended structure of the pilot course was determined after significant research and reflection on how best to achieve the thoughtful fusion of online and in class experiences described by Garrison and Vaughn, including reflection on student intellectual development, scaffolding needs and the cognitive task requirements of the course and professional development performance objectives. Key components of blended learning course design are: Thoughtful integration of online and face to face, optimization of student engagement, and restructuring of class hours to replace in class time with on line. (Garrison and Vaughn, 2008)

For the blended course, the plan was to reduce the lecture component and increase the whole group discussion component to arrive at ~ 26 hours. To achieve this, materials must be moved on-line and coordinated with additional curriculum development. Nominal weekly schedules, for 2014 and planned for 2015, are set out in the Table 3.1.

Table 3.1. Current and Planned Flipped Lecture Schedule for CH E 435/465

	Current schedule		Planned schedule	
	TU	TH	TU	TH
14:00-14:50	Lecture		Lecture & whole class discussion	
15:00-15:50	*Lecture *Some whole class discussion		*Free form, self-organized, unsupervised, individual and team project work. *Free form access to all members of the instructional team. *Free form access to a TA regarding process simulation.	
16:00-18:00	*Free form, self-organized, unsupervised, individual and team project work. *A scheduled, once a week group meeting with a designated member of the instructional team (40 minutes). *Free form access to a TA regarding process simulation.		*Free form, self-organized, unsupervised, individual and team project work. *A scheduled, once a week group meeting with a designated member of the instructional team (40 minutes). *Free form access to a TA regarding process simulation.	

The 2014 course web site included an extensive collection of materials from background documents (optional reading), sample interim assignment responses and final design project reports from prior years, recommended reading, power point slide packs related to lecture materials, guides for performing specific types of calculations, marking templates, and self-assessment forms. None of the materials were interactive; just still images and text intended to support live in-class teaching. The teaching team's current use of marking, and tracking features in the LMS is developing. Clearly, the teaching and learning objects on the site require one or more of the following: revamping with respect to the media used, their duration, assessment, incorporation of monitoring, and automated marking. If a blended learning format is to be adopted, new learning objects are needed. Quizzes or self-check items must follow self-directed, online learning and teaching objects.

Some topics or activities are better accompanied with live in the classroom teaching (process design drawings – P&IDs, PFDs; introduction to process simulation). These topics are "new" for the students and are already interactive. There are lots of questions and there is good discussion. Approximately one third of the lecture material falls into this category. There is another third of the material that should be on-line. Examples include aspects of: team building; team management; team self-assessment; process safety (PSV design, Fire and Explosion Index usage in design); unit operation design (not all students use the same unit operations in their designs). As to the remaining third of the course materials, reflection and perhaps exchange of materials with CHE 464 is needed to determine their disposition.

3.4. Integrated Educational Research Plan

The Blended Teaching Award pilot project included a collaborative educational research component coordinated with CTL. Dr. John Nychka, the past CME department undergraduate chair, and Tracy Onuczko, an Education Developer in CTL, provided the research data table presented as Table 3.2. These research questions are designed to capture instructor and student experiences arising from the change in instruction format. The thesis research questions posed include:

- Does flipped learning lead to equivalent or better outcomes for Design II students?
- Is CEAB Graduate Attribute development demonstrated from data collected?
- Is student effort and quality of the final report equivalent or better for flipped learning students?
- Does a flipped learning structure produce equivalent or better academic performance?
- Is the co-op program a predictor or factor in student outcomes in design?
- Is the co-op program a predictor or factor for student results in a flipped structure?

While this thesis does capture instructor experiences, the focus of the data analysis is on student measures, specifically performance related to final grades in the capstone course and student perceptions of their skills. Comparisons with the historical data are made where possible. The highlighted items in Table 3.2 indicate the sources of data that are analyzed. The first four questions are considered to varying degrees and the final question is answered based on the completed student performance analyses, observations made and feedback from students and instructors. These question are investigated and answered in the broader context of the ongoing work at the University of Alberta Department of Chemical Engineering to provide meaningful transformational learning experiences for their students and the requirement to demonstrate CEAB graduate attributes.

With the flipped and blended learning structure and the research questions in place, an understanding of the learner group (Chapter 2), a context for the course teaching and learning objectives (CEAB graduate attributes) connections among learners and desired learning outcomes, on-line learning objects

Table 3.2. ChE435/465 Flipped Classroom Research Data Table	
Research Questions	**Possible Data Sources**
1. What is the instructors' experience in developing and implementing their blended learning course?	Instructor's critical incident journal/log
	Individual interviews with instructors (3, 30-45 minutes)
	Focus group interview with each course team (2, 60-90 minutes)
	Focus group meeting with all teams (2, 60-90 minutes)
	Classroom observations, descriptive notes taken (3 per course)
	Examples of lesson activities and handouts.
	Video record of some class activities
2. What is the students' experience of the blended learning approach?	Individual interviews with students (1, 30-45 minutes)
	Focus group interview with students in the same course (1, 60-90 minutes)
	Survey items
	Course analytics
3. What is the impact on student engagement?	Student engagement survey items (blended learning course survey results are compared to traditional delivery course)
	Students asked to compare to other similar courses.
	Classroom observations from #1
	Video record from #1
4. What is the impact on student learning?	Compare GPA of BL course to traditional delivery course.
	Each course may want to compare specific assessments.
	Examples of student work
	Student interviews and focus groups from #2
5. What is successful? What is unsuccessful?	All data described above are used to answer this question.

and assignments crystalize. This understanding provides a basis for the development of a comprehensive and integrated course plan detailed in the next chapter.

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4. Flipped Capstone Design Course Teaching Plan

The Flipped capstone design course teaching plan development was launched by systematically mapping CEAB Graduate Attributes (GA) to course objectives. This process led to iterative revision of the existing course teaching plan, and refinement of the learning objectives for students and the scaffolding needed for them to meet these learning objectives. The iterations were layered. The *ability of students to demonstrate* the GA (an outcome) in a course is related to the *focus of the learning materials, activities and assessment requirements*. The integration of these elements into the course required a rapid iterative design approach with overall department and faculty support for continuous and ongoing improvement of the course. It is the instructor's responsibility to design a course to *allow for student demonstration* of CEAB GA requirements. It is the students' responsibility to engage with instructors, materials and assignments to *provide evidence of development*. The faculty and the department are responsible for *providing a collaborative environment* where instructors are encouraged to and rewarded for designing courses focused on progressive and comprehensive student development of program objectives. Successful implementation necessitates contributions and collaboration from all stakeholders. The pedagogy underlying the development of the course plan and the final course plan are presented and discussed in this chapter.

4.1. Student Development - Perry's Schema

William G. Perry Jr., as project director of a contract study for the US Department of Education led a team with the purpose of classifying thought patterns and development of liberal arts students at Harvard University as they progressed through the four year program. The team studied specific classes in 1958, 1962 and 1963. The methodology was to have graduate student judges evaluate student thought patterns based on the criteria of the schema that was developed previously. The schema itself was developed circa 1954 and had nine classifications as published in the final report on "Patterns of Development of Thought and Values of Students in a Liberal Arts College" (Perry, 1968). The first three are related to a dualist perspective where the student's worldview is thought and actions are perceived and classified as right or wrong. The three stages describe the development from an absolute dualist perspective to the recognition of the existence of multiplicity. The middle three describe a student worldview in transition from dualism through multiplicity towards relativism. According to Perry's schema, in these six stages a student may retreat or escape as a reaction to the new worldview where authority does not have all the answers. The last three stages describe the transition from the initial commitment stage to developing commitments and essentially embodies the transition from a student subject to a teaching authority to becoming a junior peer and part of the “authority”. This stage describes the transition to contextual knowledge and the ability to create and contribute to knowledge. More recently, it was observed that the more years of university study a student experienced the more likely the student was to use internalizing, open strategies, and deep level learning approaches to study (Watkins & Hattie, 1981).

University of Alberta design instructors have observed that the median student entering Design I is often at the multiplicity stage and some are dualists. Dualist students tend to believe that there is a right answer and the instructor knows it at the beginning of the course and multiplicity stage students believe that there is a right way to get the answer and the instructor knows it. In either case, the instructor can be perceived as withholding known information. In addition, there are students who are at the relativist or commitment stages. They tend to be more mature and/or have industry experience. For a complex design problem, an instructor may have several ideas or preconceptions of the solution, but none of these may turn out to be the best solution. Solutions tend to evolve, as a design problem becomes better known over time through an iterative, integrated and evaluative process. There are, of course, better answers than others as solutions are contextual. Students looking for a “yes” or “no” answer struggle with “it depends”. By the end of the first design course, most but not all students have shifted from a dualist stage to one of the other stages along the intellectual development continuum. A version of Perry’s Schema outlines these developmental stages and is summarized in Table 4.1. Students completing the first design course tend to be at the multiplicity or relativism stage. According to Robert Irish of the University of Toronto, instructors can provide a learning environment that precludes retreat to the comfortable lower levels of development and encourages student exploration of knowledge, analysis and higher level cognitive tasks. In the higher levels of development authority (or instructors) take on a different role and lose the power to judge right and wrong. (Irish, 2015) This shift requires a change in evaluation from the right answer to a justified answer, a key development in the student ability to solve open-ended problems in design.

Acknowledgement that all students entering a course, even if they have equivalent academic credentials, may not be at the same cognitive development level according to Perry’s schema informs course design. Students working in teams with an instructor as a guide is a strategy to meet students’ needs at all levels. Asking students, "What do you think?" is often an appropriate response as is the answer, "it depends." Both lead to the contextual discussion and student development. Already having experience in Design I and being in the senior undergraduate year, many students entering CH E 435/465 are at the multiplicity stage and some are at the relativism stage highlighted in Table 4.1. Most have not yet come to the conclusion that knowledge is contextual, and reflection on experience is limited. One senior student commented, *"I've never had to discuss why I would choose a solution directly with a professor before."*

Table 4.1. Perry's Schema: Stages of Student Intellectual Development. Adapted from: http://www.cse.buffalo.edu/~rapaport/perry.positions.html by G. Maheux-Pelletier and N. Saranchuk University of Alberta Center for Teaching and Learning. (Shading depicts the perceived majority of students entering Design II)

	Most entering students/ Dualism	**Most undergraduates / Multiplicity**	**Some Seniors / Relativism**	**Some graduates / Committed Relativism**
Knowledge	All knowledge is known; there are clear right and wrong answers	Most knowledge is known; there are right and wrong ways to find answers	Most knowledge is not known; everyone is entitled to their opinion	All knowledge is contextual; within a context, there are right and wrong answers
Instructor	A source of knowledge	A source for the right way to get knowledge	Instructors provide either (1) a resource for the thinking process or (2) is irrelevant	Sources of expertise
Student	Receiver and demonstrator of knowledge	Must learn how to learn and to work hard	Must learn to think for oneself, to support opinions	Study different contexts and perspectives
Peers	Peers are not considered to be a source of knowledge	Beginning to be viewed as a possible legitimate source of knowledge	Can be considered legitimate sources when following reason and provide support	Knowledge is learned from others, along with experience and reflection

The CEAB graduate attribute for students regarding investigation suggests student cognitive development should reach a commitment level where knowledge is understood to be contextual. There is a right or wrong answer within a context:

*Investigation: An ability to conduct investigations of complex problems by methods that include appropriate experiments, **analysis and interpretation** of data, and **synthesis** of information in order to **reach valid conclusions**.* (CEAB, 2014 -emphasis mine)

This investigation attribute is illustrative but a number of other attributes seem to reflect this developmental milestone. The ability to reach valid conclusions, to design to meet specified needs, to understand limitations, understanding interactions and uncertainties predicting interactions between engineering solutions, economic, social, health, safety, legal, and cultural aspects of society all seem to require abilities outlined in the commitment stage. As a Bachelor of Science in Chemical Engineering is the practicing degree and allows students to register as an EIT with the professional association, the accreditation expectation that graduating students attain development described at Perry's commitment level is reasonable. Moving from the dualist perspective to the commitment level for students within two semesters in the context of the regular program progression from Design I to Design II is a challenging goal. Co-op program students have an eight-month work term between Design I and Design II, and their stage of cognitive development may change significantly between the two courses. By contrast, regular program students commence Design II less than one month after completing Design I. Students entering Design II possess a broad range of intellectual development. Their engineering skill levels are equally diverse but by the time students have completed Design I most have some experience with synthesis and evaluation level engineering skills (Pick & Jamieson, 2014).

Diversity of intellectual development and engineering skills are two key challenges faced in Design II course design, in general, and in the preparation of materials to support student learning, in particular. Frequent meetings between instructors and individual teams are central to student intellectual development. The role of the instructor as a guide is critical to the intellectual development. Feedback from multiple instructors and industry contacts increases the number of different perspectives and contexts students are presented with for consideration. Additional opportunities for student intellectual development, both in class and online, are incorporated into the flipped course teaching plan.

4.2. Flipped Lectures and Student Development

Changing the lecture structure from a traditional one to online video instruction with connected active learning in class components is intended to enhance the intellectual development of graduating students in their final term. In Engineering, students in traditional lecture courses work on higher level learning skills, such as applying or analyzing, when completing assignments either on their own or in ad hoc groups. (Cussler, 2015) The intent of the flipped classroom is for students to work asynchronously to comprehend content. Students apply, analyze, synthesize, and evaluate materials together as part of in-class activities that culminate in a completed assignment. Opportunities for team discussion and integration of individual perspectives arise naturally, as do design project specific applications and knowledge extensions beyond the scope of the assignments.

The lecture structure of Design II (pre-flipping) followed a traditional pattern. Although topics and content were adapted starting in 2010 to an internship model, the structure of the course remained the same from 2004-2014. Implicit or explicit assignments were given after each lecture to be asynchronously completed and included in the final report. Each lecture was intended to address a particular component or requirement of the final report. For example, the lecture on heat integration was intended to introduce the students to the topic. From this base students were expected to determine the heating and cooling requirements of their design, and the potential benefits of heat integration using previous course knowledge, lecture material and additional research as required. For this particular assignment the topic appears "easy" following the lecture. However, as only the concepts of the method are discussed and not the mechanics of the analysis related to individual projects, not all students understood the mechanics or were able to determine what was required for the analysis and what to include in their final report.

In the flipped course, this lecture material was converted to short online videos and the methods described were practiced during class time. The pattern was similar for other topics. Students are introduced to topics/calculation methods prior to class and have an opportunity to try them out in class when instructors are available to assist when problems arise. After this initial application, students then continue with an assignment that is related to their project. The final report assignments pre and post flipping remain the same. In the flipped course, students have an opportunity to try an application soon after the concept is introduced and then submit their in-class work. The application of the higher-level skill is synchronous with peer and instructor assistance available. This active learning further develops students' cognitive framework and develops application and analytical skill development concurrently. The instructor is no longer seen as the source of knowledge, but rather a source of experience and expertise – a coach.

It is important to note the large number of pre class learners, who view online material independently are team taught during class time in larger groups of ~5 to 30 students. This is a critical aspect as the active learning component is the most effective in small groups (Cussler, 2015). Instructors are able to spend time with each group and discuss questions students may have from pre-class and in-class work. Cussler suggests a maximum of 25 students per small group. It is the active learning that builds on the pre class material that makes a flipped classroom successful (Lape, 2014).

Successful active learning requires groups of less than 25 students with an available instructor. Students in larger groups can elect not to participate (Cussler, 2015). Participation in the discussion is what makes many of the learning activities effective. Students who are passive participants or non-participants are not taking the risk of sharing their thoughts and experiencing either validation or dissention. These students are free to continue with their cognitive structure and conceptual beliefs in tact and maintain their current level of intellectual development. Students in a smaller group are less likely to have the opportunity to be passive or non-participants, as peer pressure and assignment focus appear to increase in smaller groups and inculcate a sense of responsibility for activity completion. The size of the group can have an impact on the learning environment quality. In a study on the effect of different active leaning environments and student outcomes the role of the student and the role of the instructor are examined (Lord, 2012). The instructor acting as a guide in a student-centered pedagogy that allows student choice is associated with life long learning. Life long learning and the final stage of Perry's schema share some common characteristics: responsibility and commitment to one's own learning and contribution. Problem based learning and student led activities tend to increase metacognitive self regulation and critical thinking while lectures even with active learning components tend to increase effective use of time (Lord, 2012). Table 4.2 summarizes structural choices made in the context of cognitive objectives and developmental goals for the flipped design classroom and Table 4.3 expands on group size and timing choices. These choices were based on an attempt to balance diverse course objectives while maintaining a learning environment that allowed for student choice guided by instructors. Principles of good practice including: student faculty contact, cooperation among students, active learning, prompt feedback, time on task, high expectations and a respect for diverse talents and ways of learning as elucidated by Chickering and Gamson (1987) were considered.

Table 4.2 Cognitive and Intellectual Goals of the Flipped Course Structure in Design II

Flipped Structure	Cognitive Objective Goal	Intellectual Development Goal
<u>Pre Class Learning Elements</u> Background information for in-class and post class activities Individual preparation for group activities	Knowledge and Comprehension Application by individual Classification of knowledge	Knowledge comes from many sources, different contexts and perspectives; the right answer depends on the context.
<u>In Class Active Learning</u> Integration of individual inputs Discussion of opinion and facts Evaluation of same and comparison with personal view Presentation of facts and opinion in light of new information	Analysis and Synthesis Evaluation of own and other's ideas and contributions Application of new knowledge Comprehension of how new knowledge fits with old knowledge	Peers are legitimate sources of input Knowledge comes from many sources and is contextual Evaluation of source, knowledge, and reflection of the value of the current thinking
<u>Post Class Project Application</u> Reflection on how new learning applies to the current project situation	Evaluation of relevance and integration with previous understanding Analysis to determine fit	Knowledge is contextual there are right and wrong answers based on the context of the project – student determines the direction and justifies it

Table 4.3. Overview of Flipped Design Classroom Structure			
	Working Group Size	**Schedule & Timing**	**Purpose**
Pre Class Location independent	Large cohort works as individuals with online material.	Asynchronous timing within the course timetable	Introduces and develops concepts and material to support in class component
In Class Large classroom cohort together, groups break off.	Small groups 12-18 for active learning such as exploration, discussion, using materials, working examples, integration of individual work	Synchronous timing of group work topics according to course progression	Uses pre class work as an input for activities, goals are cognitive and intellectual development. Bloom's higher order skills, and Perry's commitment are targeted.
Short Assignment - provides incentive to focus on in class activities Start in large classroom	Teams of 5 or 6 summarize learning (oral or written presentation) or complete an assignment template provided	Synchronous timing within class time. Uploaded to LMS prior to the end of tutorial	Formative – meant to have students summarize learning quickly, obtain feedback prior to project work.

The structure and design of individual learning elements, in class activities, and assignments play key roles in the effectiveness and pace of intellectual development and cognitive objective achievement. "*Students who make the shift to relativistic thinking are moving toward expertise; they are beginning to think like experts aiming to create knowledge, rather than novices trying to display what the Authority wants*" (Irish, 1999). Careful and thoughtful planning of assignments to motivate in class participation, reflection and use of writing as a method to deepen thinking (Stout, 1997) coupled with the objective of integrating individual experience and contribution into a team contribution may contribute to enhanced cognitive and intellectual development. *"The striking similarity of Bloom's thinking and Rosenthal's writing skills further suggests the intimate relationship between writing and thinking."*(Stout, 1997)

Although not every student is at the same level according to Perry's Schema or has the same cognitive objective development *"when faculty understand the cognitive objectives, attitudes toward knowledge, and the process of mentoring involved in moving students along the path of intellectual development, the results can be significant"* (Irish, 1999). Within the CH E 435/465 flipped classroom structure, the design of the activities impacts the achievement of course objectives and the ability of students to demonstrate the CEAB graduate attributes. The design of the activities to balance skill development and to provide challenge for a range of student abilities is likely to improve overall student satisfaction with a course. Csikszentmihalyi's flow zone, Vygotsky's zone of proximal development and Perry's pleasure zone are all linked to the identification of a learning path between activities deemed too

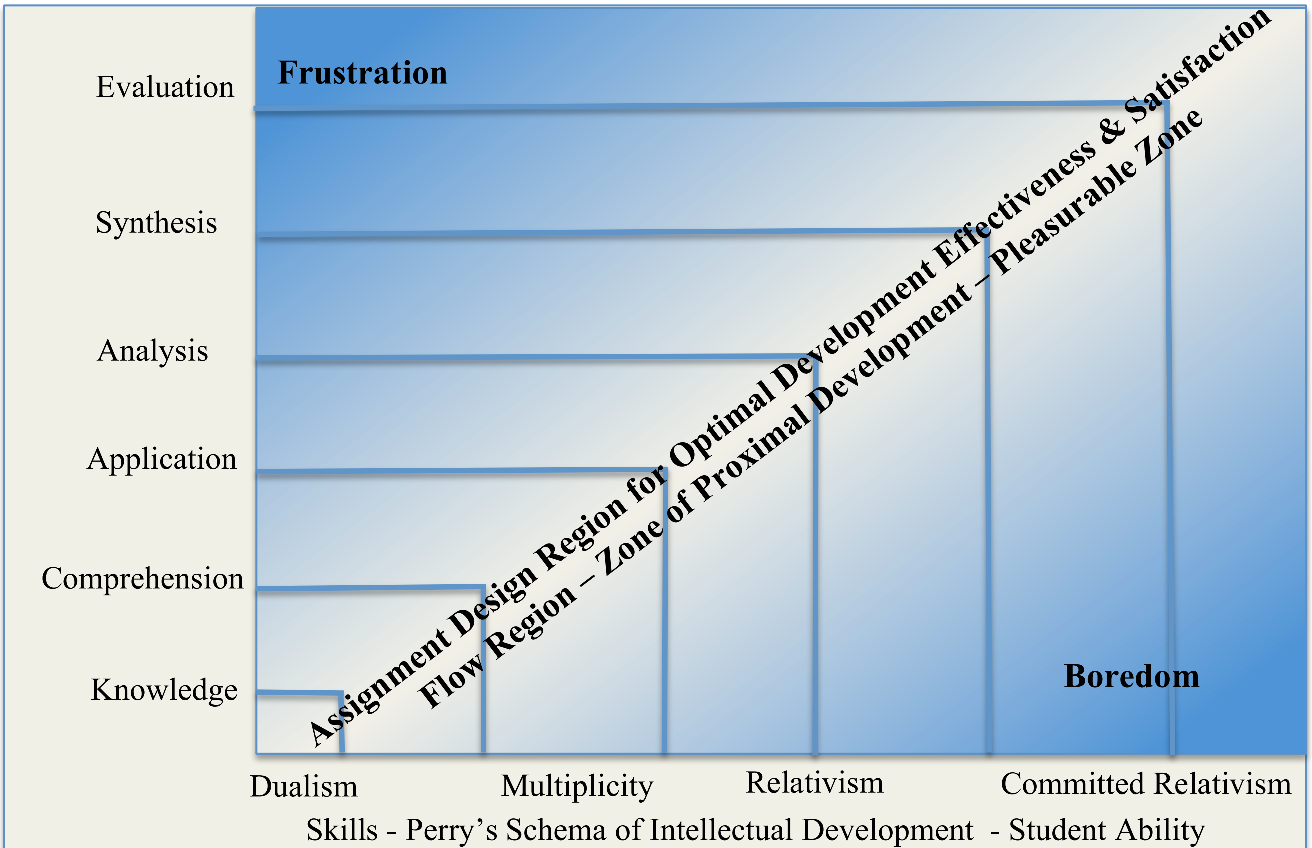

Figure 4.1. Perry's Schema vs. Bloom's Cognitive Objectives in Assignment Design

challenging or too boring for a particular individual. These theories all suggest that a balance between the student's intellectual development (ability) and the cognitive objective (task) are required for learning to be engaging and satisfying, as shown in Figure 4.1. Learning activities must have the ability to develop students both cognitively and intellectually. Vygotsky terms this "scaffolding" to enable learners to reach the zone of proximal development. Csikszentmihalyi describes this zone as the flow zone, where one loses track of time and experiences pleasure as a result of skill matching challenge. Research, writing and project-based assignments must have some flexibility in addressing this balance as students approach activities from a unique perspective on the spectrum of intellectual development. Assignment requirements and scaffolding provide the impetus and support for meeting both skill and objective requirements demanded of performance-based assessments such as the CEAB GA.

4.3. Student Development Toward Committed Relativism

Design, in any discipline, is a process of alternating creative and critical thinking in an iterative pattern regardless of what is being designed (Dorst, 2011). It is an iterative process moving between the problem space and the solution space to create a product or a system to make a product for a user group. In course design, space is required for the creative part and for the critical part. This creative and critical space is crucial for intellectual development and it is crucial for students to progress along Perry's continuum to be successful in design. Students struggle with the design process partially because of their development along Perry's continuum and partially due to the lack of creative experience within the fundamental traditional based curriculum. (Cussler, 2015) From a cognitive task perspective this process can be described using the synthesis and evaluation terms of Bloom's Taxonomy. Development of these levels of learning depends on the previous levels of learning in the taxonomy. (Bloom, 1956) **Synthesis** is the classification for verbs such as: designing, composing, creating, integrating, predicting, combining and imagining. **Evaluation** is the classification for verbs such as: rating, judging, comparison and assessing theories. The combination of these actions from the learning taxonomy into an iterative process is in effect the design process. Understanding the design thinking process early is likely more important to student success than the specific project application. Many instructors believe students benefit from exposure to the design process and thinking early in the program of study. Design has been included as a cornerstone design course in several programs including the University of Toronto. A benefit of early program design exposure is the potential for more rapid student intellectual development and progression towards relativistic commitment (Irish, 2015). As this is currently not the case in the University of Alberta Chemical Engineering undergraduate course progression, recognition of the variability of student development and experience suggests inclusion of teaching the design thinking process as an objective and including it in the instructional material.

Early in Design I the focus is on design thinking and evaluation with laboratories that have a right answer and connect with the students at the dualist phase. As the semester progresses more ambiguity is introduced in the design laboratory periods leading up to their first design project. Complexity and ambiguity increase as students move from the Design I to Design II. The course plan for Design II is divided into three phases. Table 4.4 describes the introduction and the team and project development phase of the course, Table 4.5 describes the core design phase, and Table 4.6 describes the evaluation phase. Milestones, online pre-class materials and in class assignments guide student learning and facilitate their progress toward successful completion of their design reports. Initial team, project and schedule development are strongly encouraged in the first week. The main objectives of the development stage are to develop design thinking, multiple possible solutions, team processes, a project schedule for managing design work during the term and complete a situation report. Iteration on these tasks is expected. The approved situation report, updated with the feedback from the industrial advisor at the end of the first phase of the course, becomes the backbone of the final report for many teams. Core design begins after major feedback from industry advisors and instructors. The key objectives of the core design phase are the design deliverables and preliminary evaluations. The evaluation phase begins after the system design is nearing completion and specific economic and risk analysis are completed. Regulatory, safety and economic evaluations continue to inform design iteration in both the core design and evaluation phases.

Marks are assigned for the Situation Report, the three meetings with the industrial advisor (milestone work and team evaluations) and the final report. In the flipped version of the course active learning is a critical component and a mark is given to the collection of online and in-class assignments (portfolio) to encourage participation in the in-class activities. An example of an early in class activity is peer editing of a draft situation report introduced into the course workflow. The student teams apply the grading rubric to another team's draft. Students make adjustments, using peer feedback prior to submitting their draft to an academic advisor for preliminary evaluation and informal feedback. The addition of peer feedback to the workflow exposes students to peer viewpoints on their work and provides an opportunity for students to provide peer review in a supportive environment. Student teams are then given an opportunity to revise their work prior to grading and prior to forwarding their situation report to their industrial advisor ahead of their first meeting. Students are more confident as a consequence knowing they are putting their best foot forward.

Assignments are designed to meet students at their unique level and support rapid development by forcing consideration of multiple perspectives early in the course. Often assignments have a writing component. Planning, monitoring and reflecting are built into the assignment structure and assignments are aligned with the course objectives. Teaching. Learning and Assessment Activities are aligned with the course intended learning objectives to maximize learning potential and opportunities for all levels of students. (Biggs, 1999)

Table 4.4. CH E 435/465 Design II Course Plan (Section 1: **Development**)				
Online Orientation	Introduction to the Course	Project, Schedule and Team Development - **January**		
		Project Development	Team Development	Schedule Development
Pre course	**Purpose Of Course**	Learner Objectives in project context; Learning Activities are Situation Report related		
Orientation to the course, structure, objectives, roles, plan Orientation to Team members selection Pre course section completed prior to first class	This course will include: (See **Course Objectives**) • Team, Project Management • Complex Sustainable Design • Design Evaluation <u>Learning Activities</u> Learners will: • Create (prior) and develop a team • Develop Team Charter • Develop design thinking	Learners will: 1. Manage the project 2. Elicit and articulate project requirements from client 3. Define the problem 4. Research potential plausible solutions 5. Determines appropriate regulatory, legal, environmental, social, ethical constrains and sensitivities. 6. Define evaluation criteria for solutions 7. Evaluate solutions 8. Determine the best option and propose it.	Learners will: 1. Manage the team 2. Define team norms and standards 3. Set performance criteria & objectives 4. Apply performance and deviation management techniques 5. Determine team leadership roles for all team members 6. Evaluate individual, team performance, give feedback, reflect and plan future action	Learners will: 1. Assess the tasks required to complete the project 2. Determine a time frame for task completion 3. Develop a task list to support the project 4. Resource load the tasks with appropriately skilled team members 5. Manage the project from the using the schedule and task assignments
Duration and Weighting of Assignments				
Duration	Duration: Prior to Meeting 1 ~1month Weight: Portfolio (Complete/Not Complete) 5% all term; SR 5%, Mtg1, 5%			
Info out in December Skill Assess & Team Selection -prior ~1 month	Team Selection Form Team Charter One Page initial scope Coalescer Credibility -first week	Assignment – team, project, and schedule development, assessing information, research and decision analysis, Situation Report and revisions, Meeting 1 preparation, evaluation, individual contribution evaluation and team assessment. Assignment – weekly hour and task reporting to be updated and handed in weekly.		
Learning Resources				
• On –Line orientation • On-line resources	• On line team selection • Team development learning elements • Design learning elements	• Online learning elements • Problem statement • Initial scope template • Example reports	• Templates for charter weekly task / hour reporting • Online evaluation and team assessment	• Online learning elements • MS project • Template for weekly tasks and hours

Table 4.5. CH E 435/465 Design II Course Plan (Section 2: **Core Design**)			
Technical Project Work Focus: Process Design Considerations - **February**			
Process Simulation Development	PFD Process Integration	Equip Sizing & Design	Safety & Regulatory Analysis
Learning Activities: Simulation and modeling, mass and energy balance, basic & detail process design and sizing			
Learners will: 1. Create a process simulation that reflects their proposed design 2. Validate the simulation and check energy and mat'l balances 3. Assess the viability of their design 4. Rework their design to ensure a valid and robust design 5. Produce a sustainable design	Learners will: 1. Develop the PFD based on simulation and validation results 2. Analyze the design performance; integrate and redesign based on observed performance 3. Specifically analyze the heating and cooling loads 4. Propose and develop heat integration strategies	Learners will: 1. Size equipment based on design principles 2. Validate equipment size and functionality 3. Consider process control options for PFD 4. Consider process and equipment interactions 5. Consider scale up from design data 6. Detailed Hx design	Learners will: 1. Research regulatory requirements applicable. 2. Assess impact of solution against social, safety, risk and environmental factors as appropriate for their project 3. Evaluate the design 4. Rework solution as required
Duration and Weighting of Assignments			
Duration: Between Meeting 1 and 2 Weight: Portfolio (Complete/Not Complete) 5% all term; Mtg2, 5%			
Assignments –Mass and Energy Balances, PFD, Preliminary Equipment Sizing, Meeting 2 preparation, evaluation, individual contribution evaluation and team assessment, weekly hour and task reporting to be updated and handed in weekly, portfolio assignments for drawings, heat integration and heat exch.			
Learning Resources			
• Online learning elements • VMG Sim	• Online learning elements • Example drawings	• Online learning elements • Library, databases, etc.	• Online learning elements • Library, databases, etc.

Table 4.6. CH E 435/465 Design II Course Plan (Section 3: **Evaluation**)			
Logistical, Technical, Safety, Environmental and Economic Feasibility Study - **March**			**Conclusion**
Equipment Costing & Design recycle	Economic, Safety & Environmental Analyses	Technical Feasibility and Project Execution	Final Report Final Portfolio
Learning Activities: Design evaluation, revision, and presentation, execution strategy development			Learning Activities
Learners will: 1. Consider and apply feedback from industry advisor 2. Refine solution to better meet requirements 3. Finalize Equipment list / sizing 4. Cost equipment and installation based on a factored method considering location, timing, inflation, etc. 5. Consider project execution strategies, labor market factors, and cost indexing in economics 6. Update economics with new information as it is discovered	Learners will: 1. Assess the impact of the solution against social and environmental factors as appropriate. 2. Assess the impact of the solution against risk criteria using appropriate methods. 3. Assess the economic viability or the cost of service of the project to achieve the objective. 4. Assess the labor requirements for the project. 5. Revise design or recommend revisions based on changing understanding of the project	Learners will: 1. Assess the effectiveness of the solution against the customer's requirements as well as impact on social and environmental factors 2. Develop a project execution strategy with consideration to further work required, location and market factors 3. Develop a project management schedule. 4. Revise design or recommend revisions based on changing understanding of the project	Learners will: • Complete report their team has been writing and developing during the term with final updates and recommendations • Complete a final evaluation of individual contributions, teamwork and individual skill development as part of the reflection on their learning in the course.
Duration and Weighting of Assignments			
Duration: Between Meeting 2 and 3 Weight: Portfolio (Complete/Not Complete) 5% all term; Mtg3, 5%			Duration: All term 75%
Assignment - Final power point presentation capturing project development, design, evaluation and recommendations. Meeting 3 preparation, evaluation, individual contribution evaluation and team assessment. Portfolio Assignments – weekly hour and task reporting to be updated and handed in weekly, HAZOP, interactions, economic costing and analysis.			Final report
Learning Resources			
• Economic costing template • Codes and Standards	• Analysis template • HAZOP template	• Online learning elements • MS project	Final report library from past years

4.4. Linking Course Objectives With CEAB GAA Performance Criteria

The CEAB GA for design is:

An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations. (CEAB, 2014)

Integrating course objectives and assessments with the CEAB graduate attributes and their evaluation is a key objective. While there is a strong correlation between the course objectives and the CEAB GAA, the CEAB graduate attributes are a performance-based measurement of skill and experience (ability) attained and the course objectives are guidelines (a plan) for how success is to be achieved. Course objectives outline cognitive and intellectual development goals and are specifications for the design of the learning process required to produce the expected outcomes. Specifications for a process and performance measures of the product of the process should be correlated, as it is our plan to produce the expected product, but they are not the same. The CEAB GAA performance measures provide targets. However they do not define the paths to the targets. The aligned assessment criteria can support many paths to guide, support and test student learning.

4.5. Course Objective Development in the Context of an Undergraduate Program

In a fully consistent and coordinated program of study all learning would support and demonstrate development toward CEAB GAA performance measurements. Course designers could use student performance input in a continual improvement feedback process. Performance measurement as a method of continual instructional improvement in an institutional context is supported by research outcomes. Content and process are inextricably linked (Resnick and Klopfer, 1989). How student learning is assessed impacts learning. This has led to changes in instructional/evaluation best practices over time that now include: cooperative work, writing focus, problem solving, real-world activities and de-emphasis of rote learning and teaching. (Koretz et al., 1996) (Fennimore and Tinzmann, 1990) (Resnick and Klopfer, 1989). Linking assessment and instruction are a key principle for informing student progress and development. (Herman, 1992) In A Practical Guide to Alternative Assessment Joan Herman summarizes the active nature of learning in the context of research:

> *Mere acquisition of knowledge and skills does not make people into competent thinkers or problem solvers. To know something is not just to passively receive information, but to interpret it and incorporate it; meaningful learning is reflective, constructive and self-regulated* (Wittrock, 1991, Bransford and Vye, 1989, Marzano et al., 1988, Davis et al., 1990). (Herman, 1992, p. 15)

Herman makes it clear that learning is not a linear process, but rather a multifaceted contextual process that benefits from integrated assessment and real world context. A UofA Chemical Engineering graduate demonstrates this while recollecting a design course experience from the '90's approximately 20 years later:

"The third year course ***started with a lecture series****. Dr. Mather was the professor. There was some technical learning.* ***I can hardly remember the content****. It seemed more practical than many of our other courses, which were very theory-based. Dr. Mather <u>also provided some general knowledge about large capital design project workflow</u> and <u>where the chemical/process engineer fit</u> - front-end feasibility and technology selection, followed by equipment selection and sizing. Then we "leave the project" for detailed engineering and return for commissioning and startup… There was also some economics/financial content (cash flow, NPV, ROI, etc.)"* (Hawkins, 2015 - emphasis mine)

Recollection of design course subject matter in the project context is excellent and accurate.

The CEAB GAA is *<u>the</u>* performance measure that informs the contextual cognitive and intellectual development of engineering students throughout their undergraduate program. The opportunity for students to regularly assess their progress towards these performance criteria is an integral part of the learning process (Herman, 1992 p.20-21). Additionally, the process that we use to produce our final student product may benefit from the use of the CEAB GAA skill assessment as a tool before and after courses to demonstrate developing attributes. Just as student learning and development is inextricably linked to the method of assessment chosen, so are instructor, course and program performance. The chosen performance measure informs teaching practice.

Course and undergraduate engineering program design should allow opportunities for students to first learn and then demonstrate development of performance attributes. With the possible exception of demonstrating a basic knowledge of engineering, ethics and problem solving, demonstrating performance of CEAB graduate attributes on multiple choice or standardized tests is difficult and alternative assessments are required. It is also challenging for students to acquire and practice skills required to demonstrate performance for the majority of the attributes from a traditional lecture. (Cussler, 2015) The "*ability to work as an effective team member or leader"* does not develop as a result of listening to a lecture on either topic. It does not follow that knowledge of the principles of effective leadership makes someone an effective leader. In addition, changing only the method of assessment to one that allows for performance demonstration without providing the opportunity to develop the skill with feedback is equally ineffective. Performance-based assessment must inform course objectives and the design of teaching and learning objects that comprise a course.

4.6. Linking Assessment to Content, Objectives and Performance Criteria

Anecdotally it is observed for both students and instructors that there is an optimal level of task loading where performance is excellent and beyond which individuals become overloaded and tired. As examined in Figure 4.1 that optimal loading varies between individuals. It was determined a complete examination of student and instructor loading and the impact on overall performance is beyond the scope of the current study, but recognized as a factor. From observation over the study period, items that tend to be negatively affected when instructor loading is high are:

- Quantity of direct feedback to students on formative assignments
- Quality of direct feedback to students on formative assignments
- Type and quantity of formative assignments given
- Summative grading procedures
- Time for professional development
- Time for course development (clarity, formative evaluation, constructive alignment.)

In a recent assessment meta study (Hattie 2009), the highest ranked factors for teaching or teacher related effects are: **formative feedback** to *teachers* (.90), teacher clarity (.75), reciprocal teaching (.74), **feedback** (.73), spaced vs. mass practice (.71), metacognitive strategies (.69), self-verbalization/self questioning (.64), professional development (.62). All of which require instructor time and attention making them part of the loading equation. By comparison the highest ranked factors for students are: self report grades (1.44) and concentration persistence and engagement (.48) and gender (.12). (Hattie, 2009) Self-reporting of grades is a student prediction of how well they think they can do in the course prior to summative assessment. It would appear a student's only real recourse is institution and program choice to gain access to effective learning as most of the high impact items fall directly in teacher and teaching realms. An instructor's only recourse is real implementation support from the institution for implementing time-consuming practices to design effective learning experiences for students, as methods with the highest impact also require a larger time commitment. Recognizing that the University of Alberta is a research and teaching university, the time required to be effective at new course design and instructional techniques must be taken into account as instructors investigate and implement the techniques with the highest impact for the benefit of the overall program and for meeting the CEAB GAA criteria. The number of hours available per week is fixed and the division of tasks is dictated by measured performance.

The role of formative assessment and developmental feedback in fostering professional skill performance are seen as critical aspects of course design. Constructive Alignment (Biggs 1999, 2003, 2011) requires designing assessments and activities specifically on learning objectives to actively address what students do to learn and guide their approach to learn higher-level cognitive task skills. Course sections with high enrolment are in direct opposition to the provision of quality feedback from instructors on multiple formative assignments. However, eliminating assessment linked to student development due to student numbers is to miss learning opportunities related to key objectives of the engineering program, especially the abilities to analyze, synthesize and evaluate contextual information. The development of meaningful learning opportunities to support skill development and demonstration of performance would seem to be linked. (Resnick and Klopfer, 1989; Biggs, 1999) In addition one of the features of the flipped pilot was to increase formative student assignments to support in class participation, learning, and development. Currently formative assignments are marked as complete or not complete and feedback is given as instructor time permits or as peer feedback.

The integration of the CEAB performance objectives into the design of the course and allowing for students to use automated processes and tools to assess their own performance and that of their peers are valuable feedback mechanisms for student development. Students may use formative feedback during the course to improve both their processes and their performance, however they are unable to use the final report summative feedback to improve their performance *during* the course. An opportunity to improve formative assessment within the design course as an ongoing method to improve student performance and potentially course design was identified prior to the flipped version and several methods were included in the pilot version. Automation of formative assessment grading was actively being investigated.

In the flipped version of the design course, on line learning elements expose students to team thinking processes and development. Students consider individual skills and the skills of their self-selected team members to determine where development is critical to project success. This information is available for students to resource their design project schedule, an experiential learning activity designed to enhance cognitive development and student development as life long learners. The link between course objectives and learning activities is clear. The link between assessment and course objectives for major objectives is also clear. Specifications for the final report relate directly to the course objectives, as do those for the situation report. For summative assessment the links are well established.

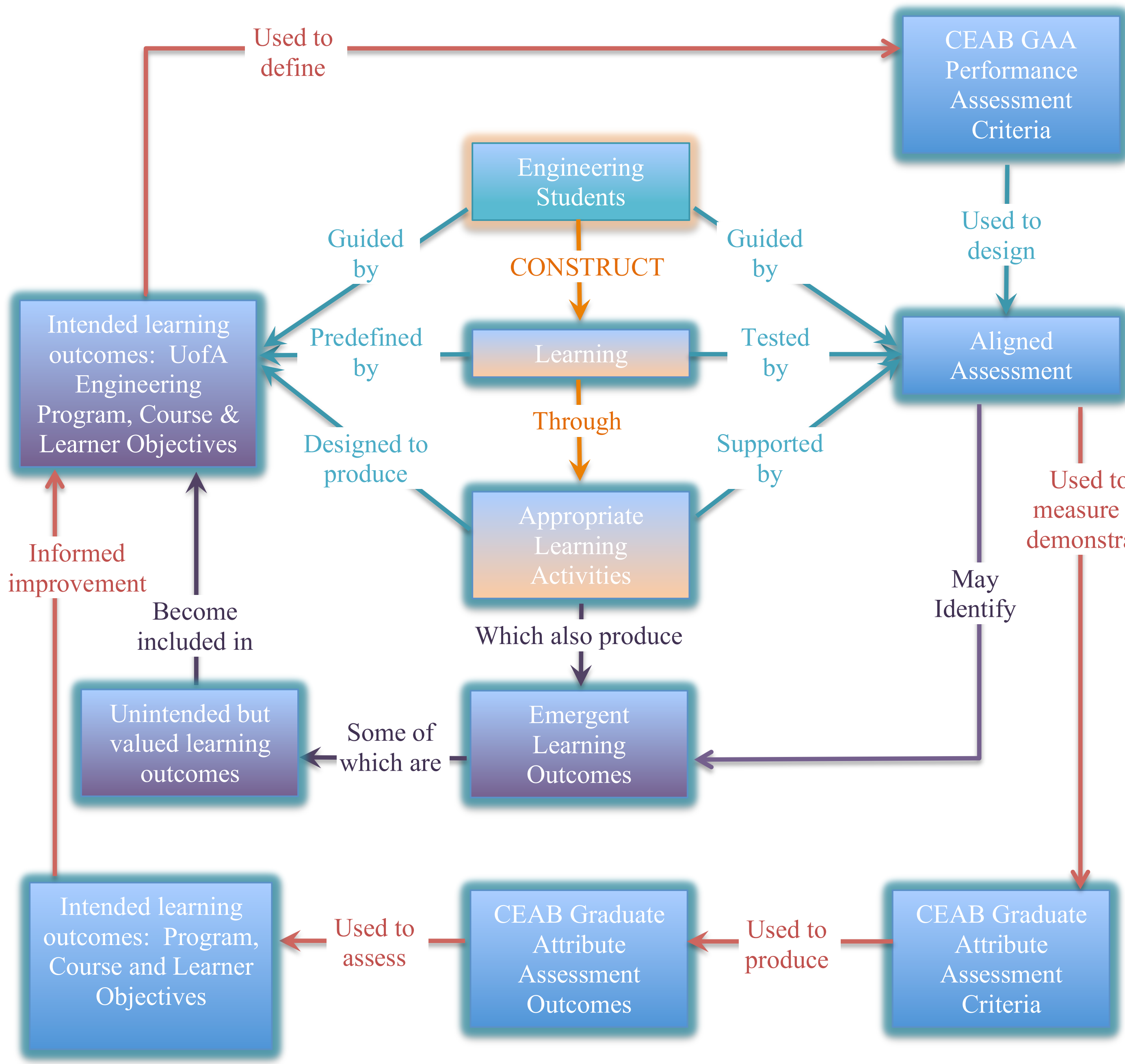

Figure 4.2. Continual improvement process algorithm for the University of Alberta Engineering Program Curriculum and Course Design Using CEAB GAA performance criteria based on a curriculum design process concept map (Hattie, 2009) illustrating constructive alignment (Biggs, 1996) as a core element and the feedback process of graduate performance measurement to inform program and course design (Jamieson 2015) -Adapted by MV Jamieson, 2015

4.7. Summary

A framework for course design, illustrated in Figure 4.2, developed in the context of the overall undergraduate program is presented in this chapter. It is based on constructive alignment (Biggs, 1996) and curriculum design processes (Hattie, 2009). The framework is intended to place course design in the broader context of overall undergraduate program curriculum design, CEAB performance based assessment of graduates and an integrated continual improvement process. High stakes performance based assessment provides a means to assess higher-order thinking skills and helps support students in developing a deeper understanding of content by causing a shift in choice of instructional methods from teacher centered methods (lecture) to student centered methods including open response, problem solving, creative/critical thinking and inquiry based methods. (Vogler, 2002)

With this overall framework in mind and in the context of continual improvement, implementation planning for enhancement of aligned learning materials, the stage is set for the preparation of activities and assessments to support student intellectual development balanced with depth of cognitive task challenge coupled with measurement to inform the feedback process. Methods to measure learning and performance are considered along with what to measure. The easiest items to measure are not always the most indicative of success or change. Consideration is given to the meaningfulness of possible measurements and how to collect meaningful data demonstrating performance and development of the CEAB GAA performance criteria recognizing that learning and performance are not the same.

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5. Data Capture for Evaluation and Continual Improvement

Several tools are available to capture data on student development, performance, and interaction with course materials. The Moodle Learning Management System (LMS) activity completion option allows for resource access and course progression to be tracked. Student access is automatically recorded and stored in legacy logs. Individual student access and use data for all on-line learning objects and resources from the 2014 and the 2015 versions of the course are available. These data are a rich source for evaluating and comparing student use of online materials. In addition, team self-selection and team performance self-assessment during the term were targeted as a process for automation and data capture. Student grading and the automation of grading of some aspects of assignments is also investigated as part of this work. The goal is to use instructor time to provide improved formative feedback and reduce administrative time spent on grading completion-based assignments or on feedback that could be comparatively obtained by an automated method. Summative final report grading, performed manually, is expected to remain unchanged.

5.1. Resource Access Monitoring Tools

Heat maps and frequency access diagrams are used to track student access to materials on a team and time basis. Custom templates must be coded for each tutorial/class. For the pilot, heat map analysis was completed for team-based usage of materials in tutorials 1,2,3 and 10 (Indiogine, 2015). Results of this analysis are reported in Chapter 8. The access logs provide the type of resource accessed, time of access and by whom. Students are grouped as teams for assignment submission and tracking purposes on the LMS and this was a useful grouping method for analyzing access patterns. Results based on team usage are analyzed and compared to the overall team grade and the final report grade. Access patterns are sorted into types: total access, URL access, file, folder, page, forum, and assignment access. Overall frequency of access to the LMS indicates overall student usage of the LMS for cohort comparison. URL access is similar, but not identical to learning element access. It provides a rapid analysis of whether students have accessed a specific video based learning elements during the course. File and folder access typically indicate access to posted course resources and for analysis these are combined. Page access is indicative of course information resource access. Assignment access indicates frequency of access related to course assignments on eClass. As portfolio assignments comprise a new element in the course, there are more assignments in the flipped version of the course than in the 2014 version. The forums incorporate peer based feedback and assessment into the course and are also a new element. Forums provide spaces for online class or paired team interactions. Detailed analysis of when student teams access specific materials in relation to the in class component is provided by frequency access. The LMS is an important source of information to characterize student access to the course. The access data analysis results are presented in Chapter 8.

5.2. Team Development, Student Skill Levels and Automated Data Collection

As course objectives were reviewed, consideration was given to how the redeveloped course could demonstrate achievement of CEAB GA criteria. A pedagogical tool had previously been developed to assist students in self-selecting their teams with the objective of having skills required to be successful in the course represented on the team. A plan to address gaps was required prior to team selection being approved by the instructors. The student skill assessment form and the CEAB GAA are well aligned. For a team to be successful in the design course, the skills identified by instructors were typically found on the team – each individual did not have to be strong in every skill but the team needed to be strong in every skill area. This tool was redeveloped as an online individual skill assessment process that automatically compiled results into a proposed team composite skill profile. Students used this composite to assist in self-selection of team members, to create a development plan addressing skill gaps, to construct a team charter, and to assist in resourcing the design project schedule. Individual skills were classified according to the CEAB graduate attributes and the course objectives were linked to the attributes. The data was captured electronically to facilitate pre and post course result comparison.

A Moodle plug in was designed and developed for the purpose of supporting team self selection and to assess student skill levels classified as CEAB attributes before and after the course. The customizable plug in is available for any course to use for team selection and/or skill self-evaluations. Specifications for the online team selection tool can be found in Appendix E. CEAB GAA student assessed performance data collected due to team selection process automation is analyzed in Chapter 8 and used to evaluate the performance of the design course in further developing graduate attributes prior to graduation.

5.3. Team and Individual Contribution and Evaluation Tools

Improved team learning and development processes for students were targeted for automation. Since 2010, team evaluation, reflection and development processes have been evolving. Student evaluation of their own performance, their teammates' performance and the functionality of the team in order to improve performance are not covered elsewhere in the undergraduate curriculum. At times, students found it challenging to differentiate between tasks, terminology and process. At times, it was perceived as a policing check to determine adequate student participation rather than as a development opportunity making completion a process of ticking the boxes rather than input to inform improvement. As teamwork is inextricably linked to engineering work in design, operation, production and research in many modern contexts, the clarification of team learning objectives and simplification of activity execution was identified as an opportunity. An advantage of automating this process is to collect developmental data previously collected manually - that was difficult to analyze or use for course improvement. Automation of this particular process provides an opportunity to collect data to demonstrate student life long learning skills. Students are given a real world opportunity to self evaluate, evaluate others, assess group functionality and reflect on how they might change their individual actions to affect the overall performance outcome. Specifications for the automation of data preparation, capture and analysis on this topic can also be found in Appendix E.

5.4. Performance Criteria and Tracking: Student Grades

An objective of the blended learning pilot project is to improve demonstration of the CEAB graduate attributes for accreditation purposes. To this end the CEAB graduate attributes were reviewed and linked to several aspects of the capstone design course:

- Pre and post course student skill self assessments
- Design course objectives
- The team assessment rubric (Appendix E)
- Learner objectives for specific learning elements and topic areas.

The goal is for students to understand that their performance and progress are being measured. Every effort is made to ensure that, how they are being measured and how topics and activities in the course are intended to improve their ability to achieve the performance measures, is transparent. This is consistent with the theory that people perform better when they know the goal, see models, and know how their performance compares to a standard (Herman, 1992). Linking performance assessment to learning content and instructional goals visibly and consistently is intended to enhance student performance.

The automation of student skill assessment, progressive individual and team evaluation and reflection processes creates automated and mineable data to demonstrate CEAB GAA from a student perspective and perhaps more objectively for the peer based individual and team work GAA: "*An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting"*. The next question raised in course development was overcoming the challenge of effectively grading formative feedback during the course to enhance student learning and improve performance.

5.5. Principles of Formative Assessment and Automated Grading

Student grades in the capstone design course are largely determined by two factors: evidence of project progression though milestone stages (20%) and final report quality (75%). The term work (5%) is not evaluated from a quality perspective, but rather a completion perspective. Regular formative feedback to student teams is ongoing from several sources including the team itself. The major differentiating factor for student performance is the final report. Automation to reduce instructor administrative time on completion grading increases the time available for content formative feedback and benefits students.

A result of assignment and grading automation, the ability to track student development electronically during the course may be a useful formative feedback mechanism enhancing student learning, performance, and demonstration of CEAB graduate attribute progress. Immediate automated feedback for written work from a style, clarity, grammar and genre perspective could be of value to students revising written work prior to submission. Students develop deeper learning and higher level thinking skills while writing (Stout, 1997). However, written work is the most time consuming for instructors to grade. This is especially true when instructors are grading for clarity and content. Prior automated feedback on clarity and ensuing revisions would inform student learning and improve content feedback from instructors.

Current investigation has produced several options. One option, evaluation of assignment text extracts for grade level analysis utilizing script files and automatically scoring completion based on specified criteria solves the problem of administrative time but does not enhance the level of formative feedback. Another option, Automatic Essay Scoring (AES) has reached a level of maturity that it is being used for constructed response testing in medicine for both formative *and* summative grading. Research at the University of Alberta Center for Research in Applied Measurement and Evaluation in the area of AES has been ongoing for more than 5 years and work has been completed with testing agencies to implement AES. Conclusions from a 2014 paper published in Medical Education strongly support the application of AES to formative assignment feedback:

> *"Automated essay scoring…offers educators many benefits for scoring constructed-response tasks, such as improving the consistency of scoring, reducing time required for scoring and reporting, minimizing [associated] costs…and providing students with immediate feedback on constructed response tasks." (Gierl, 2014)*

It would appear the application of writing assignments to develop higher level thinking skills in large classes is nearing the reach of instructors. The social acceptance of automated essay scoring may be a barrier to implementation and should be considered carefully when determining the use of AES (Gierl, 2015). With appropriate tools instructors can develop grading criteria and provide students with formative feedback and completion grading. The entire purpose of formative assessment is learning and the application of AES to enhance the learning process may be more likely to gain acceptance. The percentage of the final mark allocated for portfolio and term project work is similar to that of problem sets – just enough to ensure students complete the work.

An AES system builds a scoring model by extracting linguistic features from a specific written-response pre-scored by instructors and maps the linguistic features to the human scores. Written work submitted by a new group of students is classified according to the linguistic features mapped in the algorithm (Gierl, 2014). Since the design course requires assignments to be submitted in electronic form, the ability to apply this technology to current assignments with minimal pre-processing is high. Natural Language Processing (NLP) is a method to analyze text using linguistics and machine learning algorithms. After considerable testing in 2012, AES is considered reliable in low stakes testing such as formative assessment and potentially even summative evaluations (Shermis and Hamner 2012).

Previously, instructor graded material and criteria for grading the summative final report could potentially be used to develop a formative computer assisted model to pre-grade various report sections as students write their final report during the term. As the main purpose of formative feedback is learning, this particular AES application need not have any grading associated with it at all. Table 5.1 shows a reflective rating of the proposed student use of AES to inform situation and final report section revision prior to summative instructor grading. (Biggs and Tang 2011) In addition, AES could be used to give feedback on aspects of portfolio and term project work that are currently completion graded with minimal instructor feedback. Again, learning would be enhanced. In the event that AES grading is not a viable option given the current state of the art, feedback to improve student writing clarity and grammar would be of value and can be accomplished with freely available on line programs such as Grammerly. Content and clarity feedback to students would be superior to clarity and style alone.

Table 5.1. Reflective Assessment Scale: Student used AES applied to Final Report Sections		
Formative	F<-------|------------------->S	Summative
Involving Students	F<-----|--------------------->S	All teacher Controlled
Using Open Ended Assessment Tasks	F<-----|--------------------->S	Using Closed Ended Assessments
Authentic Tasks	F<--|------------------------>S	Decontextualized Tasks
Criterion Referenced	F<------|-------------------->S	Norm Referenced
Using Grading Criteria	F<----|---------------------->S	Using Model Answers
Awarding Grades for Quality	F<|-------------------------->S	Awarding marks for quantity
Assessing the task as a whole	F<--------------|------------>S	Assessing Individual components of the task

5.6. Data Gathering and Management for Constructive Alignment

Assignment and assessment design based on learning objectives and using features of the LMS, customized automations, and automatic essay scoring allows for multiple pathways to meet students at their current level of development and to provide necessary feedback to support individual student development, continual course improvement, and program performance criteria. These are scalable.

LMS, AES, process and grading automations can be used to manage large classes while maintaining the quality and alignment of course objectives, learning activities and performance assessment demonstration to an accreditation body. Performance results can be analyzed to provide quality input to ongoing course improvement in addition to student opinion and satisfaction with their learning. The ability of instructors to make use of these tools is essential in large classes. They support the intellectual development of students, and enable higher-level cognitive task development while maintaining a reasonable amount of teaching and contact time. Initial development of automated assessment processes is time consuming, particularly for AES, and normally requires significant support for instructors.

The course structure determined, objectives and assessment constructively aligned, assessment methods and data gathering considered along with the student intellectual ability range determined the next step in the process was content development. The intersection of these requirements coupled with the desire for increased student engagement online and in the classroom guided the development of the learning elements from previous course materials.

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6. Creating Learning Objects for the Design Course

Learning elements typically comprising videos + supporting materials were created in two phases: the first ahead of the 2015 pilot of the course, and the second subsequent to the first delivery of the flipped course. The second phase is ongoing and includes revision to the first generation learning objects, based on feedback from students and teaching team members or reflection, and the creation of new ones ahead of the 2016 iteration of the course. Learning element creation was informed by experiences from other blended learning courses, CTL seminars, and instructor evaluation. The preparation process rapidly became a collaborative and iterative design and learning experience. Prototype learning elements were prepared and revised following feedback prior to their use by students. This was useful for determining the format that was to be used and the best tools to develop the online learning objects and is known as the Successive Approximation Method (SAM) (Allen, 2012). SAM is similar to the ADDIE method except teaching materials are evaluated and revised before being tested in the classroom. The ambition to flip all the lectures led to several time crunches in developing and producing online materials for the 2015 pilot. This has left room for further improvement of materials for use in the 2016 course iteration. Preparation of high-quality learning objects, essential for learning, is time consuming and Non-technical content issues such as audio quality, text animation, and animation in synch with script highlighting and audio links with visual cues all take time to master. This chapter focuses on an exposition of the methods used to create learning elements.

6.1. Structure of Video Based Learning Elements

Observing YouTube videos and watching recorded lectures helped the design team form opinions on effective methods. Use of recorded lectures as a content delivery method was ruled out. However, a full transcript of the 2014 lectures including question and answer periods was available. The transcript, prepared live by Louella Webber to assist a hearing impaired student, was used as a starting point for script preparation along with the existing power point slide decks. During the review of transcripts, some repetition of material was identified. This repetition was not evident during live delivery. As rapid prototypes of the videos on specific topics were developed it became clear that:

- Transcript documentation editing was necessary to produce focused scripts.
- Time compression for a 50-60 minute lecture was substantial. Equivalent online learning elements totaled 15-20 minutes even if they were based on two lecture sessions.
- PowerPoint was a useful tool for story boarding and animation development.
- Animation action on screen was needed to maintain focus on learning elements. Some animation was completed in PowerPoint and some post production using Camtasia.
- Shorter learning elements were found to be better than longer ones. About 5 minutes is optimal.

- Teaching team members are good critics. They inform revisions much like team writing and editing is more effective for producing a quality product. Editing and feedback from teaching team members allowed for rapid iterative development without student testing.
- The preparation time is high. 20 + hours for each learning object initially.
- The selection of audio/video tools impacted quality and the time required to edit/modify learning elements.

Audio quality proved particularly challenging. Learning elements were recorded using various methods, computers and microphones. It is difficult to watch to a video with bad audio. Background noise, such as computer fans, is difficult to remove and reduces overall quality. Having a proper recording area with dedicated equipment and the correct software is essential for producing high quality videos for student use. Quality counts. Attempts at using various tools for recording audio met with various degrees of success. Poor audio quality makes learning elements less effective and attractive to students. Recording issues are frustrating for instructors. Significant effort is expended in developing an engaging recording. Approximately two to three times the actual recording length can be spent recording to obtain usable tracks. Repeating the process for sound quality issues and technical difficulties wastes instructor and production time. A high quality microphone connected to the final production software is essential. File conversion of sound files between programs can cause quality deficiencies. This is not a place to "save" money in developing course materials. More time and money is required to do rework otherwise. Recording in Camtasia directly with a Yeti or gaming microphone in a very quiet location produces good results. Other options evaluated (computers with cooling fans, garage band converted to iTunes, SOM audio conversion, etc.) produced sub standard audio. Rerecording and significant additional editing were required to produce a passable audio.

Learning object videos were created for most of the tutorials. The title, length, overall time compression from the lecture delivery method and the expected student timing for use (pre or post class) with respect to the in class activity are provided in Table 6.1. Conversion of lecture materials to learning elements typically resulted in less total time to deliver the same material content, even with the inclusion of the associated in-class activity is included. Compression varied depending on the objectives for the learning element, animation and script development.

Table 6.1. Online Video Learning Elements Created for the Design II				
Tutorial Number	Learning Element Title	Length (min)	Pre/Post Class	Highlight
1	Self Managing Teams	4:19	Pre	Team use, charter development
1	Organizing your Team	6:07	Pre	Time commitment & structure
1	Team Problems & Resistance	3:51	Pre	Conflict and resolution
1	Getting Started	4:48	Post	Project process intro, initial scope
1	Total for tutorial	19:05	1:3	Compression
2	Surviving and Thriving	7:44	Pre	Overall project schedule
2	Managing & Developing the Project	5:05	Pre	Project cycle & task development
2	Critical Path Analysis	7:03	Post	Critical Path & Gantt Charts
2	Total for tutorial	19:52	1:6	Compression
3	Introduction to Sustainable Process Design	8:19	Pre	Sustainability concepts: technical, environmental, safety, economic
3	Conceptual Process Analysis	2:24	Post	Process on a page
3	Hydrocarbon Characterization	8:14	Post	Uncertainty in simulation due to feedstock characterization
3	Shale Oil Characterization	11:45	Post	Characterization of a feedstock for a process model (New)
3	Total for tutorial (excl. Shale)	18:57	1:4	Compression
3	Total for Tutorial (incl. Shale)	30:42	N/A	New material
4	Intro to Process Simulation	13:04	Pre	Case study: Methane Liquefaction
4	How a Fridge Works	4:12	Pre	You tube Video (remedial)
4	Data and Model Cross Validation	19:02	Post	Validation of simulation
4	Total for tutorial	32:06	1:2	Compression (New material incl.)
5	Chemical Reactor Simulation & Design part I	5:57	Post	Introduction
5	Chemical Reactor Sim… part II	4:11	Post	Simulation modeling: Reformer
5	Chemical Reactor Sim… part III	3:11	Post	Simulation: Methanol Synthesis
5	Total for tutorial	13:19	1:4	Compression
8	What is a PFD?	6:24	Pre	PFD description
8	What is a P&ID	3:14	Pre	P&ID description
8	Acid Gas KO PFD	3:07	Pre	AGKO as PFD
8	Acid Gas KO P&ID	6:45	Pre	Conversion to P&ID
8	Total for tutorial	19:30	1:5	Compression
9	What is a Plot Plan?	7:21	Pre	Plot plan description
9	Preliminary Plot Plan Study	4:38	Pre	Isomerization example
9	Plot Plans in Use	2:45	Post	
9	Total for tutorial	14:44	1:4	Compression
10	Energy Intensity Min.	2:51	Pre	Introduction (added)
10	HX Network Design I	9:28	Pre	Heating and cooling loads
10	HX Network Design II	5:29	Pre	Pinch analysis
10	HX Network Design III	4:07	Post	Simulator application (added)
10	Total for tutorial	21:55	1:4	Compression
11	Heat Exchanger Fouling & Corrosion	4:21	Pre	Fouling and corrosion

11	Heat Exchanger Design	7:59	Pre	Preliminary design
11	Heat Exchanger Types	9:16	Post	Exchanger types
11	Total for tutorial	21:36	1:6	Compression
17	Capital Cost Estimating BM	4:31	Pre	Factored cost estimates
17	Project Cost Estimating	9:11	Pre	Overall costs
17	Adjusting F_{BM}	8:28	Pre	Location impacts
17	Project Contingency	9:29	Post	Contingency development
17	Total for tutorial	31:39	1:4	Compression
19	Economic Evaluation of Capital Projects	5:08	Pre	Economic measures and comparison
19	Case Study Descriptions	6:13	Pre	
19	Total for tutorial	11:21	1:5	Compression
20	Project Execution Strategies	5:11	Pre	Strategy development
20	Project Execution Strategies EPC	7:11	Pre	
20	Project Labor Estim. & Planning	6:33	Pre	
20	Total for tutorial	18:55	1:5	Compression
22	Mixing in Design	5:12	Pre	
22	Mixing II – Scale up	5:17	Pre	
22	Total for tutorial	10:29	New	Compression not available

6.2. Structure of Text Based Learning Elements

Some learning objects were text based and written as a stand-alone narrative. Others were developed as companion resources for video based learning objects. The design intent was for students to watch video based material once and then access a companion reference if required while applying the materials. Companion materials typically used graphics from the video material, the script text and at times a more detailed explanation was provided. Assignments and in class activity templates were typically text based objects. Activity templates were done in MS Word so students could edit them and hand them in. Materials meant for reference were typically PDF files. Development of good supporting text resources was time consuming. Teaching material in written format was organized in a lesson format and was based on learner objectives.

6.3. Structure of Flipped Delivery Lecture

Relating Learning elements to the CEAB GAA criteria early and developing linked concepts was found to be a useful structure for some learning elements. For technical content learning elements, the ideal structure was to start with examples most students would find easy and develop more complex ideas and concepts from there. Links to more complex ideas were developed by using examples and animations in a progressive manner similar manner to that of a mentor explaining the idea. The first video was often basic, the second developed the intended application and the third might stretch some students, but had an application in their project work. In some cases a fourth video was developed for enrichment.

Table 6.2 shows the heat integration lecture conversion. As a traditional lecture, students were provided the materials ahead of time, but frequently did not look at them and required significant guidance in class to comprehend "above the pinch" heat exchanger network calculations. No evidence of performance was collected. In the flipped version, students watched three short videos, as noted in Table 6.2, performed the "above the pinch" as an asynchronous exercise and during the in class activity most students were able to complete much more challenging "below the pinch" heat exchanger network calculations and to evaluate the utility of various options. Students used more complex material, less total time, and demonstrated better learning.

Table 6.2. Heat Integration: Structure of Related Learning elements and In Class Activity

Learning Element	Length (Min)	In Prev. Lecture?	Pre/Post Class	Objective
Energy Intensity Minimization	2:51	No	Pre Class	**Introductory** - Understand reducing heating and cooling loads with simple integration examples: feed effluent exchangers
Heat Exchanger Network Design part I	9:28	Yes	Pre Class	**Conceptual** - Determine overall process heating and cooling load for a process and pinch
Heat Exchanger Network Design part II	5:29	Yes	Pre Class	**Example** related to in class work - Pinch analysis example explains how to integrate above and below the pinch and considerations for pairing streams
Heat Exchanger Network Design part III	4:07	No	Post Class	**Extension** - How concepts are used in a process simulator
Total video time	21:15	14:57	60 min	Time previously spent in lecture
Pre Class time	17:08		4:07	Post Class Time
Compression	1:4	15:60	Delivery time reduced 75% 1:4	
New Class Activity	50	No	**Solving** below the pinch - active learning with peer and instructor help completed and handed in. Previously left to students to do on their own.	

6.4. Structure of In Class Activities, Assignments and Assessment Alignment

A portfolio assignment category worth 5% of the final mark was created to ensure that assessment was aligned with the learning objectives. The learning objectives were used to create the learning elements. In turn, the learning elements were used to create the in class activities and assignments. Assignments were then "completion graded" with feedback when possible and counted toward the portfolio grade. Other assignments counted as part of the portfolio include the weekly tracking and reporting of tasks and hours, the team selection and skill development plan, the team charter, a one page initial scope and the final skills assessment. The portfolio grades align assessment with the course objectives and create an environment where assessments and course objectives are used by the students to construct learning in an environment supported by instructors acting as guides. These assessments also demonstrate progress toward or achievement of CEAB graduate attributes.

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7. Data Analysis Methods

The educational experience for students in the capstone chemical engineering design course is quite variable. Students have had different instructors with different foci for core courses; are following different subspecialties from biomedical, to computer process control, to oil sands; are following either a co-op or regular program; have taken diverse elective courses; and have had diverse industry/academic placements. Their programs of study and work experiences may also be well or poorly aligned with the design project they and their team select. It is not possible to explore this diversity in its entirety.

The chemical engineering capstone design course is one of the few courses where all regular and co-op cohorts are evaluated together *after* co-op students begin their work experience in second year. This feature is a factor that has a potential influence on student performance data and must be considered in the analysis of the flipped learning pilot because the co-op program provides a stronger experiential education, and participation in the co-op program is normally competitive. Starting in 2010, the capstone design course was reformatted to mimic the work environment of an EPC office with supporting in person lecture-format tutorials and weekly project team meetings with the same instructor providing project management support and advice. Student: Instructor (SI) ratios varied during the study period, as did the regular and co-op cohort make up and size. As noted in Chapter 2, in the period immediately preceding the flip, the average performance of students in the regular and co-op cohorts appeared similar but it is important to examine the impacts of flipping and potential causalities on both a cohort and individual basis.

7.1. Evidence Hierarchy and Study Methods

Evidence hierarchy and classification methods inform experimental design. In epidemiological studies an evidence hierarchy, as shown in Figure 7.1, is used. Randomized Control Trials (RCT) are at the top of the hierarchy for individual experimental design (Petrisor, 2007). Meta study, the systematic review of many studies, is thought to provide the best evidence (Burns, 2011). The Meta analysis of educational strategy and assessment impact on learning outcomes, discussed in Chapter 4, is an example of this type of study (Hattie 2009). Analytical study designs require specific causality to be investigated and hence are at the top of the pyramid. The highest applicable study method in the evidence hierarchy was chosen to guide analyses. The evidence-based hierarchy was used to classify the reliability and applicability of the selected analyses. The Grounded Theory of Causal Generalization as proposed by (Shadish, 2002) and based in previous education experimental design (Campbell, 1966) was used to guide causal inference and testing. The five principles suggested are: surface similarity, ruling out irrelevancies, making discriminations, interpolation and extrapolation, and causal explanation. These principles were used to guide analysis selection based on the evidence hierarchy to answer the research questions posed.

Experiments in education are often designed as quasi-experiments and can provide useful information for the advancement of research, the key difference being the lack of randomization of study groups. (Leedy & Ormrod, 2010). The ability to fully control all the study variables and to randomize study groups was impacted by the cohort selection process as detailed and examined for potential bias in Chapter 8 Section 1. The use of intact groups for this study was required (Creswell, 2005) and randomization was not possible as the study is retrospective and constrained by program requirements.

As this analysis only studies the chemical engineering design classes at the University of Alberta from 2004 – 2015, Retrospective Cohort Analysis is the highest level of analysis that can be used to determine co-op vs. regular program impact and the impact of flipped vs. traditional delivery on student performance. The lower evidence hierarchy levels are descriptive studies and they are useful for

Figure 7.1. Evidence Hierarchy of Study Types

generating hypothesis by examining trends. Ecological studies are at the top of this level and are useful when examining possible relationships at the group level. This approach will be used to examine the class averages of co-op and regular program students and to examine possible bias between the co-op and regular cohorts. It will also be used to examine possible student to instructor ratio correlation and the number of students per team and performance.

At the ecological level, statistical process control analysis concepts were chosen to assess impacts of program choice and pedagogical variance on class-average grade data for the ecological study. A multivariate comparison was completed to identify out of control points for dependent variables. Simple regression was used to examine possible correlations. Conclusions that apply to the overall success of educational strategies clearly do not extend to individual students. It is possible for a cohort to have an improved class average and yet have individual students with poor results. An ordinal data logistical regression was completed to study individual performance data for co-op and regular program cohorts and to observe cohort individual performance trends completing the ecological study.

After trends were identified a retrospective cohort analysis was completed. The regular stream students were classified as the control group and the co-op students as the test group. These groups were used to determine the overall impact of program choice on capstone performance during the study period. The last two cohorts were then compared using the 2015 flipped cohorts as the test group and the 2014 cohorts as the control group. For some analyses the 2015 cohort is compared to the 2004-2009 cohorts and the 2010-2014 cohorts. The groups were compared based on previously examined data and odds ratios for grade outcomes.

Next a case control study was used to compare the 2014 and 2015 cohorts to determine LMS use and compare effort requirements. LMS access data were sorted by team, categorized and compared for 2014 and 2015 to understand changes in LMS use between flipped and traditional classrooms. A comparative analysis of time required to complete the flipped and traditional versions and a comparison of methods is completed.

A case based study analysis of the 2015 cohort is also performed using self-assessed student perceptions, student and instructor feedback on the learning materials and on course structure. Case based studies uncover trends, patterns and lessons learned. They are used to examine situations where the diverse and complex nature of social, program, and educational outcomes cannot be attributed to a single cause. Using case studies implies that the evaluation relies on demonstrating plausible associations rather than measurable outcomes. This type of study was used to examine the flipped classroom in the published "Chemical Engineering Case Study" that can be found in Appendix B (Jamieson, Nocente, Shaw, 2015).

As there are specific data available for analysis for the average grades of the cohorts and the individual grades within the cohorts, the ecological study and the retrospective cohort study methods can be used to examine the final grade performance of students to attempt to answer the research questions. Comparative data for the shift in the student's perception of their skills relating to the CEAB graduate attributes before and after the course is unavailable making a case based examination of this data the best option. Student feedback, instructor observations, survey items and course analytics can be used to support the case based analysis and comparison of the 2014 and 2015 cohorts.

7.2. Ecological Study and Statistical Process Control Methods

An ecological study examines the relationship between exposure and outcome at the population level rather than the individual level. The groups tend to be defined by time and or by place. In this work groups are defined by both time (chemical engineering design classes between 2004 and 2015) and place (the U of A). The overall examination of the co-op and regular class performance in the context of the study population is useful to examine shifts in course structure in the context of cohort to cohort impact. The relationship between exposure to the co-op program and the outcome of capstone design performance is studied with the regular student cohort classified as the control group. The student: instructor ratio varies during the study time frame and is examined for correlation with student performance.

Final team grades are typically the same for all individuals on a team regardless of cohort placement. Some teams self-select all co-op students, all regular students, or a mix of both and teams may include one or more subprograms of study. Teams are asked to select on the basis of skills required to complete the course and not on the basis of program of study. The mix of students on teams also varies from year to year. These aspects of the study population are neither investigated nor controlled. The number of students per team and possible performance correlations are briefly examined.

The same year student cohort cannot be used to test a flipped and traditional version of the design course. Splitting a class into two randomized sections is essentially equivalent to comparing 2014 and 2015 cohorts with the exception that it is not carried out in the same time frame. Controlling for co-op and regular program cohort influence is a confounding factor that would require randomization of the two program groups at entry. As this is a retrospective study this is not possible. Comparing two program cohorts from year to year rather than a single year class split trial allows for a comparison of program results under normal course conditions. To this end, the class average for co-op students, the class average for the regular students, and the complete cohort class average are studied for all years including the flipped year.

Univariate and Multivariate Statistical Process Control methods are used to examine cohort outcomes and formulate hypothesis for further testing. As graduates are a product of the education process, studying the variability of the graduate performance is indicative of the effectiveness of the transformation process when the inherent bias and variability of the incoming cohorts is compared.

7.3. Individual Study Ordinal Regression Analysis

Ordinal regression is the method used to examine individual student performance for all study years including the flipped version. Examination of individual outcomes is first investigated using ordinal regression, and then retrospective cohort analysis is performed. Ordinal regression analysis examines the specific effects of the exposure to flipped learning on individuals and on their individual performance. Students are classified by course year in class, co-op and regular cohorts for the analysis. Student: Instructor ratio (SI ratio), course year and program choice are investigated as predictors of student outcomes. Ordinal regression is done using the final letter grade assigned to individual students. Student identifying information is not a part of the analysis. Only the student attributes of course year, grade, SI ratio and cohort. Enrico Indiogine completed ordinal regression calculation as part of the blended learning pilot project. Results are reported and discussed in Chapter 8 Section 4.

7.4. Experimental Design for a Retrospective Cohort Study

The evaluation of the question "Does being a co-op student improve capstone design outcomes?" and then further evaluation "Does flipping the course impact student outcomes?" required the design of a cohort based data analysis plan to evaluate the impact on individuals rather than cohorts. A randomized control trial (RCT) was not considered because selection of students for the co-op program is not random. Although there are some random aspects, such as the students desire to complete the program in four years rather than five, there is one feature of the selection process that fails the random test. The co-op program has limited spots and entrance is determined competitively. Although economic climate may influence students in their choice along with other personal and random factors, more often than not students with the lowest grades must accept the regular program and thus cohorts are not randomized. Further analysis was completed using retrospective cohort analysis for the entire study population to determine the odds ratio for grade outcomes for the co-op (test group) and the regular (control group) cohorts.

Table 7.1 Odds Ratio (OR) Construction to Determine Whether an Exposure is Related to an Outcome. OR=(a*d)/(c*b)

	Grade obtained (i.e. A+)	Not grade Obtained (i.e. not A+)
Exposed to co-op	a	b
Not exposed to co-op	c	d

A retrospective cohort study data analysis fits this type of group selection criteria as the groups are only observed in the study. No specific intervention is offered to one group and not the other from a design course teaching perspective. The specific intervention offered to the co-op cohort and not the regular cohort is the experiential learning in the form of industry work terms as a natural consequence of grouping. As such this intervention can be evaluated in this type of a study by investigating performance differences between the cohorts.

Intervention is offered in specific years in the form of course design changes to both cohorts at the same time. Although instructors certainly made efforts to assist all students no specific intervention was offered to a specific group of students to assist them in their efforts to obtain higher grades in all years. Interventions offered to student cohorts have taken the form of course design (2010), reduction of student/instructor ratio (2010, 2013), increasing and maintaining contact time throughout the term (2010), the flipped pilot (2015), improving feedback and assessment techniques (2013). These interventions were offered to both the co-op and regular program students so their effects must be analyzed as a secondary impact to the co-op regular program cohort effects.

RCT, cohort studies and case control studies are all analytic study designs and although RCT is at the top of the evidence hierarchy the data collected and the observational nature of this study lend themselves to a retrospective cohort study, the third level of the evidence hierarchy illustrated in Figure 7.1. A cohort study allows causality to be addressed using odds ratios (OR) in a defined study population (table 7.1). For this study we define our study population as the students completing first year engineering accepted into the Chemical Engineering undergraduate degree program between 2004 and 2015. The students are divided into two groups based on "natural causes". The study does not create the exposure but a system that is not under the control of the analyst does. This "natural cause" is rule based and is a selection process that is consistent from year to year. It can be relied upon as a process that is objective to the study analyst. The two groups studied are co-op and regular and the impact of the exposure to co-op on capstone design grades for cohorts from 2004 to 2015 is studied. The impact of the course design, the student to instructor ratio change in 2010 and the course flip in 2015 are considered as subsets of the analysis. An investigation of the cohort characteristics is presented in section 8.1.

7.5. Experimental Design for a Case Control Study: Time and Effort

The LMS student access data were available for the 2014 lecture and the 2015 flipped versions of the design course. This allowed for a case control study design. The 2014 cohort is the baseline or control group access and the 2015 is the case study access. The purpose of this study is to determine the relative frequency of student access to the flipped course material, especially pre class learning element material. The access to this material was of interest as it was previously delivered in the lecture format and counted as accreditation units. In the process of converting the material, time compression was observed and as such a time analysis was completed for pre class and in class activities for 2015 and compared to the 2014 baseline or control year. The purpose of this study is to determine if flipping impacted student time commitment or effort requirements for the capstone design course.

7.6. Case Study Design: Student Perception of Competencies

Online data available for considering student pre and post course self assessed perceptions was only available for the 2015 version. An analysis of the CEAB graduate attribute skill assessment using pre and post course student data is presented and these self-assessments are examined for perception shifts. For the 2014 version the students assessed slightly different skills pre course only as an input to team selection. The design for this data analysis is a case study as the data is not comparative to other years and the study time frame of interest is over the term the course was offered. Comparison with the pre course results from 2014 would give a cohort to cohort comparison for entry in to the design course but would not allow for any conclusions to be drawn as the changes the students perceived in their competencies as a result of their last chemical engineering term.

The results of this comparison should be interpreted in the context of the student perception of themselves at the beginning of term 8 and at the end of term 8. The resultant change in their perception of their skills may have been caused by other course activities and events of their final term. The design course is one of several causalities of student development in the final term. The survey as designed is unable to distinguish the causality of the perception change only where the shifts are observed and to identify areas where greater progress may be achieved in future program and design course iterations.

7.7. Case Study Design: Student Material Access, Feedback and Observations

Case studies for specific tutorials were conducted for student access to specific materials and the frequency of the access by team. Enrico Indiogine, as part of the blended learning project, plotted heat maps and frequency access diagrams. Analysis of the heat maps and frequency access is found in Chapter 8. Additionally students provided feedback on aspects of the pilot they liked and did not like. Instructors provided feedback on what they perceived as more and less effective and student response to assignments and behavior during the term. Some was in the context of comparison to previous experiences for both students and instructors.

7.8. Summary of Studies and Evidence Levels

The highest evidence level possible was chosen for each study performed in order to have the best quality results. The cross section of studies, summarized in Table 7.2, provides depth to the analysis and corroboration from varying perspectives. The ecological studies measure the grade performance of the groups and investigate possible causality for the observations. The retroactive cohort studies attempt to quantify the impact of the flipped classroom after examining the co-op and regular program performance differences. Case based studies examine perceptions, time requirements and resource usage comparisons.

Table 7.2 Study Summary	
Evidence Level	**Study Description**
Ecological Study	Cohort Comparison
Ecological Study	Regression analysis for hypothesis testing
Ecological Study	Statistical process control analyses
Ecological Study	Ordinal regression
Retrospective Cohort Study (observed natural groupings)	OR comparison of grade performance between co-op and regular cohorts
Case Control Study	LMS access data and time required analysis for flipped and traditional lecture methods
Case Study	Comparison of student skill perception 2015
Case Study	Lessons learned
Case Study	Student and instructor feedback and observations
Case Study	Access to tutorial material by team and time

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8. Results and Discussion

The individual study and analysis methods detailed in Chapter 7 are applied to the study group with the goal of understanding impacts of blending instruction in the capstone design course (CH E 435/465) on student performance. The academic abilities and achievements of students in the study group are characterized by their previous academic performance: admission to the Faculty of Engineering, as lowest accepted performance; chemical engineering program admission GPA, adjusted for course weighting after first year engineering; and their capstone design course mark. Students are separated into co-op and regular student cohorts for the study and examined as a graduating class and separate cohorts. Regular students in the regular four-year engineering program complete first year engineering a year after the co-op student cohort. The co-op student cohort completes 20 months of industrial work experience as part of their program. Impacts of direct admission into the second year regular program from the Faculty of Science at U of A or elsewhere, a small number of typically well-qualified students, and students dropping out of the co-op or regular programs, or deferred for a time are ignored.

8.1. Ecological Study: Cohort Examination

Capstone cohort class average performance is shown in Figure 8.1and program entry average GPA performance is shown in Figure 8.2 for comparable graduating cohorts. Variance for all cohort means is shown in red. In addition, variance for 2004-2009 grouped cohorts and post 2010 cohort variance shifts

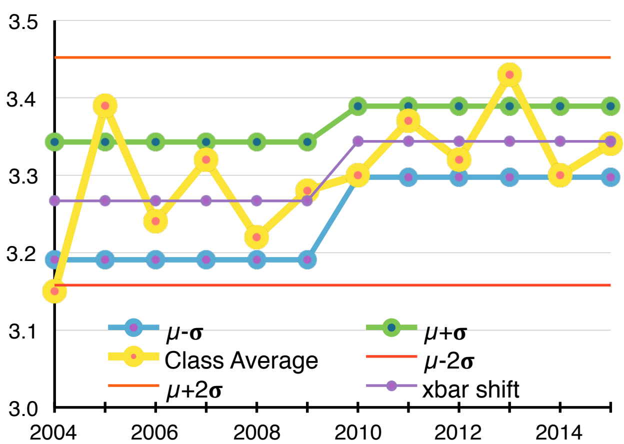


Figure 8.1. Complete Cohort Capstone Final Mark 2004-2015

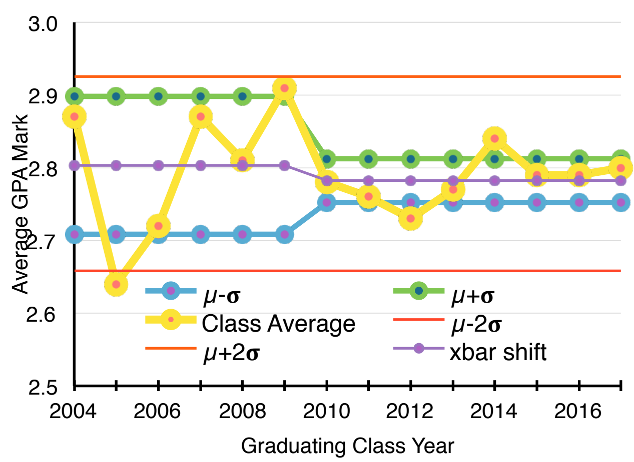


Figure 8.2. Complete Cohort Entry GPA 2004-2017.

are studied within specified time frames. Post 2010 observed class average variance is less for capstone and entry average cohort performance combined for graduating year, however no significant correlation between overall capstone cohort performance and average entry GPA performance is observed (R^2=0.2). Correlation for co-op cohort entry and capstone performance R^2=0.02 and regular cohorts R^2= 0.06 is even less likely. Post 2010 capstone average performance shows a minor increase while the entry

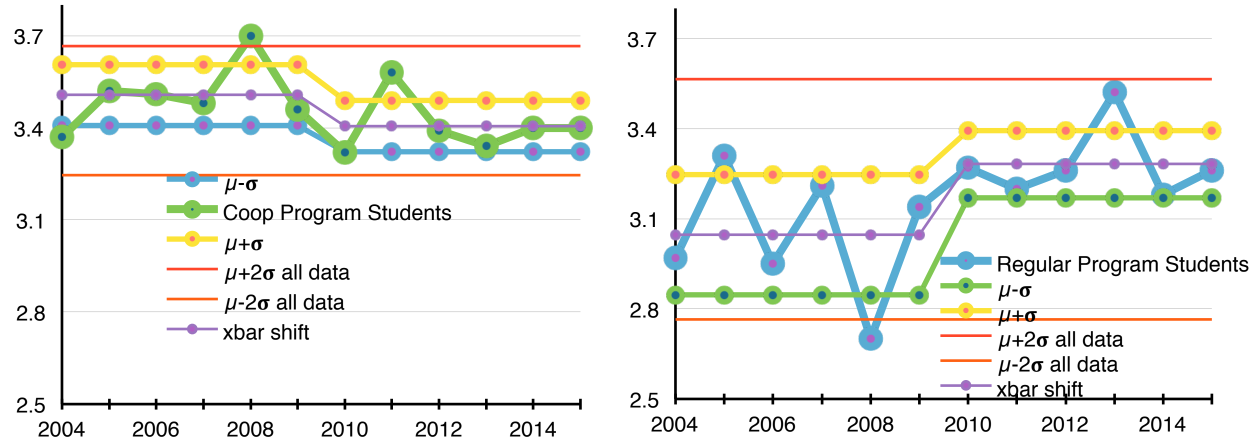


Figure 8.3. (a) 2004 -2015 Coop cohort higher mean, lower variance, similar for both time periods

(b) 2004-2015 Regular cohort lower mean and higher variance for 2004-2009 and reduced post 2010

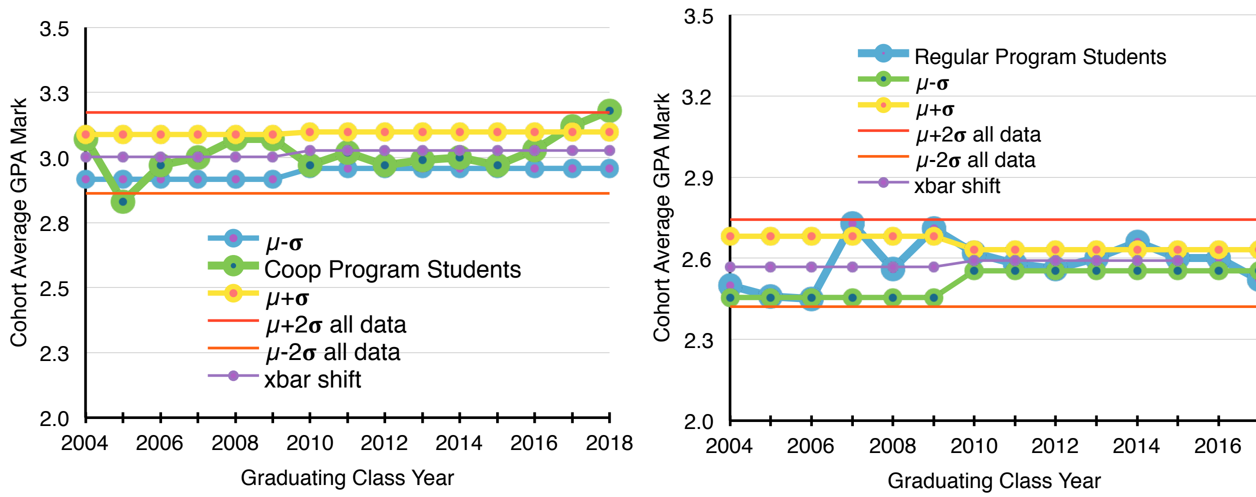


Figure 8.4 (a) Coop program cohort entry average GPA for Graduating Classes 2004-2018

(b) Regular program cohort entry average GPA for Graduating Classes 2004-2017

average does not change significantly. Figure 8.3 demonstrates differences observed in co-op (a) and regular (b) cohort capstone performance during the study period. Figure 8.4 illustrates cohort entry GPA variance according to capstone/graduating year. The Co-op cohort has a higher and less variable entry average. This observation extends to the capstone design course performance. Post 2010, Co-op entry and capstone performance show some correlation (R^2=0.6). The regular cohort has a lower and more variable entry average than the co-op cohort and shows no significant performance correlation. Using all study years, performance variation for both cohorts increases in the capstone course to near double for co-op and regular cohorts when viewed separately.

Table 8.1. Program Stream Class Average Variability at Entry and Capstone								
Data type	Regular Program		Co-op Program		Class Average		GAP Co-op – Reg.	
Time	Mean	Std Dev of Mean	Mean	Std Dev of Mean	Mean	Std Dev of Mean	Mean	Std Dev of Mean
Entry 2004-2015	2.57	0.07	2.99	0.04	2.79	0.07	0.42	0.08
Capstone 2004-2015	3.16	0.15	3.46	0.09	3.31	0.06	0.29	0.2
Entry 2004-2009	2.57	0.10	3.00	0.07	2.81	0.08	0.43	0.09
Capstone 2004-2009	3.04	0.17	3.51	0.07	3.27	0.06	0.46	0.21
Entry 2010-2015	2.60	0.02	2.99	0.02	2.78	0.02	0.38	0.03
Capstone 2010-2015	3.28	0.08	3.41	0.06	3.34	0.04	0.123	0.125

These cohorts are compared using entry averages to determine inherent bias due to the program selection process. Program selection is based on student request combined with first-year academic performance. Figure 8.5 illustrates the current trend to increased competition for co-op program entrance and the corresponding regular cohort negative trend. After 2010 program entry GPA variability is less and GPA gap between programs is consistent. GPA gap is not a predictor of class capstone performance *on average*. For classes graduating in 2016-17 the gap is higher but does not impact the study period.

A comparative analysis of program entry GPA and capstone results for regular and co-op cohorts is reported in Table 8.1. Other than in first year, class average performance is not a useful cohort comparison because co-op and regular cohorts are separate during the majority of their chemical engineering undergraduate program. The class average for each course tends to be relative to the cohort evaluated rather than between cohorts because averages are normed. Capstone class averages tend to be about 3.3 regardless of the mark distribution with a variance

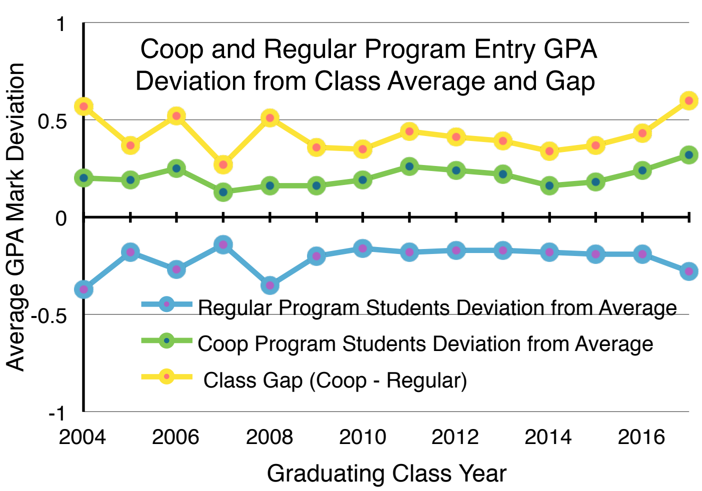


Figure 8.5. Variation between Coop and Regular Cohort

of about 0.06. No significant change is observed for the capstone class average during the study period. The class average for entry GPA is also relatively consistent over this period at about 2.8, however data variability was higher prior to 2010.

Faculty of Engineering minimum entrance requirements for Alberta students is shown in Table 8.2, an increasing trend is observed for first-year engineering admission at the U of A in recent years.

Table 8.2. Faculty of Engineering Entrance Minimum High School Average (Data provided by the Faculty of Engineering)

Admission Year	**Mark (%)**	**Graduation Year**	**Co-op Graduation**
2000	79	2004	2005
2001	78	2005	2006
2002	80	2006	2007
2003	80	2007	2008
2004	80	2008	2009
2005	80	2009	2010
2006	80	2010	2011
2007	80	2011	2012
2008	80	2012	2013
2009	80	2013	2014
2010	80	2014	2015
2011	80	2015	2016
2012	81	2016	2017
2013	83 AB	2017	2018
2014	85 AB	2018	2019
2015	85 AB	2019	2020

Previous the lowest accepted mark was stable at about 80% for nearly a decade and for much of the study period. This would seem to indicate a high academic quality of all students entering the first year program in general. Yet some students struggle in first year and GPA results impact program selection and cohort placement. It is apparent that all students within the regular and co-op cohorts in chemical engineering are drawn from top high school performers in the requisite subjects. There is a slight academic cohort bias as students more successful at adapting to the fast paced and heavily loaded first year tend to be in the co-op program. As described in Figure 8.5, an academic performance bias between co-op and regular cohorts at entry is ~ 0.4 for graduation years 2010-2015, but fluctuates between 0.2 and 0.5 for graduation years 2004-2009. The grade gap for the capstone course is typically 0.2 or less for 2010-2015, but fluctuates between 0.2 to 1.0 between 2004-2009. The selection and types of students entering each cohort after first year may have an impact on the capstone performance. However, other factors impact final outcomes as evidenced by the entry and capstone data comparison (Table 8.1).

Figure 8.6(a) demonstrates the ranges for course weight adjusted average GPA at program entry by cohort graduating year. Figure 8.6(b) illustrates the variance within individual cohorts by graduating

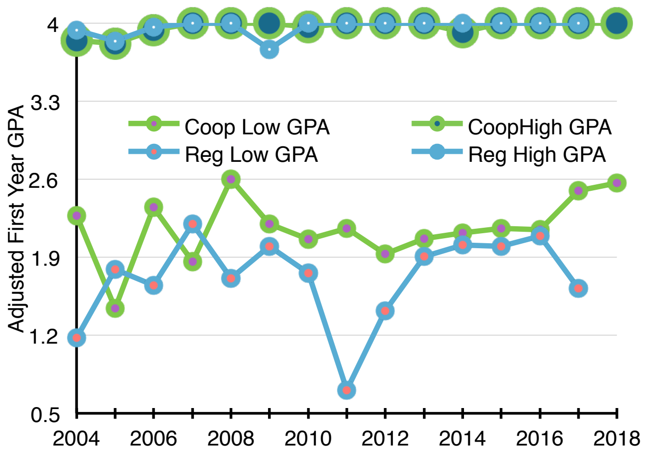


Figure 8.6 a. Coop and Regular Adjusted Entry GPA Ranges

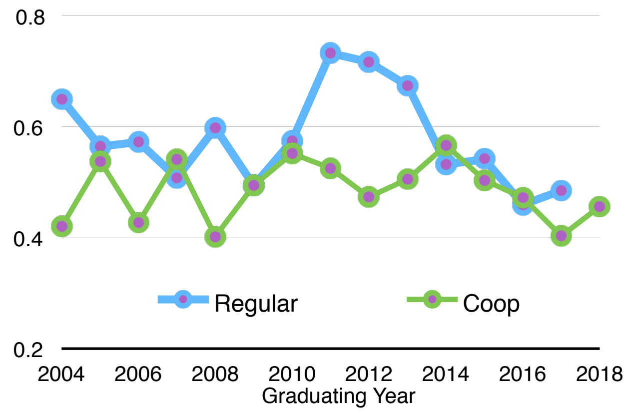


Figure 8.6 b. Entry GPA Variance within Cohorts

year. All cohorts in the study period 2004-2015 have a similar GPA range. The variance within regular program cohorts has a tendency to be higher (0.5-0.75) than co-op (0.4-.0.55) and the average for co-op cohorts tends to be higher.

Circumstances surrounding individual entry GPA results and program path are unknown in this study. Both cohorts are observed to have students with high to low academic standing at program entry. However, all students had high academic standing at initial faculty admission. The lowest adjusted GPA average for both programs is typically 2.0 for both cohorts at entry. Regular cohorts tend to have a lower program entry average for all study years and higher variance within the cohort grouping. At the time of capstone summative assessment, co-op cohorts have an additional year of experiential education compared to the regular cohorts. Although co-op and regular program cohorts both have excellent admission credentials, first year performance variability is higher for most regular cohorts. Students with the lowest academic performance are typically in the regular cohort, but for many cohorts the difference is the number fraction of lower performers rather than their quality. For cohorts prior to 2008, students with a lower GPA had the possibility of choosing co-op. Cohorts after 2008 have consistently had a higher cut off than observed for the regular program.

Studying co-op and regular cohorts separately to better understand pedagogical decisions and work experience with its potential resultant intellectual developmental impacts on capstone performance is required. Findings based on group outcomes do not apply at the individual level and are useful only for assessing overall impacts of educational strategies on average performance or on a comparison of average performance between cohorts to examine potential bias between the groups. Initial analysis indicates design course changes in 2010 had a positive impact on regular cohort performance and no significant impact on co-op cohorts. Co-op and regular program cohort performance analyses are completed separately to understand if pedagogical strategies impact cohorts differently.

8.2. Ecological Study: Student Instructor Ratio, Team Composition

Additional factors identified as having potential to impact overall student performance are student to instructor ratio, instructor loading, student workload, team cohort composition, and the number of students per team. These factors are examined to varying degrees depending on available data, time constraints, and preliminary performance correlations identified. Tables 8.3 and 8.4 describe actual capstone design course scenarios for students and instructors during the study period. The number of projects per instructor impacts students from two perspectives: the quality of advice as the instructor has more background work to complete for additional unique projects, and the quality of final assessment as the instructor has more reports to mark individually and less double marking is feasible.

The number of students per team is included in the tabulated data and compared with average performance and specific team performance. No correlation was found with student team size and performance. Often teams were mostly six or mostly five members in a given year. In years where there were only a few six member teams they did not outperform five member teams consistently. Team size may or may not be an advantage depending on observed team composite ability, cohesion, and organization. Data was compared for cohorts during the study period. Similar results were found for all cohorts examined.

Table 8.3. Design Course Scenarios 2010 – 2015

Year	2010	2011	2012	2013	2014	2015
Number of Students	129	143	126	129	123	127
Number of Instructors	3	3	3	5	5	4
Number of Teams	22 21(6)+1(3)	24 23(6)+1(5)	22 16(6)+6(5)	24 9(6)+15(5)	24 3(6)+21(5)	25 2(6)+23(5)
Number of projects/ instructor	7.3 1(6) +2(8)	8 3(8)	7.3 1(5)+4(6)	4.8 1(4)+4(5)	4.8 1(4)+4(5)	6.25 3(6)+1(7)
Student/ instructor ratio	43.0	47.7	42.0	25.8	24.6	31.8

Table 8.4. Design Course Scenarios 2004 – 2009						
Year	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Number of Students	96	81	89	101	131	119
Number of Instructors	2	2	2	2	2	2
Number of Teams	24 24(4)	16 16(5)+1(1)	18 16(5)+2(4)	17 1(5)+ 6(6)	26 1(6)+25(5)	24 23(5)+1(4)
Number of projects/ instructor	12 2(12)	8 2(8)	9 2(9)	8.5 1(8)+1(9)	13 2(13)	12 2(12)
Student/ instructor ratio	48.0	40.5	44.5	50.5	65.5	59.5

Analysis of an observed co-op regular cohort capstone grade gap and SI ratio during the study period yields a linear correlation with R^2=0.67 indicating correlation as illustrated in Figure 8.7. By contrast the number of students on a team compared to the more variable regular cohort average (Figure 8.8) shows no dependency on grades or gaps with R^2=0.01, and this factor was not pursued further as a plausible explanation of performance variation. Instructor loading was initially studied as the number of projects per instructor. As with student loading, this is difficult to quantify with a single measurement. Instructor project loading was found to vary with grade gap in the same manner as student: instructor ratio and was

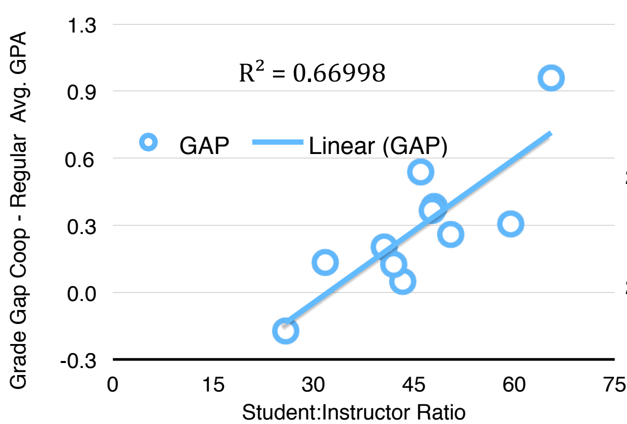


Figure 8.7. Grade gap dependency on student:instructor ratio.

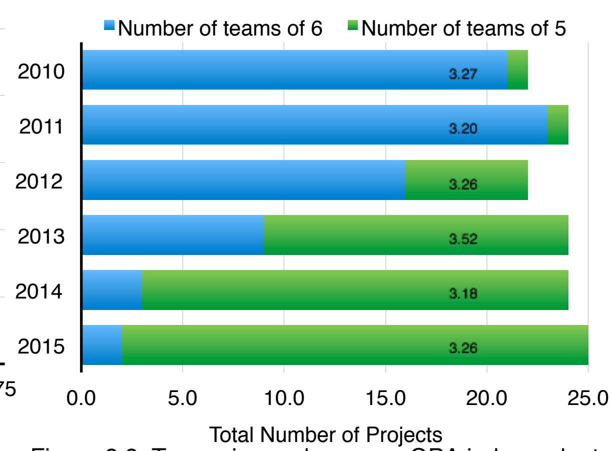


Figure 8.8. Team size and average GPA independent compared to regular cohort average 2010-2015

correlated with SI ratio, since SI ratio showed a higher correlation with grade gap, it was chosen for additional investigation.

Further comparison of cohort grade gap performance (Figure 8.5), student instructor ratios and project instructor ratios as shown in Tables 8.3 and 8.4 suggests an optimal number of about 30-36 students per instructor depending on the number of students per team. Depending on other duties or commitments, the optimal number of projects per instructor appears to be between 5 and 6. This allows for many of the projects to be double marked and other duties to be accomplished. Figure 8.9 demonstrate the results of double marking for recent cohorts achieved within the grading window.

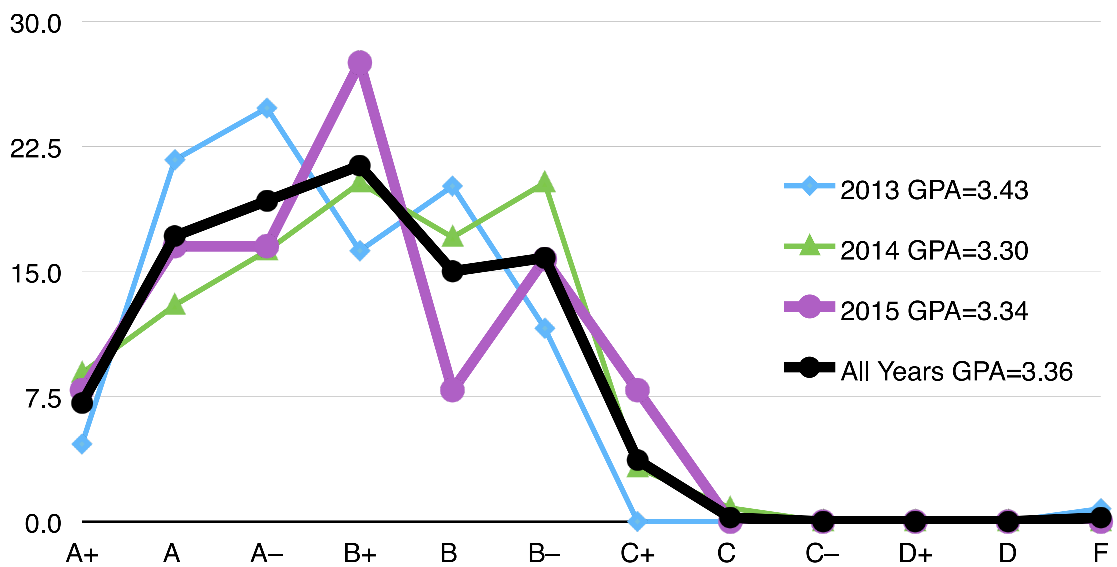


Figure 8.9. Final Grade Distribution and Class Average GPA 2013 - 2015

8.3. Ecological Study: Application Statistical Process Control Analysis Principles

Starting in 2010, newly developed in person lecture-format tutorials were provided in two hour blocks twice weekly to support student progress at various project stages. Weekly project team meetings with a specific instructor assigned to the project followed and the structure of the course moved closer to mimicking a real world design office. Team and project management supports were put into place and the SI ratio decreased. These changes form the rationale for separating the Statistical Process Control (SPC) analysis into two parts. The design course education process had been changed significantly. This is comparable to modifying a production process. One would expect the product to be impacted by the change and the measurement data could be viewed on separate control charts or with shifted upper and lower control limits. Hence the two time frames are 2004-2009 and 2010-2015. The overall control limits for all the data are calculated and compared to the split time frames to determine the impact of post 2010 changes on co-op and regular cohorts. The rationale for splitting the entry GPA data into two time frames is to investigate the possibility of impacts to the program selection process including shifts in the popularity of chemical engineering as a selected discipline. The flipped course version is included in the latter time frame as this process change is being investigated in the context of whether or not the process remained in control despite the disturbance of flipping the lectures.

The type of data collected for regular and co-op cohort average grades in the capstone chemical engineering design course is periodically collected data. The subgroup size is not independent of the choice of subgroup frequency. The "sample" size is dictated by the year the data are collected and several observations cannot be collected for the time frequency. For this reason, the average data is treated as periodically collected data and the XmR charting method (average moving range) is used for analysis. It is frequently the most sensitive type of chart for this type of data. (Wheeler & Chambers, 1992) It is also a slowly changing process. It takes four to five years to move through the undergraduate program and implemented changes are measured on a yearly basis. The logical subgroup size is n=1 as each measurement represents one "batch" and the measurements are widely spaced in time as one class per year. For this study the upper control limit is defined as:

$$UNPLx = Average + 2.66(AvgMR) \tag{1}$$

and the lower control limit defined as:

$$LNPLx = Average - 2.66(AvgMR). \tag{2}$$

The multiplier of 2.66 is 3.00 divided by 1.128, where 3.00 is the number of standard deviations that describe the typical variation of a normal distribution and 1.128 is the value for the bias correction factor. (Wheeler & Chambers, 1992) This is an estimate of the natural process limits and can be used to predict what a stable process is likely to produce in the future. A stable process is one where observed data points reside within the upper and lower control limits. Clearly, a disturbance introduced to a stable process may produce a result outside these limits hence the point would be considered to be out of control and of interest to investigate the causality of the disturbance. Previous examination of the data indicates the majority of the observation fall within two sigma of the mean for all cases indicating a stable process for both capstone design performance and program entry. These limits are translated to the multivariate analysis to determine the expected control ellipse for the process with dependent variables. Points outside the ellipse are classified as out of control even if they are in control for the single variable analysis.

The analysis is summarized in Figure 8.10 for the capstone cohorts and Figure 8.11 for the same cohorts at program entry. On average the summation effect of 2010 capstone design course changes had a positive impact on regular program students and minimal or no impact on co-op program students. In addition, changes made to the pilot flipped version in 2015 show no significant impact to either co-op or regular cohorts average performance based on the study population and time frame.

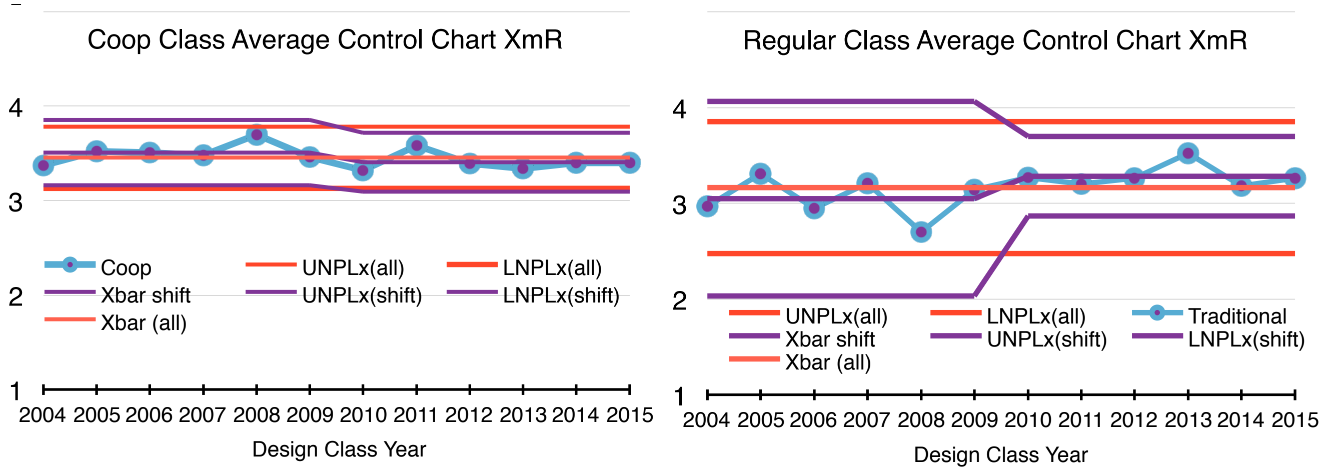
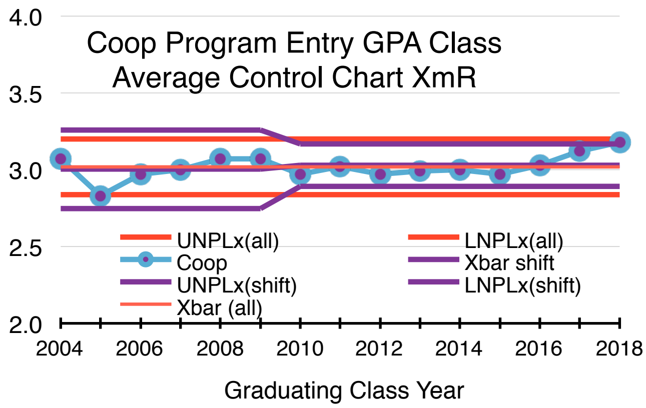


Figure 8.10. (a) Coop Cohort XmR Analysis (b) Regular Cohort XmR Analysis

For the co-op cohorts, Figure 8.10(a) demonstrates the control limits for all data points and the control ranges calculated based on the 2004-2009 and 2010-2015 times frames are not significantly different. The educational process changes made in 2010 and 2015 did not have an impact on co-op cohort average performance. By contrast, Figure 8.10 (b) demonstrates a shift in the control limits from 2004-2009 to the 2010-2015 period. Although all points are within the control limits calculated for all data points, the inherent process variation is changed post 2010. For the capstone course the regular program average demonstrates a shift up along with the reduced cohort-to-cohort variability. For the regular cohort entry data shown in Figure 8.11(b), the cohort-to-cohort variance is reduced, but there is no shift in the mean. There is an observable positive impact on regular program capstone performance not observed in the entry cohort data for post 2010 changes and no impact observed for 2015 changes *on average*.

In Figure 8.11 the entry program cohort analysis shows minimal variation for both the co-op and regular programs. Typically the entry average is 3.0 for co-op cohorts and 2.6 for regular cohorts. There is a slight reduction in program entry average variability after 2010 for both groups. This reduction is more significant for regular program cohorts. Observed regular cohort entry GPA variability significantly increases in the capstone design course from 2004-2009. Post 2010 it more closely resembles capstone cohort variation. Entry cohort variability is carried through to the capstone design course performance.



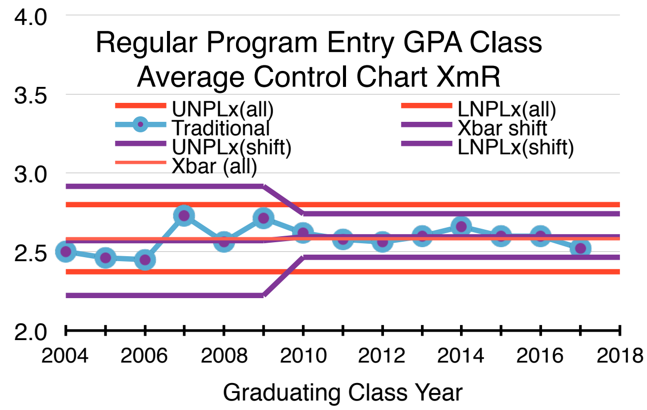


Figure 8.11. (a) Coop Program Entry GPA (b) Regular Program Entry GPA

However, the variability is reduced post 2010 for both entry and capstone data for the regular cohort. No significant changes are observed for the co-op cohorts.

The observed entry variation may reflect available chemical engineering positions consistently being filled with less variable cohorts for co-op and regular as observed in Figures 8.6 and 8.7. For graduating classes between 2010-2014 corresponding entry cohort data indicates a higher variability within the regular cohort for a similar range with a lower mean. Typically this indicates more students with higher averages are choosing the regular program at this time. The reverse of this is true for the graduating classes of 2017 and 2018 where more students with higher entry GPA's are choosing co-op.

In the preliminary analysis, section 8.1, a hypothesis was formed that there might be a relationship with SI ratio. When SI ratio is above a certain point, instructors are not as able to provide consistent quality and quantity of feedback and project monitoring to all students. Regular program students appear to suffer more than co-op students under these circumstances.

The co-op cohort average and the regular cohort average are thought to be independent variables. There is some evidence in the preliminary analysis to suggest this may not be entirely accurate going forward. There appears to be a trend shown in Figure 8.11 toward the co-op entry average increasing and a corresponding decrease in the regular program average. Coupled with the enrolment trend shown in Figure 2.1, pressure on the existing program instructional systems/practices and processes can be anticipated. The variables are only independent if the number of co-op positions available is more than the demand for those positions. This may vary from year to year, adding complexity to the study. For most study years the cohort averages are stable and are used in a multivariate analysis to confirm relationships. Figure 8.12(a) shows the multivariate analysis of the capstone cohort relationship revealing two out of control points. The control ellipse is estimated based on the xy scatter plot of the points and previously calculated upper and lower control limits. (Shah, 2015) The control ellipse can be rigorously

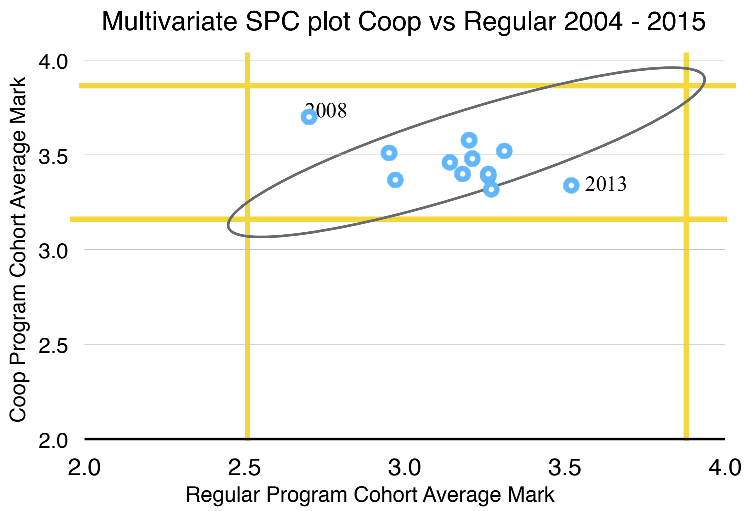
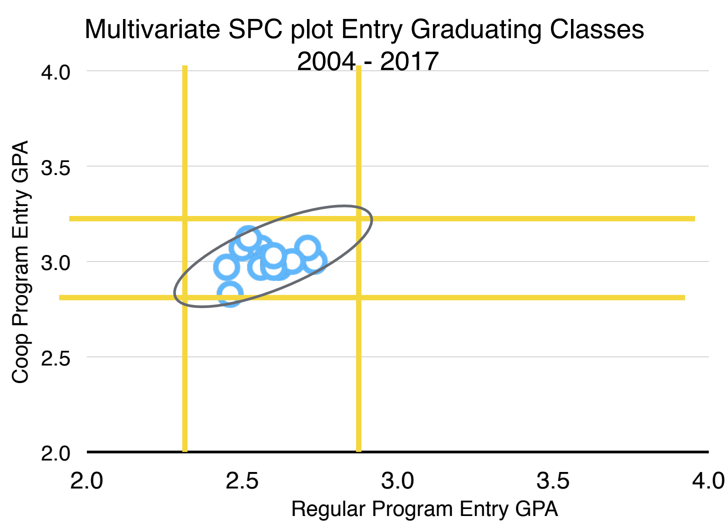


Figure 8.12. (a) Capstone Design Cohort Relationship

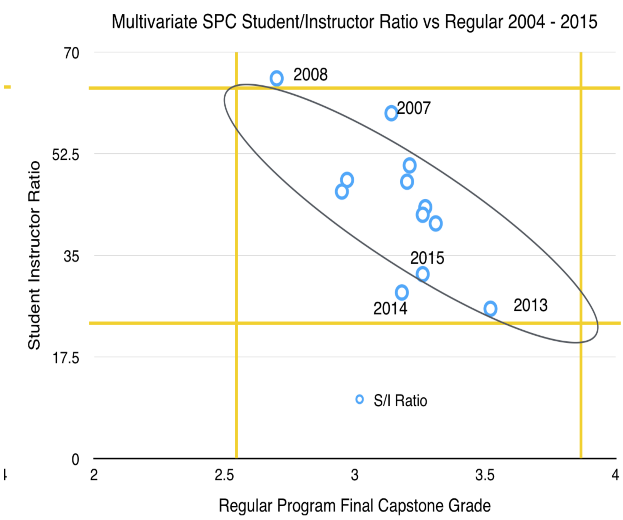
calculated for specific confidence intervals (Kourti & MacGregor, 1996) but this is beyond the scope of the analysis. The results from 2008 and 2013 are outside the expected region. In 2008 capstone co-op class average was unexpectedly high and in 2013 the regular class average was unexpectedly high. In 2008 there were only two instructors for a very large class, supporting the SI ratio hypothesis. In 2013, a higher than expected failure rate in a prerequisite class, highlighted another potentially related factor: program impacts. Both 2008 and 2013 had potential causalities for observed anomalies in the cohort relationship. Figure 8.12(b) illustrates the comparative variability of cohorts at program entry. No out of control points are observed providing further evidence causality resides within the capstone course transformation process or the undergraduate transformation process and is not only a result of initial cohort bias. Observed variance at the capstone level is significantly higher indicating that the capstone course and/or prerequisite courses can act as amplifiers. Higher variance is observed with the 2004-2009 course designs than the 2010 -2015 course designs. Repeating the analysis for 2010-2015 capstone and entry cohorts reveals less variability. However, the 2013 capstone regular average remains an exception.

The 2013 regular cohort succinctly illustrates the process nature of education. A disturbance in a previous course causes a disturbance in the measurement of the following course. The undergraduate program itself is integral to capstone performance. As students "flow" through the program, individual perquisite course results and disturbances impact "downstream" courses taken later in the program. The



8.12(b) Cohort Relationship of Entry GPA All Study Years

2010 capstone program changes demonstrate process modifications can impact the performance observed. As education is a process, it can be designed, monitored, modified and improved. Concepts from Statistical Process Control can be applied for analysis and determination of limits and hence exceptions can be identified. Monitoring of the education process with a process control mindset can help identify causes of variation and impacts of process modifications on student performance.



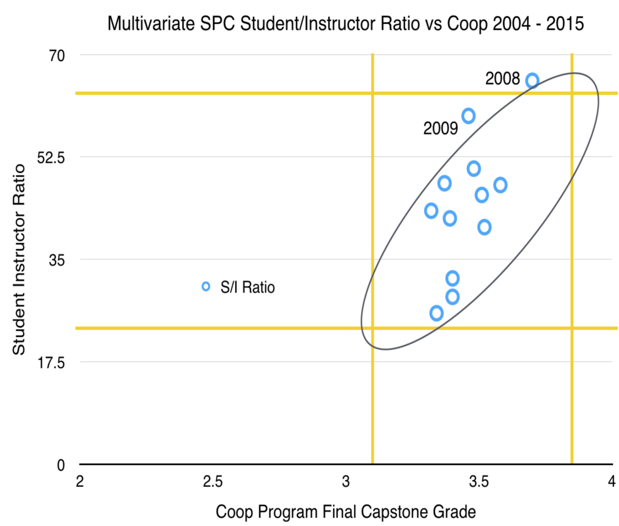


Figure 8.13 MVSPC Student: Instructor Ratio Relationship with Cohort Performance.

Figure 8.13 illustrates multivariate analysis of student instructor ratio vs. cohort performance. Co-op cohort analysis reveals an additional high student: instructor ratio, 2009. In this case, the co-op cohort performed worse than expected if only student instructor ratio impacted performance. Further investigation into plausible causes reveals the regular cohort entry average and cohort variance was nearly identical to the co-op cohort entry GPA for 2009. Although there was a reduction in total projects from 26 the previous year to 24, aggregate regular program student ability may be a plausible explanation for the observed outcome (Figure 8.11b). Although both 2009 co-op and regular entry cohorts are similar (Figure 8.11), on average co-op students performed better than the regular cohort. Regular capstone cohort and SI ratio multivariate analysis revealed 2007 and 2008 as anomalies. SI ratios were high both years. However the 2007 cohort performed better than expected indicating another possible influence. The regular cohort entry average is again higher than average providing a plausible explanation. This analysis supports the hypothesis that student performance is impacted by SI ratio but co-op cohorts experience a lesser impact than most regular cohorts and the impact for co-op cohorts is positive. As the average grade changes little from year to year (Figure 8.10) a potential explanation for the differential impact is: on average, student intellectual development as classified by Perry's schema (Table 4.1) is at a different stage for co-op students; student instructor ratio impacts cohorts differently as they have different feedback needs while attempting the same cognitive tasks. Occasionally, regular cohorts with higher entry performance characteristics match co-op performance *on average*.

The course model change in 2010 to mimic an EPC office was implemented in the same manner for co-op and regular cohorts and appears to have had a larger positive effect on average regular cohort performance – the intended outcome. It is difficult to separate and quantify the relative effectiveness of the real world environment and the subsequent improvement in feedback to students without designing experiments to test outcomes for each individual change. Consequently, the analysis is based on plausible causes for observed changes in measured data. Educational practice effect size (Hattie, 2009) can help support plausible causes. Given that formative feedback, spaced vs. mass practice and metacognitive strategies are ranked as the highest effect classroom strategies (Hattie, 2009), it is plausible that post 2010 course changes implementing greater feedback, progress monitoring and evaluation/reflection activities impacted the regular cohort performance. It is also plausible the co-op cohorts demonstrate different support needs based on intellectual development for completing the same cognitive tasks.

From this analysis the impact of flipping the lectures on the co-op cohort is negligible (Figure 8.10a) for similar reasons the impact of the 2010 changes on co-op cohort average performance are negligible. There is a small positive impact observed between the 2015 and 2014 regular cohort class average performance. This change is within the anticipated variability of performance (Figure 8.10b).

Entry cohort average variability is lower than capstone average performance variability for both co-op and regular cohorts (Figure 8.11). Capstone performance variability has decreased significantly post 2010 and plausible causality for perturbations is proposed. Program of study entry indicators of student performance are not highly correlated to capstone results. Post 2010 Co-op cohort entry and capstone performance shows significant correlation, while the regular cohort performance does not. Regular cohort individual student membership may have a change pattern not investigated in this study.

Flipping the design course in 2015 had no impact on co-op or regular cohort performance at an ecological study level.

High SI ratio has a significant negative impact on regular program cohort performance relative to co-op cohorts. Follow up study on pre course student intellectual development differentials between cohorts and potential impact on capstone design performance could be of interest in developing course activities to support further intellectual development. Utilization of the high impact methods identified in the Hattie 2009 meta study may further support this development for both co-op and regular program students.

8.4. Ordinal Regression Analysis: Impacts on Individual Students

A polychoric model of individual final grades considering the impact of the student instructor ratio, co-op vs. regular program, and the blended program is presented in Figure 8.14. At higher SI ratios the plot density shows more regular program students (co-op=false) with lower grades and at low SI ratios the frequency of low grades is significantly reduced for all students. Program entry data is not included.

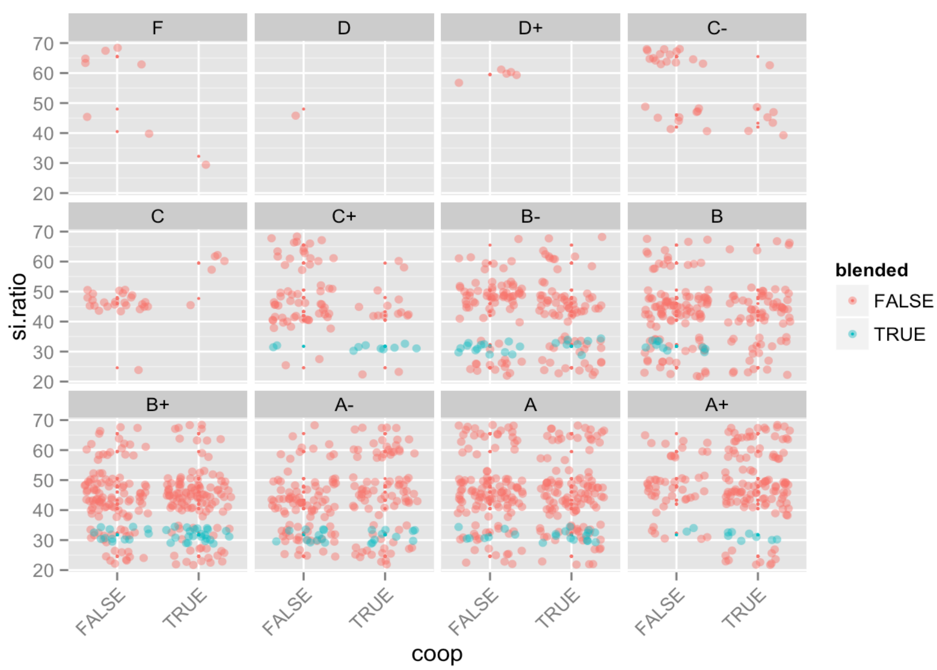


Figure 8.14. Individual student performance vs. S:I ratio (2004-2015). (Plotted by E. Indiogine, 2015)

Notes:

- Individual students are shown as red dots for all study years from 2004 – 2014
- Flipped pilot course students are shown as blue dots for 2015
- Regular program students: co-op =false
- Co-op program students: co-op=true
- Students are classified in grade bins for all study years

Figure 8.15. 2004-2009 Individual grade performance vs. SI ratio and program (Coop=blue, Regular=red) (Plotted by E. Indiogine, 2015)

Notes:

- Individual regular program students are shown as red dots for study years indicated.
- Individual coop program students are shown as blue dots for study years from 2004 – 2009
- Students are classified in grade bins for study years – scatter is for presentation clarity.

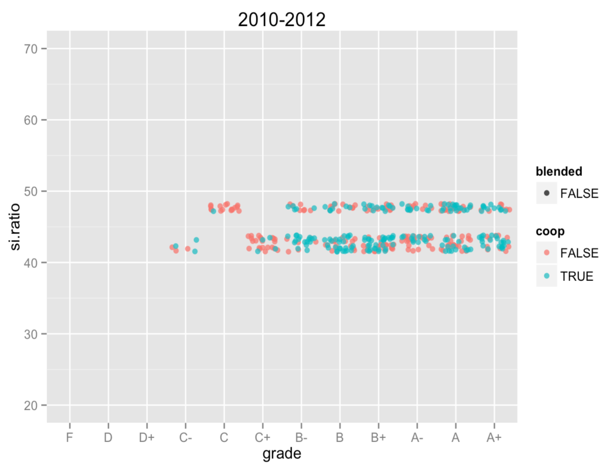
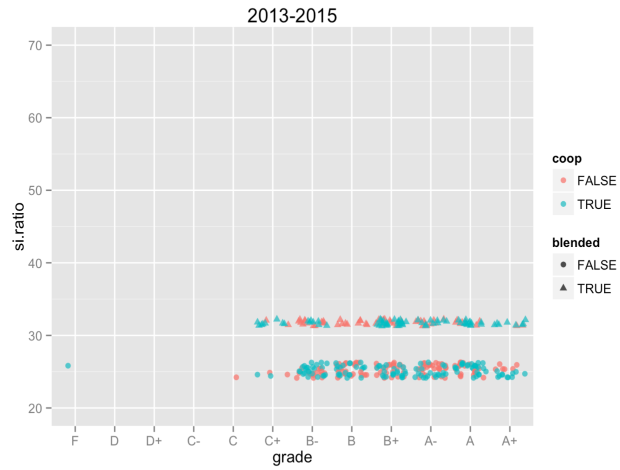


Figure 8.16. (a) Individual performance comparison with student instructor ratio and program choice



(b) Individual performance comparison with student instructor ratio, program choice, and flipped pilot course structure. (Plotted by E. Indiogine, 2015)

At SI ratios below 40, students rarely experience below C$^+$ performance levels regardless of program. In addition, the frequency of C$^+$ performance is reduced. To further investigate, student performance prior to 2010 was plotted vs. SI ratio in Figure 8.15. The majority of low performing individuals are regular program students (red), in years where the SI ratio is high.

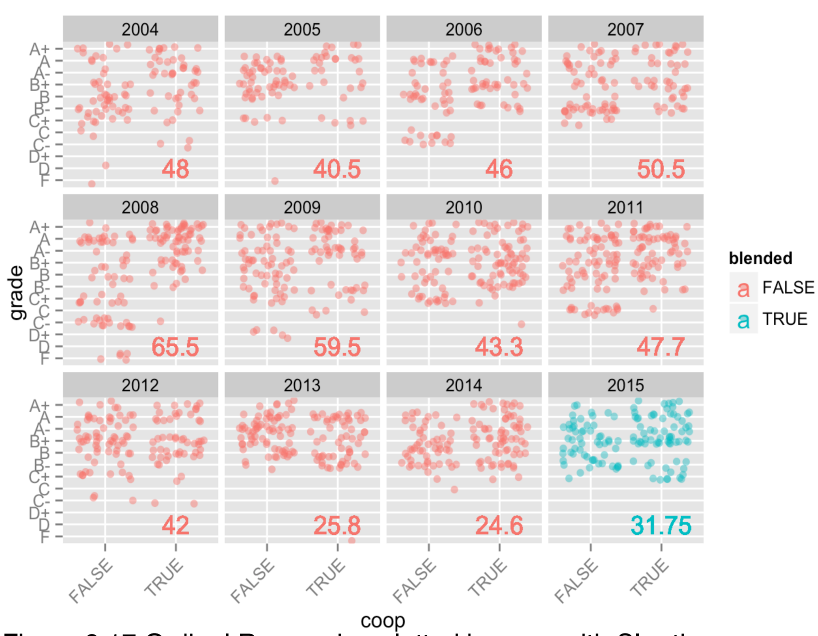


Figure 8.17 Ordinal Regression plotted by year with SI ratio. (Plotted by E. Indiogine, 2015)

Data in Figure 8.16 are grouped for comparison of (a) change to real world project design mimic, 2010- 2012; and (b) 2013-2014 similar instructor compliment, SI ratio, course structure and content for comparison with the 2015 flipped class structure. Lowest individual performance level is comparable for similar SI ratio. Performance in the flipped pilot is comparable for individuals compared to the pre flipped structure. Most individuals performed at the B$^-$

level or higher in 2013-2015 cohorts. The combination of low SI ratio and the flipped version actually gives the best individual performance results: C^+ is the lowest grade with the lowest probability in the 2015 cohort. Figure 8.17 illustrates changes on a yearly basis identifying step changes in performance for 2010 and again in 2013. As changes continued past the year first observed it is unlikely to be cohort related changes and more likely to be related to instructional changes. The 2015 flipped pilot had no impact on low level individual performance compared with 2013 and 2014 offerings where other course variables were essentially the same. This result is consistent with the ecological SPC class average study (section 8.3).

Ordinal regression analysis suggests that co-op or regular program choice is a significant predictor of individual grades in the capstone course. This observation was investigated further in the retrospective cohort analysis. SI ratio was not a predictor of individual grades but is a predictor of the probability of low grades. Flipped instruction was not a predictor of individual grades or probability of low grades for the capstone design course for the years studied.

8.5. Investigation of Effect and Causality Retrospective Cohort Comparison

The observed capstone design performance gap between co-op and regular program students is rooted in the competitive discipline selection process. For the capstone chemical engineering design course, the performance gap is closed by employing a real world design organizational structure employing regular ongoing feedback and lower SI ratio to ensure quality feedback as students develop design projects based on real-world process design projects.

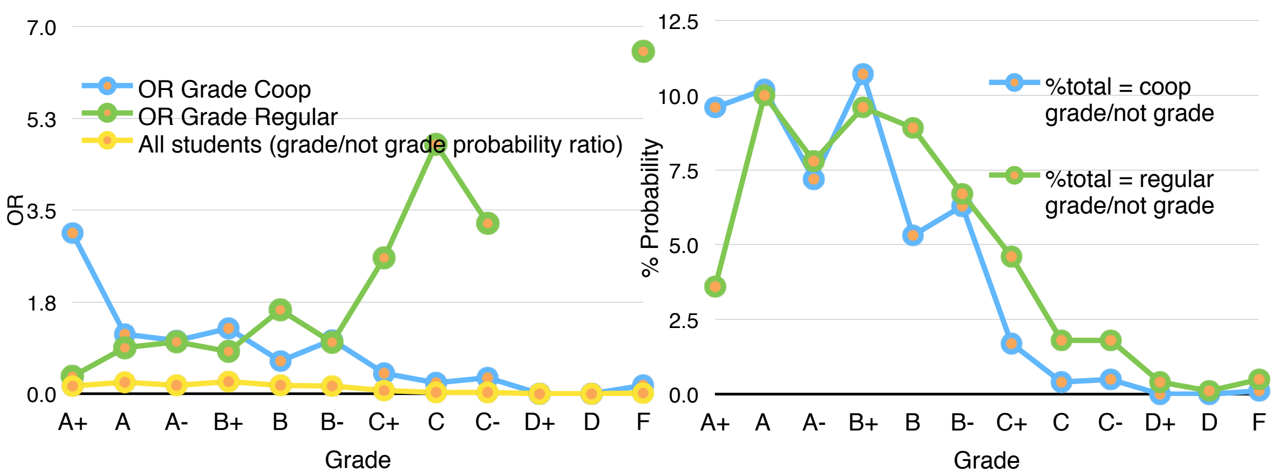
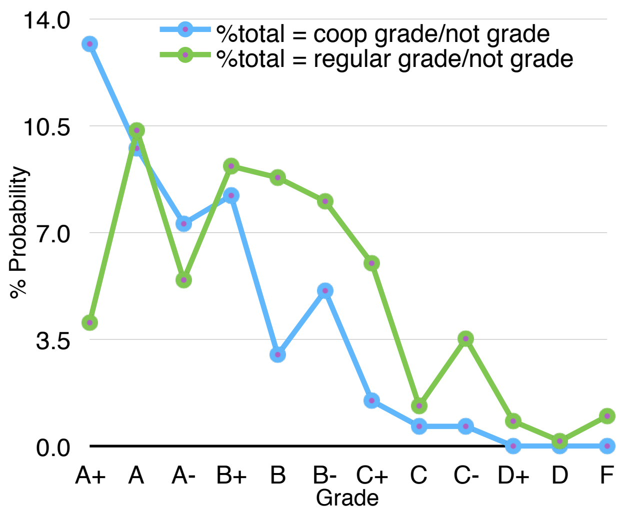


Figure 8.18 Retroactive Cohort Perfomance Analysis Study (a) Odds Ratio (b) Grade Probability 2004-2015

Although the gap has closed on average, Figure 8.18 demonstrates the impact of co-op program status on individual performance in the chemical engineering undergraduate program during the study period. The odds ratio (OR) (Figure 8.18(a)) for most grades is the same for both programs. The A^+ OR is almost 3.5 for a co-op student and the OR for a B is 1.8 for a regular student. The probability of a grade as shown in Figure 8.18(b) shows the central tendency for regular program students is a B, however the central tendency for the co-op program is higher. Log odds analysis reveals students in both programs have an equal likelihood of obtaining a grade between A and B^-. Regular students are more likely to obtain lower grades and co-op students are more likely to obtain A^+ grades. The co-op program offers students a performance advantage in the capstone design course. Post 2010 the OR of an A^+ for a co-op student decreased to 2.4 from 3.4 for all study years and the OR for all grades between A and B^- are similar for both cohorts. The probability of either cohort obtaining grades C and below is low, however if that grade is obtained it is much more likely to be a regular program student. Figure 8.19(a) illustrates the grade probability for co-op and regular programs split into the 2004 - 2009 mentorship course model with higher SI ratios and (b) the post 2010 internship course model with lower SI ratios. Students are more



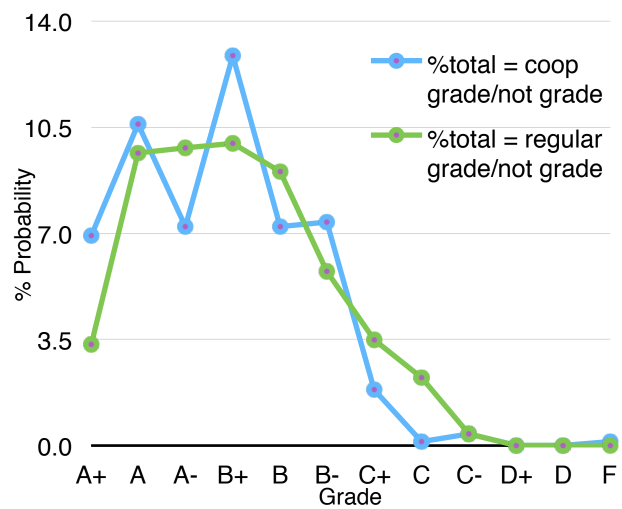


Figure 8.19. Probability of a Grade for Coop and Regular Program (a) 2004-2009 Mentorship course structure with higher SI ratio and (b) 2010-2015 Internship course structure with lower SI ratio.

likely to achieve higher grades post 2010 with the exception of co-op A^+ grades, which are less likely.

Figure 8.19 illustrates the case based odds ratios for achieving a grade in (a) the mentorship course model and the (b) internship course model. Changes made in 2010 to the course structure have evened the odds for students in both co-op and regular programs to achieve most grades. However Co-op students are still more likely to achieve A^+ and Regular students are more likely to achieve C or C^+. Neither cohort is likely to perform at a level lower than C^- post 2010. Post 2010 course structural changes and decreasing SI ration have had a positive impact on student performance for both cohorts.

Student performance in the flipped classroom is compared to performance in all other years in Figure 8.20. The OR analysis indicates Co-op students are as likely or more likely to achieve a grade of B^+ or higher in a flipped classroom. Co-op students are unlikely to achieve a B, equally likely to achieve a B^- as previous years and co-op students are more likely to achieve a C^+ in the flipped version than in the lecture format of the design course. Regular students were as likely or more likely to achieve a grade in the A- to B- range in the flipped classroom. They were less likely to achieve a mark of A^+, A or C^+. Overall students were more likely to achieve a grade higher than B^- or a B^-/C^+ in the flipped pilot.

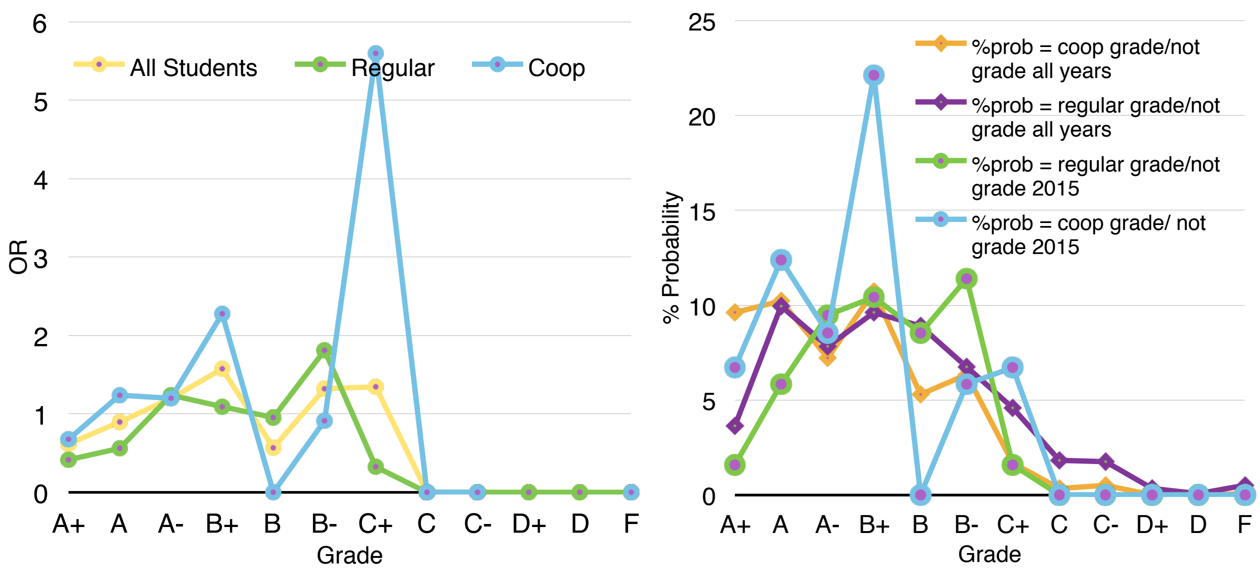


Figure 8.20. (a) Case Based OR Comparison of Student Performance in 2015 Blended Classroom vs. Traditional (2004-2014) and (b) Grade Probability Comparison of Blended Classroom (2015) and all previous years

Comparing the blended pilot to the mentorship course model and higher SI ratio results in enhanced performance for most students, slightly lower highest grade achievement and no low grade performance. Co-op students are more likely to achieve a B^+ or better and regular students are more likely to achieve a B^- or better in the flipped course compared with the recent lecture version. The probability of a low grade for regular students is reduced and increased for co-op students.

The Retrospective cohort analysis suggests the cohort performance for most grades is similar. Co-op students are more likely to receive an A^+ and regular students are more likely to receive a C^+. This finding is consistent with the entry GPA cohort bias, cohort characterization, the ecological study and the ordinal regression results. The blended classroom appears to have resulted in a bimodal distribution increasing the likelihood for some co-op students to achieve a higher grade and a lower grade (C^+). Regular students are more likely to obtain B^- than C^+ and grades lower than C^+ are not observed.

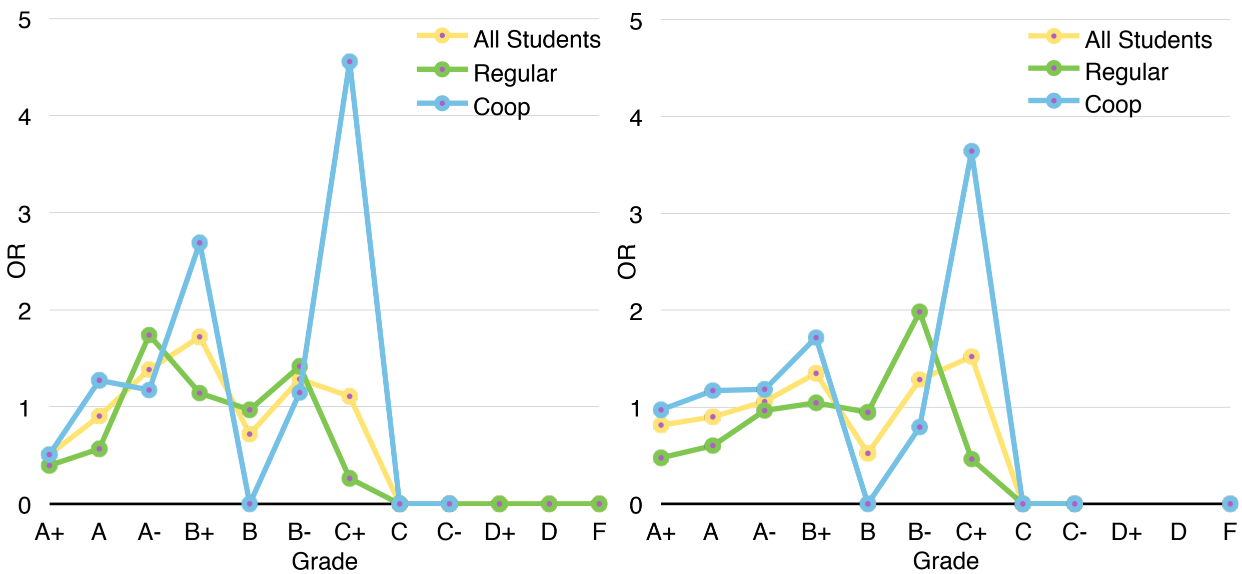


Figure 8.21 Comparison of OR of Grade Performance in the 2015 Blended Classroom Pilot vs. (a) Traditional Lecture 2004-2009 and (b) Traditional Lecture 2010-2014

In Figure 8.21 comparison of the blended classroom with the 2004-2009 mentorship model and higher SI ratios indicates co-op program students are as likely or more likely to achieve A, A^- and B^+ grades, slightly less likely to achieve A^+, not likely to achieve a B, equally likely to achieve a B^- and more likely to achieve a C^+. Comparison of the co-op cohorts and the 2010 - 2014 internship model indicates co-op students are equally likely or more likely to achieve a B^+ or higher with the blended version, equally likely to achieve a B- and more likely to achieve a C+. Regular program students were less likely to achieve a C+ in the flipped version compared to either the internship or mentorship course models. Compared to the mentorship model regular students were more likely to achieve and A^- or a B^- in the blended version. Compared to the internship model more likely to achieve a B^- in the blended version. For regular students the blended version is more likely to result in better performance. For many co-op students the blended version is also more likely to result in enhanced performance as summarized in Table 8.5.

Table 8.5 Blended Class Grade Performance Summary by Program Cohort

Grade	Co-op	+/-/N	Regular	Grade	Co-op	+/-/N	Regular
A^+	Neutral		Slight -	C^+	+		-
A	Slight +		Slight -	C	Neutral		Neutral
A^-	Slight +		Neutral	C^-	Neutral		Neutral
B^+	+		Neutral	D^+	Neutral		Neutral
B	-		Neutral	D	Neutral		Neutral
B^-	Slight -		+	D^-	Neutral		Neutral

8.6. Comparative Analysis: Traditional and Flipped Approach Delivery Time

This analysis is a case control study of the time required for students to complete pre class and in class activities compared to the traditional lecture delivery of the same material. In addition to data comparison this case study uses student and instructor comments and observations from the 2015 pilot to evaluate material reception and perceived effectiveness.

The 2014 traditional lecture version of the course can be compared to the 2015 blended version on a time required to deliver materials basis. "Heat Integration" detailed in Chapter 6 Table 6.2 is "Tutorial 10" in Figure 8.22, a comparison of time required for course material delivery as a traditional lecture and as a flipped online video learning element with in class activity. New material was added to online material to enhance student learning and the in class application was added. The lecture time compression ratio achieved varied from 1:2 to 1:6 depending on lecture materials being converted, the learning objectives for the tutorial, and time spent crafting the learning elements.

Key learning from conversion and student feedback is summarized:

- 20 minutes is too long for video presentations – students complained.
- Three five-minute videos are easier to watch than one fifteen-minute video.
- Pre class material is better received than post class.
- Tuesday Post class material and Thursday pre class material are done at the same time.
- Post class material is sometimes viewed as optional.
- Connection between related learning elements is needed.
- Progression of a topic is a useful structure.
- Division of topics is equally useful for related concepts covered at the same depth.
- Learning elements are information dense – high compression rate.
- Time must be allowed for student processing.
- Written notes to support videos are effective and useful to students.
- In class active learning is critical to make connections and process material.

The capstone design class ends at 6:00pm after project meetings and intense work for most students and instructors. Most are tired and need a break. Having less work required before the Thursday class is better but not always possible in the topic progression. A student comments on the longer videos:

> *"Also, the videos are relatively long. I can't express how much easier it would be to come home after a tutorial and read through/consult a document as opposed to sitting through a 20 minute video and then trying to remember everything you've covered." (Design Student 2015)*

After this feedback on video length, the maximum length was about 10 minutes and the aim was for five. Just because more material ***can*** go into a video format ***does not mean*** that it ***should***. Time alone is not a good measure of content when comparing delivery methods. My experience in searching for possible direct use video material was if video lengths were much greater than ten minutes I would not test it. I did not want to invest that much time in something that I wasn't sure was going to suit my purpose. Most of the videos I tested were listened to on the fastest speed to screen material for items of value. Like students, my time is limited and I prioritize to get maximum benefit for time invested.

Using video resources for my own learning and observing how I learned or didn't learn from them helped to clarify the student experience of the material. Long was out, and concise with illustration and animation was the most useful. A clear script is also essential. Having notes was useful if I wanted to skim the material and determine if I wanted to watch it. Skimming written material tends to be faster than screening video material. However, when material was deemed important the written material was of value to eliminate the note taking process for future reference.

> *"We would be much better off if the same information could be put in a document for our reference, so that we wouldn't have to watch the videos over and try to remember the important elements or take notes." (Design Student 2015)*

My experience working with video learning echoed this sentiment. I took notes when using videos for learning where I wanted to be able to ***apply*** the material, or to ***integrate*** the material into my work. I did not want to go back and watch the video to refresh my memory. A skim through my notes prompted

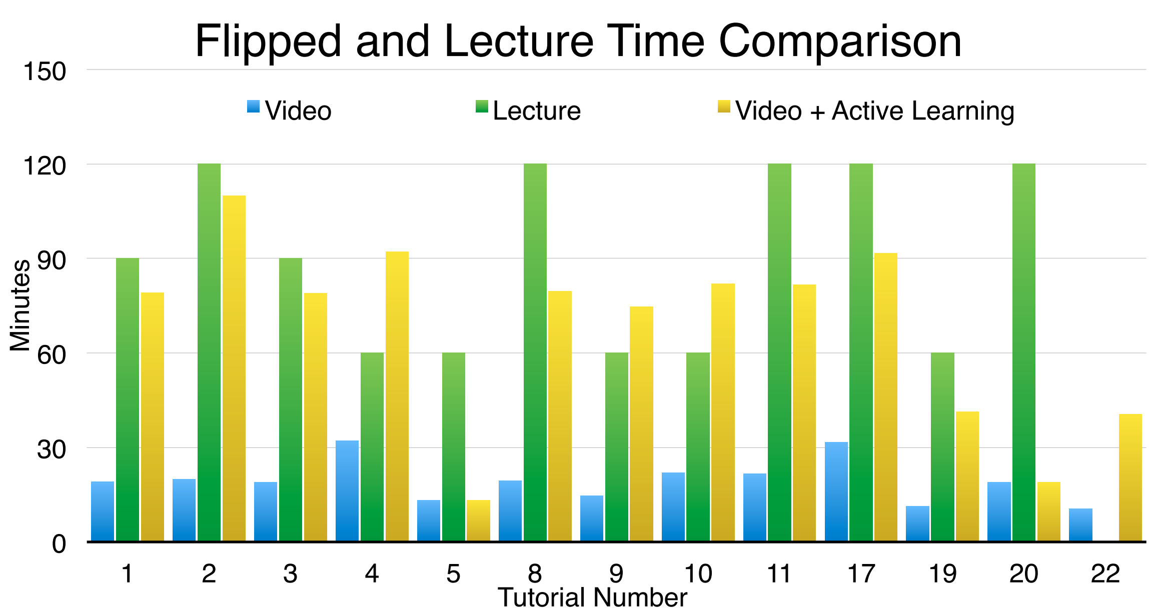


Figure 8.22 Comparison of Structured Time Blended and Traditional Lecture Format

recall and took less than a minute. To find the video and watch it again would take more time. Providing written reference material is critical for students to use material in their project effectively at higher levels of learning. Students are only expected to listen to a lecture once and are provided with reference material or take notes to review prior to applying the material to problems. Learning elements should be considered information dense lectures, although time compressed they are delivered once. Written reference materials should be provided for easy review and reference while working with the material in assignments or projects.

Heavy workloads during mid term weeks and when concurrently required lab course assignments are due are not optimal times for student learning in design. It causes overload and students must then choose priorities based on maximizing grade performance and satisfaction. Overall integrated program planning for the term is an essential element in optimal learning. Student feed back from all cohorts from 2010 – 2015 confirms this. Specific feedback from a 2015 design student:

> *"Do professors get together and plan for everything to be due at the same time just to make it more stressful for us?" (Design student 2015)*

The student made the comment in jest during a weekly project meeting when the team had little to report as a consequence of their decision to focus their lab report. It is indicative of the workload peaks experienced by students due to schedule coincidence. The design course is a heavy contributor to workload in the final term. Although a majority of teams had similar impacts on their schedule, some teams plan effectively for peak workloads. Although a great lesson in unplanned schedule impacts, it speaks to the pressure of peaks in a heavily loaded schedule in the undergraduate curriculum. Allowing for peak workloads when designing the timing of on line materials and formative assignments affords students scheduling opportunities.

With compression in the delivery of materials, there is a temptation to add more material to "lectures". This is a mistake. Even though the material is compressed, it does take students time to work with it and digest it. While developing mixing learning elements with Suzanne Kresta she noted:

> *"I've seen a number of theses learning elements now and they are information dense." (Kresta, 2015)*

This is important to note. Reduction in learning element length compared to traditional lecture delivery does not mean material is eliminated. Rather, presentation of the material becomes illustrative and deliberate. Instructors no longer take cues from their students as to whether the material is too fast or too slow for understanding. The material is presented at the pace of the script and animation.

Students may require time to pause, think about the material, and review accompanying written notes. This must be considered when calculating the pre class time equivalent to the lecture delivery method. Although material is compressed students still process information and make connections at the same rate as they did previously. The traditional lecture pace is approximately equal to the student processing pace. Students need time in class to work with an instructor and peers to develop a deeper understanding of the material. The active learning component is essential to deeper learning.

Overall time spent using online learning elements once and participating in class activities is summarized in Table 8.6. This does not include time spent on assignments prior to the end of class. For some topics students spend less time than the traditional lecture methods. For other topics they spend more time. The time spent learning is similar but possibly more efficient as activities and methods are changed from passive to active with flexible learning locations and timing. Most students were using higher-level cognitive process that more academic students use spontaneously (Biggs, 1999) as a result of the in class activities.

Table 8.6. Comparison of Flipped Online and Traditional Lecture Delivery methods

Total Time Required	**Flipped Online & In Class**		**Flipped Online**	**Traditional**
Minutes per tutorial	Video Only	Active Learning	Combined	Lecture
Average	19.5	48.5	68	90
Maximum	32	60	92	120
Minimum	11.5	30	41.5	60

8.7. Effectiveness Evaluation of Flipped Approach vs. Traditional Lecture Delivery

Assessment of student use of the on line material and demonstration of student use to ensure equivalent accreditation unit assessment for the capstone design course CHE 435/465 was a blended pilot project objective. Time spent on flipped learning pre class and on in class activities is similar to the time spent in lectures for the traditional version of the design course. Effectiveness measurements considered were: online quizzes, in class assignments, LMS access monitoring and equivalent student performance results. Student performance results for summative assessment are found to be equivalent on an average and individual result basis.

For the first iteration of the blended course online quizzes were not included. Initially considered as a tool to assess access to online learning elements, time constraints dictated a focus on the development of learning elements and in class activities. The utility of online quizzes to demonstrate student on line material engagement is under consideration for the second iteration of the flipped course (winter 2016).

Table 8.7 Design Course Assessment Structure				
Assignment	**Traditional Structure**		**Flipped Structure**	
	Value (%)	**Purpose**	**Value (%)**	**Purpose**
Pre course skill assessment	0	Formative	P	Formative
Team Selection	0	Formative	P	Formative
Portfolio (In Class Work)	N/A	N/A	5	Formative
Team Charter	0	Formative	P	Formative
Initial one Page Scope	0	Formative	P	Formative
Situation Report Draft		Formative		Formative
Situation Report Final	5*	Summative	5*	Summative
Meeting 1 planning		Formative		Formative
Meeting 1 evaluation	5*	Formative	5*	Formative
Mass and Energy Balances		Formative		Formative
Meeting 2 planning		Formative		Formative
Meeting 2 evaluation	5*	Formative	5*	Formative
Client Presentation		Formative		Formative
Meeting 3 planning		Formative		Formative
Meeting 3 evaluation	5*	Formative	5*	Formative
Final Report	80	Summative	75**	Summative
Final team evaluation	0	Formative	P	Formative
Post course skill assessment	0	Formative	P	Formative

*Assignments were graded together 5% is the total allocated
**Final Report Marking was done using the same rubric and scaled to accommodate the portfolio

On line quizzes may check immediate retention but without connected in class active learning, retention may not be long term or evidence of ability to use knowledge (Sidhu, 2015). In planning for quizzes or in class assignments as a tool for constructive alignment of assessment, to support student learning and CEAB GAA demonstration the purpose served is important. The assessment structure for Design II is outlined in Table 8.7. With the addition of the portfolio to encourage formative work, quizzes are not needed to demonstrate material access.

In class assignments were typically employed to ensure student interaction with the material and online access logs were used to evaluate access frequency. In class assignments typically required the students to engage with each other and submit a team assignment at the end of class. Students also reported their findings to the class as a whole in some cases. Student access frequency of total LMS course material is shown in Figure 8.23 for 2014 and 2015 on a group basis. Group access is reported in random order with average cohort access for each year shown in red. The number of groups varied between years, but the number of students per team and the number of students per cohort was similar.

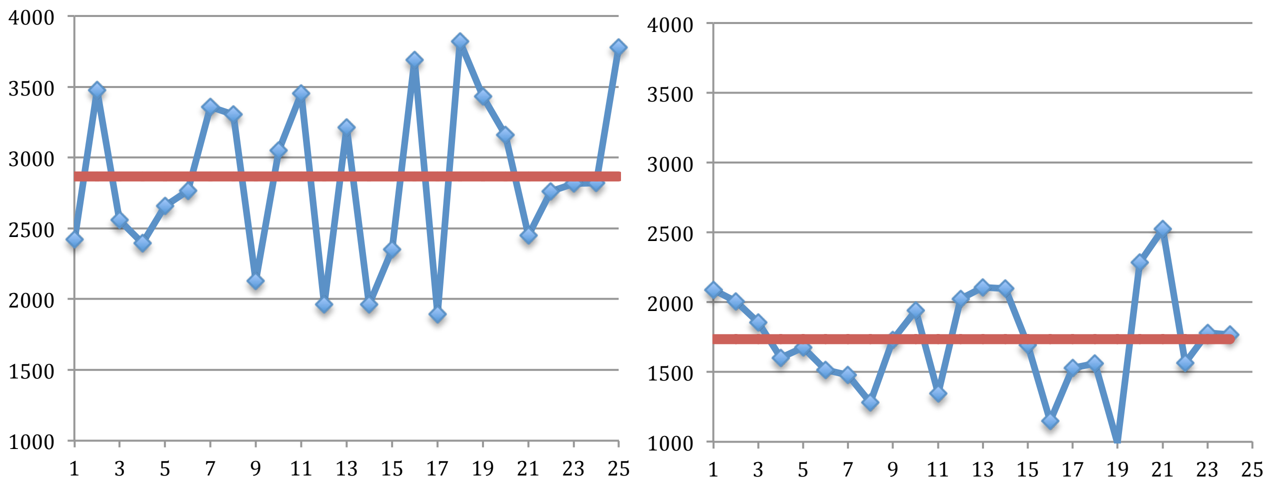


Figure 8.23. Comparison of (a) 2015 Blended and (b) 2014 Traditional Cohort LMS Access (Group totals)

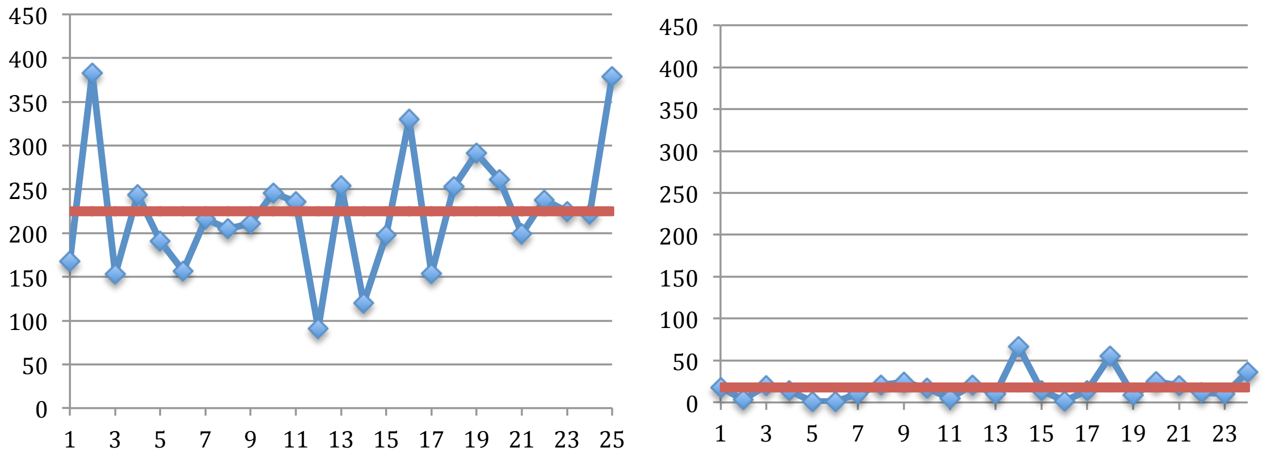


Figure 8.24. (a) Access to Video Learning Elements in the 2015 Flipped Pilot compared with (b) Lecture based version URL Access to other web materials. (Group totals)

Different types of material access can be determined by understanding how materials were typically classified and presented. URL access was used for the video learning elements in the flipped version. This type of access was used in the traditional course for website based references and was limited. A comparison of this type of access provides an overview of how often student groups used video based material is shown in Figure 8.24. File and Folder access was typically course resources and includes lecture notes, assignment instructions, and text resources. Similar for both cohorts, group access is shown in Figure 8.25.

Course pages typically contain information about the course structure and requirements. Access was similar for both years. Assignment access increased for the flipped pilot as the in class assignment component was increased in the flipped version. For 2015, the in class assignment access and uploading are tracked with the comparable assignments for project development and tracking in the traditional 2014 version. Figure 8.26 examines this change and the variable team response and access. Assignment access may include team members checking that responsible team members submitted the assignment. Forum

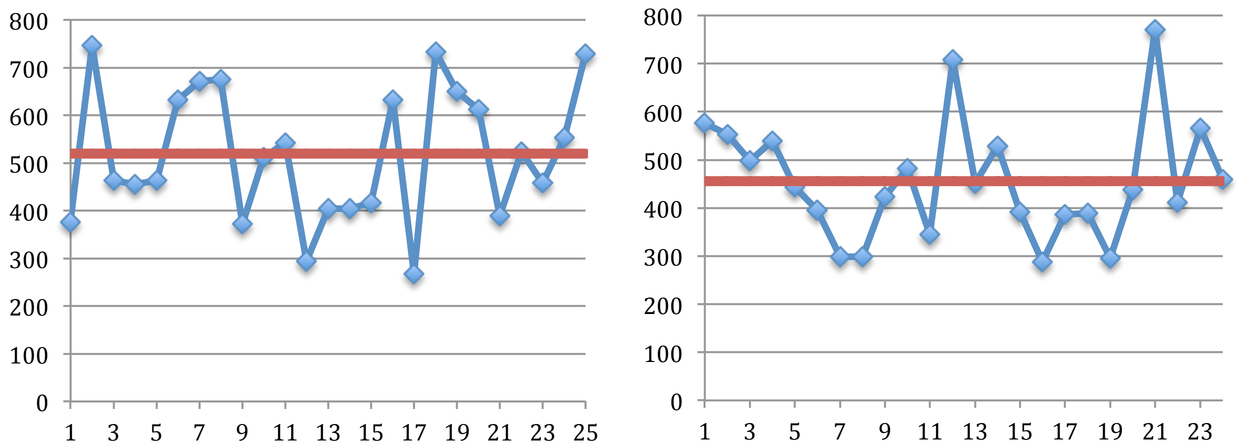


Figure 8.25. File/Folder Resource Access by Group for
(a) 2015 Flipped Pilot and (b) 2014 Traditional Lecture Version

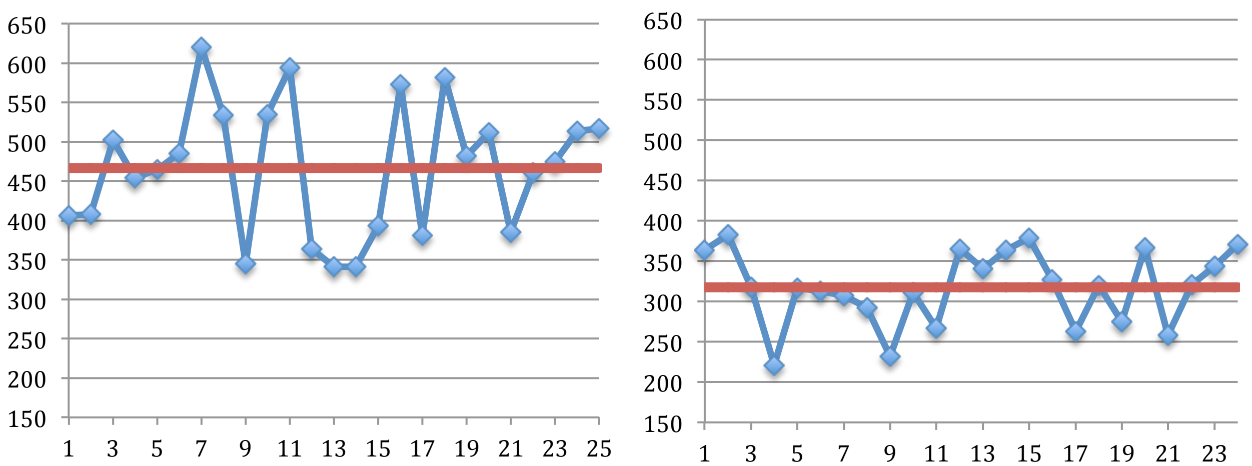


Figure 8.26. Team LMS Assignment Access
(a) 2015 Flipped Pilot with In Class Assignments (b) 2014 Traditional Lecture Version

access, Figure 8.27 (new for 2015), was used for peer feedback activities and as a tool for some in class activities. It is included to demonstrate a range of participation frequency for this activity.

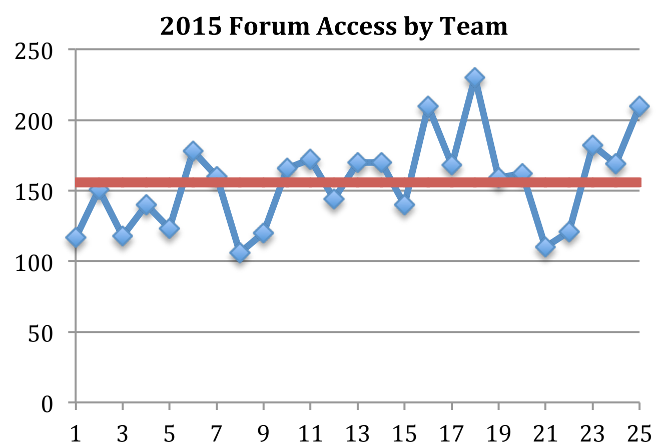


Figure 8.27. Forum Access for Peer Review and Feedback Activities.

Observations and data indicate some teams watched the videos together, some individually and some skipped some of them. All teams watched most of the video learning elements, attended most class activities and handed in all assignments. Course effectiveness is not evaluated on whether or not students were able to check off all activities as complete but rather that students accessed materials necessary for their individual development and project completion. The purpose of this analysis is to demonstrate student access to the LMS and participation in LMS activities required for the course. Students do access online resources and are motivated to use them for their learning and/or project completion. Quality of resources and relevance to required project activities impact ongoing use of resources. Essentially students use what helps them complete project work and items that are required for course credit. They attempt to maximize project value for time spent. Ongoing evaluation and revision of on line material for the next course iteration are aimed at clarity, brevity, organization, and enhancing connections with student learning modalities. Changes include:

- Better organization of Moodle class block for simplicity
- Removal of assignments from tutorials to an assignment block
- Remove resources from the main block in Moodle to a separate resource section.
- Students requested key items be highlighted.

Instructor notes and specific student feedback are invaluable in the improvement process. All instructors reported increased student engagement and interaction in class and in the weekly meetings. All LMS indicators report increased access to online materials in comparison with the lecture version of the course. Students did participate and did access required materials. Instructors observed the depth of the questions students asked increased as the level of engagement increased. Did increased access to LMS resources and activities have an impact on student performance? Access data are examined in Figures 8.28 and 8.29 with respect to performance.

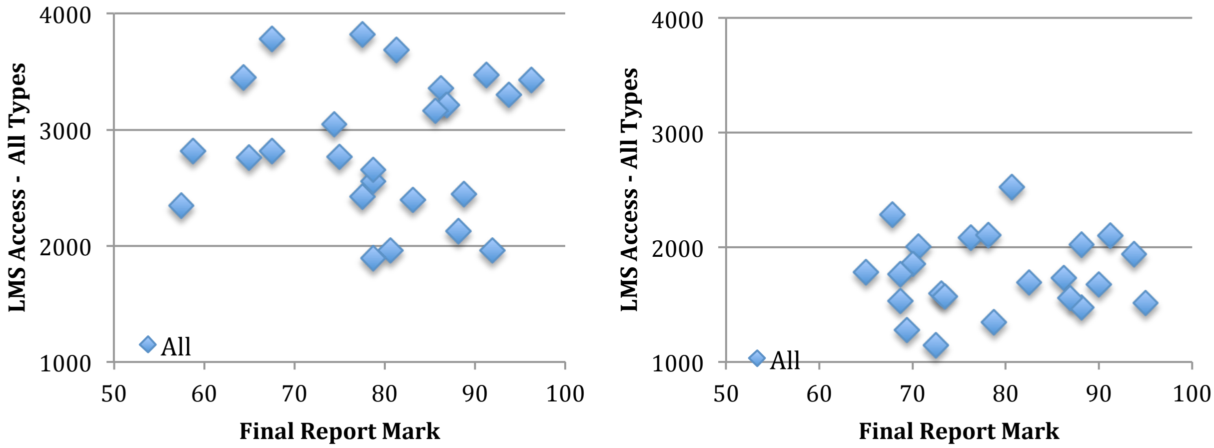


Figure 8.28. Correlation of Design Final Report Mark and Group LMS Frequency Access for
(a) 2015 Flipped Pilot (b) 2014 Traditional Lecture version

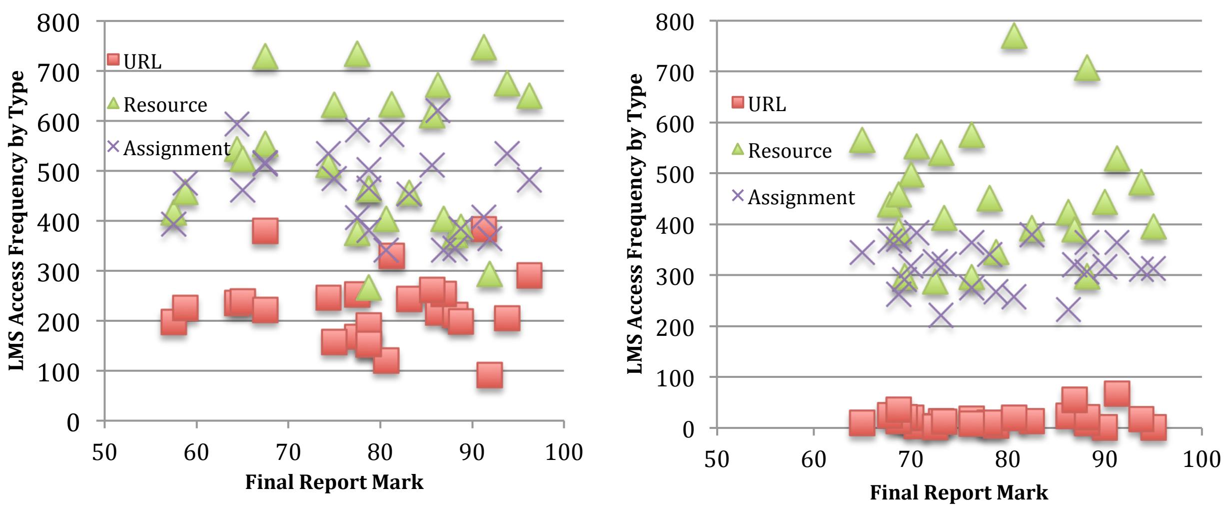


Figure 8.29. Comparison of LMS Access Type and Final Report Performance
(a) 2015 Flipped Pilot (b) 2014 Lecture Version

For the 2014 lecture/project version of the design course there is no correlation between final mark or final report mark performance and access to LMS materials or a specific type of LMS material. The same finding held for the 2015 flipped classroom version of the course. Performance would appear to be linked to student centered factors rather than course delivery mode. Students taking the flipped version accessed the LMS more frequently for URL (video learning elements), forum, and assignment activities. Resource and course page access were similar for both flipped and lecture student groups. Final report performance was not related to LMS access for either group.

Certain organizational and delivery items can be significantly improved on in the next iteration. Negative student feedback centered on organization of the LMS, ability to find items when needed, an overwhelming amount of information, missing final report assignment items and video quality. Positive feedback was focused on team development, classroom interactions, presentation opportunities, and more project time. Overall, students engaged with the online material, classroom activities, instructors, TA, and project activities.

8.8. CEAB GAA and Skill Self Assessment: Pre and Post Course Comparison

Students self select their teams in the capstone design course. Consideration of individual strengths and weakness is part of the team selection process. Students attempt to assemble a team with requisite skills for successful design project completion and identification of skill development areas. The existing skills inventory (Appendix D) resembled but was not identical to the CEAB graduate attribute performance criteria. The form had been in use for many of the course iterations in the study period but the instructions and evaluation process used evolved over time. Team selection was completed, in class, ahead of project selection on the first day of classes from 2004 to 2009. From 2010 onward students were asked to complete their team selection in advance of the course.

For 2015, the skill inventory was reorganized into CEAB GA categories and converted from a paper format to an electronic format. Students evaluated their skills in advance of the course by answering questions in an electronic survey, in a secure environment that allowed them to see a spreadsheet composite of team results. A CCID sign on was accepted in lieu of a signature. The instructions provided for the skill inventory were:

This skill inventory is based on the Canadian Engineering Accreditation Board (CEAB) Graduate Attribute Assessment (GAA). The first task for this course is self-reflection and evaluation. This reflection is structured and based on the learning outcomes from the CEAB. This evaluation is based on a scale from 0-3.

0 = No or introductory experience

1 = Developing proficiency

2 = Proficient

3 = Mastered

Once you have completed this form the ratings that you have given yourself will be transferred to your team selection form composite as strengths or weaknesses. You will be required to sign that form with your team members indicating the skills and attributes that you are able to contribute to them team. The team selection form will become part of your team charter, which will be handed in for approval.

<u>After you have completed this course you will be asked to re evaluate yourself using the same criteria.</u>

All students responded to the pre course survey, as it was a requirement for the team selection. The post survey was "low stakes" by comparison and approximately 40% of the students responded. Only data for students responding to both is used in the comparative analysis. The CEAB graduate attribute is the header for each result section. Density plots (present means as indicators of central tendency) giving an indication of the response distribution and the shift of the mean. These plots are used to demonstrate a tendency visually as the data are discrete responses from the population rather than continuous functions. A similar plot is being considered to represent the class median response and indicate where the individual student would be relative to the class as formative feedback. Likert plots ("Proficient" and "Mastered" are grouped on the right hand side and "Introduced" and "Developing" are grouped on the left hand side) are presented for each attribute and indicate the discrete nature of the data. The responses are broad based and intended for students to consider their confidence in their ability to apply skills and concepts related to the word(s) used to name the skill area.

1. A knowledge base for engineering: Demonstrated competence in university level mathematics, natural sciences, <u>engineering fundamentals</u>, and **<u>specialized engineering knowledge appropriate to the program.</u>**

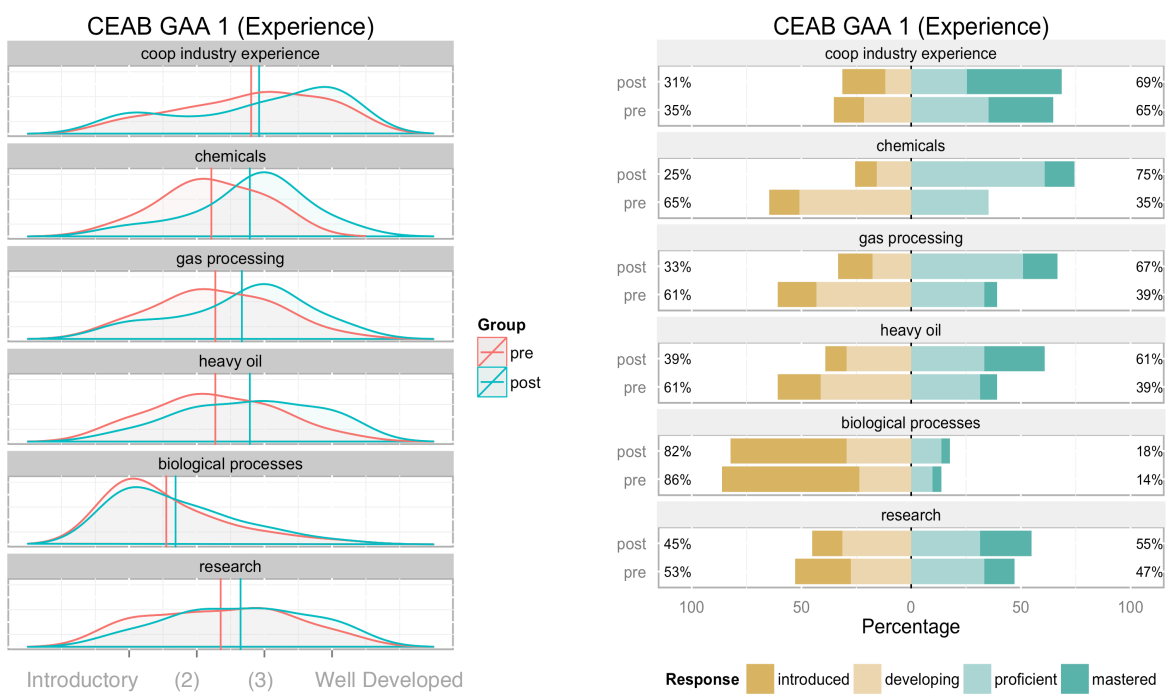


Figure 8.30. Comparison of Student Evaluated Specialized Engineering Knowledge as Industrial Experience by Area (a) Density plot and (b) Likert plot (Indiogine, 2015)

The types of projects offered in the design course are often natural gas processing, petrochemicals, refining and upgrading. At times projects offered investigate biological processes. Students appear to perceive their experiences over the last term prior to graduation as contributing to their knowledge in chemicals, gas processing and heavy oil processes according to results shown in Figure 8.30. Figure 8.31 shows student perception of their skill shift for engineering topics as a result of their term work. The largest shifts from introduced/developing to proficient/mastered were seen in the areas of material selection (25%) and process equipment (20%). This shift was between 10-15% for most other topics with the exception of distillation (5%), which showed a high level of proficiency in the pre course results. In all topics students typically indicated an increase on the scale with few students indicating only

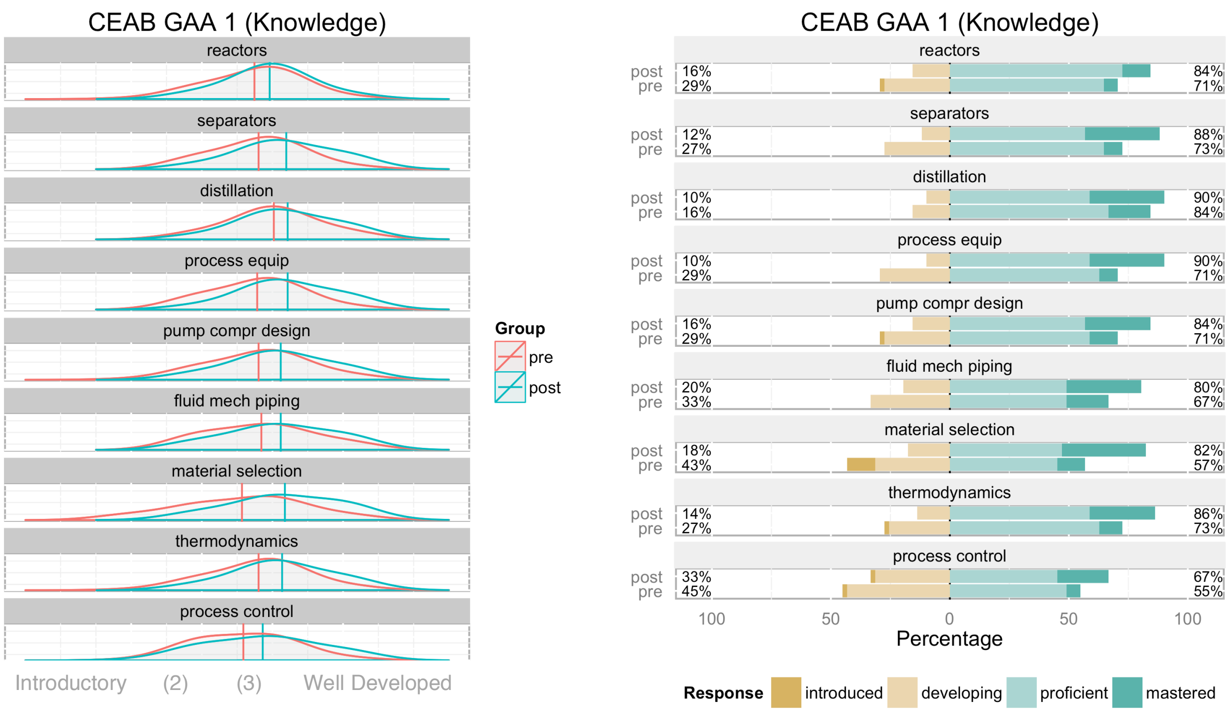


Figure 8.31. Student pre and post course rated skill levels in chemical engineering topics related to project work (a) Density Plot and (b) Likert Plot (Indiogine, 2015)

introductory knowledge in the post course results. Process control was indicated post course as developing or introduced by 33% of students indicating an area of improvement. In concurrence, instructor observations of students while working on PFD loop diagrams identified this as an area for future course improvement. Currently there is no tutorial information on basic loop design in the capstone design course. The required process control course has been included as a prerequisite for Design II for future iterations. Learning element development is being considered.

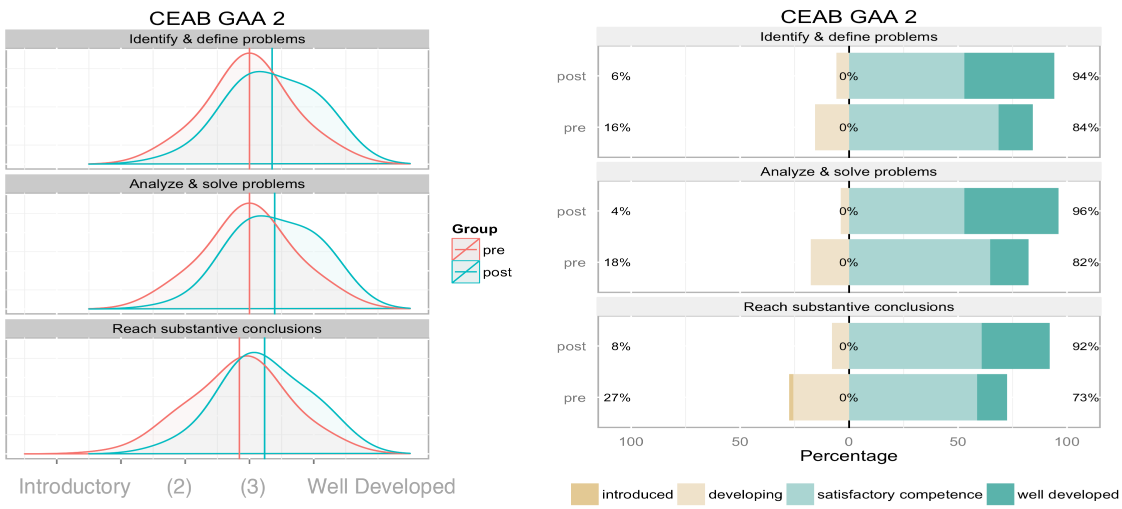


Figure 8.32. Student pre and post course rated skill levels in problem solving topics related to project work (a) Density Plot and (b) Likert Plot (Plotted by E. Indiogine, 2015)

2. Problem analysis: An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.

As illustrated in Figure 8.32 over 80% of students perceived a proficiency or mastery of problem identification and mastery prior to the design course. This shifted to over 95% post course approximately 40% of students in the stronger category indicating a well-developed level. The largest shift was realized in the category of reaching substantive conclusions with a 20% shift towards proficient/well developed.

3. Investigation: An ability to conduct investigations of complex problems by methods that include

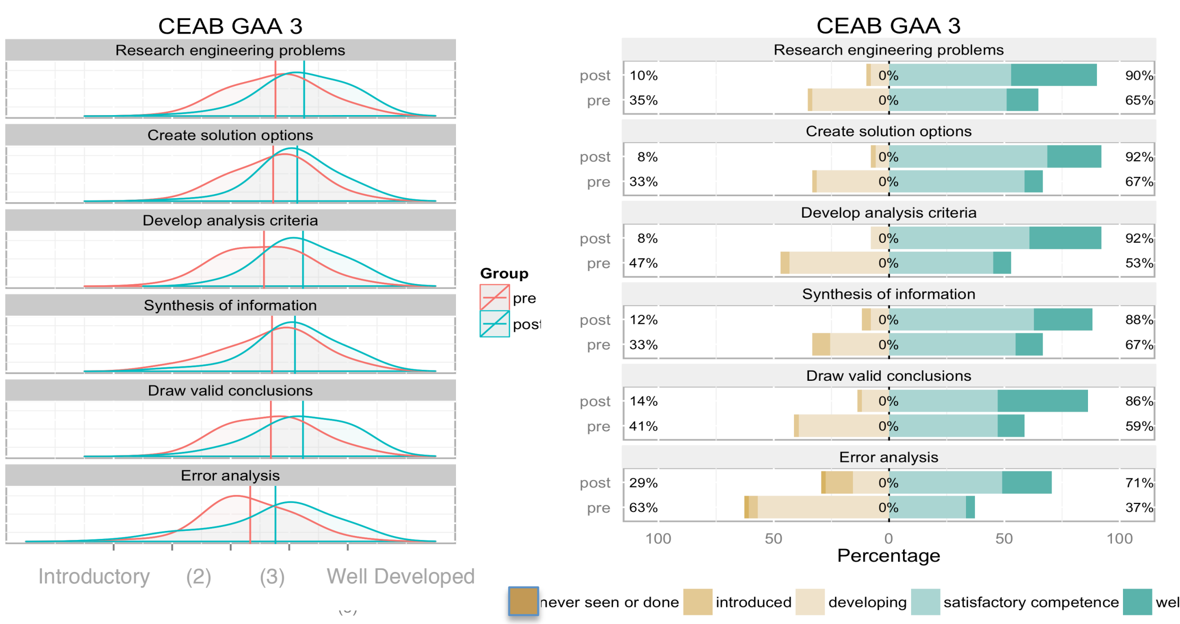


Figure 8.33. Student pre and post course rated skill levels for investigation topics related to project work (a) Density Plot and (b) Likert Plot (Indiogine, 2015)

appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.

Investigation related skills were rated as developing by one third to over half of the respondents at the pre course survey as shown in Figure 8.33. At the post course survey between 85% and 90% of respondents rated themselves as proficient or mastered for researching engineering problems, creating solution options, developing analysis criteria, synthesis of information and drawing valid conclusions. Only 71% indicated satisfactory competence or higher for error analysis indicating an area for possible improvement in future course iterations, however this particular skill was shifted significantly from pre to post course responses. Significant time was devoted to in class work on decision analysis, criteria formation and project application, while no class time was devoted specifically to error analysis. Some time was spent on uncertainty in modelling and simulation due to characterization of feeds.

4. Design: An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.

Figure 8.34 illustrates the student perception of development for design skills. The ability to develop boundary constraints shifted from 60% of students rating themselves as introduced or developing

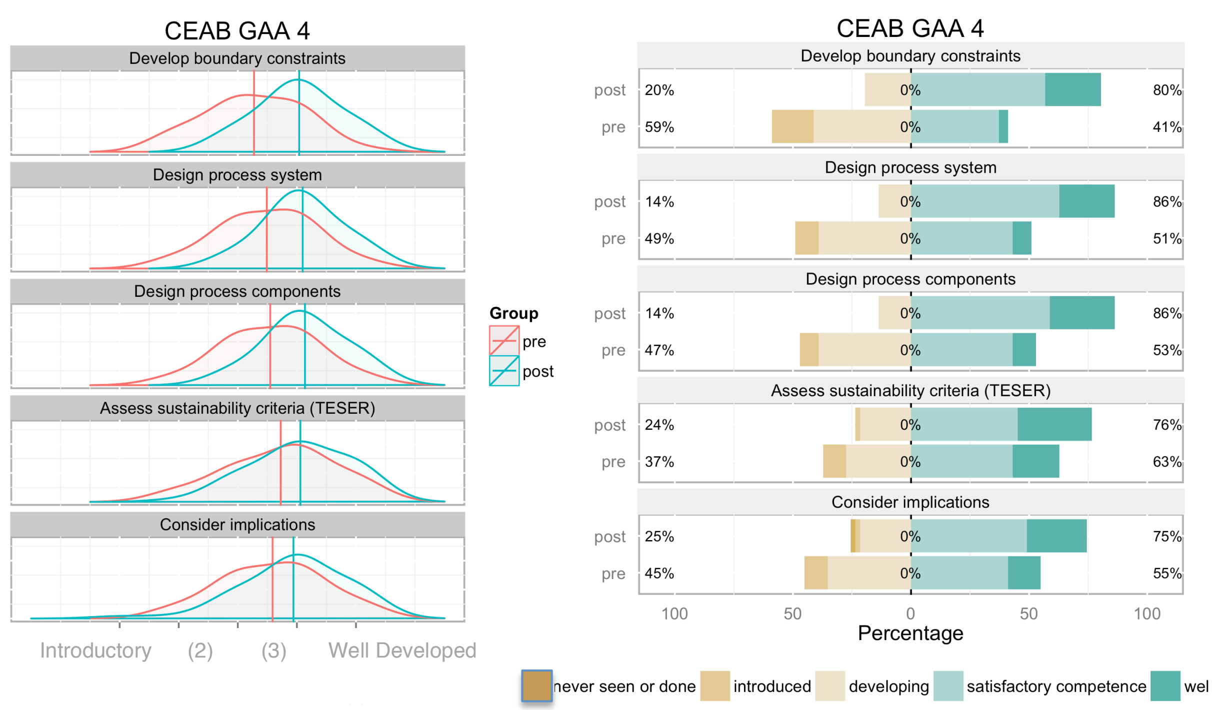


Figure 8.34. Student pre and post course rated skill levels for design topics related to project work (a) Density Plot and (b) Likert Plot (Indiogine, 2015)

to a post course rating of 80% rating as satisfactory competence or mastered. Design a process system increased from about half the respondents indicating confidence to 86%. Design process components showed a similar increase. Assessment of technical, economic, safety, environmental and risk components of the design increased by about 13% and consideration of implications increased by about 20%. In this particular iteration of the design course, the material typically used in the HAZOP and risk analysis methods was not able to be converted to learning elements due to time constraints and in class activities were related to identifying risk rather than applying methods. For the 2016 iteration of the course this will be changed to include learning elements for these topics and the HAZOP topic is being considered for one of the seminar topics pending available facilitation. The students in the post course assessment students reflected what instructors had previously observed in their course observations.

5. Use of engineering tools: An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.

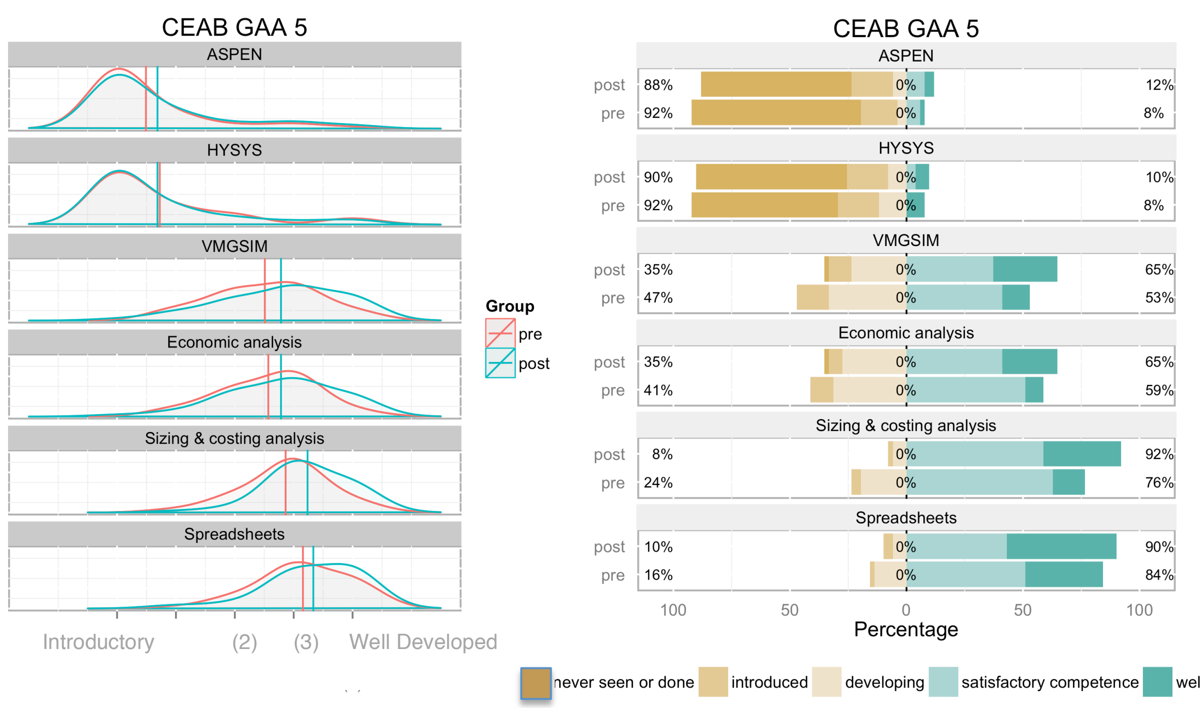


Figure 8.35. Student pre and post course rated skill levels for use of engineering tools related to project work (a) Density Plot and (b) Likert Plot (Indiogine, 2015)

Figure 8.35 illustrates the survey data gathered for skills related to the use of engineering tools. A major tool used in the design course is the process simulator for modelling. However, not all processes are modelled well using the simulator and other tools must be employed. In addition pre course work in other simulators students may from prior work experience is welcome as a team selection skill, but this should not change for the majority of students from pre to post course as the only simulator students have at their disposal is VMG Sim. A few students may encounter the other simulators via industrial advisor interactions. A shift for other simulators would be indicative of unreliable results for the self-assessments. Although this does not validate results with skill testing, it is an indicator that students are relatively reliable when assessing their experience. The biological processes question is another reliability indicator. The majority of students do not have experience with this in the undergraduate curriculum and the exposure to this area in the design course is minimal. Other specified tools increased between 5% and 15% from developing to proficient. Economic Analysis techniques and VMG Sim could be targeted areas for improvement, while sizing and costing appears to be effective.

6. Individual and team work: An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.

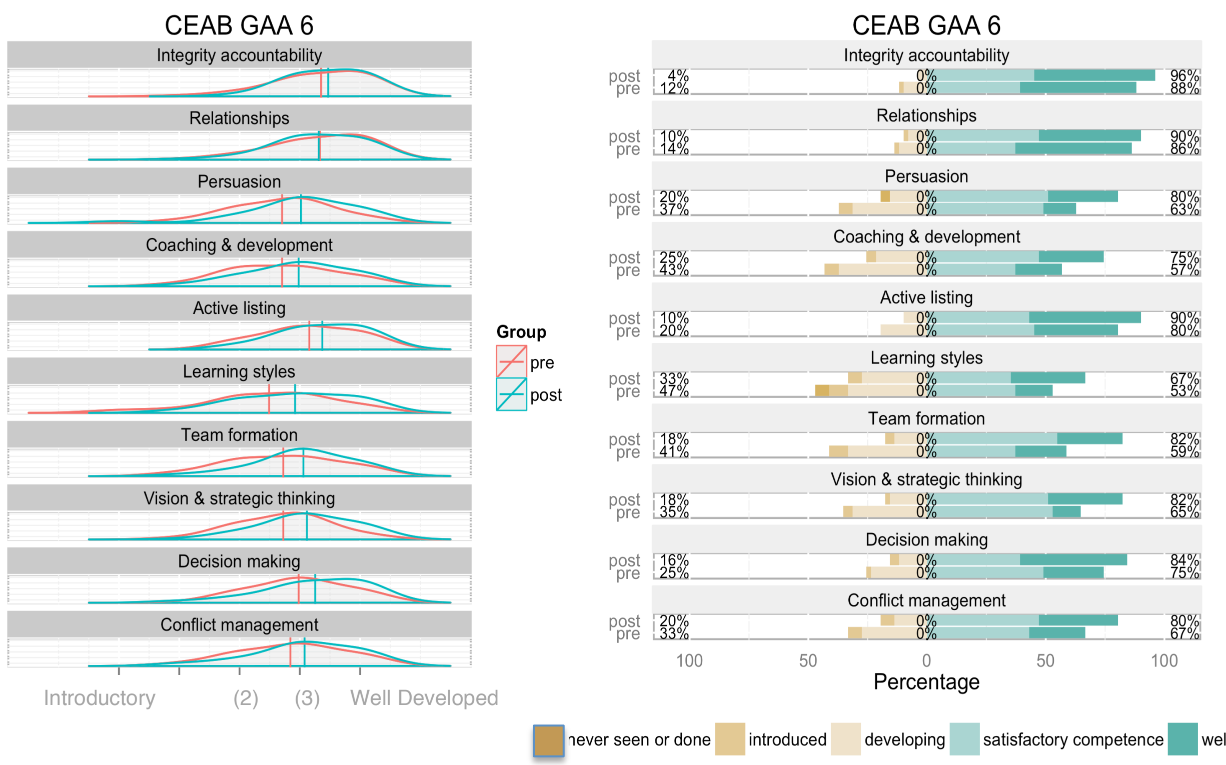


Figure 8.36. Student pre and post course rated skill levels for team work related to design project (a) Density Plot and (b) Likert Plot (Indiogine, 2015)

The chemical engineering capstone design course works with conceptual design concentrating on the application of chemical engineering knowledge to early project analysis. As such it is not a multidisciplinary team environment, none the less it is a team environment structured in a way to give students an opportunity to develop team skills prior to graduation. The student perception their team skills is summarized in Figure 8.36. Post course results indicate that 80% or more of the students view their skills as a satisfactory or well developed competence with the exception of learning styles. Learning styles was a self directed optional activity, while the remaining skills were active topics for learning elements, in class discussion and activities and project applications.

7. Communication skills: An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.

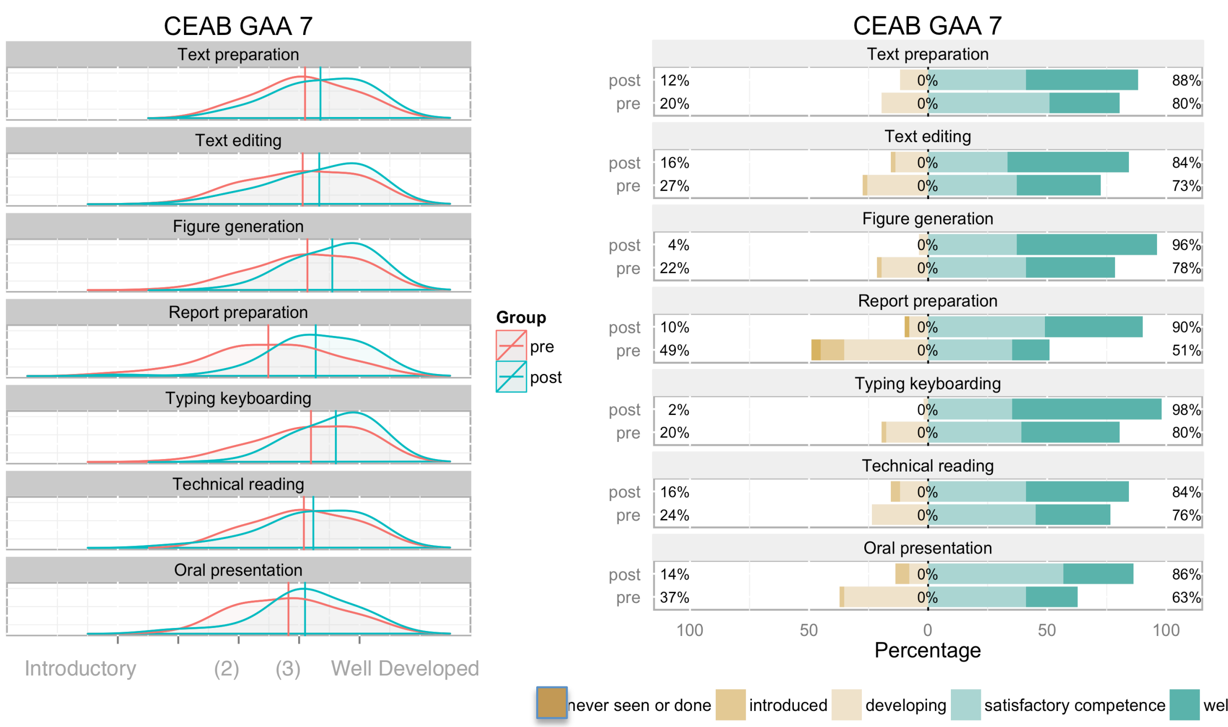
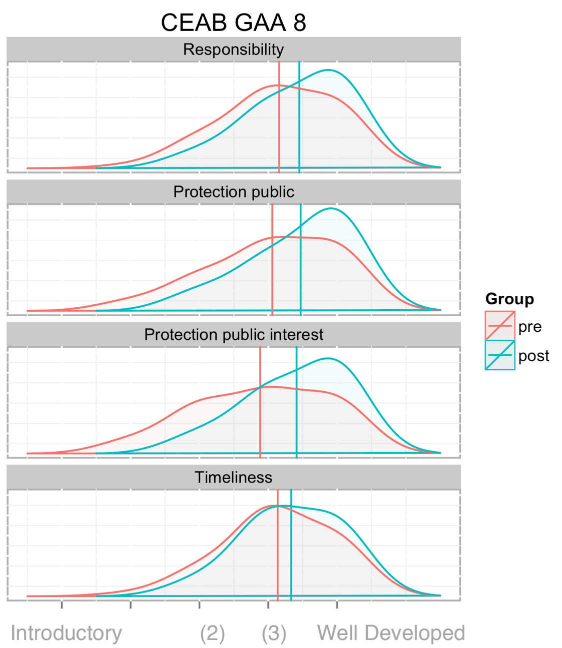


Figure 8.37. Student pre and post course rated skill levels for communication work related to the design project (a) Density Plot and (b) Likert Plot (Plotted by E. Indiogine, 2015)

Student perception of their communication skill competence improved in all areas surveyed as shown in Figure 8.37. The largest shifts were observed in oral presentation and report preparation. Oral presentation was a larger part of the design course this year because of the in class activity sharing. The requirement to report results to the class gave students and opportunity for impromptu speaking in addition to the formal meeting requirements with their industrial advisors. Almost all students felt proficient at figure generation and keyboarding after the course, however 10% - 15% of students still felt they were developing in the categories of technical reading, text preparation and text editing by the end of the course. Given the importance of written communication to engineering, this area is targeted for additional support for the 2016 iteration. Seminars specifically aimed at supporting student writing and metacognitive development are planned and discussed further in Chapter 9.

8. Professionalism: An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.



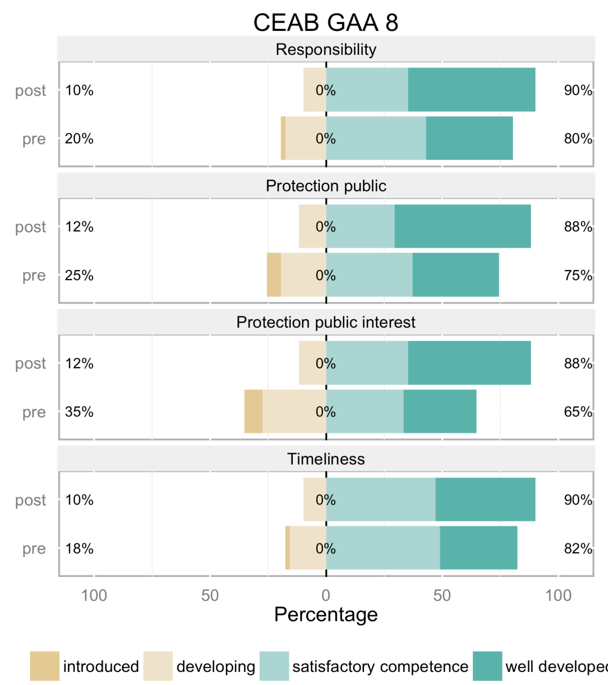


Figure 8.38. Student pre and post course rated skill levels for professionalism related to the design project (a) Density Plot and (b) Likert Plot (Plotted by E. Indiogine, 2015)

Figure 8.38 summarizes student perception of their professionalism pre and post course. For the items surveyed 90% of students viewed themselves as having a satisfactory or well developed competence post course with approximately 10% of students rating these areas as developing. Pre course 65% - 80% of the students rated themselves as satisfactory or well developed competence.

9. Impact of engineering on society and the environment: An ability to analyse social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.

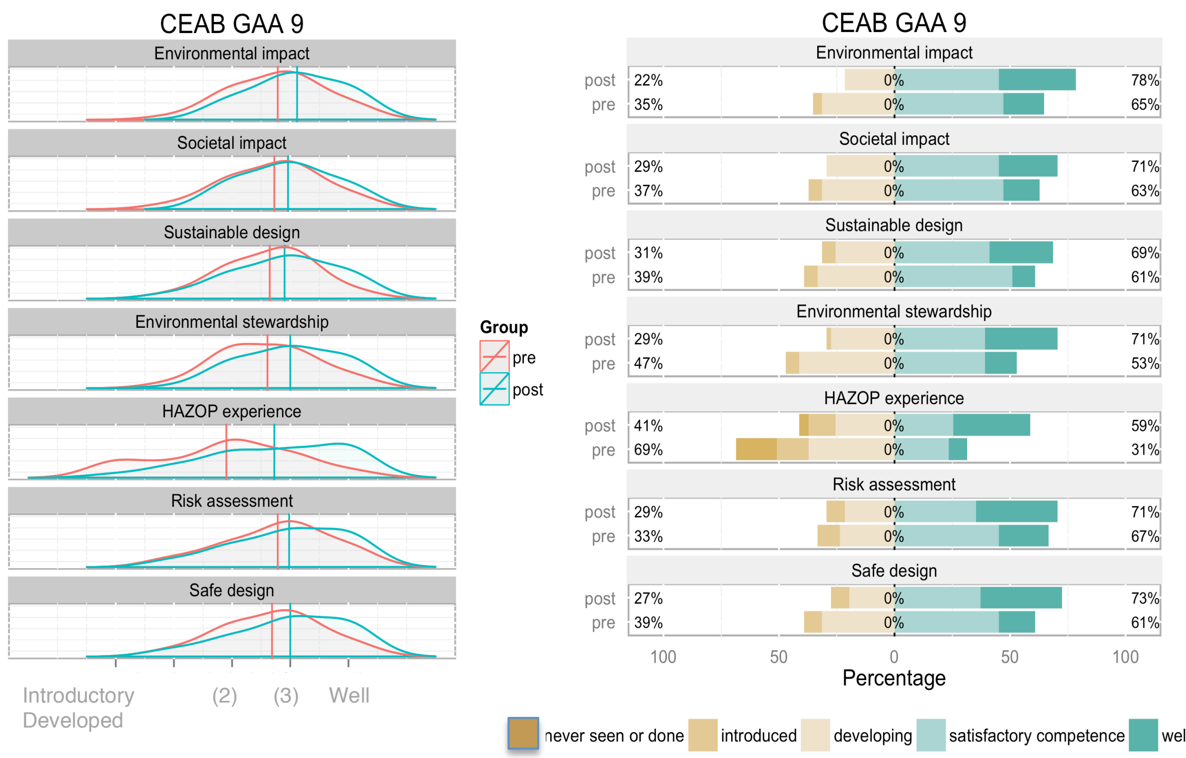


Figure 8.39. Student pre and post course skill levels related to analyzing engineering impacts on society, safety, and environment for the design project (a) Density Plot and (b) Likert Plot (Plotted by E. Indiogine, 2015)

Figure 8.39 indicates student skill assessment of pre and post course skill levels related to analyzing the impact of engineering on society and the environment. For HAZOP experience 70% of students viewed their ability as developing pre course and 60% viewed their ability as satisfactory or well developed post course. The remaining items showed a marginal shift of 5% for risk assessment, approximately 10% shift for environmental impact, societal impact, sustainable design and safe design. Environmental Stewardship was a perceived shift of approximately 15%. The redevelopment of the 2015 course utilized externally sourced material for pre course work and in class activities were not as targeted to objectives as they could be. Improvements in this area could be potentially be targeted and realized in future iterations.

10. Ethics and equity: An ability to apply professional ethics, accountability, and equity

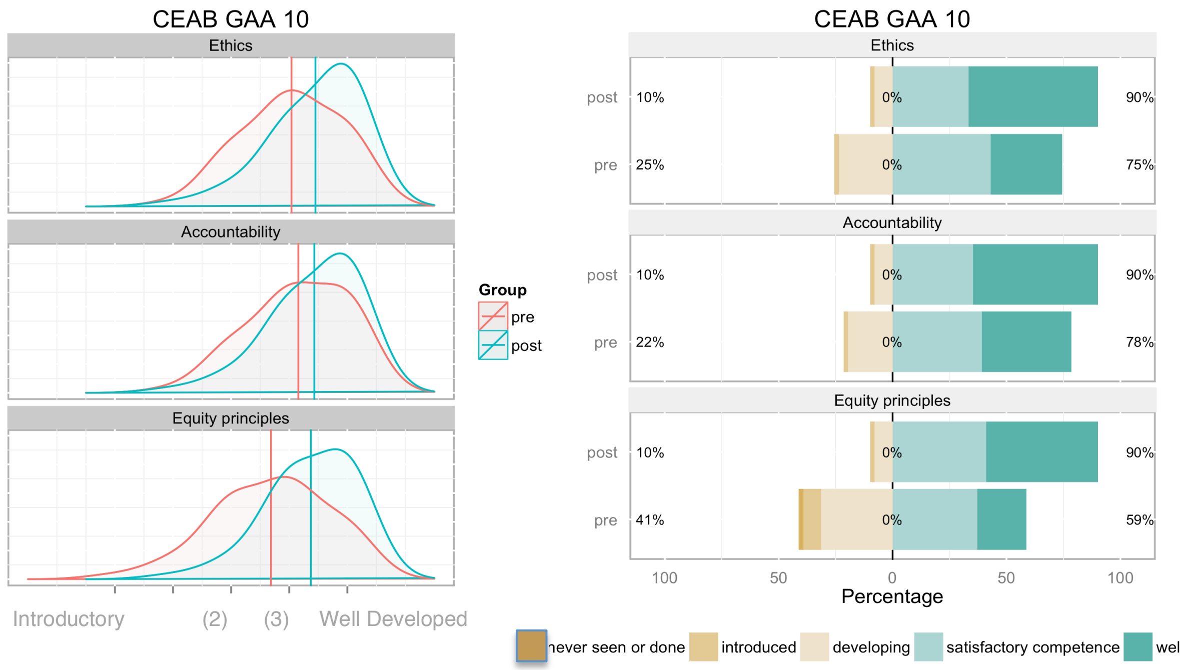


Figure 8.40. Student pre and post course rated skill levels related to ethics and equity principles and the design project (a) Density Plot and (b) Likert Plot (Plotted by E. Indiogine, 2015)

Pre course 59% of students rated themselves as satisfactory or well developed in their understanding and application of equity principles post course this shifted to 90% of responding students rated at this level. Post course 90% of students perceived their abilities in applying ethics and accountability principles to be at least a satisfactory competence, roughly a 15% shift. The student perceptions for ethics and accountability are shown in Figure 8.40. The shift is mainly attributed to student responsibility for managing their teams and project work during the term as no specific instruction in equity principles or ethics is given. It is implicit in project management, task resourcing, task distribution and team selection assignments.

11. Economics and project management: An ability to appropriately incorporate economics and business practices including project, risk and change management into the practice of engineering and to understand their limitations

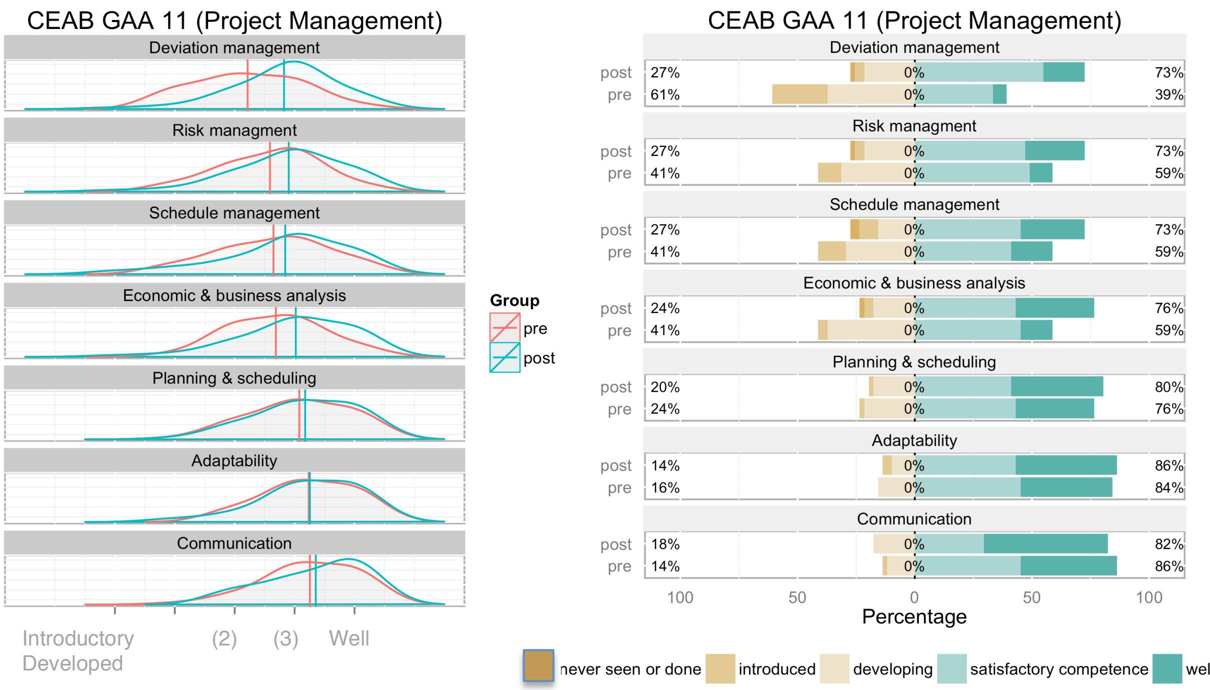


Figure 8.41. Student pre and post course rated skill levels related to economics, project management and the design project (a) Density Plot and (b) Likert Plot (Plotted by E. Indiogine, 2015)

Shifts in student perception of their abilities in the surveyed items relating to economics and project management are shown in Figure 8.41. The largest shift observed is deviation management from 40% to 70% rating their abilities as satisfactory competence or better. Next largest shifts of about 15% were observed in economic and business analysis, risk and schedule management. Minor shifts were observed in planning and scheduling and adaptability. A shift to the left from pre to post course is observed for communication related to project management. It was hypothesized that students may rank themselves lower in the post course survey if they realized a skill was not as well developed as they may have thought. This was the only skill where a shift to the left is observed in the post course results. The shift is observed from students previously rating themselves in the satisfactory competence range. There is an overall increase of students in the well developed competence category. Students were not given their pre course results during the post course survey as a comparative measure to gauge their answers.

12. Life-long learning: An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge.

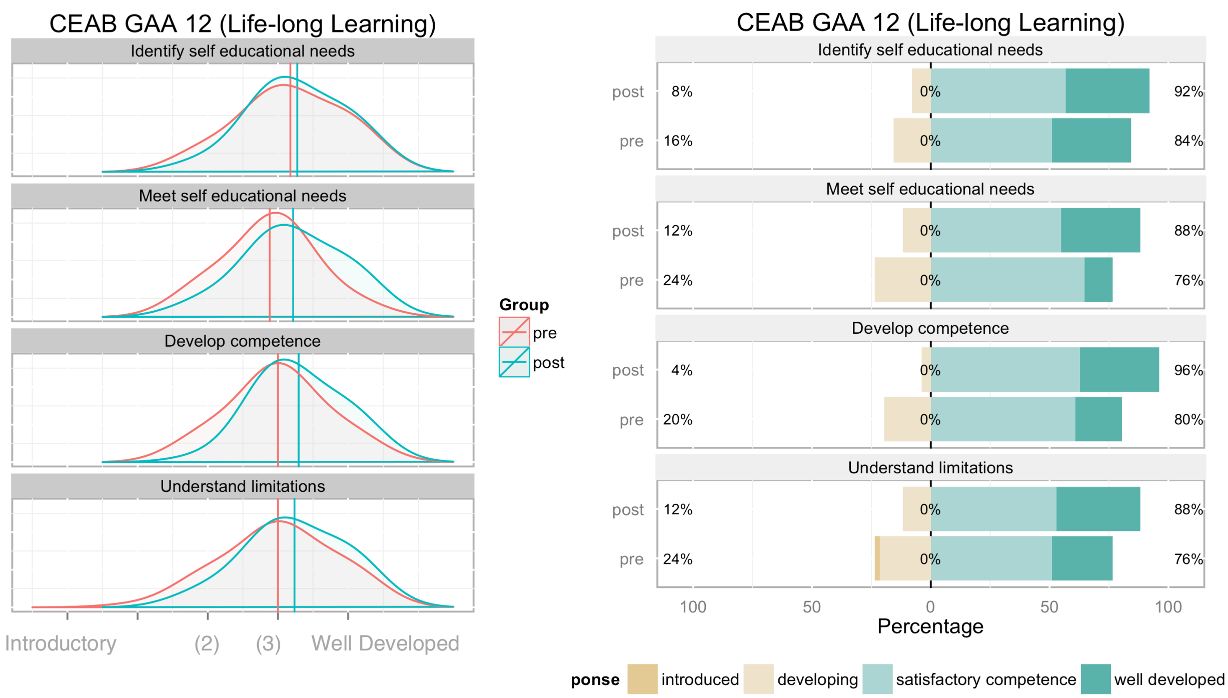


Figure 8.42. Student pre and post course rated skill levels related to lifelong learning and the design project (a) Density Plot and (b) Likert Plot (Plotted by E. Indiogine, 2015)

The majority of students self assessed the skills in Figure 8.42 related to life long learning as satisfactory or well developed competence in the post course survey. The ability to develop competence and the ability to identify self-educational needs were rated as satisfactory or better competence by 96% and 92% of post course respondents. Some students were less confident in their ability to meet self education needs and understand limitations. Both attributes were observed to have 88% of students self assess at satisfactory competence or better.

A positive self-assessment shift for students in the majority of skills or attributes surveyed was observed post design course. Some attributes and skills had a large student perspective shift towards satisfactory competence and others less so. Some of the observations were correlated with instructor observations in the course and directly related to areas that could be improved in the next iteration of the course. This tool does not prove students have attained a certain level of competence in any of the attributes, however it does indicate where students perceive they have developed and as such is good feedback for course continual improvement. Given the observation that student prediction of their performance ranks the highest in Hattie's 2009 meta study of educational effects, student perceptions of their performance do have a correlation to their performance. The exact nature or correspondence of their perceptions and their actual skill level is likely variable from student to student. The post course survey was completed prior to students receiving their final grade for the course.

Table 8.8. Summary of Pre-Post Course Graduate Attribute Shift from Introduced or Developing to Satisfactory or Well Developed.

CEAB GAA	Avg. Shift	% Students Satisfactory or Well Developed
1. A knowledge base for engineering	~10%	~90% (Weakest: process control ~60%)
2. Problem analysis	~20%	~95% (highest gain: reach substantive conclusions)
3. Investigation	~30%	~90% (weakest: error analysis ~70%)
4. Design	~30%	~80% (weakest: consider implications and assess sustainability)
5. Use of engineering tools	~20%	~75% (weakest: simulation software)
6. Individual and team work	~20%	~90% (weakest: coaching & learning style)
7. Communication skills	~15%	~90% (highest gain: report preparation)
8. Professionalism	~12%	~90%
9. Impact of engineering on society and the environment	~15%	~70% (weakest: HAZOP)
10. Ethics and equity	~15%	~90% (highest gain deviation management)
11. Economics and project management	~20%	~75% For PM skills higher for support skills: planning, communication, etc. ~80%
12. Life-long learning	~12%	~90 to 95% (weakest: understand limitations and meet self education needs)

A comparison of the subsample data for the pre course and the entire class for the pre course skill survey do not indicate a significant difference between the two groups. As summarized in Table 8.8, the largest shifts were noted in researching and investigating problems, design, team, report preparation, project management and accountability skill areas. Some areas such as use of engineering tools, error analysis, HAZOP and process control require further development and will be the focus of course improvements.

8.9.Examination of the Research Questions in the Context of the Study Results

This section examines the thesis and general research questions in light of the findings of the various studies performed. The thesis questions are specific to the design course(s) and the chemical engineering program factors. The general research questions were posed for blended learning in general and are discussed in the context of flipping the chemical engineering capstone design course and the work completed for this thesis.

Research questions posed for this thesis include:

- Does flipped learning lead to equivalent or better outcomes for Design II students?
- Is CEAB Graduate Attribute development demonstrated from data collected?
- Is student effort and quality of the final report equivalent or better for flipped learning students?
- Does a flipped learning structure produce equivalent or better academic performance?
- Is the co-op program a predictor or factor in student outcomes in design?
- Is the co-op program a predictor or factor for student results in a flipped structure?

Does flipped learning lead to equivalent or better outcomes for Design II students?

In the context of the ecological study, the ordinal regression analysis and the retrospective cohort analysis flipped learning did lead to an equivalent outcome for Design II students. There is evidence that students in the co-op program have been more likely to achieve A+ grades in the past and are still more likely to do so in the flipped version. Although regular program students were more likely to achieve lower grades in the past, the flipped version there is a decreased likelihood of a C+ and an increased likelihood of a B-. Regular students have an equal likelihood of achieving grades between A^- and B as in past lecture versions of the course. For co-op students there is a significantly increased likelihood of a B^+ and a nil chance for a B in the flipped version. There is a small group of students who were not significantly disadvantaged nor were they advantaged by the flipped version compared to other versions of the course. The groups that achieved in the C^+ region, including some co-op students was small. For co-op students there was an increased likelihood of a C+ grade in the flipped version, but a low probability of occurrence.

Further study and better organization of the course could be of interest to determine how much of an advantage flipped learning may give students. It does appear that there may have been some advantages to student performance.

Is CEAB Graduate Attribute development demonstrated from data collected?

The case based study of student skill assessment demonstrates student perceptions of their development of skills supportive of the CEAB attributes. The performance measures for the summative assessments of the situation and final reports are unchanged from previous years. Markers, marking and criteria remained the same and performance on average and on an individual basis maintained expectations. A case based study of student use of the LMS materials and time spent on flipped and traditional methods yielded results of similar time spent on study and projects with the flipped version demonstrating increased LMS access in support of assignments and accessing pre class material.

Is student effort and quality of the final report equivalent or better for flipped learning students?

Yes. The results of the case based LMS access, project tracking worksheets and final report marks indicate that effort was equivalent or greater in the flipped version of the course. The quality of the final report materials was shown to be similar to recent performance.

Does a flipped learning structure produce equivalent or better academic performance?

Yes. There is some preliminary evidence to suggest for some students it could be improved and for some students it could be less that expected. Further research is required. On average the outcomes are equivalent. On an individual basis an equivalent grade bin distribution was observed.

Is the co-op program a predictor or factor in student outcomes in design?

Co-op students are more likely to achieve an A+ than regular program students, however that likelihood has decreased since 2010. Students from both programs from 2010 to 2015 essentially have the same likelihood of achieving grades from A to B-.

Is the co-op program a predictor or factor for student results in a flipped structure?

Co-op students are still more likely to achieve an A+ in the flipped version of the course. They were also more likely to achieve a B+ over a B in the flipped version. Not all co-op students achieve excellent results, not all regular students achieve poor results. Since 2010 students in both programs have typically achieved performance better than a C^+.

Research questions posed for the broader investigation of blended learning, which this thesis contributes to include:

- What is the instructors' experience in developing and implementing their blended learning course?
- What is the students' experience of the blended learning approach?
- What is the impact on student engagement?
- What is the impact on student learning?
- What is successful? What is unsuccessful?

What is the instructors' experience in developing and implementing their blended learning course?

The instructors experience was generally positive. Students were observed to stay in the classroom after the in class time working in small groups and interacting with instructors often until the end of class at 6:00 pm or beyond. Instructors observed less email questions and more in class questions. Students were often prepared for class activities. If they were not, they were observed preparing in class. Since there was an assignment to hand in they were motivated to participate in the learning activities. There were more software downloads for VMG Sim, Visio, and MS project as students needed the software for class. The simulator TA was busy with questions two weeks earlier than previous years and the questions tended to be related to projects and not software. The first preliminary report and other milestone activities were often handed in early, some were handed in several days early and there was less recycle on the first report. This was not typically observed in previous course iterations. Most teams were able to achieve an early start to their project with the flipped version of the course.

What is the students' experience of the blended learning approach?

The student experience varied from comments that it was terrible to it was the best experience. Being a pilot version using online materials for learning, there were more LMS organizational and presentation limitations that impacted course perception than anticipated. Quality and organization count. Students are often used to only seeing one set of lecture notes as they progress through a course and not all the feature of the LMS. For some it is a significant change from previous experience.

Students appreciate clarity in understanding the rules, the goals, the assessment requirements and the ability to find resources easily. In the pilot version the focus was on converting material to on line and preparing in class activities more than on presentation organization. This had a significant impact on the student experience.

What is the impact on student engagement?

In the classroom students were engaged in discussion, assignments, and presentations. This was a stark contrast to the regular lecture version where students are typically passive. What was the impact of this changed engagement? That is still unknown. Questions as to whether students experienced enhanced intellectual development as classified by Perry's schema are not answered by student performance alone. Students may have developed further, written a good report and lost marks for missing required elements. This study did not investigate the causality of the lower marks or the effect of student engagement on performance.

What is the impact on student learning?

The impact on student learning in the context of the chemical engineering program is student achievement of objectives is possible. Some students did very well in the environment, enjoyed the format and excelled. Other students disliked the format and still did well. Grade performance summative assessment results on average and for individuals was similar to previous years

One of the major impacts on student learning was the proliferation of information on eClass and the overwhelming appearance of some tutorials. This has been flagged for redevelopment for the next course iteration.

Student self-assessment of skills demonstrated an overall positive shift in the number of students perceiving their abilities as satisfactory or well developed competencies.

What is successful? What is unsuccessful?

The flipped design classroom was successful in:

- Faster team and project start up
- Maintaining grade performance and meeting course objectives
- Improved grade performance for some students
- Increasing in class engagement
- Shifting student perception of their competencies
- Providing flexibility for students
- Shifting instructor focus to feedback, guidance and support rather than lecture preparation
- Shifting student focus to active and in control of their project

The flipped design classroom was less successful in:

- Preventing information overload for students in the first iteration
- Convincing students that flipped learning was easier than sitting in a lecture
- Improving grade performance for all students
- Reducing instructor time devoted to course preparation

The flipped design classroom has many advantages demonstrated by study results and experiential data including flexibility, data collection and analysis to inform continual improvement, maintenance and potential improvement of student performance. Targeted improvements to teaching and aligned assignments to advance student intellectual development and enhance cognitive task performance can be identified and carried out in the context of the design course and potentially the undergraduate program.

Initial development and revision of materials was time consuming and often limited time available for providing feedback in the pilot version even though more opportunities existed, taking advantage of them was not always feasible. It is expected this will improve for future iterations. Logistics for the design course and implementation of high effect teaching tactics such as meta cognitive strategies, self-questioning/reflection techniques, additional feedback and co-operative learning opportunities are significant tasks. Improving teaching clarity and professional development require time to complete. Resources and strategies required for additional support are required on top of an already logistically complex current course structure.

8.10. Summary

The flipped classroom with the online component provided students with equivalent learning and potentially deeper learning opportunities. Performance was demonstrated at an equivalent level with previous cohorts. CEAB GAA development was demonstrated from the student perception data and in the summative assessment of the final report. Academic performance was similar to previous cohorts from an ecological and individual perspective. Student effort required to produce a report and learn required material was similar. The flipped approach required an equivalent or more total time input for learning as the traditional approach from an accreditation hours perspective. In general co-op students are more likely to demonstrate A^+ performance than regular program students regardless of the course structure. Regular students are slightly more likely to demonstrate B- performance. The source of this bias may be multifactorial and causality was not investigated in this study. Comparison of specific grade performance of co-op and regular cohorts between flipped and traditional course delivery methods did not indicate a significant change indicating blended learning using a flipped course design structure is a feasible method of scaling the capstone design course to accommodate student enrolment growth.

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9. Addressing Program Growth and Solutions to Maintain Teaching Quality

Blending the design course led to equivalent learning outcomes and to several positive impacts including time compression of learning material delivery, more in class engagement, additional opportunities for formal and informal feedback, discussion, and presentation of learning. As the class grows from 125 students (2015) to 170 students (2016) and then to 200 students (2018), can a blended learning environment maintain or enhance the quality of the student learning experience, support instructors in maintaining best practices, and leverage available technology? Quality and quantity of feedback to students has already been identified as a significant contributor to improving student performance especially in the regular cohort. Although student motivation is recognized as a significant effect in student performance, investigation of possible instructional solutions and effects is the focus of this discussion.

9.1. Blended Structure Supported by a Collaborative Teaching Team

Maintenance of a low enough SI ratio is critical to providing quantity and quality feedback to design teams during the course. This aspect of the course is not scalable and staffing design course positions is challenging (Forbes, 2015). In addition, identification of suitable industry sponsors and unique projects is also challenging. The minimum number of projects required for 170 students is 29. For 200 students, 34 projects are required if maximum team size is restricted to six students. Ideally there should be 5+ and 6+ instructors guiding student teams respectively. Such large numbers of projects and the corresponding number of instructors will be a challenge to achieve in the time frame expected. The current number of instructors (four) will be inadequate even for the second iteration (Winter 2016) of the blended version of the course from this perspective. Table 9.1 outlines possible scenarios for managing 170 students and indicates possible preferred solutions. Maintaining the current number of instructors would result in a lower quality teaching and learning environment. Implementing metacognitive strategies in a community of inquiry (team) structure where students construct their learning requires advisor resources to guide the inquiry (White, 2005) and provide specific scaffolding for learners. Instructor/team interaction is a key consideration for implementation of high impact teaching strategies. Meaningful feedback to inform improvement and for summative assessment, opportunities for spaced practice and multiple attempts at learning material, creativity programs, and metacognitive strategies all require significant instructor interaction with students, and is particularly important in a capstone design course.

An alternate solution to higher staffing levels considered is to remove the unique project aspect from the capstone course and run the same project with multiple teams. This concept is currently being piloted in the Fa2015 version of CH E 464 Design I. It may reduce the instructor loading as the instructor has fewer projects to be familiar with. The risk of providing the same project to multiple teams is the possibility of unwanted collaboration across teams, making assessment of individual contributions more unclear and challenging. The gain in reducing the requirement of the instructor to be familiar with multiple projects may be lost as the instructor now needs to add evaluation of cross team contribution concerns to the assessment of student work. This strategy may represent the instructor as an expert and allow for students to retreat to this "safer" level and may require effort to actively manage what occurs naturally with unique projects: the instructor cannot be the expert in each individual project or have the "right answer" – only guidance.

Table 9.1 Possible Scenarios for Managing 170 Students in the Design Course						
Number of Instructors	4	4	5	5	6	6
Number of Teams	29 25(6) + 4(5)	34 34(5)	29 25(6) + 4(5)	34 34(5)	29 25(6) + 4(5)	34 34(5)
Number of projects/ instructor	7.25 3(7) +1(8)	8.5 2(8) +2(9)	5.8 1(5)+4(6)	6.8 1(6)+4(7)	4.8 1(4)+5(5)	5.7 2(5)+4(6)
student/ instructor ratio	42.5	42.5	34	34	28.3	28.3

9.2. Meta Cognitive Strategy Implementation: Writing Across the Curriculum

Findings from student cohort examination, classification of design course cognitive tasks requirements, and the evaluation of the quality range of student final reports indicate additional formative feedback for writing development could aid student development and would support course task challenges and student development. The student self-assessment for report writing, Figure 8.36, concurs. Only half of the class grade themselves as "satisfactory" or better in this area at the start of the course. The teaching team spends significant effort on improving report-writing skills and at the end of the course there is a marked improvement.

For the second iteration of the flipped and blended course, the teaching team has formed a partnership with Writing Across the Curriculum (WAC). Increasing spaced practice will provide students with scheduled feedback opportunities with a technical writing consultant in a seminar series. Topics will target style, credibility, arguments and the role of writing in thinking. The seminar design is intended to provide resources and opportunities for students to construct learning experiences to further develop metacognition, and encourage ongoing writing and revision through out the term of the reports they prepare for formative and summative assessment. Writing experiences and guided practice support learner objectives and relevant tasks while globally supporting overall cognitive development of higher-level task skills and contextual relativism skills (Bean, 2011) directed at advancing and demonstrating performance of the CEAB graduate attributes. To maximize cognitive development opportunities seminar organization includes:

- Instructor/Team small group project development and managements interactions;
- Writing and thinking about short duration and major assignments, individual reflection and team reflection;
- Active learning with peer based interaction. Collaborative, evaluative written and discussion activities.

This seminar strategy draws on the highest impact educational strategies (Hattie, 2009) including: feedback, spaced vs. mass practice, metacognitive strategies, creativity programs, self verbalization, self questioning, professional development, co-operative learning and worked examples.

Metacognition has two parts: the knowledge of cognition and the regulation of cognition. The understanding of learning strategies, understanding personal performance and how to learn is knowledge of cognitions. Regulation of cognition is the ability to plan and evaluate the cognitive process. Metacognition can be enhanced by writing and by evaluation of writing and thinking processes (Hacker, 2009). One seminar objective is student self-evaluation of their writing, thinking about their arguments and justifications, and how to build credibility in communication. Metacognitive skill development is part of developing life long learning and self-evaluatory skills (Avis, Fischer & Thompson, 2010).

The proposed topics for the seminar are detailed in Table 9.2 alongside the in class topics. The integrated strategy is designed to assist students to develop better final reports and afford specific opportunities to develop CEAB graduate attributes. The seminar design is in keeping with the overall

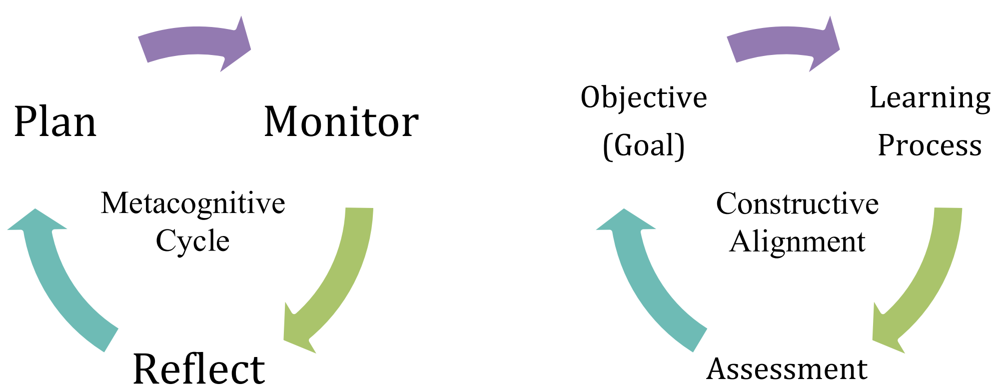

Figure 9.1. Comparison of Metacognitive Cycle and Constructive Alignment Learning Cycle

course metacognitive cycle: Plan, Monitor and Reflect. The partnership will also allow the teaching team to focus on students' technical, organizational, and team skill development. The metacognitive cycle is compared to the constructive alignment learning cycle in Figure 9.1 to demonstrate congruence with course design and philosophy.

The seminars begin with support for initial project research and progress to source credibility as students develop their initial report. Revising for clarity, organization and argumentation coincide with the peer and instructor feedback on their report to develop a more polished product for the industrial advisor. The seminars leave space for team evaluation and reflection when students have formal meetings. The final report look ahead begins early February coinciding with the start of the core design section. The aim is to have students writing up their work as it is completed and gaining feedback as it develops. As the report grows the focus is on review, editing, conclusions and recommendations.

In Table 9.2 milestone activities are shown in red and in class activities are shown in blue.

9.3. Team Skill Self Assessment and CEAB GAA Demonstration

For the 2015 flipped version the team selection form was reorganized to mirror the CEAB GAA numbering and headings. Students were made aware of the course objectives and outline prior to self-assessing their skills using an online survey. The online survey populated a team composite and students could determine their team strength and plan for development. The electronic data collection allowed for the post course evaluation to be easily completed providing an opportunity to assess developmental progress as perceived by individual students. This type of process targets feedback to the instructor or other evaluators on the effectiveness of the course. The highest educational effect (d=0.90) is formative feedback to the instructor (Hattie, 2009). This type of course evaluation based on student perception of their skills is objective, specific, measureable, attainable, realistic, and timely. It is easily accessible to the instructor and can be aligned with course objectives, e.g.: CEAB graduate performance criteria. It gives feedback to the students as their progress towards the CEAB objectives as they progress through their courses and it gives clear formative feedback to instructors where students perceive their development and where they do not. Although this application was developed specifically for the capstone design course as a team selection tool, it is now generally available in Moodle (feedback tool) and can be accessed by instructors. Survey questions can be targeted for specific courses. This type of course evaluation is also consistent with the metacognitive development cycle of plan, monitor, and reflect for both students and instructors.

Consideration is being given to the concept of ongoing access of students to their own evaluation results comparison for courses in the program using the feedback tool to track development of skill through their program. The idea of an individual portfolio as a measure of student development has been brought forward by CTL as an option for consideration (Nocente, 2015) as has the idea of gamification. The significant concept in gamification is that of a progression through the course material with feedback on how the student is doing relative to performance measures. A possible combination of program progression related to CEAB GAA skill development attached to a student portfolio may be a useful to for tracking and assessing student learning and development as they progress through the program. It could be a significant source of data to objectively determine what is effective and what requires improvement on a program basis.

For the second iteration of the flipped course, the post course self-assessment will be integrated with final report submission. Submission of the final report will remain incomplete until team members complete the self-assessment. Further, the self-assessment tool was deployed in Design I, CHE 464, at the start of the Fall 2015 academic term. Individuals used the tool to assess their own skills and then select their teams. Teams have completed two CATME evaluation cycles and most are happy with their team and individual performance. A small number of performance concerns have been identified. This is consistent with instructor observations of self-selected teams in Design II. Feedback has been provided via CATME to those students and the final report evaluation and final exam is incomplete at the time of writing.

9.4.Team Self Evaluation, Reflection and CEAB GAA Demonstration

The development of on line measurement tools to enhance quality of formative feedback to students from instructors and peers can be valuable to students, instructors and the evaluation of the CEAB graduate attributes. The following is an example that applies to teamwork and life long learning criteria. The capstone design course objectives and the CEAB Graduate Attributes include:

- Inculcate life-long learning and teamwork strategies through completion of self-directed group projects.
- Develop and demonstrate team, planning, logistics, leadership, deviation management and communication skills. Demonstrate professionalism and accountability.

The team evaluation and reflection process automation is meant to provide scaffolding for students to achieve course objectives, support team self-management and achieve a metacognitive cycle of plan, evaluate, and reflect. Automated grading of submissions and collection of student perceptions in a data mineable form is intended to further inform course improvement. Automation of this process provides

Table 9.2 Design II: Course Overview by Week (Colours indicate milestone assignments)

Week	In Class Topic (ETLC 1-003)	Seminar Topic (Cameron Library B-12)
1	Project Selection (2pm) Team Conflict Case Study & Team Charter Project Management (MS Project) Review Charter and Initial Scope (2-4pm)	Project Research: Where to start the search? Refworks: Start building your final report today (Resources: Librarian, Academic Advisors, Simulator TA)
2	Sustainable Design Decision Analysis Process Simulation (VMG Sim) Methane Liquefaction Simulation	Writing to Understand - The Situation Report Develop Potential Solutions and Credibility Coalescer Information Source Evaluation (Writing Across the Curriculum)
3	Situation Report Peer Edit (Due 2pm) Draft 2 (Due 7pm) Situation Report Feedback Reactor Modeling	Revising your Situation Report – Team Document Review: Arguments, Organization, Clarity (Writing Across the Curriculum)
4	Meeting 1: Situation Report PFD & PID Liquid carry over analysis	**No Seminar** (Assignment: Meet, Discuss & Report Post Meeting 1 Individual &Team Evaluation) **No Project Meeting** with Academic Advisor
5	Plot Plans Plot plan improvement Heat Integration HX network pinch design	Building your Project Description: Justification and Argumentation (Writing Across the Curriculum)
6	Heat Exchanger Design HX design selection & start Pump and Compressor Details	Looking Ahead: Turning a Situation Report into a Final Report – Planning Your Document (Writing Across the Curriculum)
7	Reading Week: No classes, seminars or project meetings.	
8	Separators, Distillation & Rector Design Process Interactions & Component Design Fluid Flow and Material Selection Impacts Considerations of interactions (scale up)	Open Session – Bring your questions! (Writing Across the Curriculum)
9	Meeting 2 Mass & Energy Balances HAZOP Practice HAZOP techniques	**No Seminar** (Assignment: Meet, Discuss & Report Post Meeting 2 Individual & Team Evaluation) **No Project Meeting** with Academic Advisor
10	Capital Cost Estimation Using the factors for your project Quantify & Manage Risk (F&EI, CEI) Hazard ID Peer Review	Building your Economic Evaluation (Writing Across the Curriculum)
11	Capital Project Economic Evaluation Project Case studies Project Strategy and Execution Schedule	HAZOP Meeting
12	Work Period (Project Meetings 2-4pm) General Questions 4pm Work Period (Project Meetings 2-4pm)	Final Report: Text Review, Recommendations and Conclusions (Writing Across the Curriculum, Academic Advisors)
13	Work Period (Project Meetings as needed) Meeting 3 Final Presentation	**No Seminar** (Assignment: Meet, Discuss & Report Post Meeting 3 Individual & Team Evaluation)
14	Final Report Adjustments & Polishing Final Report Due (2-4pm ETLC 1-003)	Report Polishing & Final Questions Post Final Report Individual &Team Evaluation

infrastructure for students, to complete the activity and develop their team and for instructors, to monitor and evaluate student success in meeting the course objectives and requirements.

Developing skills to individually reflect fairly on their own and teammates performance and reflect within a team context are both valuable skills and are the basis of life long learning and development as an individual and as a team member (Avis, Fischer, & Thompson, 2010). Immediate feedback is a requirement for individuals and teams to create an optimal or "flow experience". It is of equal importance to clear goal setting (Csikszentmihalyi, 1990). An exercise that supports individual and team reflection activities may be of more value than ranking individual contributions. While the latter serves the purpose of identifying members with a lower contribution, it is not clear that it supports the objective of developing life long learning and teamwork strategies. The CATME evaluation process tends to give students good information about how their team members perceive them and their contributions to the team. It is less useful for a team to identify team behaviors correlated with performance outcomes. The team assessment rubric adapted from Newell et.al. (Appendix E) is more concerned with the evaluation of the team functionality related to team outcome and the individual contribution to that function. Both methods serve a purpose. One is intended to evaluate individual contribution and the other is intended to give feedback on outcomes relative to performance related behavior. Evidence of individual and team contribution during the online process may make demonstration of student growth in the performance behavior area easier, much like the CATME online feedback is easier for individual performance in a team. Although the current method of CH E 435/465 team performance assessment requires all team members to sign the team evaluation and electronically upload the form there is no way to understand how individual students participated or learned from the experience or analyze data for trends and shifts. An online format would enhance instructor understanding of the team performance function.

Several attempts to steer students in the direction of self-evaluation and then team evaluation using a manual process have met with partial success. Automating the process, tracking individual results and team revisions can give evidence of student development while leaving the control of the evaluation, discussion, and deviation management in the hands of the students. This is another key ingredient in creating an optimal experience: a sense of control over one's actions. The tools must support the completion and guide but leave control with the students. Such an automated tool may be in place for the 2016 iteration of the capstone design course.

The purpose of the team evaluation tool is to allow students to rank their team behavior performance and obtain feedback regarding individual performance from their team members. Discussion of peer evaluations and individual assessments is part of the team reflection and development process. The purpose of the team assessment rubric (cross referenced with CEAB GAA) is to allow students to place their team behaviors in a framework that predicts performance providing them with feedback on their team performance. As such the individual should complete the evaluation ranking and initial team assessment first. Allowing the student the freedom to formulate their thoughts on their performance and their team's performance prior to team discussion gives students time to reflect on their own first. It allows for honest identification of problems earlier rather than later in the term, giving students a chance to resolve concerns early. The process overview, shown in Figure 9.2, should be student controlled, as

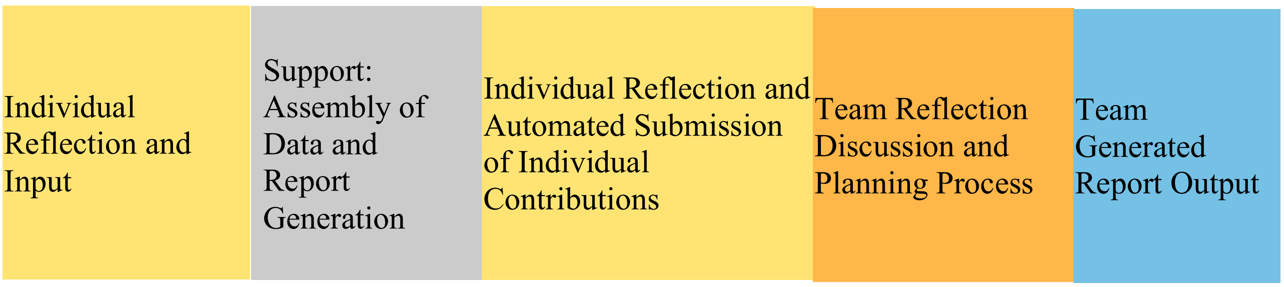

Figure 9.2. Team Behavior Assessment Process Overview

teams are self-managing. Automation will provide a consistent process and structure for the students to use within their teams. Ranking is to be anonymous. However, over all rankings must be discussed by the team. If a team member gives the team as a whole or other individual a poor ranking they should be prepared to explain their concerns at a team meeting. Since the ranking is done on a scale from 1-5, the meaning of those numbers may vary from person to person. Allowing the team an opportunity to discuss variance prior to submitting a completed team assignment is valuable. Having individual rankings on record is a resource for instructors in the event of a dispute requiring resolution. To this end the individual results of the team assessment rubric and individual evaluation ranking are to be submitted automatically as an individual component for each student and accessible to the instructors as individual documents if required. The individual responses will be compiled into an editable team document.

An additional reason for having the students provide comparative feedback to their teammates is to avoid problem situations near the end of the term where student contributions are identified as inadequate. At this point requests for differential grades are made when it is too late for corrective action or feedback to the affected student. A process to identify concerns and provide timely peer feedback at evaluation opportunities coupled with an in class process for the team to resolve concerns and document the resolution is integral to the course. Since it is required work, all students have had an opportunity to raise concerns and resolve them. If unresolved there is a basis for further action and escalation. It becomes an automated tool for teams to manage performance, to gain experience in evaluating performance, deviation management, and planning. Additionally it assists instructors to better manage grading and student complaints regarding individual performance during or near the end of the term.

9.5. Summary

Blended lectures are scalable and lend themselves to team teaching of larger classes with small group activities used for in class learning. In class activities require one instructor per ~30 students. A team instructional approach can provide a consistent student experience with an additional instructor joining the team for Winter 2016 and again for Winter 2017. This strategy allows students access to a variety of perspectives and experiences. This in turn gives students an opportunity to develop intellectually.

Individual pre-post course CEAB GAA skill based student self evaluation surveys provide instructors with objective formative feedback with regard to which learning objectives have been achieved and which GA is perceived to be developed during the course. The survey skills should be aligned with the course objectives.

The metacognitive cycle of plan, monitor and reflect is a key element when attempting to design a course to develop the CEAB GAA performance objectives. Professional knowledge and higher level cognitive skill development are transformed into self regulated student behaviors as students are required to reflect on their own development and success (Zimmerman, 2011).

Increasing metacognitive activities supports student development by requiring writing, self-assessment and reflection to be a part of the education process. By automating formative and team assessment and management tools, students obtain rapid relevant feedback, and instructors can intervene only when necessary. Fully automated tool development is an ongoing process. The addition of formative assessment and support for students and instructors are high value strategies for effective learning. As the class size grows these activities become prohibitive without automated support. Ongoing constructive alignment with the CEAB graduate attributes is a critical part of student development and performance criteria success.

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10. Addressing Student Development and CEAB Performance Success

Consideration of how the undergraduate chemical engineering program supports student performance in the design course(s) and how the design course supports the CEAB Graduate Attribute development and performance assessment is ongoing. Time constraints for capstone design and introductory design do not support significant review time of material from previous courses intended to develop knowledge, comprehension and application of those concepts. Additionally, process design requires students to reach well beyond their first undergraduate knowledge courses in areas of investigation to discern complex process and design considerations. Ability to break the problem into constituent steps, formulate potential solutions for each part, evaluate them and integrate the best solutions into a proposed system is required. Students must research new aspects and extensions of materials previously introduced. As evidenced by grade performance some co-op and regular program students are prepared for this leap and others are overwhelmed. The question now put forward is: Why?

10.1. Cognition, Prerequisites and Capstone Design Objectives

In the 1956 Taxonomy of Educational Objectives Handbook Bloom describes the initial transitions students move through from ability to acquire knowledge, ability comprehend and interpret knowledge and then progression to application of knowledge. Application builds on the construction of cognitive abilities in knowledge acquisition and comprehension. Application is demonstrated by applying the appropriate abstraction without being told which abstraction is correct or how to use it in a new situation. Comprehension differs in that the student can use the abstraction where specified. The ability to progressively master the range of cognitive domain tasks is dependent on student skill and ability as put forward in Figure 4.1. Progression to higher level cognitive tasks requires intellectual development, learning activities and experiences. The rate of progress may be dependent on program design, pedagogy, student perspective and motivation. A process analogy would be mixing of reactant components. Components can be added in a process where mixing is impeded and only single file diffusion occurs, the rate is slow; where mixing is slightly better and diffusion is the controlling process, the rate is slightly improved; where agitation is added, the rate is dependent on the speed and type of agitation. Results are highly variable depending on how the reactor is designed, the process objectives, the reactants and the time and type of measurement used to control the process. So it is with learning. Results are highly variable depending on the educational process design, whether cognitive task matches intellectual development, and whether learning objectives and assessments are aligned. Student reflection on progress towards goals on a planned path with specified activities aids in metacognition and motivation.

Analysis, a more advanced cognitive level, "*emphasizes the breakdown of the material into constituent parts and detection of relationship of the parts and of the way they are organized*". (Bloom, 1956) Figure 10.1 demonstrates this principle as it can be applied to transport phenomena. It is clear that in order for analysis to occur students must comprehend the knowledge acquired in fluid mechanics, heat transfer, and mass transfer, be able to find relationships and determine underlying principles. Ability to discern when to apply abstraction is also required. A sample of an analysis classification, by Dr. Kresta in 1998, for use as a tool for students to comprehend relationships is found in Appendix E. Students who have the ability to analyze knowledge, recognize relationships and underlying physical principles that govern the elements of their assembled knowledge are at a distinct advantage over those who are still in the process of forming these connections. Tools that help students develop analysis skill provide necessary scaffolding to a successful design project by providing connection between areas of study.

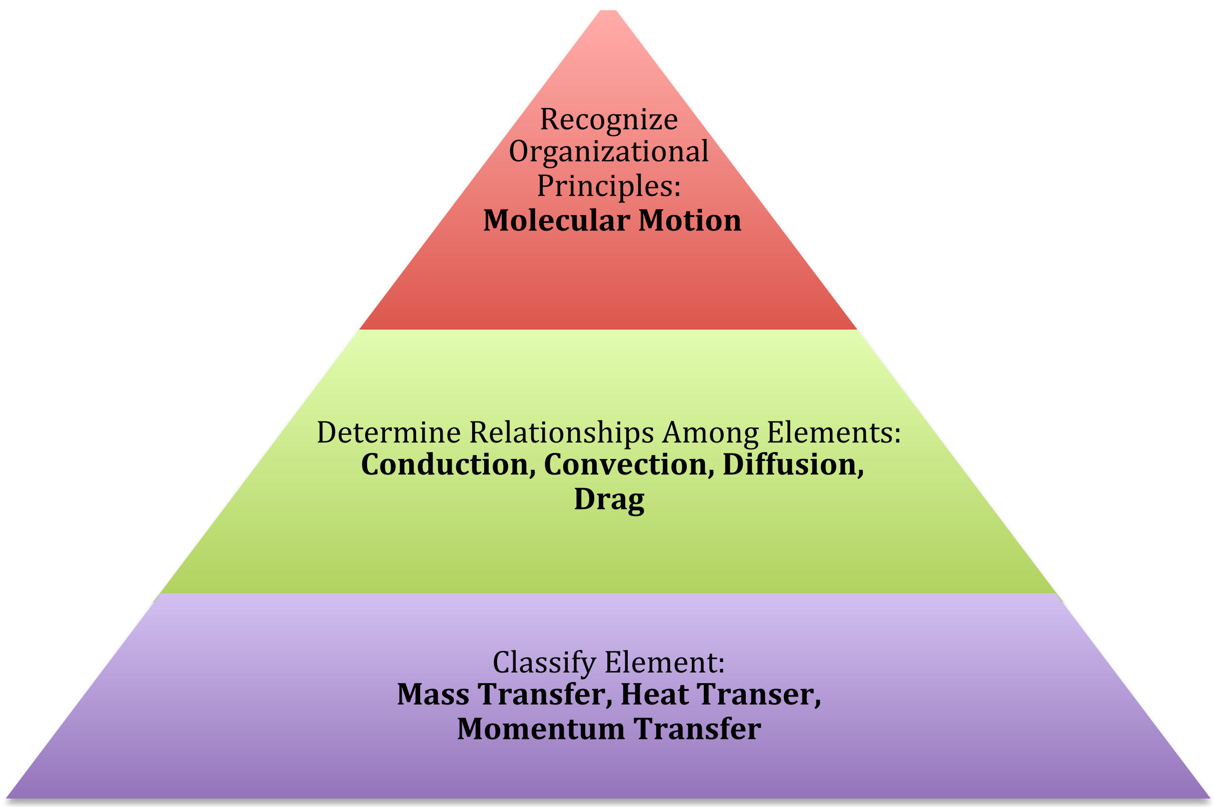

Figure 10.1. Analysis cognitive task level applied to Transport Phenomena

Design requires the ability to go from abstraction to concrete in an iterative manner applying convergent and divergent thinking models to synthesize and evaluate a solution to a complex problem. (Conklin, 2007; Dorst, 2011; Moraes, 2015) Synthesis is defined in Bloom's taxonomy as *"putting together of* *elements and parts so as to form a whole. This is a process of working with elements parts, etc., and combining them in such a way as to constitute a pattern or structure not clearly there before. In Synthesis a student must draw upon elements from many sources and put these together in a structure or pattern not clearly there before. (p.162)"* (Bloom 1956) In other words – design. This may be novel or recombination of previous experience.

The knowledge of how knowledge is related is a required input to conceptually designing a process system to achieve an end result, to design a component of the process to achieve an intermediate objective and to recognize interactions as component parts are linked together to effect the end objective. To design novel processes the designer needs to understand the problem from different perspectives. Know possible, previously attempted, and working solutions; understand connections between product specifications, the process users, the product end market, the economic, safety, risk and environmental implications and the interactions between the process and the process equipment. The designer works with the solution set in response to the evolving problem and constraints: testing solutions against many parameters using different types of thinking processes, considering how something might work or how it could work in addition to why it will not, progressively building and evaluating the solution. One of the objectives developed for the flipped version of the design course is for students to demonstrate both synthesis and evaluation levels of learning (Bloom's Taxonomy) for engineering knowledge gained throughout the undergraduate curriculum by designing and developing solutions for complex open ended problems and critically evaluating those solutions with respect to their technical merits, economic, environmental and safety impacts on society. Clearly, the expectation for students to design a process system at the conceptual level of detail requires the first four levels of learning described in Bloom's taxonomy to be well underway if not completed for this objective to be met. Students who typically obtain grades of A or A^+ in this course demonstrate this synthesis creatively, yet within constraints and have evaluated their work with respect to several criteria including technical feasibility, economic and market possibilities, safety and risk management criteria, environmental regulations and stewardship and finally project execution criteria. This evaluation is complex and can be overwhelming, especially for students who are unprepared for the cognitive task challenges of synthesis and evaluation. It is the cornerstone of what constitutes the transition from student to engineer: *Does my work meet the value constraints required by society for all criteria?* The evaluations and subsequent judgments will likely require adjustments to the design. This requires the ability to be flexible in thinking even in the face of a heavy time investment in the project. The professional ability to return to the design stage to make adjustments and rework the synthesis is a skill not explicitly shown in the taxonomy but is discussed by Bloom:

> *Although evaluation is placed in the last cognitive domain because it is regarded as requiring to some extent all other categories of behavior, it is not necessarily the last step in thinking or problem solving.* ***It is quite possible that the evaluative process will in some cases be the prelude to the acquisition of new knowledge, a new attempt at comprehension or application, or a new analysis or synthesis.*** (p.185) (Bloom, 1956)

The design courses are rich learning environments for students especially in the last two cognitive domains of synthesis and evaluation. Most design students when asked about their learning in design will answer they learned a great deal, yet the performance of most design students is variable. To maximize student success, the program leading up to the capstone design experience requires extensive experience at all four lower cognitive levels and some experience at the top two. The ability to move quickly and adeptly from one domain to another speeds the process of design as students are able to apply thinking techniques that broaden and narrow the solution field at appropriate times. Students who have spent the majority of their time in the knowledge, comprehension and application cognitive levels are ill equipped for the challenge and creative aspects of design. (Cussler, 2015) They are more likely to experience frustration as they attempt open-ended tasks.

10.2. Design, Blended Learning and Accreditation

The cooperative spirit in the Chemical Engineering Department at the University of Alberta has historically led to major collaborative breakthroughs in program and course development. The 2004 CEAB Accreditation and procedures outline the purpose of accreditation and how the criteria at that time were intended:

2.1.1 The criteria are intended to identify those programs that **develop an individual's ability to use appropriate knowledge** and information *to convert, utilize and manage* resources optimally through *effective analysis, interpretation and decision-making*. This ability is **essential to the design process** that characterizes the practice of engineering.

2.1.2 The criteria are intended to provide a broad basis for identifying acceptable engineering programs, to prevent over-specialization in curricula, to provide sufficient freedom to accommodate ***innovative educational development***, to allow adaptation to different regional factors and to permit the expression of the institution's individual qualities and ideals.

2.1.3 The criteria are intended to reflect the need for the engineer to be ***adaptive, creative, resourceful and responsive*** to changes in society, technology and career demands.

The criteria appear to be intended to identify and encourage programs that develop students in all areas of Bloom's cognitive domains and the iterative nature of cognition in design. This ability is recognized as

essential to the practice of engineering. The criteria also allow for innovative educational development and seem to encourage instructors to model adaptive, creative, resourceful and responsive behaviors to students.

Undergraduate program integration work has been supported and attempted in various topics such as reactors, distillation, separation and introductory design with varying degrees of success. Curriculum planning with integrated course development can be a creative and resourceful way to prepare students to connect knowledge used for the design experience. In addition, student's ability to distinguish between types and levels of thinking processes enhance ability *to convert, utilize and manage resources* ***optimally*** *through effective analysis, interpretation and decision-making.*

Prior student experience differentiating between individual, team, project and strategic thinking processes is an advantage. An experienced designer approaches a problem already familiar with the overall structure of the design process and the iterative nature of design thinking. An experienced designer expects to use convergent and divergent processes and knows that a solution, even an incorrect one, assists in complex problem understanding. A novice designer has a tendency to spend a lot of time exploring a complex problem not making progress on the solution. (Conklin, 2007; Moraes, 2015) This can appear as procrastination. A solution is picked with the realization time is running out. The evaluation phase can be superficial as time and ability to change the solution is limited. The student tries to follow a linear process possibly because they don't yet have confidence to move back and forth from problem to solution space or it *has not been modelled for them*. Co-op program students benefit from working with experienced engineers and have a higher probability of being exposed to iterative problem solving in industrial placements. Generally, co-op students seem to be more comfortable with this process. There is not always a clear or "right" answer but a range of possibilities that interact with boundary constraints. They may observe designers with some experience have different approaches, starting points and concerns because of varied individual background and experience. Different designers may visit the same issues while working through the problem however the sequence and emphasis may be different. The ability to use and manage this process in a team is a critical engineering skill as identified by the CEAB.

Earlier program exposure to design thinking and ambiguity in problem solving could be an important element in increasing the speed at which students make the transition through the stages of Perry's schema to contextual relativism. Developing course objectives related to all levels of Bloom's taxonomy and aligning assignments with course objectives in subject areas might be of value to increasing the rate of student development. Teamwork including evaluative and reflective processes to complete assignments is of value and should be encouraged at all levels of the program. Active learning and engagement can prepare students for the design experience by challenging their perspectives. Metacognitive processes support the development of many CEAB requirements.

10.3. Flipping, Student: Instructor Ratio, Engagement and Discussion

Pre blended pilot attempts to engage students during the lecture times in a classroom with between 115 and 140 students were typically met with silence. Typically responses were minimal and involuntary, often solicited by calling on specific students. Some discussions were tentative. Students may have been concerned with giving the wrong answer or an answer that the instructor was not looking for. Whatever the reason, participation was limited and uncomfortable therefore discussion and accompanying learning from the peer group was minimal during the lecture time frame. Many instructors have observed this in other traditional classroom situations. Active learning techniques such as think/pair/share were not employed in the large class situation until 2015. In 2010 several changes in the structure of the design course were effected: mandatory weekly meetings with a specific instructor throughout the term, three instructors instead of two, and a shift from mentoring teams to managing teams. The shift from mentoring teams to managing teams was brought about by role changes, organizational changes and developing self-management functions within the team such as schedule development, management, and reporting. These changes resulted in a decrease in the variability of student results as measured by their final grade in the course and by the co-op vs. regular program GPA gap as shown in Figure 10.2

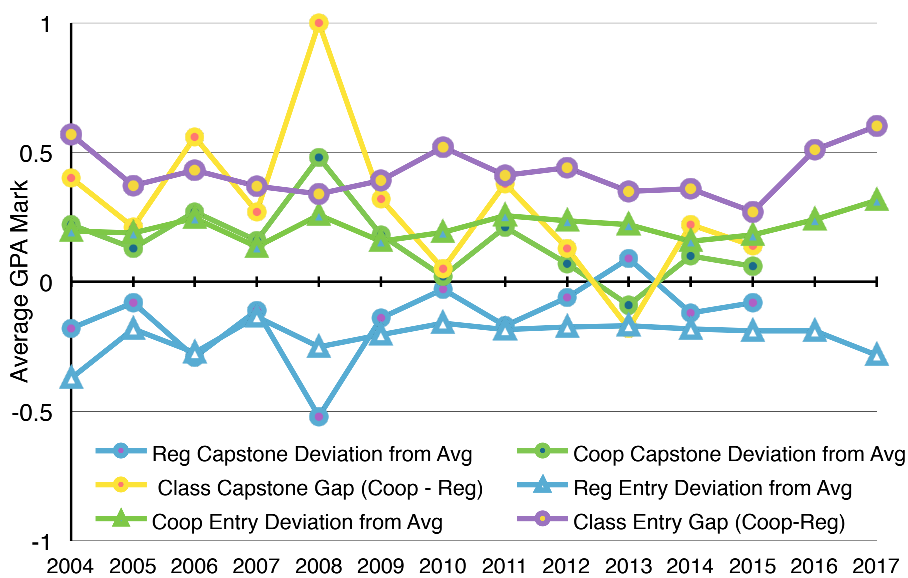

Figure 10.2. Impact of Program entry GPA delta on Capstone Design

Also demonstrated is the recent trend to higher co-op average and less variation within the cohorts leading to increased grade segregation between the cohorts. This trend may make engagement, active learning techniques and student instructor ratio more valuable as program pressures increase.

Engagement and active learning techniques seem to prepare students for the challenges of the capstone design course. These techniques are best supported with smaller class sizes (Cussler, 2015). However think/pair/share can be used in any size class with an electronic reporting mechanism such as Socratic classrooms. Blended learning with active in class techniques supports this possibility with team teaching and break off groups (Michaelsen, 2002). With these techniques student discussion and engagement was high.

10.4. Instructional Considerations

Results suggest that there may be an optimal number of students per instructor. Ratios above this optimal are typically more stressful for instructors and students as the same amount of available time is distributed between more students and typically more projects the instructor is required to be familiar with. Things are more likely to slip through unnoticed longer and/or continue until the instructor notices late in the term leaving little time for correction. Students contributing less or inadequately are more likely to pass through the system. The optimal team size according to Bruffee's review is five students and six works almost as well (Bean, 2011). Based on a team size of six students the number of projects and the number of instructors should be calculated to be about five to six teams per instructor.

On the other side of the optima, more instructors are more likely to pick up on individual student contributions or concerns as they have more time to notice, more time to investigate and more time to ask questions about student activities and monitor student progress. More students may get more help, but more flaws are also likely to be uncovered as more reports are double marked. In additional too low of a student instructor ratio allows the instructor to become too familiar with the details and overly involved in the student project. This, of course, is not the point of the design course. The course should be designed for the students to have an experience in researching and developing a design and evaluating the project rather than assisting the instructor who gives them the path and the solution. Both the linear and the second order correlation are weak suggesting that other factor influence student success. Clearly the skill of the student is a significant factor in the grade achieved in the course. The probability of getting a higher mark in the capstone design course is 2:1 for a co-op student; so clearly student skill, experience, contacts, and resources may contribute, as co-op students are more likely to have industrial experience and contacts. Clearly regular program students may have these attributes because of their previous experience prior to engineering, summer work experience, or personal contacts. Conversely co-op students may miss placements prior to their capstone design course experience or may not have capitalized on the experience or developed the skills in other courses. There is a range of grades for both regular program and co-op students in all years, however co-op students are more likely to perform better in the design course regardless of the student instructor ratio.

10.5. CEAB and Program Considerations

Changes and developments in the overall chemical engineering program and including introductory and capstone design courses must support the accreditation of the Faculty of Engineering and the Department of Chemical and Materials Engineering. Failure to meet the expectations of the accreditation board will have consequences for students and staff and is clearly not an option. The CEAB Graduate Attributes are summarized in Appendix D.

Student intellectual development is progressive and required to accomplish the performance tasks set out by the CEAB graduate attributes and the capstone design course. The performance of the criterion based tasks of the capstone design course require students to have developed cognitive skills at all levels of Bloom's taxonomy. An engineering program that can integrate student intellectual and cognitive development into the program design may be able to increase student performance in the capstone course and demonstrate enhanced graduate attribute development in the majority of students. The criterion for the capstone design course final report are performance based and do not change from year to year.

Student development and learning can be enhanced by using metacognitive strategies, feedback, engagement and spaced vs. mass practice. Including some of these strategies throughout the program increases the space of the practices and introduces students to skills required for meeting the performance criteria earlier in the program. Some student suggestions for earlier courses have included technical reading, technical writing, and design problems. Working in teams earlier and more frequently for goal oriented tasks could be advantageous in developing required skills for capstone design, such as collaborative learning, leadership, task planning and work strategies (Bean, 2011).

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11. Conclusions and Recommendations

11.1. Conclusions Related to Research Questions Posed

The capstone design course teaching delivery model was switched from a primarily face-to-face lecture delivery format to a flipped and blended delivery format for the Winter 2015 academic term, as part of a two-year pilot project funded by the Provost's Digital Learning Initiative. The project supported by The Centre for Teaching and Learning (CTL) and the Department of Chemical and Materials Engineering (CME).

The key research conclusions of this work are:

- The traditional lecture format and blended learning format led to equivalent outcomes for Design II students on an aggregate and individual basis. Although some students may not have achieved high performance levels, all students achieved performance levels comparable to the recent traditional delivery course. Median achievement outcomes for the co-op and regular cohorts remained undifferentiated.

- CEAB Graduate Attribute development is demonstrated from the pre - post course self-assessments based on the CEAB GAA skills associated with the capstone course. This information provided excellent formative feedback to the instructional team as to what areas required further instructional development.

- Student effort and the quality of the final reports are equivalent for blended learning students compared with the traditional learning cohort examined.

- A blended learning structure using a flipped model produces equivalent academic performance and is within the expected process variation for course iterations from 2010 – 2014.

- The co-op program is a predictor or factor for high student performance outcomes in Chemical Engineering Design II. Co-op students are significantly more likely to achieve an A^+ in both traditional and blended delivery modes.

- The co-op program continues to be a predictor or factor for A^+ student performance outcomes, over all, irrespective of course delivery mode.

- Blended course delivery permits instructors to scale course material delivery as class size increases, while protecting aspects, such as individual and team meetings with instructors that are not scalable and which comprise a critical component of design education.

- Support for course conversion and development of on line course elements require significant instructor time commitments in development and in follow up formative grading.

11.2 Reflections on the Continuous Improvement of Chemical Engineering Design Education

Flipping and blending the capstone design course, for the Wi2015 term was the second step change in course delivery model, over the 2004 - 2015 study period. The first change, ahead of the Wi2010 term, included reducing the student to instructor ratio and going from a mentorship to an internship course model. The 2010 change in teaching approach was largely grounded in providing early examples of reports, early feedback, team formation support, early scoping, research and formative reporting requirements. All interventions were aimed at students starting early and getting feedback early on their first of several iterations. This first step change, led to significant positive impacts on learning outcomes for regular program cohorts. Impacts on the learning of the co-op cohorts were minimal. These changes *were* undertaken to provide additional support for regular cohorts. They had the intended effect but it is not possible to attribute the improved learning outcomes for the regular cohorts to one or the other change individually because they were made simultaneously. However, with these changes, the regular and co-op cohorts achieved comparable mean learning outcomes in the run up to the blended pilot (Wi2012 through Wi2014 course delivery). The following are recommendations for continuous improvement practices:

- Student and Instructor experience and satisfaction was variable during the pilot. It was an ambitious conversion project. The input from student and instructor feedback combined with performance results and student skill perceptions will inform continual course development and improvements, particularly ahead of the second iteration of the blended design course pilot project (Wi2016).
- In the blended design classroom faster team start up and project launch was observed along with more software downloads, in class questions and teams being ahead of schedule early in the term. Instructor focus shifted from preparation and lecture to guiding and supporting student learning. **LMS organization can be improved to enhance student satisfaction and reduce frustration.**
- Student engagement was much higher compared to past iterations of the course. Feedback from University of Alberta design students (2015) suggested the active learning done in groups of 12-18 was the most effective. Most in class activities were initially designed to use groups between 12 and 30. **Better interactions were observed with the smaller groups and activities will be reworked to use smaller groups.**
- Various lengths of learning elements were experimented with. More positive comments were received with shorter productions. Some new materials were added after instructors realized conversion of learning elements reduced the delivery time required. This was not always well

received by students. Adding material because delivery time is compressed is not always helpful. **Maintaining learning element length at approximately five minutes is recommended.**

- Flipping the course in a blended structure has the advantage of visibly incorporating the CEAB graduate attributes in a meaningful way into the curriculum and has further developed the internship model of learning. Student self assessment of attribute related skills at the beginning and end of the course demonstrate a shift over the term to both student and instructor and cause both to reflect. **Metacognitive aspects have been included or highlighted as learning activities are redeveloped to support the life long learning graduate attribute.**
- The automated self-assessment tool and the integrated team selection tool developed as part of this project were found to be particularly beneficial. The underlying code is being further developed for applications in other courses where teams self-select with constraints. These are found in numerous courses across all faculties and a general Moodle plug-in is being prepared. The pre-post self-assessment tool is also being further developed so that individual **students can observe their skill levels and changes in their skill levels in the context of their peers.** With minimal custom coding, these tools could be easily applied to any course.
- In the capstone design course, **data collected in an automated manner demonstrate skill levels and changes in skill levels relative to the CEAB graduate attributes**. These data have a number of purposes and will inform continual improvement of the design course and courses that underlie it.

Targeted examples for enhanced learning topics in Design I and/or Design II include:

- a specific focus on **control loop design**;
- **error analysis**, specifically identification of sources of uncertainty;
- **sustainability evaluation criteria**, specifically Hazard identification, risk analysis, HAZOP and environmental metrics;
- **simulator usage**, specifically the ability to model unit operations and using the simulator as a tool;
- **project management skills**, specifically items related to team and work processes;
- **understanding educational needs** and meeting them.

The biggest surprises for the capstone design team were the weak areas of process control and simulator proficiency as the students perceived their skills. The design of the in class and on line activities for HAZOP and risk assessment for the Wi2015 iteration did not produce the hoped for results and the ability of students to evaluate the hazards, risks and environmental constraints of their projects was limited. Specific attention will be required to the development of learning elements for these topics, as the use of third party material was not as effective as previous traditionally delivered lectures.

The ability of students to identify their own educational needs to complete the project and their ability to meet those requirements by researching topics is addressed in the Wi2016 iteration by the seminar schedule including research and report preparation. The sustainability and simulator weakness have been addressed to some extent in Design I as of Fa2015 and will continue to be topics in CH E 435/465 with additional resources being allocated to appropriate learning development.

11.3 Recommendations and Further Work

Future work planned ahead of the Wi2016 iteration of the Blended pilot:

- Team evaluation of individual contributions and assessment of how the team works together have been significantly developed since 2010. For the flipped version of the course this process was conducted as the manual version. For the 2016 course revision this process is being studied for automation with the objectives of reducing cognitive overload in the course and improving process effectiveness. The data from both of these tools will be stored electronically allowing for data analysis and continuous improvement of the course based on student skill and experience profiles.
- Increase feedback opportunities for students from multiple sources. Implementation of a Writing Across the Curriculum strategy or writing in the discipline strategy to further develop metacognitive skills and life long learning earlier in the program would be of value.
- A Writing Across the Curriculum (WAC) joint seminar support initiative to assist students with metacognitive development, report writing, is in place for the Wi2016 term. Evaluation of the success of this initiative from a performance and learning standpoint should be undertaken.
- Student grading and the automation of grading some aspects of assignments is being investigated for future applications. Consideration is being given to Automatic Essay Scoring and automatic document checking for completion marking. Both are for formative marking.

- Implement automatic completion grading for meeting assignments, individual and team evaluations and reflections. Keep the metacognitive aspects of the assignments and increase student participation in reflection and peer review.
- Beyond the pilot course and as student enrolment continues to increase more design instructors are required for both the introductory and capstone design courses to provide a consistent and sequential program that targets the CEAB GAA performance criteria at the higher cognitive skill levels of analysis, synthesis, evaluation and creativity.
- Six instructors are required for the 2016 Design II iteration and seven for 2019 as this most closely resembles the most successful scenarios and allows for continued creativity in applying new strategies to improve student performance.
- Including design thinking and processes in earlier course work would be advantageous to students. A first year design experience including writing about design thinking, failure and iteration would be ideal. This does not preclude integrating design sections and ideas in unit operation and knowledge based courses as a method of teaching.
- Team and small group interactions for goal oriented smaller technical reporting projects earlier in the program would develop student team work skills when the stakes are lower.

Appendix A: CH E 435/465 Grading Procedure

1. Grading Procedure: Capstone Design Final Reports

The grading procedure for the Capstone Design course evolved as instructor support for the course has increased and the student instructor ratio has decreased. From 2004 – 2009 the reports were marked using similar criteria as from 2010 – 2015. Jamieson, Pick and Shaw most recently revised the final report specifications prior to the 2014 offering of the course. The same specifications were used for the 2015 course offering.

From 2010 to 2015 the instructor who met with the team on a regular basis was the first marker on all reports. The second marker was determined by requirement and interest. All markers were required to mark at least one additional report from each of the other instructor's student project teams. As other instructors chose reports the selection was reduced. The result of this procedure was that with 5 instructors managing 5-6 projects each, most instructors marked between 9 and 10 reports and most reports were double marked.

After the design reports were marked the markers discussed all reports, including single marked reports. Justifications for marks were discussed and disagreements were resolved. If disparities were not able to be resolved a third marker read the disputed report and adjudicated. Most of the time report grades agreed within 5 marks on an 80 mark scale.

The final report was worth 80 percent of the final mark for the course from 2004 – 2014. For 2015 the final report mark was scaled from a mark out of 80 to a course component of 75 percent. Marking will continue out of 80 marks and be scaled to ensure that marking is consistent and comparable across cohorts for the final report. From 2015 onwards students will have a 5 percent credit for portfolio assignments completed during the course. These assignments were in addition to the regular milestone assignments that students in all cohorts were required to complete.

The grading procedure is in compliance with the University of Alberta Grading Procedure: https://policiesonline.ualberta.ca/PoliciesProcedures/Procedures/Grading-Procedure.pdf. As such there are no predetermined number of particular letter grades for any one term and student work is graded on a merit basis. The number of particular grades varies from year to year, but the tendency for the overall class average to remain at ~ 3.3 is consistent over the study period. The qualitative marking guide outlined below is provided to students at the start of term along with the marking rubric, final report specifications and requirements.

CH E 435/465 Final Report Marking Guide

This guide is meant to be used as a qualitative guide and will be used in conjunction with the marking scheme and the final report specification to be found in the course outline. This guide is meant to assist you with project planning and scheduling.

<u>For a team to get a mark of C- or greater there must be clear evidence that most of the required analyses for the course have been completed. There may be errors and quality issues.</u> (Satisfactory)

Process Simulation and calculations for the reaction and or separation
Validation of the simulation
Material and Energy Balances
Process Flow Diagram
Size of Main Process lines
Size of Equipment
Utility Requirements
Control Instruments
Plot Plan
Design Specification
Detailed design for a piece of equipment
PSV sizing
P& ID for a selected piece of equipment
HAZOP and Risk Assessment
Economic Analysis (including discounted cash flows, tax tables, sensitivity analysis, investment schedule and a plan for financing)
Project Management and Schedule Analysis
Project Execution strategy
Environmental Requirements have been identified and addressed
Legislative requirements have been identified and addressed
Writing is adequate and documentation is adequate

<u>For a Team to get a mark of B- or greater all of the above are completed and are mostly correct. In addition there must be clear evidence of most of the following in the report:</u> (Good)

Analyzing the problem
Creative thinking (brainstorming)
Research (peer reviewed literature or published books)
Decision-making
Design development
Design Analysis
REDESIGN PROCESS
Rationale exists
Team work with a minimum of conflict, team was motivated; team demonstrated research abilities and found mentors/guidance.
Writing is mainly clear and Documentation is good

<u>In order for a team to get a mark greater than an A- all of the above criteria must be true and there must be more evidence of the following:</u>
(Excellent)
Analyzing the problem - the solution and the report address the initial interest of the client or have taken it in a new direction because of the research that has been uncovered. Enrichment topics such as process control, heat exchanger network design, risk mitigation strategy, etc. must be clearly and correctly developed and add to the project.

Creative thinking (brainstorming) - unique, fresh, stands out in some way – synthesis is evident.

Research (peer reviewed literature or published books) - it is evident that research was undertaken in a serious manner and has been applied to the design, used to validate the models, etc.

Decision making that is carefully considered at an in depth level. All the tools that were required to be used, such as economic analysis, sizing and costing, HAZOP and risk assessment were completed and considered in the selected solution. Other tools that were not required may have been used. A weighted system may have been used. Evaluation is evident.

Design development details were important, and the design is correct! Minimal errors.
Design Analysis errors that were found were corrected and the Design is elegant, original thinking and synthesis is evident in the solution. Many ideas were brought to together.

REDESIGN PROCESS demonstrated more than once and how the analysis affected the recommendations and conclusions is clear.

Rationale exists and is clear
There is no digging required to understand all aspects of the solution. If need be the appendices are clear and support the solution but the report is convincing on its own.

Team worked very well together, mentors and guidance was used, a collaborative relationship was developed with the Industrial advisor. Relationship with the faculty advisor was also collaborative. Team may have developed collaborative relationships with more than one instructor.

Exposition and Documentation are excellent.

2. Conversion from the Nine Point Scale to the Four Point Scale

The University of Alberta changed the grading scale for student marks September 1, 2003. All cohorts for the capstone design course from 2004 – 2015 are graded using the four-point scale for individual and class averages. When investigating the second year program entrance marks for program selection biases the nine-point scale was encountered for grades earned previous to 2003. This necessitated a conversion algorithm for comparison to post 2003 first year averages used to determine program selection for co-op and regular student cohorts.

The University of Alberta Registrars Office provides some guidance in the matter: http://www.registrarsoffice.ualberta.ca/Assessment-and-Grading/Students/Grade-Comparison-Guide.aspx

Table A2.1 is the comparison provided at the above link to assist in the interpretation of University of Alberta transcripts where a student has completed course work in the previous nine point grading system.

Table A2.1. Comparison between the University of Alberta's Old and New grading Systems

Nine Point Grade prior to September 2003	**Letter Grade** effective September 2003	**Grade Point Value** effective September 2003
9	A+	4.0
9	A	4.0
8	A-	3.7
7	B+	3.3
	B	3.0
6	B-	2.7
	C+	2.3
5	C	2.0
	C-	1.7
4	D+	1.3
	D	1.0
3	F	0.0
2	F	0.0
1	F	0.0

An algorithm was developed to convert average grades for first year GPA data from 2000 – 2003 academic year ends from the nine point scale to the four point scale. As student data was provided on an anonymous basis for class aggregate and program comparison (Matthias, 2015), individual course conversions and weighting could not be applied. Only the final weighted grade could be converted.

Algorithm for grade conversion from 9.0 scale:

9=>4.0

8=>(ABS(8-GPA)*0.3)+3.7 =3.7

7=>(ABS(7-GPA)*0.4)+3.3 =3.3

6.5=>3.0

6=>(ABS(6-GPA)*0.6)+2.7 =2.7

5=>(ABS(5-GPA)*0.7)+2.0 =2.0

5=>2.0

4=>(ABS(4-GPA)*0.7)+1.3 =1.3

3=>1.3-(ABS(4-GPA)*0.6)+0

3.5=>1.0

Reference:

http://www.registrarsoffice.ualberta.ca/Assessment-and-Grading/Students/Grade-Comparison-Guide.aspx (Accessed May 2014)

There was some discussion as to whether an A+ = 9.0 =4.0, an A = 8.0 = 4.0 and A- = 7.0 = 3.7 for Chemical Engineering grades over the period in question. The decision was made to follow the Registrar's guidance as outlined in Table A2.1. Data discontinuities due to this conversion did not show as out of control points in the data analysis, but caution should be used for first year data for graduating classes with converted grades.

The current grading system for the University of Alberta is explained at http://www.registrarsoffice.ualberta.ca/Assessment-and-Grading/Students/Grading-System-Explained.aspx (September 2015). The grading expectations for undergraduate students are different from graduate students. Table A2.2 examines the four-point scale from a quality of work perspective for undergraduates.

Access to previous final reports is provided as required by the University policy on access to evaluative materials: https://policiesonline.ualberta.ca/PoliciesProcedures/Procedures/Access-to-Evaluative-Course-Material-Procedure.pdf. In accordance with student record privacy no evaluation or classification of the materials is provided. Students must make their own assessment as to what constitutes a quality report based on the qualitative information provided and their access to representative samples of student work.

Table A2.2. Letter Grading System (effective September 1, 2003) Course Grades Obtained by Undergraduate Students		
Descriptor	**Letter Grade**	**Grade Point Value**
Excellent	A+ A A-	4.0 4.0 3.7
Good	B+ B B-	3.3 3.0 2.7
Satisfactory	C+ C C-	2.3 2.0 1.7
Poor	D+	1.3
Minimal Pass	D	1.0
Failure	F	0.0

The definition of excellent work is work that is distinguishable as outstanding and meets almost all if not all course objectives and final report specifications. The definition of good work is work that meets the majority of course objectives and final report specifications. The definition of satisfactory work is that is meets the majority of course objectives and final report specifications, but the work contains significant errors. The definition of marginal work is that is marginally meets course requirements objectives with or without errors.

Table A2.3. Capstone Design Course Final Percentage Conversion to Letter Grade and Grade Point		
Percentage	Letter Grade	Grade Point Value
95-100	A+	4.0
90-94	A	4.0
85-89	A-	3.7
80-84	B+	3.3
75-79	B	3.0
70-74	B-	2.7
65-69	C+	2.3
60-64	C	2.0
55-59	C-	1.7
50-54	D	1.0
0-49	F	0.0

References:

Matthias, R. (2015). Personal Communication.

University of Alberta Policies:

https://policiesonline.ualberta.ca/PoliciesProcedures/Procedures/Access-to-Evaluative-Course-Material-Procedure.pdf. (Accessed November 2015)

https://policiesonline.ualberta.ca/PoliciesProcedures/Procedures/Grading-Procedure.pdf. (Accessed November 2015)

University of Alberta Registrar's Office:

http://www.registrarsoffice.ualberta.ca/Assessment-and-Grading/Students/Grade-Comparison-Guide.aspx (Accessed May 2014)

http://www.registrarsoffice.ualberta.ca/Assessment-and-Grading/Students/Grading-System-Explained.aspx (September 2015).

Appendix B: Publications Resulting from Thesis Work

Jamieson, M.V., Shaw, J.M., Nocente, N., (forthcoming). A Case Study in Chemical Engineering. In L. Santos Green, J. R. Banas, & R. Perkins (Eds.), The flipped college classroom: Conceptualized and re-conceptualized. New York: Springer. 4 pages.

Jamieson, M.V., Church, L.C., Vagi, F., Pick, W., Onuczko, T., Nocente, N., Shaw, J.M. (2015). The University of Alberta Design Course Goes Flipped! CEEA conference proceedings May 31-June 3, 2015, McMaster University. Paper 093. http://library.queensu.ca/ojs/index.php/PCEEA/issue/view/544

3. Course Structure and Implementation: A Book Chapter Case Study

A case study describing the instructional content, structure and implementation, and lessons learned during the CH E 435/465 Blended Learning pilot was developed for Part II of The Flipped College Classroom: Conceptualized and Re-conceptualized, edited by: Ross Perkins, Boise State University; Lucy Santos Green, Georgia Southern University; Jennifer R. Banas, Northeastern Illinois University. The June 28, 2015 copy to the editors is included. Less than 10% of proposed materials submitted for this book were accepted at this point. The format required brevity and is not expanded.

3.1.Instructional Content

1.1.1 Chemical Engineering Capstone Design Course Description

During this course, teams of 5 or 6 students undertake engineering projects proposed by practicing professional engineers who also act as industry advisors. Each team must integrate chemical engineering practice, theory, and economics into a validated and sustainable design of a complex open-ended engineering capital project. Four co-instructors teach the course. Each instructor meets weekly with 6 to 8 teams to mentor, monitor and evaluate their progress. Figure B1.1 illustrates the course model based on real life work structures.

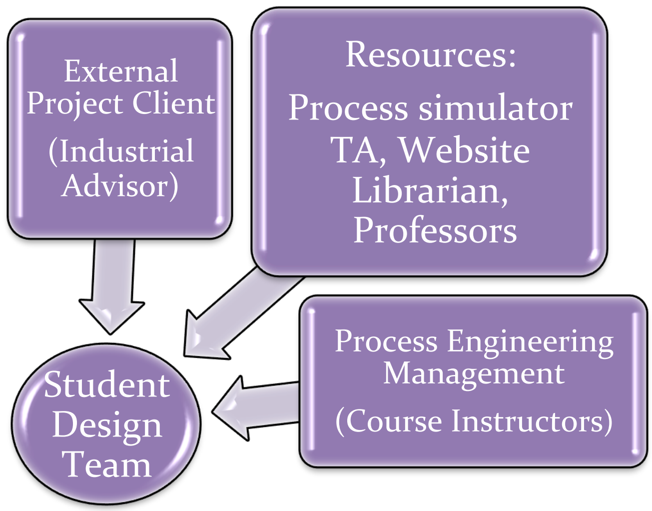

Figure B1.1. Course model based on engineering design work

1.1.2 Place of Course in the Program of Study

Students take this course during the final term of their undergraduate program, following completion of fundamental knowledge based courses and an introductory design course.

1.1.3 Learning Goals of the Course

The goals for students in this course include the ability to:

- synthesize and apply engineering knowledge;
- design and develop solutions for complex open-ended problems;

- evaluate proposed solutions critically with respect to technical merit, economic criteria, environmental and safety risks and impacts on society; and
- engage in life-long learning, leadership, management, communication, planning, logistics, teamwork strategies, professionalism and accountability.

1.1.4. Description of the Learners

Entrance into the degree program requires an 85% average from high school. Approximately half of the students follow a regular 4-year undergraduate program (~30 % of whom are international students) and half follow a 5-year co-operative education program including 20 months of industrial experience. In addition to developing knowledge and skills in core chemical engineering subjects, some students have developed specialized knowledge in computer/process control, biomedical, or oil sands.

1.1.5. Rationale for Flipping

The flipped approach was catalyzed by a desire to more effectively address student learning depth and heterogeneity, engagement, and to enhance student and instructor interaction quality. Flipping increases in class time available for students/teams to interact with instructors formally and informally, and provides a strategy for accommodating expected enrolment increases while improving learning quality.

1.1.6. Models and Theories Used to Guide the Flipping

Experiential learning (Dewey, 1938) informed the development and implementation of in-class learning activities. The team approach embodies social constructivist and collaborative learning theory (Laurillard, 2012; Vygotsky, 1978). Teams provide safe and constructive environments for articulation and evaluation of ideas, and for achieving consensus. Theories from Csikszentimihalyi (1990) and Vygotsky (1978) guided many pedagogical decisions related to online content where resources, advanced/remedial supplemental materials in audio, visual and print formats were used to scaffold the instruction. This strategy assisted students with lower level skills, and challenged students with higher level skills. An effort was made to keep all students in the zone of proximal development. Concepts found in the ADDIE instructional design model, and the iterative Successive Approximation Model (Allen & Sites, 2012) were used for content development and for selecting materials to be delivered online or as in-class activities. Rapid prototypes were prepared, critiqued and modified prior to delivery. Students contributed to the evaluation of materials post delivery. Their evaluations are informing revisions for the second iteration of the course.

3.2. Structure And Implementation

Table B1.1. Structural Comparison of the Course (hours per week)	
Previous Format	**Flipped Format**
No Pre Class Work	Pre Class Work (~0.5h)
Traditional Lecture (4h)	Active Learning (2h)
Weekly Team Meeting (0.5h) Independent Project Work (1.5h+2h)	Weekly Team Meeting (0.5h) Independent Project Work (1.5 h+2h) Instructors Available for Consultation (2h)
Outside class project time (8-16 h)	Outside class project time (6-14 h)

1.2.1. Structure of the Flipped Course

Moving instruction online opened up time for in-class application of concepts and more time for the teams to meet and work together when all instructors were available for questions/discussion. The online learning elements accommodated the variable individual learning needs within and among teams. Table B1.1 provides a comparison of the course before and after flipping.

Students attend two four-hour sessions per week. Each session includes pre class online elements such as short videos starting with content students should be familiar with and then developing concepts further. Active learning techniques are used in class to apply online elements to a formative assignment related to the design project. Additional in-class time is used for group discussions, project work and formal team/ instructor meetings. Post class elements were developed for application and extension of knowledge related to group projects. We were careful to ensure that the total time students spent on the course did not exceed what was expected previously.

1.2.2. Preparation of Learners

Advice on how to succeed in a flipped classroom was provided. The role and importance of pre class learning, participation in in-class activities and submission of active learning assignments was emphasized. All assignment types, their requirements and deadlines were presented during the first class.

1.2.3. Description of In and Out of Class Activities

The design of this course paid specific attention to the integration of online and in-class components. It is important students see a strong relationship between the two. Online materials were organized under four major headings: Pre Tutorial, Tutorial, Post Tutorial, and Resources. Pre Tutorial materials provided the content background required for the in-class portion of the course. Agendas and worksheets for class activities and Post tutorial online materials addressing stretch goals were also provided in the Learning Management System (LMS).

The Heat Exchanger Network Design session exemplifies the approach taken:

- **Pre Class Work –** Prior lecture material converted to three 5-minute videos was posted on the LMS as "Pre Tutorial". The first two videos covered energy integration concepts, method description, and a method example application solving "Above the Pinch". The third video introduced the in-class activity.
- **Active Learning –** The in-class time was used to solve a more complex version of the online design example. A worksheet was prepared for learners to solve the "Below the Pinch" case. Teams worked on solving the problem and were required to report on the outcome by posting a solution to the LMS by the end of class. Concurrently class time was used for team meetings with instructors, and independent student/team learning. The teams were also asked to apply their pre tutorial learning to their own project.
- **Post Class Time -** Students were asked to determine energy integration potential for their projects and to report results in their final report. A fourth video describing energy integration incorporation into process simulation software was provided for enrichment.

1.2.4. Tools Used to Support the Flipped Process

Online materials were developed using PowerPoint for storyboarding, sequencing and animation, Garage Band for recording, Camtasia for assembly and postproduction editing. Images were sourced from Shutterstock and instructor materials. Forums, assignments, resources and links were presented and organized using the Moodle LMS.

1.2.5. Differentiation of Instruction

Differentiation of instruction was multifaceted. Online instructional materials provided students with flexibility in controlling the pace of content delivery while in-class activities provided students with just in time teaching. Additional resources were added to the LMS and students were directed to resources specific to their needs. The students also facilitated differentiation of instruction as they provided peer support in the collaborative team structure. Instructors and industry advisors provided feedback.

1.2.6. Assessment of Student Learning

Assessment was based on milestone assignments (20%) intended to progress students through their project, a portfolio grade (5 %) intended to encourage completion of in-class active learning assignments, and a final report grade (75%). In previous offerings of the course the portfolio was not required and the final report was weighted 80%.

3.3.Lessons Learned

1.3.1. The Instructor Experience

We found short, focused, and well-scripted videos reduced time spent delivering content. Content typically taught during a 50-minute lecture was covered in videos with a total duration of 15 minutes or less. Additionally we learned written materials must accompany online videos in order to accommodate student study and review preferences. During the pilot, we didn't always have written materials prepared and students missed them.

Carefully crafted videos and related in-class activities take significantly more time to prepare, but with these now in place, future preparation time will be reduced. In-class activities require innovative thinking, iteration, and adaptability to match the activity to the learning requirements and skills of students. When the right mix is achieved the learning and the energy in the classroom is uplifting. At times tasks were beyond some students' skill levels. In the future, these activities will require more guided analysis/scaffolding.

In-class interactions were enhanced and were valuable to learning. They also strengthened relationships among students and between students and instructors.

The relationship between the online content, the related in-class activity and team projects must be explicit. It was worthwhile to review these connections at the beginning of each class.

Automated on-line data gathering should be used whenever possible. Making better use of the LMS and online tools for student assignment creation provides digital data collection opportunities and facilitates the analysis of instruction effectiveness. Examples include the frequency and timing of materials use, pre and post course student skill assessments, monthly team self-evaluations, formative assignment and final project evaluations. These tools can be used to provide rapid feedback to students/teams on their progress and their needs. Automation also provides mineable data that is accessible for accreditation audits and research.

1.3.2. The Student Experience

Students provided feedback throughout the course and participated in an online survey at the end of the course. Their reactions to the blended format were mixed. This was related to the transitional organization of content on the LMS as the course was redeveloped. The volume of resources available and increased online instruction/direction made it difficult for some students to find what they needed when they needed it.

Students were often prepared for tutorials and at times had already applied their learning to their projects ahead of class. Although the final marks and team performance were comparable to previous cohorts, individual experiences were varied. Student perception of their role and the instructors' roles may account for some variability of experience. The course redevelopment further shifted the responsibility and accountability for learning from the instructors to the students and some students resisted this shift.

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4. The University of Alberta Chemical Engineering Capstone Design Course Goes Flipped!

Proc. 2015 Canadian Engineering Education Association (CEEA15) Conf.

THE UNIVERSITY OF ALBERTA CHEMICAL ENGINEERING CAPSTONE DESIGN COURSE GOES FLIPPED!

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Abstract *–The Capstone Design Course instructional team was selected to participate in the digital learning initiative at the University of Alberta. The goals of this initiative are to increase student engagement and promote flexible, independent learning. The objectives of the instructional team were to enhance the interactions between instructors and student design teams in the face of increasing enrolment and to align the course strategically with attributes expected for graduating engineers set out by the University and elaborated in the Canadian Engineering Accreditation Board (CEAB) Guidelines. Existing course materials were redeveloped to an asynchronous online format for individual student engagement and related activities were completed in class. Course delivery effectiveness is being evaluated by comparison with previous cohorts, improvements in post course student self-assessment, student engagement and satisfaction, and will include post course interview and survey data. This preliminary report focuses on elements of course design and preliminary findings.*

Keywords: CEAB Assessment, Digital Learning, Capstone Design, Course Design, Course Evaluation, Student Assessment, Student Engagement, Flipped Classroom, Problem Based Learning.

1. INTRODUCTION

1.1. Motivation

The goals of the University of Alberta digital learning initiative (to promote flexible, independent learning and increase student engagement) were combined with the capstone design course instructional objectives (to enhance quality interactions between design instructors and student design teams). The Capstone Design Course in Chemical Engineering is a project course where approximately 25 teams of 5-6 students each complete a unique industry sponsored design project. Students must research the project, identify and compare competing options using sustainable design criteria, develop a team structure, a project plan and schedule and then complete the design project. The five capstone design instructors teach as a team in the same section.

1.2. Literature Review

The field of engineering requires ongoing development of new professionals and scholars through effective education programs. Students who wish to work as engineers acquire knowledge of fundamental concepts, gain skills required to apply knowledge to tasks, solve problems, construct and validate models, and evaluate data produced, whether in research, design or operations contexts [10, 15]. How best to prepare students and assist them to develop these skills is a complex issue involving consideration of curriculum, policy, accreditation, pedagogy, and institutional leadership [5, 9, 19]. The traditional lecture format, where instructors transfer their knowledge to largely passive students and which some suggest has not changed significantly in the last thousand years [4], continues to be the most widely used instructional approach in engineering education [10, 19], even though a growing body of education research indicates it is a less effective than active instructional approaches [10, 14, 15, 19]. A recent review of discipline based education research (DBER) related to science and engineering found that:

> *... research-based instructional strategies are more effective than traditional lecture in improving conceptual knowledge and attitudes about learning. Effective instruction involves a range of approaches, including making lectures more interactive, having students work in groups, and incorporating authentic problems and activities* [5, 15].

Why then, given the evidence that active learning methods are more effective, is the lecture format so common? A number of factors may serve as barriers to the implementation of active learning approaches [2, 10], one being “the persistent myth that all active learning methods require more faculty time than lecturing" [19]. While active learning approaches may require additional development time initially, effectively designed courses can ensure coverage of content as well as opportunities for active learning without significantly more faculty time [8]. This is the primary benefit of the flipped classroom.

1.3. Problem Definition

Previously, in the Chemical Engineering Capstone design course, lecture-format tutorials were provided in two-hour blocks twice weekly to support student learning and successful project completion. Thirty-minute team meetings with individual instructors, and open format question and work periods followed. The planned increase in enrolment from 125 students this year to 170 students next year requires more teams and this restricts the time for individual questions and meetings with instructors unless the instruction time is reduced.

1.4. Solutions Considered

A new course structure was developed using flipped classroom ideas and principles alongside technology advances in course delivery. Pre-class materials now typically comprise a brief video, a short reading, and a formative assignment to prepare students for in class interactive activities that apply online materials. Students submit brief reports based on in class activities at the end of class. Post-class students apply their learning to their open-ended design projects. Infeasible alternate solutions required additional in class time or additional instructors.

1.5. Flipped Classrooms and Engineering

Flipped classrooms, also called blended or inverted learning environments, change the way instructors and students work together. A key aspect of the flipped approach is the integration of face-to-face and online (individual) learning with the aim of enhancing the classroom experience with active learning [20]. For many instructors, a flipped approach means providing students with access to videos, readings, or other instructional material that enable students to learn concepts asynchronously prior to coming to class. Class time then becomes available for active learning which may include projects, collaborative work, problem based learning, or other activities [8, 10]. As such, a key feature of flipped learning is a shift from teacher-centered lectures to student-centered instruction [20]. Flipped approaches may also influence student engagement [6, 7, 19].

Flipped classroom approaches have the potential to enhance the quality of engineering education by providing opportunities for instructors to implement active learning strategies during class time. Currently, there is a limited body of research that has investigated flipped approaches within the context of engineering courses; however there is evidence for the benefits of active learning approaches in engineering education [14, 17]. Where flipped or blended classes have been implemented in undergraduate engineering programs, there is evidence that student satisfaction is greater and that levels of class attendance, motivation, and collaboration among students is higher than in traditional lecture format courses [12]. Student engagement is widely acknowledged as being important to their post-secondary success [1] and development of conceptual understanding [11]. In addition, the connection between student engagement and active learning is well supported in the literature [10, 15]. The impact of the implementation of a flipped classroom approach and active learning strategies on student engagement is a principal thread in the current study. Csikszentmihalyi's concept of flow [3, 16], wherein an individual is engaged when: they are intensely focused on their current activity, feel intrinsically rewarded and in-control, feel that the task is neither too difficult nor too easy, and may lose track of time (experience temporal distortion), underlies our work. His concept is illustrated in Figure 1.

2. STUDENT ENGAGEMENT

2.1. Challenge vs Skill: Moving to the Flow Zone

The Chemical Engineering design course is based on independent learning in an interactive team environment. Students collaborate to develop a team structure, a project scope and plan. A process was developed to guide students through individual preparation, contribution of work and ideas, team evaluation and integration of contributions, product production, tracking and reflection. In our experience, providing scaffolding and feedback for the learning experience is a critical part of the success of a project based course that relies on individual and team contributions [6, 7]. The capstone design course provides a challenging open-ended project that is supported by an instructor and an industry sponsor, both providing feedback and advice. Tutorials in the capstone course are designed to address skill gaps for students as they work on their design project. They provide an opportunity for students to direct their own learning, to develop their skills, to contribute to their team, and to complete their design projects successfully. Students with lower skill levels may experience anxiety or stimulation as they attempt to complete their project, as shown in Figure 1. The teaching in the capstone design course is intended to reduce student anxiety and to support skill development. The teaching (in the form of online instructional and reference materials) is available when students need it even if the instructor is not. Students, who have already developed skills, can challenge in class activities ahead of schedule. Students may approach the flow region from the motivational perspective. They have the skills and they have been presented with the challenge. The need to address a broad range of entry skill levels is typical for capstone design student cohorts because students from all programs including co-op, and traditional streams, with differing specialties and experiences are taught jointly.

2.2. Tutorial Structure and Content

The new teaching format is designed to enhance student engagement by converting existing lecture materials into brief videos students watch prior to class. Table 1 compares the previous lecture and the current flipped format. Pre-class materials introduce a topic and link it to project requirements. The teaching objective is to connect with all students regardless of entry skill level and to develop the skills rapidly to a higher level using a shared experiential approach. Typically videos are limited to 5-6 minutes as they are "information dense". A one-hour lecture can often be compressed to fifteen minutes of video presentation. However, students need time to reflect in between [8] and two or three shorter videos are easier to review. A tutorial topic is further developed in class with an activity to apply the pre-class material. Student discussions within teams and in larger groups are built into in-class activities, as are opportunities for students to share their findings with the class and leverage learning.

There is a brief assignment, usually a report on the results of the activity that is due at the end of class. Students are given an opportunity to apply the teaching in class. Instructors are available to answer questions and to help if required. The in-class assignments are typically relevant to all design project requirements. Post tutorial learning elements extend the in class learning and link further skill and knowledge development to individual design project and final report requirements.

Post-class, individual students and design teams apply their learning to their design projects. For example, the topic "Team Formation and Team Management" includes short readings, a self-assessment and a video prior to class. In class, case studies describing poorly performing teams are discussed and evaluated, and outcomes presented to the class as a whole by groups of teams. Following the class, each design team prepares a charter outlining their team structure, their expectations of one another and their performance deviation management plan.

Tutorial content was developed based on existing course objectives that are correlated to the Canadian Engineering Accreditation Board Graduate Attributes Assessment (CEAB GAA). Tutorials provide a review and further development of key areas related to Chemical Engineering fundamental knowledge, and its application in the design process. In addition, an overall course plan was created and learning objectives were developed for individual tutorials. An integrated instruction strategy with the introductory design course was also developed.

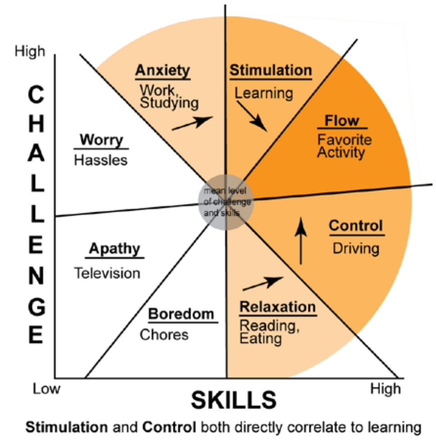

Fig. 1. Flow Diagram Adapted from Csikszentmihalyi (1990)

Table 1: Tutorial Structure

Previous Format	Flipped Format
No pre class work	Pre class work (~0.5h)
Traditional Lecture (2h)	Active Learning (1h)
Weekly Team Meeting (0.5h) Project Time (1.5h+2h)	Weekly Team Meeting (0.5h) Project Time (2.5h+3h)

3. EVALUATION METHODS

Previously, student teams self-assessed, and were assessed by instructors based on their performance ahead of and during meetings that linked interim deadlines for producing a planning document for their course work, a mass and energy balance for their process, a final presentation of their findings, as well as a final report. The final report comprised 80% of the course mark and was summative in nature.

To provide ongoing feedback and opportunities for students to develop their skills, enhanced self-assessment and formative assessment tools were included as part of the course redesign. A CEAB based skills and attributes self-assessment tool was developed to determine how students viewed themselves prior to and following the course. Data collection was automated and students made use of the pre-course assessments to select teams. Formative assignments related to tutorial topics and final report requirements were also added. The project planning and the final reports continue to be summative assessments and comprise 80 % of the course mark.

3.1. Individual and Team Assessment

To assess the scope and quality of the contributions of individuals to team performance, and team performance as a whole, two formative assignments are repeated during each of the four phases of the course: researching and developing a client proposal; engineering analysis and design; project analysis; and on completion.

Team evaluation forms were developed for students to rate themselves and team members individually based on the quality and quantity of their contributions to the work done at each phase. At a team meeting, students compare and discuss individual results then prepare and submit a rating table that includes both self and average team assessed ratings for individual students. All team members sign the submitted copy of the ratings table. The discussion of this evaluation is private to the team.

After considering individual behaviors, students are then asked to reflect on team, technical and project logistics performance and to rank their team according to criteria in a reflection tool based on group dynamics, adapted from Newell et al. [13]. Behaviors observed in design teams and correlated with capstone project grades are described. Student teams are asked to comment on the ongoing development of their team skills relative to this rubric and to submit an account of their observations and plans for improvement at each major project milestone.

3.2. Individual Self-Assessment

Just prior to the course, individual students self-assess their skills and abilities using the online CEAB GAA tool. Students are able to assemble a team and view their team composite skill and attribute data prior to finalizing their team selection. The goal is to assemble a balanced team. The self-selected teams are accountable for ensuring they have the skills required, for establishing an agreed upon team structure, team values, performance and work quality norms. Students repeat the individual CEAB skill self-assessment at the end of the course. The composite data is used for course effectiveness evaluation. Examples are provided in the Results section.

3.3. Formative Assessment

All milestone and portfolio assessments are formative. The students are marked on completion of the requirements. The marking scheme is based on completion and on-time criteria as outlined in Table 2.

Table 2: Formative Assignment Structure

Milestone Assignments	Portfolio Assignments
Based on product delivery Project based Phase completion	Based on developing Tutorial based Starting point for project
Marking: complete, on time, received by sponsor	Marking: complete, on time, thoughtful, reflect activity

3.4. Assignment Retention for CEAB Evaluation

All assignment related materials and supporting documents are accessed online, and all assignments are submitted online by each team within a Moodle learning management system. The course is stored by cohort and all information can be retrieved electronically including examples of students' work. The use of online materials and student progress are both tracked and all the information is retained and accessible following the course. As course work is graded by team, the development of a team and their project can be reviewed along with the materials the team accessed, their in class participation, and project milestone progress including individual student contributions and time sheets. The ready availability of detailed data sets for individual teams, linked to grades and CEAB attributes is expected to facilitate the next CEAB review, scheduled for 2017.

3.5. Data Gathering Methods

Data were gathered during the course for the purpose of evaluating the effectiveness of instructional methods and student engagement. Student access of online material was tracked and collected. Individual student timesheets and contributions to their team project were tracked using weekly reports. All students were asked for course feedback on a regular basis. Effectiveness is being evaluated by comparing performance with previous cohorts, improvements in post course student self-assessment, student engagement and satisfaction surveys.

3.6. Online Access Monitoring

Individual access to online materials was recorded on e-class and reported by team. Students submitted one assignment per team. Time of assignment submission was automatically recorded. This particular feature was in place for the previous cohort.

Heat maps (Figure 2) were developed to visualize resource usage by teams. In this example, the frequently accessed items are the pre tutorial videos (bottom four rows), samples (top yellow band), materials for in-class activities and assignments (mid yellow band). Resource materials and alternate delivery modalities (previous lecture notes - top purple) were accessed less frequently - if at all.

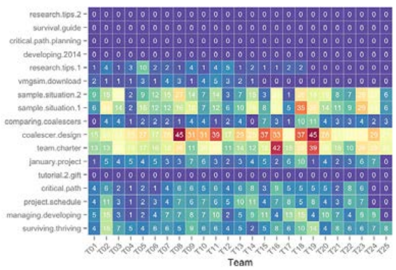

Fig. 2. Tutorial 2 Heat Map of Online Material Access

Frequency distributions were used to determine how often on-line materials were accessed and when in relation to the relevant tutorial. Certain materials were accessed on an ongoing basis as students were developing their own work and pre tutorial materials were typically accessed prior to class. Figure 3 provides the frequency and timing of student access to an example interim report. Access by each team, tracked by colour, is spread over a two-week period. By contrast, pre-class video access frequency charts show a dense cluster of points twenty four to thirty hours prior class.

3.7. Instructor Observations

The instructors and the teaching assistant (TA) were asked to make notes after tutorials regarding observations on student engagement, learning, quantity and quality of questions students asked, and changes from the previous cohort to the pilot cohort. Observations were made regarding when students submitted assignments relative to due dates, assignment completeness and quality.

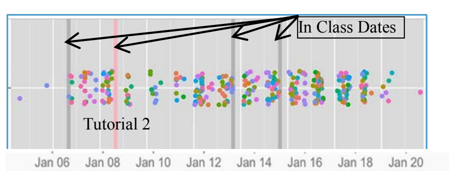

Fig. 3. Frequency and Timing of Student Access

3.8. Student Feedback

Student feedback on the course was collected in the form of surveys after the first month of the course, after a specific new tutorial and at the end of the course. The intermediate feedback surveys were based on students' perceptions of whether or not the course objectives were being met and whether the learning objectives for a specific tutorial were being met.

4. RESULTS

Results at the time of writing are preliminary and are based on observations during the term, resource access frequencies, preliminary comparative CEAB GAA results, and preliminary student feedback. A complete data analysis and course evaluation is in progress. We plan to use access data, student feedback and final report results to improve course organization and delivery. Initial findings of the student access of online resources is promising and methods to gather data on individual and team access, timing and frequency of access are providing a promising framework for automating data collection, the collection of student example work, and formative assessments in the capstone course.

4.1. CEAB Self-Assessment of Skills

The before and after comparison of student self-assessment of CEAB GAA data is in progress. At the time of writing 30% of the class (more than 40 students) has completed the post-course assessment. Figure 4 shows students' views of their pre and post course ability to design a process system. Figure 5 shows the progress the students' views of their ability to develop competence. The development of skills for lifelong learning is a critical aspect of an engineering education and a core goal for the CEAB GAA.

4.2. Course Effectiveness Evaluation

Observations and data indicate some teams watched the videos together, some individually and some skipped them altogether. All teams attended all class activities and handed in assignments. The course effectiveness is not being evaluated on whether or not students were able to check off all activities as complete but rather that students accessed materials necessary for their individual development and project completion. Ongoing evaluation will address the issue of ensuring that online materials address student learning modalities and enhance student skills required to develop and complete a team based capstone design project. One change being considered is to remove resources from the main block in Moodle to a separate Resource section. Highlighting key items was requested by students.

Instructor notes are invaluable in the improvement process. All instructors reported increased student engagement and interaction in class and in the weekly meetings. The depth of the questions students asked had increased as the level of engagement increased.

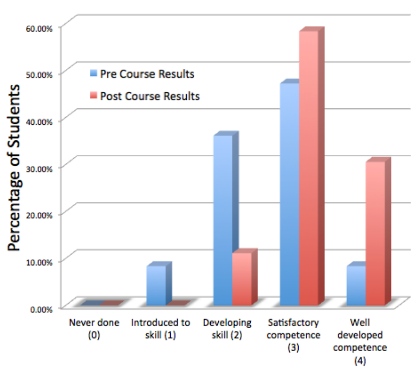

Fig. 4. Ability to Design a Process System

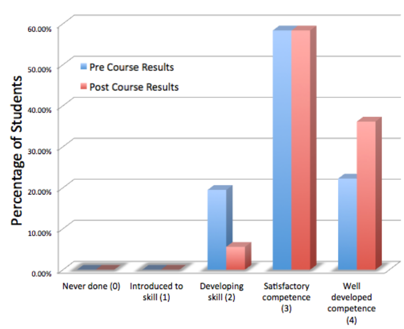

Fig 5. Ability to Develop Competence

5. CONCLUSIONS

The ability to improve course effectiveness based on student feedback and project quality is enhanced by understanding student use of resources and engagement.

Addressing the variation of incoming student skill levels by asynchronous online instruction techniques improves the overall experience for students and instructors in the course.

Automated tracking and consolidation of data facilitates preparation for CEAB and other reviews and undergraduate curriculum development more broadly.

Acknowledgements

The course redevelopment was funded by the University of Alberta's Provost Office. We would like to acknowledge the support given throughout the course by the following: Rishi Jaipaul and the CTL production staff, Enrico Indiogine, Suzanne Kresta and the 2015 graduates of Chemical Engineering - Design Class.

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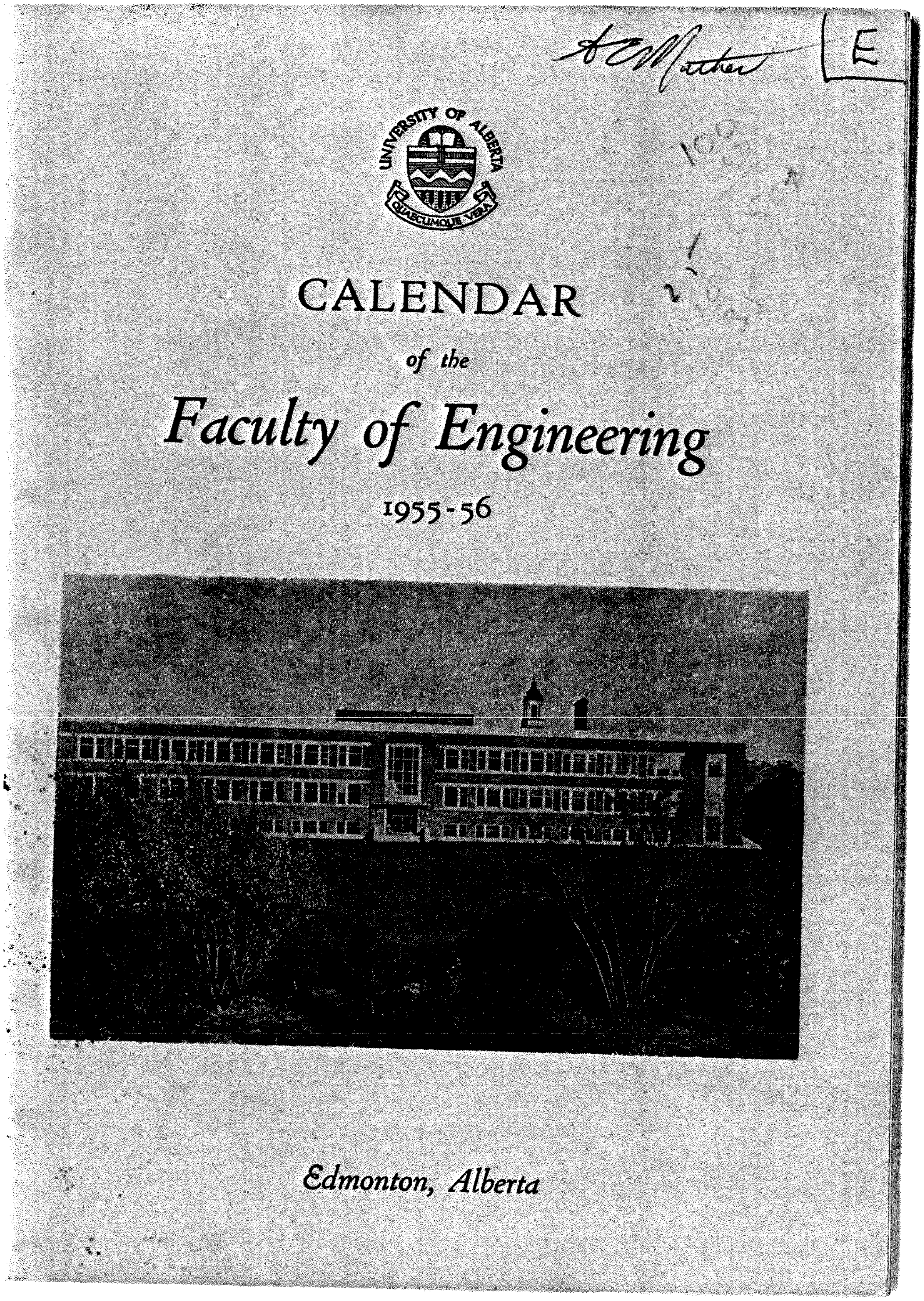
Appendix C: Design Course Historical Documents

Documents Supporting the Design Course History

Interview data and email correspondence used to construct the history were kept in confidence, but referenced as personal communication. History was reviewed with interview subjects/contributors for accuracy prior to publication. Thank you to all for their generous contribution of time and information.

1. University of Alberta Faculty of Engineering Calendar 1955-56



THIRD YEAR (1955-56 ONLY)

SUBJECTS	Course No.	First Term Lect.	First Term Lab.	Second Term Lect.	Second Term Lab.
Unit Operations I	C.P.E. 61	2	3/2	2	3/2
Properties of Petroleum	C.P.E. 63	2	...	...	3/2
Practical Experience and Summer Report	C.P.E. 73*	Summer Period			
Elementary Physical Chemistry	Chem. 54	3	3	3	3
Elementary Quantitative Analysis	Chem. 56	2	3	2	3
Elements of Electrical Engineering	E.E. 53	2	3/2	2	3/2
Advanced Calculus	Math. 58	2	...	2	...
Physical Metallurgy	M.E. 94	2	3/2	2	3/2
Non-Technical Option†		3	...	3	...

*Credit for C.P.E. 73 must be obtained before graduation.

†To be selected according to the tastes of the student and as the timetable permits from a list approved by the Department of Chemical and Petroleum Engineering.

FOURTH YEAR (1955-56 ONLY)

SUBJECTS	Course No.	First Term Lect.	First Term Lab.	Second Term Lect.	Second Term Lab.
Practical Experience and Summer Report	C.P.E. 73*	Summer Period			
Industrial Tour	C.P.E. 74	as arranged			
Unit Operations II	C.P.E. 81	3	5	3	5
Colloquium	C.P.E. 82	1	...	1	...
Research Project *or* Design Project *or* Unit Processes	C.P.E. 83 C.P.E. 84 C.P.E. 85	...	...	...	6
Thermodynamics	C.P.E. 86	3	3/2	3	3/2
Industrial Chemistry	Chem. 62	3	...	3	...
Physical Chemistry	Chem. 66	3	3	...	...
Elements of Electrical Engineering	E.E. 53	2	3/2	2	3/2
Non-Technical Option†		3	...	3	...

*Credit for C.P.E. 73 must be obtained before graduation.

†To be selected according to the tastes of the student and as the timetable permits from a list approved by the Department of Chemical and Petroleum Engineering.

C—ELI

JUNIOR

SUBJECTS
Engineering Mechanics
Mapping
Engineering Materials
Strength of Materials
Engineering Drawing
Geology
Calculus
Magnetism, Electricity and Lig
Survey Field Work
Applied Astronomy

SENIOR

SUBJECTS
Fluid Mechanics
Elements of Mech. Engineering
Principles of Elec. Engineering
Machine Design
Fundamentals of Eng. Electro
Advanced Calculus
Electrical Physics
Principles of Economics

SENIOR

SUBJECTS
Electrochemistry
Principles of Elec. Engineering
Electrical Power Transmission and Distribution
Electrical Machine Design
Electrical Communication
Problems
Fundamentals of Electrical Engineering
Power Plant Design
Electrical Instruments *and* Applications of Electrical Pow *or* Short and Ultra-Short Wave I

Fourth year project course options: research, design or unit process in chemistry.

83. Research Project (0-0; 0-6)

D. B. Robinson, G. W. Govier and D. Quon

An experimental research problem intended to develop initiative and to acquaint the student with the methods of scientific investigation. Optional with C.P.E. 84 and C.P.E. 85.

References: Killefer, *The Genius of Industrial Research;* recent technical literature.

84. Design Project (0-0; 0-6)

G. W. Govier

The coordination of basic sciences, mathematics, economics, and engineering to the design of an industrial plant. Emphasis is placed upon the method of approach and the development of student initiative. Optional with C.P.E. 83 and C.P.E. 85.

Textbook: Tyler, *Chemical Engineering Economics.*

References: Recent technical literature.

85. Unit Processes (0-0; 0-6)

A. L. Scott

The correlation of unit operations with organic and inorganic chemistry in the study of an integrated process. Emphasis is placed on the development of student initiative. Optional with C.P.E. 83 and C.P.E. 84.

References: Groggins, *Unit Processes in Organic Synthesis;* recent technical literature.

86. Thermodynamics (3-3/2; 3-3/2)

D. B. Robinson

Thermodynamics presented from the engineering viewpoint. Practice is given in the application of thermodynamics as a useful tool in the solution of problems of the process industries and the petroleum production field.

Textbook: Smith, *Introduction to Chemical Engineering Thermodynamics.*

87. Petroleum Production Engineering II (3-3; 3-3)

J. W. Gregg

A study of the scientific and engineering principles underlying the present practices employed in the exploration, drilling, production and transportation branches of the petroleum industry. Problem and experimental laboratories are conducted to illustrate application of the principles studied.

Textbook: Uren, *Petroleum Production Engineering.*

References: Recent technical literature.

88. Petroleum Reservoir Engineering (0-0; 3-3)

J. W. Gregg

A study of the physical principles underlying petroleum reservoir engineering. Consideration is given to the application of these principles to the gathering of adequate reservoir data and to the analysis of petroleum reservoirs.

Textbooks: Calhoun, *Fundamentals of Reservoir Engineering;* Pirson, *Elements of Oil Reservoir Engineering.*

Reference: Recent technical literature.

89. Natural Gas Enginee

The estimation of natu
processing, pipeline trar
natural gas. Design pro
illustrate the lecture mat
Textbooks: Monograph
Texas, *Back Pressure T*
Natural Gas; others to

Graduate Courses—

101. Advanced Thermody

Advanced applications o
tion of thermodynamic
selected topics.
Textbook: Dodge, *Che*
References: Recent techr

103. Advanced Unit Ope

An advanced study of se
References: Recent techr

104. Instrumentation and

A study of the basic ele
development to recordir
industrial processes.
Textbook: Eckman, *Pri*
References: Recent tech

105. Advanced Petroleum

An advanced study of s
Textbooks: Muskat, *Ph*
of Oil Reservoir Engine

Research

Facilities are available for g
and petroleum engineering. Pa

40. Inorganic Chemistry

O. J. Walker, W. E
Lectures: The principle
of the metals and their
Laboratory: Qualitative

Course Descriptions including number 84: Design Course. Courtesy Dr. Alan Mather.

2. Process Analysis (Dr. Reginald Wood)

PROCESS ANALYSIS

Dr. Reg Wood, May 26, 2015

In my view the impact and importance of a thorough understanding of the fundamental concepts of performing material and energy balances cannot be overstated for success as a student or as a practicing process engineer.

The role that material and energy balances play in the field of process engineering is analogous to the role of the foundations for any structure be it a residential property or a commercial structure. If the engineering design of the foundation is not correct, it is a given that this will result in problems for other components of the structure. The application of the conservation of mass and energy forms the foundation for all subsequent design of any process system. The correct application of conservation equations provides the foundation for all subsequent design calculations involving thermodynamics, the transport processes of momentum, heat and mass transfer and the design of chemical reactors.

An outstanding example of the role that the understanding of fundamental concepts applies in process analysis is exemplified by an end of term exercise. This involves an open class discussion of the information that needed to be included in a “formula sheet “ (also known as a “cheat sheet”) to be provided with the final examination. As students suggested items that needed to be provided, items were listed on a draft formula sheet. As expected there was unanimous agreement that conversion factors, gas constants and relevant thermodynamic data values needed to be included. As the various other items were considered, items such as the ideal gas law, Newton’s second law, etc. were removed since these expressions had been used so frequently no formula was required. As a result of this exercise the list of other suggested items did not even fill a single 8 ½ by 11 sheet! By the end of the course students had realized that the challenge was to formulate the appropriate balance equations by applying fundamental concepts from the introductory chemistry and physics courses and that memorization would not be a factor in success on the final examination.

Teaching Experience

After teaching a similar course (Industrial Chemical Engineering) while on staff at the University of Ottawa from 1963-1966, when I joined the Department of Chemical and Petroleum Engineering in 1966, one of my course assignments for the 1966-67 academic year was CH E 365- “Industrial Stoichiometry” (This course renamed with title of “Process Analysis”). Over my career at the University of Alberta, I taught the Department’s Process Analysis course CH E 265 (noe CME265) from the 1981-82 academic year through to my retirement as of June 30, 1997 except for the 1987-88 and 1992-1993 academic years.

A key feature of the Process Analysis course, when I taught the course was the two hour per week problem seminar period. The weekly assignment sheets were distributed at the start of the seminar period and then the students were Involved in an interactive “problem solving activity”. Students were given a few minutes to review the problem and as experience was gained to develop a simple process schematic diagram and apply the information given in the problem statement. Students were then challenged to identify the critical information not given in the problem that needed to be calculated to perform the necessary material balance calculations. In the later part of the course the complexity of the problems increased with problem solution by application of the conservation of energy principle and finally the increased complexity of problems requiring the solution of coupled material and energy balance equations.

3. Dow Chemical's Participation in the Stollery Executive in Residence Program at the University of Alberta (William C.S. Pick)

Session 1654

Dow Chemical's Participation in the Stollery Executive in Residence Program at the University of Alberta

William C.S. Pick
Dow Chemical Canada Inc.

History Of The Executive In Residence Program

The University of Alberta Department of Chemical Engineering

In 1990, Robert Stollery of Poole Construction donated money to the faculty of Engineering to provide direct contact between practicing engineers and undergraduate students. The endowment gives the faculty $10,000 per year to spend on the program.

The faculty of Engineering at the University of Alberta experimented with the Stollery Executive in Residence Program in 1991. The program was piloted by the Chemical Engineering (ChemE) Department and Dow Chemical Canada Inc. provided the author of this paper as the first 'Executive in Residence' (EIR).

The EIR's have been from major manufacturing companies which hire U of A ChemE graduates. Dow, Novacor Chemicals, Syncrude Canada, Proctor and Gamble Pulp and Paper, (now Weyerhauser), Celanese Canada, and Sherritt have participated. The Petroleum, Civil and Electrical Engineering Departments have piloted similar programs, but Chemical Engineering has made the Executives in Residence part of the educational culture. In an academic year, 8 executives from about 7 companies will each spend two weeks in the department.

Although provision has been made for the University to pay living expenses and even a portion of the EIR's salary's, to date, professional time and accommodation have been donated by the companies. Program money has been spent on tools for undergraduate use ASPENPLUS(R) and HYSIM(R) simulators, for example.

Dow Chemical Canada Inc.

Dow Chemical Canada Inc. developed University Relations Team in 1989. The Team strategy statement opens:

> "Dow Chemical Canada Inc. will foster and maintain strong relationships with Canadian Universities in order to establish the company as a preferred employer of the best graduates..."

One of the key axioms in the University Relations Team is "constancy of purpose". It was recognized that we must continue to hire co-op students even in tough economic times. And we must maintain contact with the target universities, even when economies indicate that no hiring will take place.

Subteams were developed for 7 'target' universities in Canada. These subteams contain people involved in recruiting, and/or who have a direct involvement in supervising the various disciplines which are hired.

For example the Chairman of the University of Alberta (U of A) team is a graduate of the U of A's Chemistry program. Six members are chemical engineers, 3 of whom graduated from the U of A. Computing science, electrical engineering and commerce graduates are also represented on the team. Members hold positions in Production, Process Engineering, Project Engineering, Research and Development, Sales, Information Systems, and Human Resources departments. The team originally met frequently to outline future activities, but now meets only once or twice per year. Dow had 'mentored' fourth year projects before the Executive in Residence program, but the presence of the EIR in the department has expanded this work immensely.

The Executive in Residence program at the University of Alberta meshed extremely well with Dow's University Relations Strategies and Objectives. Dow has had an Executive in the department for 2 weeks every term since the original 'pilot' in the spring of 1991.

Duties Of The Executive In Residence

There is no fixed length of stay for the EIR, but the executive in is normally in Residence for 2 weeks in one term, normally divided into two 1 week long sessions.

The duties of the Executive in Residence include:

1) Up to 5 hours/week of direct lecture.
2) Participating in design labs for 3rd and 4th year undergraduates to ensure 'real world' content. Special topics such as safety and the environment are emphasized.
3) 'Mentoring' specific projects in 3rd and 4th year. 'Mentoring' includes:

Providing a scope of work for the design projects.

Providing a frame of reference for the projects.

Supplying some (but certainly not all) public domain references.

Periodic review of progress and help with specific design problems.

4) Input to undergraduate curriculum. For example, input from several EIR's have contributed to dropping Engineering Drawing from the Civil Engineering Department as a requirement for graduation in Chemical Engineering.
5) Discussions with academics on areas of mutual interest.
6) Periods of 'open door' availability to the students. The executive has an office near the academic staff, and students are encouraged to ask questions on either technical or professional matters.

Undergraduate Lectures

Some of the lectures which have been given to undergraduates:

FIRST YEAR
1. 'Careers in Large Chemical Companies'

SECOND YEAR
1. The Mass and Energy Balance and the Alberta Petrochemical Industry

THIRD YEAR
1. Introduction To Plant Design
   - Why are we doing this?
   - The Project Development Process
2. Heat Transfer
   - What is a utility? What is it worth?
   - Process Heat Integration
   - Preliminary Design of a Double Pipe Heat Exchanger
3. Distillation
   - Distillation Train Design/Optimization

FOURTH YEAR
1. Introduction To Plant Design
   - Same as 3rd year
2. Process Vessels and Containment
   - Why?
3. Optimization
   -What should we optimize? Economic Profit
   - Heuristics: Reactor, Separators, Heat Exchange, Utilities
4. Reactors
   - Putting 'Reactors' Class in Perspective
   - Profit and Pollution Control
   - 15 Reactors at Dow Fort Sask.
5. Communication
   - Significance in Industrial Environment
6. Pollution Control
   - Groundwater
   - Fugitive Emissions
7. Conclusion
   - The 10 Things ChemE's Need to Know

Benefits To Dow

The benefits to Dow Chemical include:

Enhanced image of Dow and the Petrochemical industry with students and faculty

Before the EIR program, we at Dow believed that U of A Chemical Engineering Department placed too much emphasis on Oil and Gas examples, and gave insufficient coaching towards the province's Petrochemical industry. On campus, the perception was that Dow is too bureaucratic and secretive. For example, we were told that a month is too long to wait for the answer "we can't tell you that; the information is classified". These harsh judgments have certainly softened as a direct result of the Executive in Residence program.

Improved Recruiting Efficiency

The Executive in Residence has input the names of 'top performers' to the Dow recruiting process (sometimes the Executive is the recruiter). It should be noted that academic averages alone are not good indicators of future performance in the industrial environment. However, marks in specific classes do carry specific information. For example, key marks in design and ChemE lab classes give an indication of written communication skills. Direct contact over two weeks provides a much more effective tool to weed out poor 'people' skills than 2 one-hour interviews.

Ultimately, Dow has experienced improved hiring efficiency. That is, we have a better chance of getting the best people for our needs. We now see top candidates (not necessarily those with top marks) applying to Dow, especially for Co-op terms. We have a much higher rate of acceptance as well. There is certainly not a direct causal relationship between this improvement and the EIR program, but there is no doubt that EIR has helped this process.

Input to Curriculum

This is especially true for the design classes. Topics such as the environment and safety have traditionally taken a 'back seat' to getting the mass and energy balance and the economics right in ChemE design classes. When most of the instructors got their practical experience, this was also true in industry. Safety and environmental projects often have a far greater chance of implementation than those driven by simply by economics. And no project can be implemented without thorough reviews of both environmental and safety impacts.

The Chair of Dow's U of A relations team is now on the Dean of Engineering's advisory council. While this is not a direct result of Dow's work with the Executive in Residence program, there is no doubt that this positive contribution helped the Dean's selection.

Project Screening

Dow has used undergraduate projects as very preliminary screening tools for 'Blue Sky' projects.

Technical Networking

Technical networking on specific projects and research. Discussions with Dr. Wilson of the Mechanical Engineering department turned out to be very valuable to Dow's Process Engineering Department. Dispersion modeling and information on air currents inside buildings directly aided the author in one accident investigation. Dose modeling concepts which were introduced to Dow at Western Canada Division through the EIR process have been valuable in our emergency planning process.

Benefits To The Chemical Engineering Department

The benefits to the Chemical Engineering Department include:

Addition of practical aspects of ChemE to design labs

Course work by necessity in chemical engineering is compartmentalized. Two ChemE design classes are intended to integrate the core curriculum. Demonstrating application of fundamentals to real problems, with simple extensions and conclusions provide the single greatest benefit to the students.

Reinforcement of the need for and use of ChemE fundamentals by working Engineers

Before the EIR program, many students had trouble believing that industrial practice includes what is taught in class. For some the fact that a Mass Balance is the first step in not only design but also trouble shooting is a revelation.

Topics and mentoring for specific undergraduate design projects

There is always a problem in coming up with different, real-world projects of appropriate depth of 4th year, and especially the 3rd year design classes. Typically, between 10 and 20 projects are needed for each class. Dow now contributes two possible projects to each class every term.

Learning Experience On Teaching Methods

In industry, we find that general information can be transmitted in a one-way 'lecture' style format. Prepared slides or overheads are useful for effectively getting a large amount of information across to a large group of people. Specific information such as which equations or techniques to use, is better imparted directly (one-on-one), or through written material. General information can be presented anytime, but specific detailed material should be covered when it is needed, (but not before).

In a University classroom setting, presenting general information through prepared slides is quite ineffective. The students have the pressing demands of assignments, exams, and lack of sleep. The author found that many of the students began to work on fulfilling these other needs as soon as overheads appeared. However, if a problem is presented complete with a worked solution, students will busily copy down everything on the blackboard. Generalizations can be made at the end of such a presentation. This is more fulfilling for the instructor, and certainly more information is imparted. The best of all worlds is if the professor (or EIR with the Professor) can develop a problem set based on the lecture, and immediately reinforce the material.

While at first glance, it appeared that the techniques which used in industry (i.e. slide presentations) don't work in the classroom, reality is that the students of today, are in fact tomorrow's engineers. The best way to learn something is by 'doing', and the sooner after it is introduced, the better. For teaching undergraduates at the University, prepared slides are in general, less effective than standing at the blackboard.

Conclusions

Dow Chemical intends to continue its participation in the U of A Executive in Residence program and similar programs at the University of British Columbia and the University of Saskatchewan. The effort has been rewarded in improved recruitment efficiency and better graduates. At the U of A, our initial enthusiasm for, and continued commitment to the Executive in Residence program gives us a leg-up, we feel, with academic staff and ultimately with hiring our 'most valued resource'...new people.

The department of Chemical Engineering, intends to continue the Executive in Residence program. With 8 weeks/term of visiting practicing engineers, the program is full. However, they are continuing to diversify the types of careers and companies represented by the Executives in Residence. For example, Engineering, Procurement, and Contracting companies will be considered in future. It is hoped that continued direct industrial contact will result in more specialized courses.

WILLIAM C.S. PICK

Mr. Pick graduated with a BSc (Chemical Engineering) from the University of Alberta (U of A) in 1979. He served as a production engineer at Dow Chemical Canada Inc. Western Canada Operations for two years. He earned an MSc (ChemEng) from the U of A in 1984. Since returning to Dow, he has worked as Process Engineering Specialist, and a Production Supervisor. Mr. Pick has worked extensively in vinyl chloride, ethylene oxide, and ethylene production technologies. He has been on Dow's University of Alberta Relations Team since 1990, and was the first Stollery Executive in Residence at the U of A in 1991. Mr. Pick is currently a supervisor in Dow's Western Canada Process Engineering Department.

4. Stollery Executive in Residence (August 1991)

University of Alberta — Inter-departmental Correspondence

to: Chemical Engineering Faculty

date: Aug 19/91

our file:

your file:

from: Murray R. Gray, Chairman
Department of Chemical Engineering

subject: **Stollery Executives–in–Residence in Chemical Engineering for 1991/92**

I am very pleased to announce that four engineers from industry will visit the Chemical Engineering Department under the Stollery Executive–in–Residence Program. Each visitor will come for approximately two weeks, in some cases split into two one–week segments. They will all use Room 513 as an office. Three of the executives have been named, and the fourth will be announced later this fall.

TERM I

Bill Pick, Dow Chemical Canada Ltd., Fort Saskatchewan (Phone 998–8323)
Dates for Visit: September 30 – October 4, 1991
October ~~28~~ 21 – ~~November 1, 1991~~ Oct 25

Room 513

Bill inaugurated the program last year, so many of you have met him. He has an extensive background in process engineering, and interests in the related engineering fundamentals.

Bill Shelfantook, Syncrude Canada Ltd., Edmonton (Phone 464–8549)
Dates for Visit: September 23 – September 27, 1991
Second week ~~TBA~~ Oct 28 - Nov 1

Bill has a strong background in process design, both with Syncrude and with Colt Engineering and SNC. He is particularly interested in applications of fluid mechanics.

TERM II

Lois Cramer, Novacor Chemicals Ltd., Red Deer (Phone 342–8712)
Dates for Visit: January 20 – January 24, 1992
March 2 – March 6, 1992

Lois manages the process control group for Novacor, and has a particular interest in applications of process control.

Dow Chemical Canada – Person and Dates TBA

All of these engineers will be involved in the design courses (CH E 456/556) and the communications courses (CH E 451, 581, 583) wherever possible. Each of them has special skills which would benefit the various core courses (e.g. Pick in CH E 534, 414, 416; Shelfantook in CH E 412; Cramer in CH E 546, 562, 564). Please contact them <u>before</u> they arrive to begin to discuss involvement in various courses. They will also, of course, be interested in discussing research interests and opportunities. I hope that you will all strive to make our visitors welcome during their visits, and use their skills to enhance the education of our students.

Murray R. Gray, Chairman

5. Team Play (S. Kresta)

ChE 464: Team Play and Project Planning

Powerful team play is the topic most discussed among young professionals, mid-career professionals, and old professionals. It is not easy, but at its best it is the best part of the job. How can we build powerful, high performance teams? We need strong leadership and team play.

1. Begin with the end in mind. The team must have a clearly stated goal. They must agree on this goal, and remain focussed on the goal.

2. Teams are made up of imperfect human beings. Play to the strengths of your partners, and cover off their weaknesses.

3. Check your personal issues at the door. DO bring a sense of humor, enthusiasm for the project, and commitment to your team members as human beings. Great teams remember to play together as well as working hard together.

4. Figure out what you're good at – and do it.

5. Give a generous and committed listening to others. Committed listening requires that we fully understand, and probe both the strengths and weaknesses of any approach. Do not let your partners off the hook. Many engineers are mathematical rather than verbal, so patience and persistence in verbal communication is important.

6. Share your own ideas, understanding, and insights generously and courageously. Let your ideas (and questions) shine out: you have a responsibility to your group to engage with them in grappling with the problem.

7. Divide and conquer. Plan your work, and work your plan.

8. Identify WHO is to do WHAT by WHEN. Write this down. Meet your deadlines and hold others to theirs. This step in accountability is a core skill for effective team work, and completing projects on time. Expectations must be clear, and stated. This is particularly important for new teams as people sort out eachother's strengths and weaknesses. …see #10.

9. Everyone gets stuck. When you get stuck, get help. Not next week, but tomorrow. The problem will not go away, but it will shrink into proportion with a friend. I repeat, do not stay mired in stuck. Get help. If a teammate gets stuck, move resources into position to support them.

10. Have regular meetings. Note that meetings are not for doing tasks; they are for discussing difficult issues, for following up on progress of work, and for planning the next stage. It is helpful to have an agenda, a chair (or leader), a recorder, a proponent and a devil's advocate (critic). These roles tend to be very loosely defined in small, high functioning teams.

11. Begin with the end in mind. Standing in success, look back. What had to be done by when to get to the end? Where were the critical decision points? What are the critical tasks? What is the timeline?

Leadership is empowerment with vision. Strategic leadership will accept nothing less than a spectacular victory for the team.

Suzanne Kresta, updated February 2007

6. Biographies of Interviewees

Dr. Alan Mather

Professor Emeritus
Room 226-1, Chemical and Materials Engineering Building
Edmonton, AB T6G 2G6
Phone: 780.492.3957
Fax: 780.492.2881
Email

Research Interests
Curriculum Vitae

Dr. Mather has over 25 years of experience in thermodynamics research, mainly in the areas of calorimetry and vapour-liquid equilibria. The vapour-liquid equilibria involve systems of interest for the removal of H2S and CO2 from natural and other gas streams. Some solubility work involved the processing of bitumens and heavy oils. Much of this work was carried out in collaboration with Dr FD Otto. Dr Mather has published over 135 technical papers and made over 90 presentations at technical meetings.

Dr. S. E. Wanke

Professor Emeritus
Room 728 Chemical & Materials Engineering
Edmonton, AB T6G 2G6
Phone: 780.492.3817

Email

Note to prospective students, Professor Emeriti are retired and therefore, do not take on new students. For a list of current faculty, please click here.

Dr. Murray R. Gray

Professor Emeritus
Fellow of Canadian Academy of Engineering
Email

Research Areas: upgrading of heavy oil and oilsands bitumen; chemical kinetics; non-aqueous extraction

The conversion of Alberta oilsands bitumen to more easily transported refinery feedstocks is a fascinating challenge that involves reaction, diffusion, and aspects of colloid science and nanotechnology. Dr. Gray's expertise is on the relationship between the fundamental properties of heavy oil and bitumen materials, and how these affect potential reactions and interactions at the molecular level, which in turn affect large scale processes for upgrading, separating, and transporting of bitumen.
Technologies of interest include:

- Coking and other thermal upgrading processes
- Hydroconversion and catalytic upgrading
- Chemical structure and separation of asphaltenes
- Solvent extraction of bitumen from the oilsands, including the behavior of water and fine solids
- Novel upgrading and separations technologies for heavy oil and bitumen

Dr. Gray was the scientific director for the Institute for Oil Sands Innovation until summer of 2014, at which time he retired from the University of Alberta and became Professor Emeritus. He is not accepting any new graduate students or post-doctoral fellows.

Dr. John M. Shaw, P.Eng.

Professor
NSERC/AERI Industrial Research Chair in Petroleum Thermodynamics
Room 266C, Chemical & Materials Engineering Building
Edmonton, AB T6G 2G6
Phone: 780.492.8236
Email

Website

Research Areas: petroleum thermodynamics; multiphase chemical reactor design; heavy oil upgrading; batch gas-agitated liquid dispersions

The Petroleum Thermodynamics Research Group investigates phase behaviours of reservoir fluids, heavy oils and bitumen, providing knowledge to improve emissions, production, refining and transportation of one of Canada's richest resources. Greater understanding of the fundamental science behind these hydrocarbon resources promises millions of dollars in cost savings for one of Canada's largest industries.

Dr. Suzanne M. Kresta

Research Areas: turbulent mixing, characterization of turbulence, mesomixing and feed plume effects in reactor design and additive performance

Research Interests

The mixing unit operation is far broader than the classical well mixed continuous stirred tank reactor, and scale down of mixing sensitive processes to bench scale mixing test cells is a rapidly developing area of research. Tightly designed mixing equipment is needed to meet the demanding process specifications of both extremely large scale processes, and high value added specialty products.

Our group has long standing collaborations with both Lightnin and Syncrude, and a number of active projects which change from year to year.

Biography

Suzanne Kresta (BSc, UNB (1986), MSc, Leeds (UK, 1987), PhD, McMaster (1992)) teaches Mass and Energy Balances (CME 265), design (ChE 464) and Mixing (ChE 420 and 620), and serves as Senior Editor of the Handbook of Industrial Mixing. Her principle research contributions are related to understanding turbulence and mixing in stirred tanks (measurement of turbulence, the use of spatial statistics to define mixing and length scales, nano-particle production, solids suspension, reactor design, and additive performance) and she has collaborated with colleagues in a wide variety of industries (including oils sands extraction and froth treatment, photographic film, drinking water treatment, mineral processing and metals refining, polymer reactor design, cosmetics, mixing equipment design, fish processing, clean-up of nuclear waste, and fertilizer production). Many of her papers are both widely cited in the research literature and used for industrial design calculations.

Her teaching interests include faculty development workshops, visual problem solving tools, the use of story telling and case studies, active learning, and explicit use of cognitive levels with learning objectives. She has served as an Iron Ring Warden since 1999, as a Peer Consultant at the University of Alberta since 2004, and has won a number of national and international awards for both teaching and research.

Suzanne Kresta
Professor
7th Floor ECERF, Room 7-084F
9107 - 116 Street
Edmonton, AB T6G 2V4
Phone: 780.492.9221
Fax: 780.492.2881
Email
Website

William Pick

William Magee Chair in Process Design
Chemical and Materials Engineering
7th Floor ECERF – Room 7-036
Edmonton, AB, T6G 2G6
Phone: 780.492.8853
Fax: 780.492.2881
Email

Bill Pick comes to us from a 30-year career with Dow in Fort Saskatchewan. He helped design and expand their ethylene plant and led the expansion of their vinyl chloride plant. In 2000, he was promoted to Global Process Engineering Technology Leader for Dow's light hydrocarbons business, determining and implementing best practices in Dow plants around the world. He has been a strong supporter of the Faculty of Engineering's chemical engineering program, serving as its first Executive-in-Residence in 1989 and serving as a key mentor to design students for many years. He takes up the Magee Chair in Process Design.

Len Church

Contract Lecturer at University of Alberta

Edmonton, Canada Area | Mechanical or Industrial Engineering

Previous	WorleyParsons, Colt Engineering Corp
Education	University of Alberta

Contract Lecturer
University of Alberta
2010 – Present (5 years) | Edmonton, AB

ChE Process Design Project Team Teaching

Engineering Quality Manager
WorleyParsons
2007 – 2009 (2 years)

Enginneering Manager
Colt Engineering Corp
2000 – 2007 (7 years)

Dr. Arvind Rajendran

Associate Professor
7th Floor ECERF - Room 7-091
9107 - 116 Street
Edmonton, AB, Canada, T6G 2V4
Phone: 780.492.3912
Fax: 780.492.2881
Email
Website

Research Areas:

- Large-scale adsorption and chromatographic processes
- Carbon capture and storage
- Supercritical fluid chromatography
- Multi-column chromatography

Research Interests

Arvind's research interests lies in large-scale adsorptive separations for sustainable chemical processing. The main focus is reducing greenhouse emissions from power plant flue gases by incorporating CO2 capture and storage (CCS) and improving the sustainability of pharmaceutical processes by replacing organic solvents by environmentally benign solvents such as CO2. The group is also interested in the fundamentals of non-linear chromatography and gas separation by adsorption.

Biography

Arvind Rajendran, since Sept 2012, is an Associate Professor in the Department of Chemical and Materials Engineering at the University of Alberta. Before joining the faculty at U of A, he was an associate professor in Nanyang Technological University (NTU), Singapore. He obtained his Doctor of Technical Sciences (PhD) from the group of Prof. Marco Mazzotti at the Institute of Process Engineering, ETH Zurich. Arvind is the recipient of the highest honors for teaching and mentorship at NTU. Further, he is on the editorial advisory board of Chemical Engineering and Technology and on the scientific committees of important technical conferences.

Dr. Arno de Klerk

Professor
7th Floor ECERF - Room 7-084G
9107 - 116 Street
Edmonton, AB Canada T6G 2V4
Phone: 780.248.1903
Fax: 780.492.2881
Email

Research Areas: upgrading/refining of non-crude oil feed material (oil sands, coal and Fischer-Tropsch syncrude) to fuels and chemicals; oxygenate conversion processes; catalysis and reactor engineering; refinery design

Biography

Arno de Klerk obtained his formal qualifications at the University of Pretoria (Pretoria, South Africa). He holds B. Eng., B. Eng. Hons. and Ph.D. degrees in chemical engineering, as well as an M.Sc. degree in analytical chemistry. After obtaining his B. Eng. Degree in 1991, he started his career in forensic science at Forensic Science Laboratory of the South African Police in Pretoria. Initially he worked as analyst and later became manager of their precious metals analysis group.

In 1994 he moved to industry, joining Sasol as a process engineer in their Research and Development division based in Sasolburg. After a year he took an internal transfer to their refining catalysis department, where he was responsible for catalysis research, as well as laboratory and pilot plant design. He became a registered professional engineer in South Africa in 1999. In 2001 he was appointed as research manager of the Fischer-Tropsch Refinery Catalysis group, being responsible for catalysis research related to conversion processes for upgrading Fischer-Tropsch syncrude to fuels and chemicals. In this capacity he directed applied industrial research, as well as fundamental research in collaboration with various universities. In 2009 he relocated from South Africa to Canada and took up his present position at the University of Alberta.

Arno de Klerk served as committee member of the Northern (later Gauteng) branch of the South African Institution of Chemical Engineers since 1990 and in the capacity as branch secretary from 1994 to 2007. He is also a member of the American Chemical Society and Chemical Institute of Canada.

Frank Vagi

Consultant, Petroleum Industry

Graduated from the Royal Military College of Canada with a BSc. in Chemical Engineering in 1978, also attended the Royal Naval Engineering College Manadon in 1979, and graduated with a Masters in Advanced process control from the U of A in 1988.Frank has 36 years of engineering experience, in process engineering, process control, engineering, operations and design. My career started in the military as a marine system engineer with Canadian Navy Frigates. After leaving the Canadian Forces it progressed with the first of five upgrader projects with Syncrude in 1984, which was followed by Shell, and another upgrader project at Scotford, followed by three more with Petro-Canada from 2000 to 2007. In between those projects I helped design water treatment systems, water reclamation systems, utility plants, boilers, Sulphur recovery units, Steam methane reformers and boiler feed water treatment plants. In 2011 I retired from Suncor, and began consulting in water issues in the petroleum industry.

Source: FEGRS 2014 Panel Discussion Biographies http://www.eng-symposium.ualberta.ca/2014/index.php?option=com_content&view=article&id=7&Itemid=21

Frank Vagi has been a sessional Capstone Design Instructor since 2012.

Marnie Jamieson P. Eng

Department of Chemical and Materials Engineering

- MSc Student

Email: mvjamies@ualberta.ca

Degree:

- BSc in Chemical Engineering, University of Alberta, Edmonton, Alberta

Research Interest:

- The application of design principles to engineering education with a special interest in blended learning and project courses with industrial partnerships. The application of thermodynamics and phase behavior to novel and standard design projects with a specific interest in sustainable design that considers technical, economic, risk and environmental feasibility along with social impacts.

Work Experience:

- University of Alberta Faculty of Engineering, 2010 - present
- University of Alberta Center for Teaching and Learning, 2014 - present
- Engineering Consultant, 1988 - present
- Previously employed at Syncrude Canada Ltd.

Awards/Scholarships:

- Blended Learning Teaching Award - co-applicant with John M. Shaw, William Pick and John Nychka

Publications:

- M. Godin, B. Peachey, M. Jamieson, M. Lipsett, T. Heidrick, Evaluation of Oil Sands Research and Innovation Effectiveness, CANMET 2009, (pp 162).
- 96587 Process Design of Injection Systems, Authors: W.C. Fort III, E.S. Benn, R.C. Strong, Marnie Vegesi, NACE International Conference Papers, December 31, 1996.

FREDERICK DOUGLAS OTTO

Frederick Douglas Otto was born in Hardisty, Alberta on December 1st, 1935 and attended secondary school in Mannville. He graduated from the University of Alberta with a BSc in chemical engineering (with distinction) in 1957 and MSc in 1959. He then went to the University of Michigan and obtained a PhD in chemical engineering in 1963. He was appointed to the academic staff at the University of Alberta in 1962. He was Chair of the Department of Chemical Engineering from 1970-72 and 1975-84, Dean of the Faculty of Engineering from 1985-94, and was appointed Professor Emeritus in 1996. Otto was President and CEO of DBR International (1998-2002), which was an Edmonton, and Houston-based group of companies serving national and international organizations in the petroleum and petrochemical industries. It had been established by Professor Donald B. Robinson of the Faculty of Engineering. Specific areas of business included laboratory and fluid sampling services for specialized hydrocarbon phase behavior and fluid property studies; design and manufacture of high pressure and high temperature laboratory equipment; and engineering software that was specialized in phase behavior, fluid property and sour gas sweetening process simulations. DBR was sold to Schlumberger in 2002. Dr. Otto is an author of more than 90 technical papers. A major area of research was the development of gas treating technology and computer software for the design and simulation of separation processes. In 1998 the Gas Processors Association gave him the Donald L. Katz Award in recognition of outstanding accomplishments in gas processing research and technology and for excellence in engineering education. APEGA has recognized his contributions to the profession by awarding him the L.C. Charlesworth Award (1990), the Centennial Award (1993) and Honorary Life Membership (1997). He is a fellow of the Canadian Academy of Engineering (1991), the Chemical Institute of Canada (1975), the Canadian Society for Senior Engineers (2008) and Engineers Canada (2009).

Source: Petroleum History Society - Glenbow Museum Collection
https://www.glenbow.org/collections/search/findingAids/archhtm/extras/oilsands/Otto_Fred.pdf

Appendix D: Design Course Objectives and Graduate Attributes

1. Ch E 435/465 Course Objectives 2015

The global objectives of this course are for students to:

- Integrate, apply, and analyze the technical knowledge obtained in all preceding core and elective engineering courses. (1, 2)*
- Demonstrate both synthesis and evaluation levels of learning** for engineering knowledge gained throughout the undergraduate curriculum by designing and developing solutions for complex open ended problems and critically evaluating those solutions with respect to their technical merits, economic, environmental and safety impacts on society. (3, 4, 5, 9)*
- Inculcate life-long learning and team work strategies through completion of self-directed group projects. (6, 12)*
- Develop and demonstrate team, planning, logistics, leadership, deviation management and communication skills. Demonstrate professionalism and accountability. (7, 8, 10, 11)*

These objectives are achieved by:

- Students working in teams to complete design feasibility studies for established or experimental industrial processes over a twelve-week period.
- Students selecting team members, establishing team norms and a team charter; planning and managing their work, schedules, and consulting broadly.
- Students taking on leadership roles and being accountable within the team for various activities.
- Mandatory intermediate reporting requirements prior to submission of the design feasibility studies. The purpose of intermediate reporting is to incorporate feedback at technical, team and logistical levels and meet milestone requirements.
- Mandatory portfolio activities required for this class. The purpose of portfolio assignments is to give students a safe place to try out their ideas, develop their skills, and get feedback from peers, faculty and industry partners.

* see reference material – Canadian Engineering Accreditation Board Graduate Attributes
**see reference material – Bloom's Taxonomy

On completion of CHE 435/465, students will have synthesized prior course knowledge to produce a process design, assessed the technical feasibility of process elements, evaluated competing process elements critically and assessed the economic, safety, risk, and regulatory issues related to capital projects. More specifically, students will have completed work in the following areas (Applicable CEAB Graduate Attribute(s) follow(s) in brackets):

1. Project and Team Management (6, 8, 10, 11)*

- Ongoing group and self assessment
- Develop team charter and deviation management plan
- Project schedule development and stewardship
- Resource the project appropriately
- Develop deviation management for technical, schedule and project issues

2. Data Acquisition and Evaluation (1, 2, 3, 9, 12)*

- Scope definition
- Focused literature search
- Decision analysis – including criteria development
- Situation report – summarizing results of data acquisition, development, and evaluation
- Integrate feedback and apply simple risk assessment techniques

3. Process Flow Sheet Development and Simulation (4, 5, 6, 7, 8, 9, 10, 11, 12)*

- Synthesis of flow sheets for specific processes
- Apply process simulation tools to create mass and energy balances, and process flow diagrams
- Evaluate hazards, safety, and environmental risk as process is developed

- Integrate feedback into design

4. Process Equipment Selection and Specification (4, 5, 6, 7, 8, 9, 10, 11, 12)*
- Apply theoretical knowledge to practical problems of designing and specifying equipment
- Evaluate equipment options based on process requirements and constraints
- Select and size process equipment
- Select and specify materials of construction
- Develop a detailed design for a heat exchanger in the design
- Specify vessel wall thickness, vessel mass
- Apply standard techniques for support and auxiliary structures

5. Regulatory and Standards Issues (4, 5, 6, 7, 8, 9, 10, 11, 12)*
- Design process layouts which reflect an appreciation for relevant fire and explosion codes, and standards for access and insurability
- Address relevant health, safety, and environmental standards and regulations in the design and project execution strategy /schedule proposed

6. Hazard and Operability Analysis/ Risk Assessment Techniques (4, 5, 6, 7, 8, 9, 10, 11, 12)*
- Develop a P&ID for a single piece of equipment
- Apply HAZOP analysis techniques to a single element of the design

7. Capital Cost Estimation (2, 5, 6, 7, 8, 9, 10, 11, 12)*
- Develop a capital cost estimate for the design proposed based on factored cost methods, data regression
- Benchmark against public domain data where possible

8. Operating Cost Estimation (2, 5, 6, 7, 8, 9, 10, 11, 12)*
- Develop an estimate for annual operating costs based on: raw material, handling, utility, labour, and consumables cost estimation including the impact of inflation, start-up and demolition costs

9. Capital Project Economic Evaluation (2, 5, 6, 7, 8, 9, 10, 11, 12)*
- Complete IRR and /or NPV calculations as appropriate to determine the economic feasibility if the primary objective is profitability or cost of the project if the primary objective is environmental, safety or risk reduction related.
- Create a sensitivity analysis of project assumptions and variables

10. Project Execution Schedule and Plan (2, 5, 6, 7, 8, 9, 10, 11, 12)*
- Create a project execution schedule based on the equipment and capital requirements for the proposed project.
- Develop a critical path and consider the feasibility of the plan
- Benchmark if possible

11. Technical Report Preparation (7)*
- Preparation of an effective final report on the project and documentation of the work done to support the recommendations and conclusions
- See detailed report specification and marking guides for each report

Required or Recommended Texts/Course Material

There are no required texts. Students make use of reference materials, course notes and texts from other courses and have access many library resources and web resources. Suggested texts to have on hand are:

- Texts and notes from all previous technical courses
- Ulrich and Vansudevan (from Ch E 464)
- A handbook or resource on Engineering Communication
- A resource for teams - The Team Memory Jogger is an example
- VMG Sim Download and MS Project Download
- A device to access the internet in the classroom
- E-class moodle resources, library, etc.

Course Content

There are no formal lectures in the course as it is a problem based learning course. This course focuses on developing the top three levels of learning according to Bloom's taxonomy (see diagram) and employs the methods that educational research indicate are most effective at developing those levels. Online tutorials (30 minutes to 60 minutes) on specific design topics are provided. These are to be done prior to coming to class as they provide the background information for the activities we will be doing in class. The pattern for learning will be: On line before class – to review, gain knowledge and or comprehension of a topic; In class activity – team and group activities to analyze and apply on line and previous learning; Team time in class and after – to synthesize, create new ideas and design solutions for team projects. Some additional on line learning materials and links are provided that will be supportive of certain activities and steps in the design process. Although not mandatory for you to read we hope that you will find them useful in completing your project. In addition, student teams are paired with practicing engineers in industries related to their projects. They meet periodically during regular tutorial sessions or at industrial sites, and communicate electronically. The students also consult with members of the teaching staff. Students are encouraged to make use of their networks, library resources, and may have opportunities to consult with other student teams.

Some but not all of the students will exceed the objectives set out above. Enrichment materials including heat exchanger network design, aspects of process control, etc. will be pursued by some of the students.

Leadership Activities: Students are expected to be the leader for at least one of the following: Project Management – scheduling, resourcing and reporting; Risk Management – HAZOP preparation, leadership and reporting; Process Design – Simulation development, management and verification; Sizing and Costing Management – material selection, fluid mechanics, and design considerations of equipment; Economics - Business case development, economic analysis and reporting; Regulatory and Standards Management – assess appropriate standards and regulations that apply to the project, ensure that they are considered in the design and reporting. There are other leadership roles that may qualify for various projects discuss your ideas with your advisor. The individual leader is not required to do all the work for the particular area they are leading. The activities are still team activities. They are required to develop the steps required to complete the particular analysis, manage the analysis, and lead the team to completion.

Reference Material for Course Objectives:

Graduates of Chemical Engineering Design II should be able to demonstrate learning at all levels of Bloom's Taxonomy and be proficient in all of the Graduate Attributes of the CEAB.

2. Bloom's Taxonomy

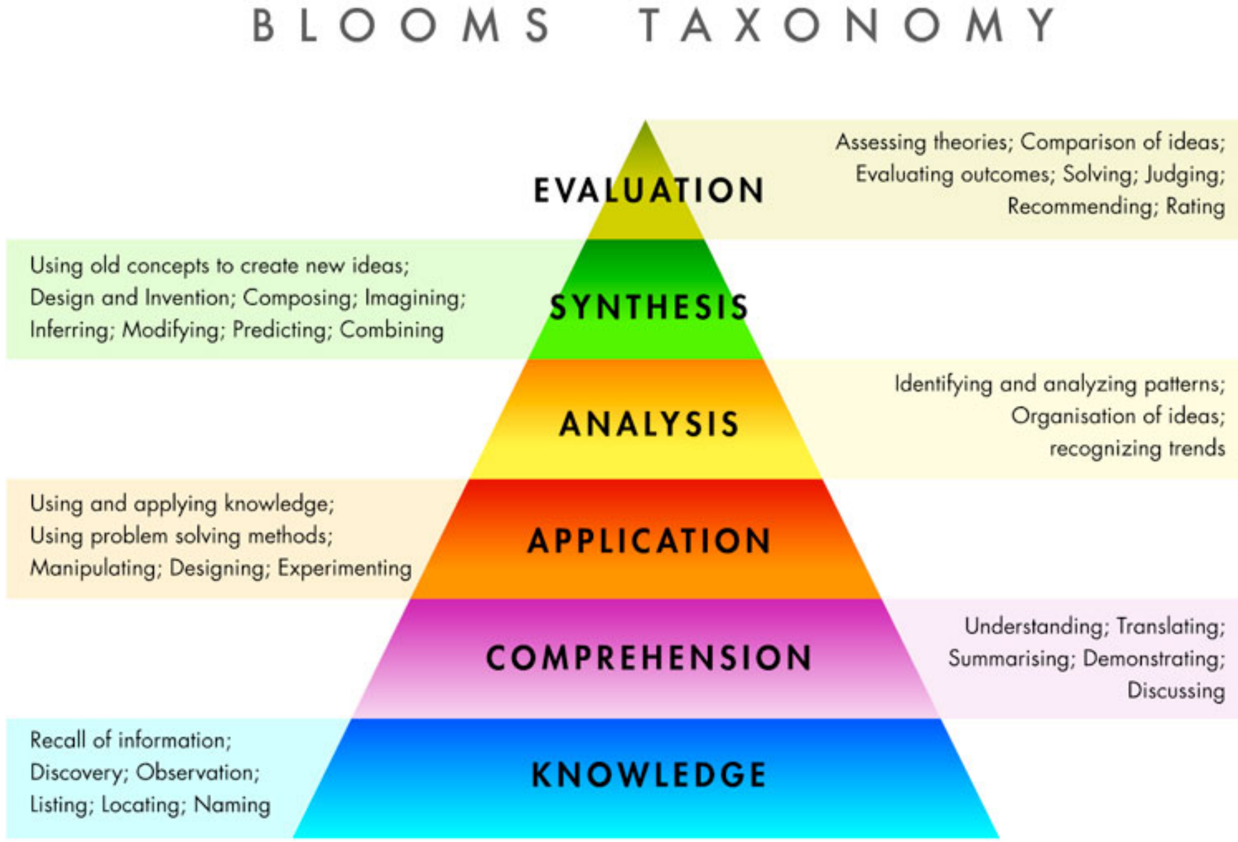


Figure C1.1. Bloom's Taxonomy of Cognitive Tasks

3. Canadian Engineering Accreditation Board Graduate Attributes Assessment Requirements

1 A knowledge base for engineering
Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.

2 Problem analysis
An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.

3 Investigation
An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.

4 Design
An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.

5 Use of engineering tools
An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.

6 Individual and team work
An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.

7 Communication skills
An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.

8 Professionalism
An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.

9 Impact of engineering on society and the environment
An ability to analyse social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.

10 Ethics and equity
An ability to apply professional ethics, accountability, and equity

11 Economics and project management
An ability to appropriately incorporate economics and business practices including project, risk and change management into the practice of engineering and to understand their limitations

12 Life-long learning
An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge
Last modified: Monday, 8 September 2014, 11:42 AM

References:

Accreditation Board

Bloom, B., Englehart, M., Furst, E., Hill, W., & Krathwohl, D. (1956). Taxonomy of Educational Objectives, the Classification of Educational Goals, Handbook I: Cognitive Domain. In Anderson. L.W., Sosniak, L.A. (Eds.), (1994) Bloom's Taxonomy: A Forty Year Retrospective. The National Society For the Study of Education : Chicago, 200 pp.{ISBN: 978-0077-5762}

Appendix E: Tools for Developing Higher Order Skills and Metacognition

Tools for building conceptual relationships, analysis, synthesis and evaluation skills lend scaffolding to students. Evaluating their project, team, and work provides a basis for developing thinking about thinking and thinking processes.

1. Team Self Selection based on Skill Requirements

For 2015, the skill inventory was reorganized into attribute categories and converted from paper format to electronic format. Data could then be used to analyze the student perspectives pre and post course and potentially feed into continual course improvement. Students were asked to consider their skills in advance of the course by answering questions in an electronic survey type format that allowed them to see a spreadsheet composite of their results. The following instructions for completing the process were provided. A CCID sign on was accepted in lieu of a signature.

This skill inventory is based on the Canadian Engineering Accreditation Board (CEAB) Graduate Attribute Assessment (GAA). The first task for this course is self reflection and evaluation. This reflection is structured and based on the learning outcomes from the CEAB. This evaluation will be based on a scale from 0-3.

0 = No or introductory experience

1 = Developing proficiency

2 = Proficient

3 = Mastered

Once you have completed this form the ratings that you have given yourself will be transferred to your team selection form composite as strengths or weaknesses. You will be required to sign that form with your team members indicating the skills and attributes that you are able to contribute to them team. The team selection form will form part of your team charter, which will be handed in for approval.

After you have completed this course you will be asked to re evaluate yourself using the same criteria.

The reorganized skill inventory is included on the following page. This inventory was adapted to an electronic survey form. This form captured data in an format that could be exported to Google docs and analyzed for the Wi2015 iteration. For the Wi2016 iteration the eClass Moodle electronic form will be implemented. This form was tested for team formation in the Fa2015 version of Design I and to gather pre and post course data for student perception of their development with respect to the CEAB GAA. This form is the source of the student perception pre and post course data analyzed in Chapter 8 Section 6.

Wi2015 CHE 435_465 Team/Project Selection Form

We expect you to think strategically about team member selection. Teams normally will be six students. After reading the "Course Objectives" and "Getting Started on Your Project and Developing your Team," complete the individual self-assessment on line. This skill inventory is based on the Canadian Engineering Accreditation Board (CEAB) Graduate Attribute Assessment (GAA). If you have team members in mind invite them to join your team. Once they accept the team selection form will start to populate with names of members and their skill assessments. Go to eClass on Moodle and start a team in the google docs spreadsheet if you are still looking for team members and/or use the team search forum to find potential members. If you need to find a team, look for posted teams who need your skills and have openings on their team. Contact the team directly or post your skills on the team search forum. Remember this will be visible to all classmates to find additional team members or find members with skills you need. You will need to complete this self-selected team form and hand it in on the first day of class (one form per team). Please do your best to ensure that the team is balanced. Try to select team members so that the strengths are complimentary and as a team there is strength in most if not all of the areas. As a minimum be aware of team strengths and weaknesses at the outset! Submit the team score, the names and signatures of the team members and your strategy for addressing **team** weaknesses[1].

Before projects are chosen at the first tutorial, we will assign remaining students to teams randomly and will assign team numbers. All subsequent course correspondence must include your team number so that we will be able to respond to project related questions efficiently. This form must be completed, signed and all pages initialed by all team members to be valid. After the plan to address team weaknesses is completed, see an instructor on the first day get their feedback and approval for your plan. Register your team and get ready to pick your project.

[1] **Show your strategy on page 3 - add pages if needed**!

Graduate Attribute/skill **Team member initials (p.1)**	**Member 1** ________	**Member 2** ________	**Member 3** ________	**Member 4** ________	**Member 5** ________	**Member 6** ________	**Team (Count of Strengths)**
1 Engineering Knowledge							
Industrial / co-op experience							
Chemical engineering practice							
chemicals							
gas processing							
oil/heavy oil							
biological processes							
research							
Chemical engineering theory							
chemical reaction (reactors)							
phase separation (separators)							
chemical separation (distillation)							
heat/mass transfer (equipment)							
pump/compressor design							
fluid mechanics (piping)							
material selection (corrosion)							
thermodynamics							
process control							
2 Problem Analysis							
Identify and define problems							
Analyze and solve problems							
Reach substantive conclusions							
3 Investigation							
Research engineering problems							
Create solution options							
Develop analysis criteria							
Synthesis of information							
Draw valid conclusions							
Error analysis							
4 Design							

Develop boundary constraints							
Design process system							
Design process components							
Assess technical, economic, safety, environmental criteria & risk Consider regulatory and societal implications of design							
5 Engineering Tools							
Process simulator							
ASPEN experience							
HYSYS VMGSIM[2]							
Computational/modeling skills							
economic analysis							
sizing and costing analysis							
analysis skills using spreadsheets							
6 Individual and Team Work							
Team work/team building							
Integrity/accountability							
Relationships							
Persuasion							
Coaching and development							
Active listening							
Learning styles/Myers Briggs Working knowledge of team formation processes							
Leadership skills[3]							
Vision/strategic thinking							
Decision making/consensus							
Conflict management/resolution							

[2] VMGSIM is the simulator that will be available to you for this project

[3] consider: ability to match work with people, create a productive team, resolve conflict, quality management

7 Communication							
Technical writing skills Text preparation and organization Text editing Figure generation Report preparations software Typing/keyboarding skills							
Technical reading skills							
Oral presentation skills							
8 Professionalism							
Responsibility of Engineers Protection of public Protection of public interest Timeliness of task completions							
9 Impact of engineering							
Analysis of environmental impact Analysis of societal impacts Sustainable design concepts Environmental stewardship							
Team Initials page 2 **Loss management skills**[4] HAZOP experience simple risk assessment safe design practices							
10 Ethics and equity							
Professional ethics Accountability Application of equity principles							
11 Economics & project mgmt							
Deviation management Risk management Schedule management							

[4] It is recommended that at least one team member is taking or has taken one of the Safety and Loss Management courses

Economic and Business Analysis							
Organizational skills[5]							
planning / scheduling							
adaptability							
communication							
12 Life-long learning							
Ability to identify educational needs for self							
Ability to meet educational needs							
Ability to develop competence							
Ability to understand limitations							
other (please specify)							

Name	**Signature (agreement p.1-3 and strategy)**
1.	
2.	
3.	
4.	
5.	
6.	

TEAM Number: Project Name:

Strategy for addressing team weaknesses (page 3):

[5] consider: task break down, scheduling abilities, an ability to track and manage a schedule

2. Team/Project Selection Form Wi2014 CHE 435_465

We expect you to think strategically about team member selection. Teams normally comprise five or six students. After reading "Getting Started on Your Project and Developing your Team," complete a skills inventory for your self-selected team (one form per team). Please do your best to ensure that the team is balanced. There is a skill matrix below. Note strengths of team members in each of the areas with an "S" and weaknesses with a "W". Try to select team members so that the strengths are complimentary and as a team there is strength in most if not all of the areas. At a minimum be aware of team strengths and weaknesses at the outset! Submit the team score, the names of the team members and your plans for addressing **team** weaknesses[6]. At the end of the first tutorial, we will assign remaining students to teams randomly and will assign team numbers. All subsequent course correspondence must include your team number so that we will be able to respond to project related questions efficiently. This form must be signed and initialed by all team members to be valid.

Skill or criterion **Team member initials (p.1)**	**Member 1** ________	**Member 2** ________	**Member 3** ________	**Member 4** ________	**Member 5** ________	**Member 6** ________	**Team (Count of Strengths)**
industrial / co-op experience							
process simulator ASPEN							
experience HYSYS							
VMGSIM[7]							
technical writing skills text preparation							
text editing							
Figure generation							
report preparations							
software							
typing							
organizational skills[8]							
planning / scheduling							
adaptability							
communication							
leadership skills[9]							
vision/strategic thinking							
decision making/consensus							
conflict management/resolution							
chemical engineering							

[6] **Show your strategy on page 2**!

[7] VMGSIM is the simulator that will be available to you for this project

[8] consider: task break down, scheduling abilities, an ability to track and manage a schedule

[9] consider: ability to match work with people, create a productive team, resolve conflict, quality management

theory chemical reaction (reactors) chemical separation (separators) heat/mass transfer (equipment) pump/compressor design drawings plant integration							
chemical engineering practice chemicals gas processing oil/heavy oil biological processes research							
computational skills economic analysis sizing and costing analysis							
oral presentation skills							
loss management skills[10] HAZOP experience simple risk assessment safe design practices							
timeliness of task completion							
team work/team building integrity relationships persuasion coaching and development							
other (please specify)							

Name	**Signature (agreement p.1 and p.2)**
1.	
2.	
3.	
4.	
5.	
6.	

TEAM Number: Project Name:

Strategy for addressing team weaknesses:

[5] It is recommended that at least one team member is taking or has taken one of the Safety and Loss Management courses

3. Team Evaluation and Assessment Tool Objectives – Automation

The purpose of the team evaluation tool is to allow students to rank their performance and obtain feedback regarding individual performance from their team members. Discussion of peer evaluations and individual assessments is part of the team reflection and development process. The purpose of the team assessment rubric (cross referenced with CEAB GAA) is to allow students to place their team behaviors in a framework that predicts performance providing them with feedback on their team performance. As such the individual should complete the evaluation ranking and initial team assessment first. Allowing the student the freedom to formulate their thoughts on their performance and their team's performance prior to team discussion gives students time to reflect on their own first. It allows for honest identification of problems earlier rather than later in the term, giving students a chance to resolve concerns early. The process, overview shown in Figure E3.1, should be student controlled as teams are self managing. Automation can provide a consistent process and structure for student team use. Actual ranking is to be anonymous, however rankings must be discussed by the team, if a team member gives the

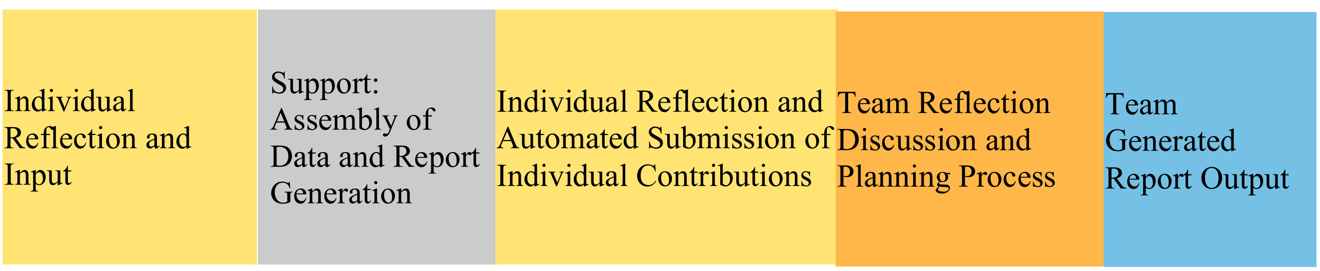


Figure E3.1. Process Overview

team as a whole or other individuals a poor ranking they should be prepared to explain their concerns at the team meeting. Since the ranking is done on a scale from 1-5, the meaning of those numbers may vary from person to person. Allowing the team an opportunity to discuss variance prior to submitting a completed team assignment is valuable. Having individual rankings on record is a resource for instructors in the event of a dispute requiring resolution. To this end the individual results of the team assessment rubric and individual evaluation ranking will be automatically submitted as an individual component for each student and accessible to the instructors as individual documents if required. The individual responses will be compiled in team documents with the assessment being editable.

An additional reason for having the students provide comparative feedback to their teammates is to avoid problem situations near the end of the term when time is limited for problem rectification. Requests for differential grades when it is too late for corrective action or feedback to the affected student are not easy to address fairly. A process to identify concerns and provide timely peer feedback at evaluation opportunities coupled with an in class process for the team to resolve concerns and document the resolution is integral to the course. Since it is required work, all students have had an opportunity to raise concerns and resolve them. If unresolved there is a basis for further action and escalation. It is a tool for teams to manage performance, to gain experience in evaluating performance, deviation management, and planning. It is a tool for instructors to better manage grading and student complaints regarding individual performance during or near the end of the term. Electronic data can be more easily studied and retrieved for continual improvement and CEAB audits if required.

Team Assessment Tool: Automated Process Development

The purpose of the team assessment tool is to allow students to compare their team behaviors to those observed in teams producing a specific quality of final report and reflect on what actions may be required to achieve their goals. The team assessment rubric has been adapted from "Rubric Development for Assessment of Undergraduate Research" (Newell, 2004). Newell et al. made observations regarding team behavior and outcomes. The design instructional team has made this paper and rubric available to design teams for many years. Between 2010 and 2012 instructors noted a strong correlation between observed team behavior and their final report grade. Some additional items and adaptations were made to the rubric to support the specific objectives of the design course. There is support in the literature for individual and group reflection on behaviors and outcomes (feedback) influencing experience quality if a certain outcome or goal is desired. (Csikszentmihalyi, 1990; Hattie, 2009; White 2005) To support the objective of developing teamwork strategies and in an ongoing effort to assist students in improving their performance in the design course a team reflection assignment was added in 2013. Teams reviewed the rubric and commented on where their team ranked and described how they could improve. As with the team evaluation some success was noted with some teams, while other teams were more superficial. The

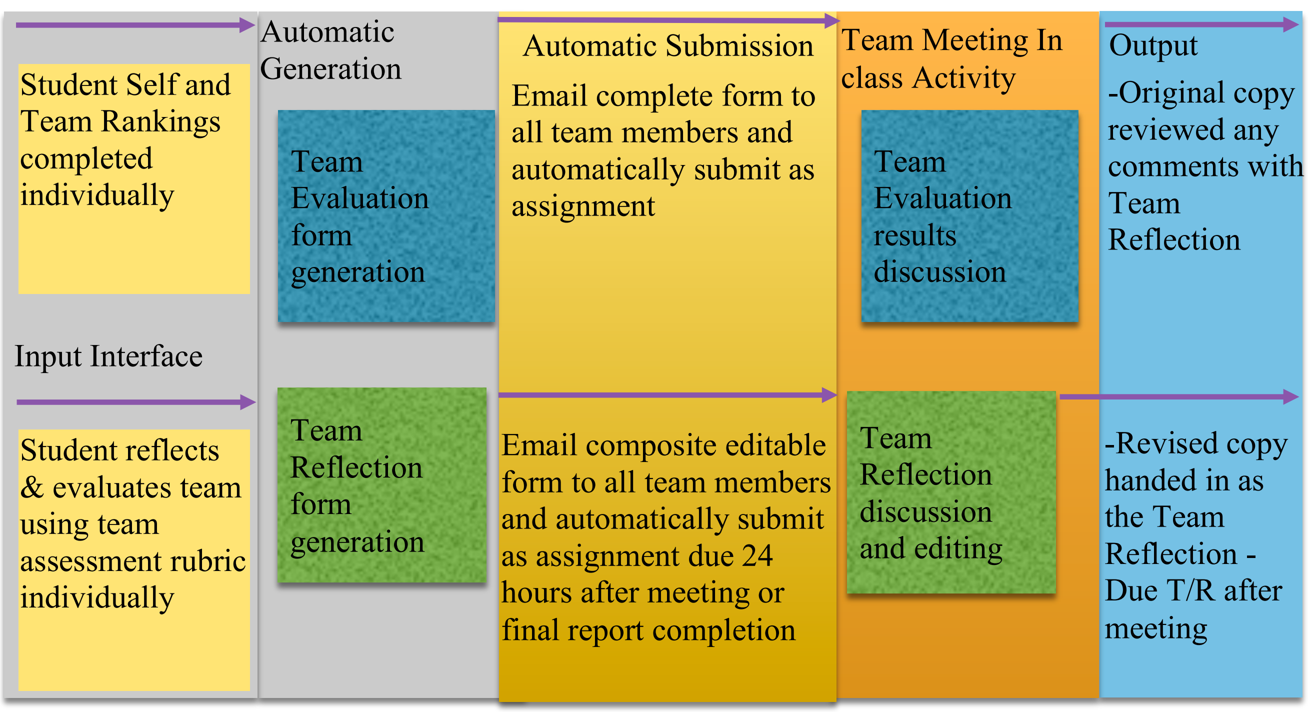


Figure E3.2. Proposed Integrated Process Structure For Team Evaluation and Reflection

assignment was meant to be an individual assessment followed by a group reflection process.

Often students were confused between individual and team evaluation and what is required for reflection as it was a new process for most. A combined automated process as shown in Figure E3.2 is proposed.

The team reflection automation will allow individuals to consider their input prior to team discussion as shown in Figure E3.3. The complete process follows the method we propose for all student contributions to their project: individual work and preparation; submission of work to the team for

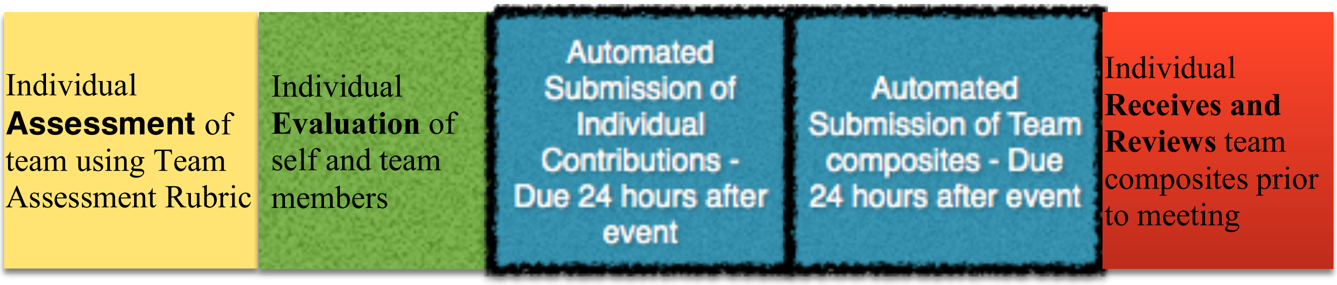


Figure E3.3. Individual work and preparation process

consideration; team review/discussion/acceptance; plan for further work or rework for individuals. The team reviews and considers individual inputs and then integrates the work into the final product. In this case the individual team members assess their team according to the rubric and then evaluate individual performance contributing to the team performance, support their choices and make recommendations for

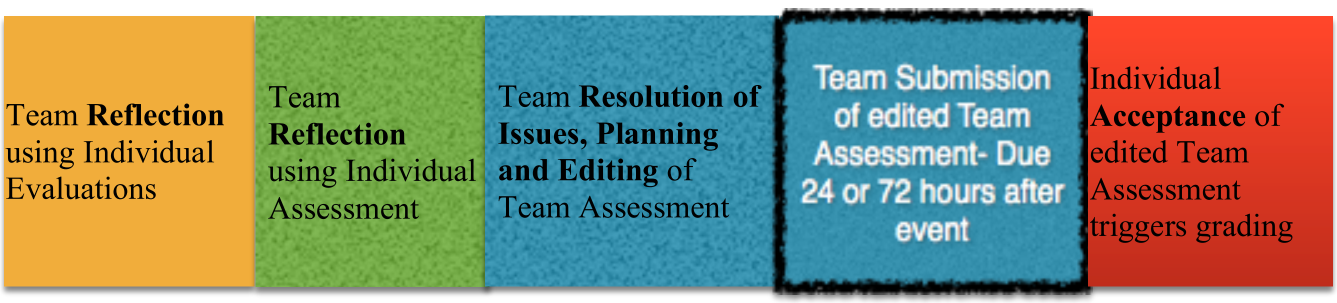


Figure E3.4. Team review and planning process

improvements.

Next, as shown in Figure E3.4, the team meets to review and edit their composite document and manage any deviations identified by the individual input process. It is crucial that students are able to integrate the individual inputs to the reflection document after review and discussion. This is their plan to improve results going forward and to resolve any team issues that may have developed. Considering solutions and solving the problems is equally important to the assessment step. The opportunity for individuals to input and consider the composite prior to meeting may improve the discussion and plan for resolution.

The integration of the two tools into one process with in class time allotted for the team activities, automation of input, and composite form generation allows for student and instructor time to be focused on improvement of the team experiences from a project perspective and an overall course perspective rather on tracking document completion status. Individual acceptance of the team submission should trigger the complete grading automatically as the team grades/approves the plan not the instructor. The instructor can review and give feedback if requested or required but the team controls the process and acceptance of the plan.

References:

Csikszentimihalyi, M. (1990). Flow: The Psychology of Optimal Experience. New York, NY: Harper & Rowe, 303 pp. {ISBN: 978-0060-16253-5}

Hattie, J. (2009). The Black Box of Tertiary Assessment: An Impending Revolution. In L. H. Meyer, S. Davidson, H. Anderson, R. Fletcher, P.M. Johnston, & M. Rees (Eds.), Tertiary Assessment & Higher Education Student Outcomes: Policy, Practice & Research (pp.259-275). Wellington, New Zealand: Ako Aotearoa

James A. Newell, Heidi L. Newell, Kevin D. Dahm, (2004). Rubric Development for Assessment of Undergraduate Research Rowan University – Glasgow NJ, Chemical Engineering Education, 38(1) 68-73

4. Team Assessment Rubric Tool For Design II

Behaviors Corresponding to Project Planning and Logistics

Indicator	"A" Team	"B" Team	"C" or Lower Team
Organized Project	Effectively organizes project tasks to minimize time and wasted effort.	Identifies relevant tasks but may struggle with setting priorities and planning.	Has difficulty identifying relevant tasks and setting priorities.
Met Deadlines	Consistently met deadlines.	Meets most deadlines and completes assignments even if they were not immediately contributing to their mark.	Misses some deadlines and is not prepared for weekly meetings. Members do not always have something to report and progress may be lacking.
Executed Project Plan	Effectively and safely executes the project plan. Makes significant progress each week. Modifies the plan as necessary.	Executes the project plan but has difficulty overcoming setbacks.	Does not steward to the project plan, works haphazardly, will achieve some project objectives, but not all.
Kept Detailed Records	Kept detailed records that are easily followed by others. These include computer files, schedules, simulation notes, mass and energy balances, HAZOP records, PFD's and P&ID.	Keeps records but organization is less and records may contain errors or omissions.	Keeps poor, sketchy records, or no records. (No records would describe a "D" team.)

Adapted from:

James A. Newell, Heidi L. Newell, Kevin D. Dahm, (2004). Rubric Development for Assessment of Undergraduate Research Rowan University – Glasgow NJ, Chemical Engineering Education 38(1) 68-73

Behaviors Corresponding to Technical Performance

Indicator	"A" Team	"B" Team	"C" or Lower Team
Defined Objectives	Is actively involved in defining aggressive and achievable objective that thoroughly address project needs.	Defines objectives however they may be too simplistic, unrealistic and may not address the project or client needs	Takes little initiative in defining the project objectives.
Demonstrated Technical Awareness	Clearly demonstrates awareness of the work of others and establishes a context for their project. Shows an understanding drawn from multiple literature and other sources. (Synthesis is apparent)	Shows understanding of the work in the field, but limited depth and breadth. Knowledge is based on faculty provided materials and other sources. Synthesis may be developing.	Fails to demonstrate and understanding of the work of others and how it applies to their project. Knowledge is limited to faculty provided materials or less. Able to distinguish applicable knowledge, but synthesis is not apparent
Obtained appropriate results	Obtained meaningful results with a minimum of wasted effort	Produced results but may have been too many or not enough. Wasted effort apparent.	Generated few meaningful results and no new meaningful conclusions. (Repeat of others work, conclusions non-specific to the project.)
Interpreted data appropriately	Provided thorough and correct analysis of data.	Provided analysis but may be partially incorrect or insufficiently thorough	Little meaningful analysis or blatantly incorrect.
Formulated supportable conclusions	Formulated and adequately supported meaningful conclusions.	Needed significant direction in formulating meaningful conclusions or lacked sufficient support for their conclusions	Conclusions were absent, wrong, trivial or unsubstantiated.
Properly considered error	Used appropriate mathematical and technical skills to quantitatively express limitations of the data. Proper model validation and data validation were completed	Error analysis was missing a component of the validation or there were errors in the assumptions. May have had a large qualitative component.	Sources of error were ignored, misunderstood, or misinterpreted.
Provided recommendations for future work	Insightful recommendations	Broad or obvious recommendations	Few plausible recommendations

Behaviors Corresponding to Team Performance

Indicator	"A" Team	"B" Team	"C" or Lower Team
Division of Labour	All members make significant contributions to a project that progresses satisfactorily. Roles are developed and clear, but respond to changing project needs.	Progresses satisfactorily but some members feel that workload distribution was disproportionate. Roles are not always clear or responsive to change.	Internal conflicts result in team failing to achieve project goals.
Professional Conduct	Consistently behaves in a professional manner (shows up for meetings prepared and on time, treats contacts with courtesy and respect; external communications are formal and businesslike). Dresses appropriately for industrial, faculty meetings and presentations.	Usually behaves in a professional manner (shows up for meetings prepared and on time; treats contacts with courtesy and respect; external communications are formal and businesslike). Usually dresses appropriately for industrial, faculty meetings and presentations. Does not repeat errors.	Frequently fails to behave in a professional manner. May fail to dress appropriately for industrial, faculty meetings and presentations.
Learning Experiences for all team members	All team members demonstrate a thorough understanding of the technical issues of the project and their contribution to the project. Team members feel that the workload has been distributed fairly. Team members feel that all members have contributed adequately and equitably.	Some team members demonstrate a thorough understanding of the technical issues of the project and their contribution to the project. Segmented, all team members do not have the whole picture. Team members feel that the workload was mostly distributed fairly. Team members feel that some members have contributed adequately and equitably.	Some team members have significant gaps in their understanding of the project and technical issues. Team members do not feel that the workload was evenly distributed or that contributions were adequate and equitable from all members.
Conflict Management	Minor Conflict well handled	Some conflict reasonably handled	Significant conflict and/or poorly handled
Team Structure Developed to suit the project	Team developed a working structure that worked well for the project and the people on the team.	Team developed a working structure that worked adequately for the project and the people on the team.	Team worked haphazardly and did not show indications of developing a structure that suited the project or the team members.

5. Conceptual Relationship Teaching Tool: Heat, Mass, and Momentum Transfer Analogy

Heat, Mass and Momentum Transfer

There is an opportunity to look at all of the theory and correlations you have covered in ChE 312, ChE 314, and ChE 418 before we revisit them in the context of stirred tanks. All of the transfer of heat, mass, and momentum is analogous because it is based on molecular motion (conduction, diffusion, and viscous drag), or on turbulent boundary layers (forced convection, turbulent drag). If the diffusivities and three basic molecular level laws are considered, we can show that there are general forms of correlations which should always be taken as the starting point. This idea was laid out by Bird, Stewart and Lightfoot in 1960, and it dramatically changed the way we approach transport phenomena. This is a central theme in the way we approach these topics at the graduate level. Equations and figures are given on 5 pages following.

1. Molecular Diffusivity

Starting with Fourier's law of conduction, Fick's law of diffusion, and Newton's law of viscosity, draw analogies and determine diffusivities. Note that of the three molecular diffusivities, mass transfer is 100 times slower than heat, and 1000 times slower than momentum. In the case of mass transfer, the actual molecules (not just their vibrational energy (heat), or their gross motion (momentum)) must be transferred from one layer to the next.

2. Convection

Convection is described by overall transfer coefficients h (heat transfer co-efficient), k_x (mass transfer coefficient) and f (friction factor; or N_p (power number); or C_D (drag co-efficient)). Using the ratios between momentum and heat or mass diffusivities (Pr and Sc), and the characteristic of the flow regime (Re), general forms of correlations can be developed for overall transfer rates relative to molecular transfer rates (Nusselt # and Sherwood #). The analogy is not perfect because there are 9 velocity gradients, while there are only 3 temperature and concentration gradients.

3. Notation

4. References

Bird, R. B., W.E. Stewart and E.N. Lightfoot, 1960, *Transport Phenomena*, John Wiley and Sons, Toronto.

S. Kresta, 3/15/98

5. Figures

Table 1: Analogies between heat, mass and momentum transfer (from BSL)

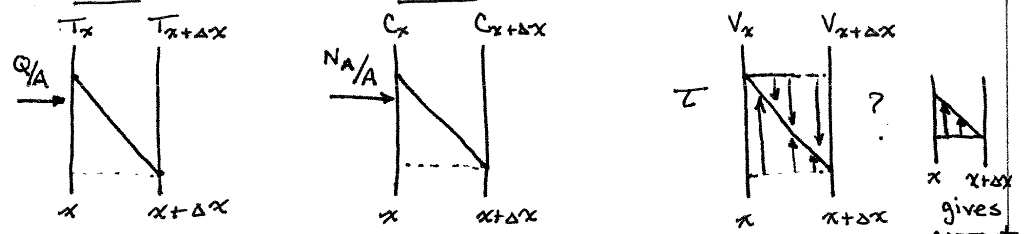
Entity Being Transported → / Type of Transport ↓	Momentum	Energy	Mass
TRANSPORT BY MOLECULAR MOTION	1 VISCOSITY μ Newton's law of viscosity Temperature, pressure, and composition dependence of μ Kinetic theory of μ	8 THERMAL CONDUCTIVITY k Fourier's law of heat conduction Temperature, pressure, and composition dependence of k Kinetic theory of k	16 DIFFUSIVITY $\mathfrak{D}_{AB}$ Fick's law of diffusion Temperature, pressure, and composition dependence of $\mathfrak{D}_{AB}$ Kinetic theory of $\mathfrak{D}_{AB}$
TRANSPORT IN LAMINAR FLOW OR IN SOLIDS, IN ONE DIMENSION	2 SHELL MOMENTUM BALANCES Velocity profiles Average velocity Momentum flux at surfaces	9 SHELL ENERGY BALANCES Temperature profiles Average temperature Energy flux at surfaces	17 SHELL MASS BALANCES Concentration profiles Average concentration Mass flux at surfaces
TRANSPORT IN AN ARBITRARY CONTINUUM	3 EQUATIONS OF CHANGE (ISOTHERMAL) Equation of continuity Equation of motion Equation of energy (isothermal)	10 EQUATIONS OF CHANGE (NONISOTHERMAL) Equation of continuity Equation of motion for forced and free convection Equation of energy (nonisothermal)	18 EQUATIONS OF CHANGE (MULTICOMPONENT) Equations of continuity for each species Equation of motion for forced and free convection Equation of energy (multicomponent)
TRANSPORT IN LAMINAR FLOW OR IN SOLIDS, WITH TWO INDEPENDENT VARIABLES	4 MOMENTUM TRANSPORT WITH TWO INDEPENDENT VARIABLES Unsteady viscous flow Two-dimensional viscous flow Ideal two-dimensional flow Boundary-layer momentum transport	11 ENERGY TRANSPORT WITH TWO INDEPENDENT VARIABLES Unsteady heat conduction Heat conduction in viscous flow Two-dimensional heat conduction in solids Boundary-layer energy transport	19 MASS TRANSPORT WITH TWO INDEPENDENT VARIABLES Unsteady diffusion Diffusion in viscous flow Two-dimensional diffusion in solids Boundary-layer mass transport
TRANSPORT IN TURBULENT FLOW	5 TURBULENT MOMENTUM TRANSPORT Time-smoothing of equations of change Eddy viscosity Turbulent velocity profiles	12 TURBULENT ENERGY TRANSPORT Time-smoothing of equations of change Eddy thermal conductivity Turbulent temperature profiles	20 TURBULENT MASS TRANSPORT Time-smoothing of equations of change Eddy diffusivity Turbulent concentration profiles
TRANSPORT BETWEEN TWO PHASES	6 INTERPHASE MOMENTUM TRANSPORT Friction factor f Dimensionless correlations	13 INTERPHASE ENERGY TRANSPORT Heat-transfer coefficient h Dimensionless correlations (forced and free convection)	21 INTERPHASE MASS TRANSPORT Mass-transfer coefficient k_x Dimensionless correlations (forced and free convection)
TRANSPORT BY RADIATION	*Numbers refer to the chapters in this book*	14 RADIANT ENERGY TRANSPORT Planck's radiation law Stefan-Boltzmann law Geometrical problems Radiation through absorbing media	*This book may be studied either by "columns" or by "rows"*
TRANSPORT IN LARGE FLOW SYSTEMS	7 MACROSCOPIC BALANCES (ISOTHERMAL) Mass balance Momentum balance Mechanical energy balance (Bernoulli equation)	15 MACROSCOPIC BALANCES (NONISOTHERMAL) Mass balance Momentum balance Mechanical and total energy balance	22 MACROSCOPIC BALANCES (MULTICOMPONENT) Mass balances for each species Momentum balance Mechanical and total energy balance

1.

Analogies Between Heat, Mass and Momentum Transfer

I. Consider molecular diffusion of:

Heat | Mass | Momentum

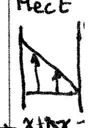


gives correct analogy

	Heat	Mass	Momentum
distance:	Δx	Δx	Δx
flux of: $\left(\frac{Qty}{s \cdot m^2}\right)$	heat $\left(\frac{W}{m^2}\right)$	mass $\left(\frac{mol/s}{m^2}\right)$	momentum $\left(\frac{kg\,m/s^2}{m^2} = \frac{N}{m^2} = Pa\right)$
gradient:	$\frac{T_{x+\Delta x} - T_x}{\Delta x} = -ive$	$\frac{C_{x+\Delta x} - C_x}{\Delta x} = -ive$	$\frac{V_{x+\Delta x} - V_x}{\Delta x} = -ive$
	heat flows downhill	mass flows downhill	momentum flows downhill too

Note: MecE convention → -ive flux of momentum! OK-as long as consistent

MecE



$\tau = \mu \frac{dV}{dx}$

So...

$$\frac{Q}{A} = -k_T \frac{dT}{dx} \qquad \frac{N_A}{A} = -\mathcal{D} \frac{dC_A}{dx} \qquad \tau = \cancel{-}\mu \frac{dV}{dx}$$

for -ive velocity gradient

Fourier's law of conduction | Fick's law of diffusion | Newton's law of viscosity

In terms of diffusivity, we would like units of m^2/s, so

$$\frac{k_T}{\rho C_p} = \frac{W}{m\,°C} \; \frac{m^3}{kg} \; \frac{kg\,C°}{J} = \frac{m^2}{s} \qquad \mathcal{D} = \frac{m^2}{s} \qquad \frac{\mu}{\rho} = \frac{kg}{m\,s} \cdot \frac{m^3}{kg}$$

(C_A in mol/m^3)

$$= O(10^{-7}\,m^2/s) \qquad = O(10^{-9}\,m^2/s) \qquad = O(10^{-6}\,m^2/s)$$

Heat　　　Mass　　　Momentum

rewriting the equations in terms of diffusivity:

$$\frac{Q}{A} = -\boxed{\frac{k}{\rho C_p}}\frac{d(\rho C_p T)}{dx} \qquad \frac{N_A}{A} = -\boxed{\mathcal{D}}\frac{dC_A}{dx} \qquad \tau = -\boxed{\frac{\mu}{\rho}}\frac{d(\rho V)}{dx}$$

$$\rho C_p T = \frac{kg}{m^3}\,\frac{J}{kg\,°C}\,°C = \frac{J}{m^3} \qquad C_A = \frac{mol}{m^3} \qquad \rho V = \frac{kg}{m^3}\frac{m}{s} = \left(kg\,\frac{m}{s}\right)/m^3$$

Concentration of heat, mass and momentum!

II Now consider convection

$$\frac{Q}{A} = h\,\Delta T \qquad \frac{N_A}{A} = k_M \Delta C_A \qquad \tau = \rho V^2$$

$$\frac{W}{m^2\,°C}\,°C = \frac{W}{m^2} \qquad \frac{m}{s}\frac{mol}{m^3} \qquad \frac{kg}{m\,s^2} = \frac{N}{m^2}$$

to compare convection with diffusion, need similar units, so consider

$h D_I$　　　$k_m D_I$　　and　　$\rho D_I V$

D_I = integral scale

To get relative diffusivities, we can now set up dimensionless groups:

$Nu = \frac{h D_I}{k_T} = \frac{\text{convection}}{\text{conduction}}$ = Nusselt number

$Sh = \frac{k_M D_I}{\mathcal{D}_{AB}}$ = Sherwood number

$Re = \frac{\rho D V}{\mu} = \frac{\text{inertial forces}}{\text{viscous}}$ = Reynolds number

transport across a film: $\frac{\text{overall}}{\text{molecular}}$ (often $\frac{\text{turbulent}}{\text{laminar or stationary}}$)

transport across a film: $\frac{\text{overall (2phase)}}{\text{molecular}}$

No? Convection here occurs through a surface within the fluid. Analogy is better posed as

$$\frac{f_{TURBULENT}}{f_{LAMINAR}} = \frac{f Re}{64}$$

(not useful tho')

BOTTOM LINE:

Nusselt number considers

- interphase energy transport (heat)
  fluid → wall
- basis for correlations of forced (& free) convection for h_T

Sherwood number considers

- interphase mass transfer (mass)
  across an interface
  - gas liquid
  - liquid · liquid
  - liquid · solid
  - gas · solid
- basis for correlations of forced (& free) convection for k_x, often combined as, for example, $k_L A$

Friction factor: Reynolds number considers

- interphase momentum transfer
  fluid → wall
  due to ~~viscosity~~ viscous & intertial forces.
- basis for friction factor - Reynolds number correlations
- basis for power number - Reynolds number correlations.

Heat and mass transfer are also strongly influenced by fluid motion, so the ratios of:

$\frac{\text{heat}}{\cancel{\text{mass}}\ \text{momentum}}$ diffusivity $\qquad \frac{\text{mass}}{\text{momentum}}$ diffusivity

Pr = Prandtl #

$$= \frac{C_p \mu}{k_T}$$

$$= \frac{\mu}{\rho} \Big/ \frac{k_T}{\rho C_p}$$

$$= \frac{\text{momentum}}{\text{thermal}} \text{ diffusivity}$$

Sc = Schmidt #

$$= \frac{\nu}{D_{AB}}$$

$$= \frac{\mu}{\rho} \Big/ D_{AB}$$

$$= \frac{\text{momentum}}{\text{mass}} \text{ diffusivity}$$

are also of interest for determining heat and mass transfer rates. ~~These~~ The general forms of correlation are thus:

HEAT: $Nu = Re^a \cdot Pr^b f(\text{geometry}) \left(\frac{\mu_{wall}}{\mu_{bulk}}\right)^c$

$Pe_H = Re\,Pr$ $\qquad$ correction

MASS: $Sh = Re^a Sc^b f(\text{geometry})$

$Pe_D = Re\,Sc$

MOMENTUM: $f \text{ (or } N_p) = Re^a f(\text{geometry})$

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III. Summary

Heat	Mass	Momentum

FLUX

$$\frac{Q}{A} = -k_T \frac{dT}{dx} = -\frac{k_T}{\rho C_p}\frac{d(\rho C_p T)}{dx} \qquad \frac{N_A}{A} = -\mathcal{D}_{AB}\frac{dC_A}{dx} \qquad \tau = -\frac{\mu}{\rho}\frac{d(\rho V)}{dx}$$

CONCENTRATION OF

$$\text{heat} = \rho C_p T = \frac{J}{m^3} \qquad \text{mass} = C_A = \frac{mol}{m^3} \qquad \text{momentum} = \rho V = \left(\frac{kg\,m}{s}\right)/m^3$$

DIFFUSIVITIES

$$\text{thermal} = \frac{k_T}{\rho C_p} = \alpha = \frac{J}{m \cdot s \cdot °C} \Big/ \left(\frac{kg}{m^3}\cdot\frac{J}{kg\,°C}\right) = \frac{m^2}{s}$$

$$\text{mass} = \mathcal{D}_{AB} = \frac{m^2}{s}$$

$$\text{momentum} = \frac{\mu}{\rho} = \nu = \frac{kg}{m \cdot s}\,\frac{m^3}{kg} = \frac{m^2}{s}$$

~~Nu~~ $Pr = \frac{\text{momentum}}{\text{thermal}} = \frac{\nu}{\alpha} = \frac{C_p \mu}{k_T}$ $\qquad Sc = \frac{\text{momentum}}{\text{mass}} = \frac{\nu}{\mathcal{D}_{AB}}$

CONVECTION VS CONDUCTION

$$Nu = \frac{hD}{k_T} = Re^a Pr^b f(\text{geometry}) \left(\frac{\mu_{wall}}{\mu_{bulk}}\right)^c$$

$$Sh = \frac{k_M D}{\mathcal{D}_{AB}} = Re^a Sc^b f(\text{geometry})$$

$$f = Re^a f(\text{geometry})$$

OR

$$N_p = Re^a f(\text{geometry})$$