A Continual Improvement Process for Teaching Leadership and Innovation Within a Community of Practice

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Dr. John M. Shaw

John M. Shaw obtained his B.A.Sc. degree in Chemical Engineering and his Ph.D. in Metallurgy and Material Science at the University of British Columbia, Vancouver, Canada, in 1981 and 1985 respectively. In 1985, he joined the Department of Chemical Engineering and Applied Chemistry at the University of Toronto, where he rose to the rank of professor. In 2001, he joined the Department of Chemical and Materials Engineering at the University of Alberta where he holds the NSERC industrial research chair in petroleum thermodynamics.

During his career he has developed expertise in the phase behavior, physiochemical and transport properties of hydrocarbon mixtures from coal liquids, heavy oils and condensate rich reservoir fluids to pure compounds. This led to the establishment of an NSERC (like NSF in the USA) Industrial Research Chair in 2001, a rare honour at that time. He has held visiting scientist/professor positions at the Technical University of Delft (Delft, The Netherlands), the Institut Francais du Petrole (Rueil-Malmaison, France), the Syncrude Canada Research Centre (Edmonton, Canada), the ITESM campus of the Technical University of Monterrey (Guadalajara, Mexico), UPPA (Pau, France) and the TOTAL Research Centre (Pau, France).

In his current role he develops enabling technologies, and methodologies for measuring and calculating thermophysical properties of hydrocarbons, and for selecting industrial processes related to the hydrocarbon production, transport and refining sectors with a global mandate.

He is an associate editor of Energy and Fuels, chairs the conference committee for PPEPPD 2019, chairs the international advisory boards for the European Community Project on Shale and the Environment (SxT) and for Science for Clean Energy (S4CE), another European Community Project (both are led by Alberto Striolo at University College London). He is on the advisory board for Fluid Phase Equilibria and is a member of the International Union of Pure and Applied Chemistry (IUPAC) Project on Recommended Reference Materials for Phase Equilibria Studies (led by Ala Bezyleva, NIST). He sat until recently on the advisory committee for the National High Magnetic Flux Laboratory Tallahassee (FTICR-MS facility, USA), and the Network Coordination Council for the Canadian Oilsands Network of Research and Development (CONRAD). He was a principal Investigator and theme leader for Carbon Management Canada (a Canadian national centre of excellence). He is called upon regularly for advice by government laboratories, universities, and corporations. He has an interest in e-learning, and he likes to ride bicycles and travel!

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Abstract

Innovation, teamwork, leadership, lifelong learning, and sustainable design are key teaching and learning deliverables for capstone design courses and are evaluated as graduate attribute outcomes integral to the Canadian Engineering Accreditation Board (CEAB) evaluation processes. Continual course improvement processes require reflection on the success of learning activities, the tools used for teaching, and alignment of learning outcomes, activities, and assessment. Peer evaluation and feedback tools can encourage student learning and leadership development. The method of data collection, the type of feedback and the contextual validity of the feedback may impact students' development of useful team behaviours and personal strategies for working in team environments. Mixed method successive case study analysis provides insights enabling targeted improvements to learning activities, outcomes, assessment and the student and instructor course experiences. **The proposed course level continual improvement process employs a sequential case study method with the intent of identifying improvement actions related to learning efficacy, course experience, and improved graduate attribute performance outcomes.** Case study data generation and assessment tools include student self-evaluations, peer and team evaluation and feedback tools, instructor evaluations, observations and reflections, and assessment of student results. These tools provide data for both qualitative and quantitative assessments for each course iteration and inform ongoing course and aligned learning activity development. A community of practice (COP) fulfills the stakeholder engagement criterion (CEAB requirement) for a continual improvement process. At a major Canadian university, instructors with a diverse mix of industrial and academic experience teach chemical process design as a team. The instructors work in close collaboration with practicing professional engineers including industrial technical specialists, entrepreneurs, and academic colleagues with an industrial focus, to prepare unique process design projects and to advise student teams. This community of practice offers students a window on engineering design practice, leadership, and innovation as they transition to the professional community. **This paper explores the role of this community of practice in the continual improvement process supporting enhanced achievement of CEAB graduate attributes including student, team and leadership development.**

Introduction

Since the implementation of the CEAB graduate attributes for outcome based program assessment, the demonstration of a continual improvement process (Appendix A) at the program level is now a requirement for accreditation in Canada (CEAB, 2018). The current rubric elements include an improvement process, stakeholder engagement, and improvement actions (CEAB CI V3.2, 2018):

"*There must be processes in place that demonstrate that program outcomes are being assessed in the context of graduate attributes, and that the results are validated, analysed and applied to further development of the program*."

"*There must be demonstrated engagement of stakeholders both internal and external to the program in the continual improvement process*."

These statements raise the questions "What do continual improvement processes "look like" and how are they actualized?"

This contribution describes a methodology developed to realize meaningful continual improvement by identifying targeted improvement actions in the context of engineering design courses supported by a community of practice. Our recent focus has been on activities and tools related to design, teamwork, leadership, and innovation. At the course level, *improvement actions* arise as identifiable course content improvements or as improvements in the assessment of outcomes. With each course iteration we identify *what needs to be improved (if anything) and what improvement actions are required.*

Background

The driving force for continual improvement is rooted in calls for engineering graduates to be better prepared for industry and to address the disconnect between engineers working in academic and industry industrial environments (NRC, 1995; NRC, 1997; Dutson, 1997; Wulf, 1998; Donnell, 2011). Many researchers, instructors, and accreditation organizations have devoted time and resources to close this gap (Pembridge, 2010; 2011; Jamieson, 2016; 2017; 2018) including the introduction of outcomes based CEAB graduate attributes (CEAB, 2014) and continual improvement process requirements (CEAB, 2018) in engineering academic program accreditation processes - as outlined in Appendix A. One of the current goals of the CEAB is the continual improvement of the quality and relevance of engineering education.

Developing a community of practice has evolved as a method for stakeholder engagement in our engineering education process. Our process design courses have a long history of industry-sponsored projects (Jamieson, 2016; 2018) and industry engagement in learning activities. These interactions have strengthened over time and have developed into a community of practice, where students learn about leadership and innovation as a consequence of engaged stakeholders, course design, and content. Our community of practice is part of our continual improvement process at the course level and supports a course-based adaptation of the OSLO innovation map (Jamieson, 2018). The innovation transfer factors (OSLO, 2005; Lhuillery, 2016) include human, social, and cultural factors influencing information transmission and learning. Innovation transfer factors are realized in the design course framework by interactions between the student design teams (innovation core team) and the organizational infrastructure including the teaching team, ad hoc faculty engagement, and industry advisor support.

At the Faculty level, a program of study based continual improvement process has been in use for several years (Ivey, 2018; 2017; Watson, 2018). Instructor measured graduate attribute indicators relevant to their courses feed into this process. Design courses typically have measures for the development of all twelve of the CEAB graduate attributes. At the end of an undergraduate program, capstone design course measures are expected to be at the advanced level. In addition, instructors complete a post course assessment with recommendations (Ivey, 2017) that addresses student preparation in advance of the course, student development during the course, and opportunities for course structure, evaluation method, and content improvement.

Team and leadership development, the subject of this contribution, were targeted for improvement actions in our capstone design course. Our students have been required to self-select their design teams based on the completion of a team skill matrix since 2004. Skills listed in the matrix, including team and leadership skills, were identified as critical to team success in the course. Not every individual on the team needed to possess all skills but the team required at least one individual who possessed strength in each skill. Student teams were approved following completion of a composite skill matrix, and an adequate plan to address areas of team weakness.

Between 2010 and 2013 team and leadership development activities were instituted and elaborated. In 2014 funding was provided by the Provost's Office for a major redevelopment of the capstone course for blended learning delivery. During the transition, course level learning outcomes were examined and mapped to the twelve Canadian Engineering Accreditation Board Graduate Attributes (CEAB GA) and the results were included in the course syllabus (Jamieson, 2015; 2016; Ivey, 2018; Watson, 2018). Learning activities were redeveloped and further aligned with learning outcomes and assessment requirements (Jamieson, 2017; 2018). Individual skill self-assessment (mapped to the graduate attributes), team selection, and the team development process (Jamieson, 2016) were among the redeveloped learning activities. Team and leadership development activities were introduced as part of the 2015 blended pilot and improved during successive iterations of the course. The redevelopment of these activities was one of several possible areas for improvement identified in a retrospective study comparing the blended learning application and the prior more traditional capstone course format (Jamieson, 2016). From this work and the new CEAB requirement for demonstrating a continual improvement process, ongoing retrospective case-based analysis was implemented for the course to identify and test areas of improvement especially those related to the blended learning pilot.

Starting in 2015, a similar process was applied to the introductory process design course, a term seven prerequisite for the capstone design course. The learning outcomes were mapped to the CEAB GA and we enhanced the alignment of learning activities with outcomes and assessments. The format of this prerequisite course transitioned to some online content with pre and post class elements directly related to in class participative and active learning style lectures. A new team selection and development process was introduced which followed the pattern of the capstone course. A mandatory pre and post course survey for student self-assessment related to the graduate attribute outcomes was also instituted. Courses improvements were identified and implemented after each subsequent iteration of the course. Team development and conflict management learning activities and learning modules were introduced in 2017 and integrated with the capstone course (Jamieson, 2018).

Program based continual improvement processes are intended to support student achievement of graduate outcome performance as they progress through their programs, graduate, and develop life long learning skills that facilitate ongoing development and competence maintenance during their careers. The accreditation board anticipates that two accreditation cycles (12 years) will be needed for full scale implementation of continual improvement processes. Their expectations for fully developed and functional processes will increase over time. Reflective self-evaluative processes of teaching, learning, engagement, and outcomes at the course level provide evidence based recommendations to the program level reflection processes and inputs to program assessments.

Frameworks and Methods

Multiple frameworks underpin this contribution and inform the research methodology[1] adopted. To set the stage, we describe the frameworks underpinning capstone design course instruction. Engineering work is ***complex***[2] and is typically a response to a real or perceived societal need. Value propositions or regulatory requirements are often associated with engineering work. Engineers attempt to become objective when analyzing a problem *and* engineers are a part of communities where their solutions are implemented. Engineers communicate their solutions, receive feedback, and interact with communities in ways that influence their solutions. Engineers become reflexive when they evaluate the impact of engineering on society. Engineering education can also be described as *complex*. When instructors are teaching they are part of the learning community using their learning materials, activities, and assessments to achieve learning outcomes. When instructors are designing and redesigning courses, aligning learning activities, analyzing and reflecting on how to improve their teaching and their course materials they become more objective *and* reflective when they evaluate the results of their teaching. Both the practice of engineering and engineering instruction require individuals to assume a relative perspective depending on the work at hand. This can be thought of as being *in* the fishbowl while describing and thinking about what it is like to be *in* the fish bowl compared to being *out* of the fish bowl while describing and thinking about what it is like to be *in* the fishbowl. Both perspectives are valid and arguably necessary. The first perspective describes the instructor while currently teaching a course and the latter describes the instructor evaluating and reflecting on the course efficacy once it is completed.

The philosophical framework described above is called Critical Realism (Bhaskar, 1975). Critical Realism allows for individual subjective human interpretation of an objective independent reality or existence (Clark, 2008). The fishbowl is the independent reality. The experience of the fishbowl is different for the observers *and* they can describe common observations of the fishbowl. Critical realism holds that we must separate ontology (views of the nature of reality and existence) from epistemology (views of the nature of knowledge and systems) (CCR, 2016). Our knowledge is transitive. Scientific knowledge is subject to change and evolution as we seek truth and learn new things about the intransitive relatively unchanging natural world we seek to know about (CCR, 2016). Society is transitive. The cultural, moral, technological, economic, environmental, and safety realities of individuals

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[1] The definition of methodology used here is a collection of methods used to perform the research and analysis.

[2] The definition of complex as outlined in Clark, et. al. 2012.

along with human beliefs have evolved over time. Students, instructors, and engineers are all a part of society and experience this reality from their own perspective. Case studies, such as this one, are inherently rooted in Critical Realism.

We use a Situative Theory framework to deliver our capstone design course. (Jamieson, 2018) This type of framework argues knowledge, thinking, and learning are situated in experience. Knowledge, thinking, and learning cannot be separated from context as they depend upon context (Lave, 1991). Situative Theory stresses the social nature of cognition, meaning, and learning, with emphasis on the importance of the *participants* and the *environment*, as well as the *evolving interaction* between the participants and the environment (Durning & Artino, 2011). We use Constructivism (Biggs, 1999; Entwistle, 1992) for the framework of aligned learning outcomes, activities, and assessment for the capstone design course.

The methodology for continual improvement, advocated in this work, requires both Situative Theory and Constructivism and shifts between them depending on whether the instructor is actively teaching, or is reflecting and evaluating between course iterations. The community of practice and innovation framework for this work is based on the innovation dynamo and innovation policy map (OSLO, 2005; Lhuillery, 2016). This dual framework is adapted and applied within the capstone process design course community of practice environment to improve innovation instruction. For engineering design, innovation can be narrowly defined and measured based on objective improvement of process or a product performance (Jamieson, 2018).

The Transformational framework (Burns, 1978; Bass, 1985) is used for leadership related learning activities. Instructors model leadership and teamwork throughout the course. We focus on the concept that leadership starts with self-knowledge (Sosik, 1999; Atwater, 1992; Colcleugh, 2013). A reflective self-evaluative process with respect to social intelligence is correlated to the development of leadership skills (Condon, 2011). The team and leadership learning activities begin with learning about self and are extended to how to inspire and lead others. Reflection based on observing the impact of team and leadership decisions is included. Self-efficacy and accountability are foundational for leadership, professional, and life long learning development. Assessment of individual skills, conflict management styles, and personality feed self-knowledge and reflection on how one's own actions impact desired outcomes (Jamieson, 2018). Linking actions and outcomes encourages empowerment, whether it has an agentic or communal orientation. A leader can better assess their actions to provide an effective work environment for their team when they are able to assess their own impacts accurately. This framework is consistent with the grassroots target level for the advocated research methodology for leadership teaching.

To be consistent with the philosophical and educational frameworks and the continual nature of the process to be evaluated, the research framework for continual improvement includes mixed methods (Creswell, 2005) and case study (Creswell, 2018) approaches. Both quantitative empirical questions and qualitative subjective questions are necessary for the continual-improvement sequential case-based analysis. Analysis of the graduate attribute outcomes of an engineering course within an engineering program necessitates examining a complex system.[3] Complex systems may have a range of short term and long-term outcomes, but they are characterized by multiple interacting factors, formulas having limited applicability. Doing the same thing twice does not necessarily result in the same outcome. The continual course improvement method advocated in this work utilizes a sequential case study approach with qualitative and quantitative questions. A quasi-experimental design is used to examine course outcomes to identify possible *improvement actions* for implementation in subsequent iterations.

Continual Improvement Methodology

The overall objective of the continual improvement process, illustrated in Figure 1, is the identification of effective improvement actions or to demonstrate the adequacy of the status quo *over time*. Improvement actions are targeted to improve graduate attribute development from an outcome based assessment perspective. The key criteria to develop an assessment system are listed in Table 1. The improvement actions identified must be evidence based and supportable from a resource perspective. Improvement actions can target course or program level improvements and should be supported by an analysis of outcomes at the course level. The method utilized to identify the improvement actions must include multiple perspectives and engage stakeholders. If no improvement actions are identified the status quo can be justified - based on the outcome based evidence assessment (Figure 2).

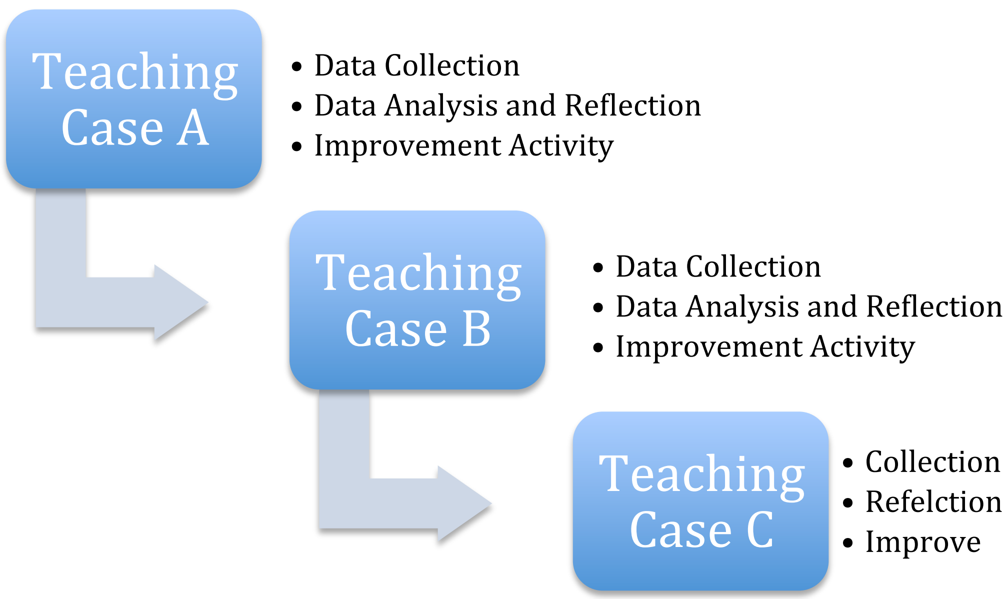

Figure 1. Continual Improvement Process Overview

An engineering program is a complex system. Instructors *and* students change from iteration to iteration as they are learning, responding, and reflecting. Students and student cohorts can be influenced by previous work experience, class size, teammates, course sequencing, extra curricular activities, life experience, performance in prior related courses,

[3] Complex system behaviour is distinguished from complicated system behaviour where outcomes can be reliably predicted from past behaviour with mathematical analysis (Clark, 2012).

different instructors may teach the same prerequisite courses, economic factors and perceived career opportunities, etc. The list of possible confounding factors is long. This observation lends support to the idea that each student experiences our design courses uniquely even though there is a common "reality" for all students. Instructors are also subject to their own learning and as the continual improvement process is applied in multiple courses within a program, learning activities and tools for learning change. Nonetheless, instructors are required to assess students on the basis of achieving course requirements, demonstrating the learning objectives, and the graduate attribute outcomes while guiding students along a path of effective learning activities intended to develop the graduate attribute outcomes and prepare students for work and lifelong learning.

Table 1. Key evaluation criteria for a continual improvement process.

Criteria	Process properties
Identify improvement actions – evidence based – improvements must be informed by graduate attribute outcome assessment	Must be able to identify outcome areas that need improvement. Assessment of ***learning activity efficacy***: students & instructors. Requires mapping of graduate attributes to course learning outcomes
Used over time	Data collected, analysed and used to identify actions on a regular basis
Identify areas for improvement – learning activity and graduate attribute matching – is the assessment valid?	Stakeholder assessments – Community of practice: Student self-assessment (pre-post course); Input from industry advisors; input from instructors.
Measure the scope of the graduate attribute while minimizing measurement points	Assess each graduate attribute for scope – set a limit on redundancy – specific assessment points that span the scope
Justify keeping the status quo	Analyze data and compare from year to year and to a target value.
Stakeholder "buy in" - process becomes part of the *culture* of the institution	Process must be *used* to be valid. Flexible and adaptable to individual course needs
Consistency	An evidence driven course based process is an input to a consistent course reflection and program feedback process

Discussion

The method developed for assessing this complex system and developing relevant improvement actions is a sequential cased based mixed methods analysis. The data collected is similar from case to case and the cases are temporally differentiated. "Case study issues represent complex, situated, and problematic issues…departing from the design of experiments and testing of hypothesis, qualitative case research focuses on relationships connecting ordinary practice in natural habitats to a few factors…"(Stake, 2006). The mixed method experimental design allows for quantitative measurements to be statistically examined as the specifics behind the measurements are examined using qualitative analyses. This leads to an enlightened understanding of the efficacy of the learning activities, the burden the course work places on students, the student view of the utility of the course and their own progress in the context of the grade distribution and cohort specific factors. This understanding is valuable in managing the teams and their learning experience during the course and later for reflecting on the efficacy of the learning activities and determining where improvements may be needed. This method requires at least one member of an instructional team or a single instructor to teach and evaluate the same course(s) for more than a single iteration. A modified version could be employed if a researcher were engaged in the course observations and evaluations over time with different instructors. The efficacy of the latter model has not been tested.

Both qualitative and quantitative data are collected while teaching the design courses, managing the teams, and their projects. The primary purpose of the data collected is student learning activities and student development during the course. Peer review and feedback is documented as a learning activity intended to be part of a self-reflective and team development process (Donia, 2015; O'Neil, 2015; O'Neil, 2018; Jamieson, 2018; Pond, 1995). Team development assignments, reflections, evaluations and peer feedback information are used as input for project management, monitoring, team and leadership development. Some data is created by and used directly by the teams for self regulation and management; some data is viewed only by instructors or individual students and used for guidance or individual development. The secondary uses of the data include assessment of graduate attribute outcomes and course improvement action identification. Qualitative data obtained via course evaluations, student peer feedback, student feedback and reports to advisors, student team reflections, industry advisor feedback to the teaching team and observations of the teaching team all contribute to a rich composite perspective. Quantitative data include formative and summative assignment marks, exam marks, final report marks, final grades, and a pre and post test skill self-assessment. The key research question asked from a continual improvement perspective for each sequential case study is the same: *What needs to be improved (if anything) and what are the improvement actions?*

The key stakeholders in the process design course are the students, the instructors, and the industry advisors. Collectively they form a community of practice engaged in teaching and learning engineering design. The input from the students as stakeholders during the course is regular. Initially students assess their skills as individuals and use this information to from teams and identify areas for development. They plan for their development; they plan leadership roles, and plan the project by breaking out tasks and resourcing them. Students regularly complete individual, peer and team evaluations and reflect on their progress and development. This information is pivotal in the development and learning for students and also for instructors guiding and managing the process. Later it can be useful for identifying areas for course and program improvements. The input from industrial partners who sponsor projects is also regular. The teaching team and the industry partners meet three times during the term and the industry advisors meet with students at least three times during the term and interact with them regularly. The input from the teaching team is also regular. The teaching team collaborates on an ongoing basis during the term, meets with student teams weekly or more, has a marking process that includes double marking and discussion, and reflects on possible areas for improvement at the end of term. This engaged stakeholder process is a key aspect of the continual improvement process. The process has formal and informal aspects and generates data that is qualitative in nature. As such it allows for excellent input to the faculty level post course reflection process.

Continual Improvement Sequential Case Structure

The impact of the capstone process design course redevelopment on student outcomes was examined after the transition to blended learning in 2015 (Jamieson, 2016). A quasi-experimental quantitative and retrospective examination of cohort grade outcomes and course changes was examined from historical and comparative perspectives. An ongoing course based continual improvement framework was developed based on this work. A pre-post course student self-assessment of the skills needed to complete the design project was

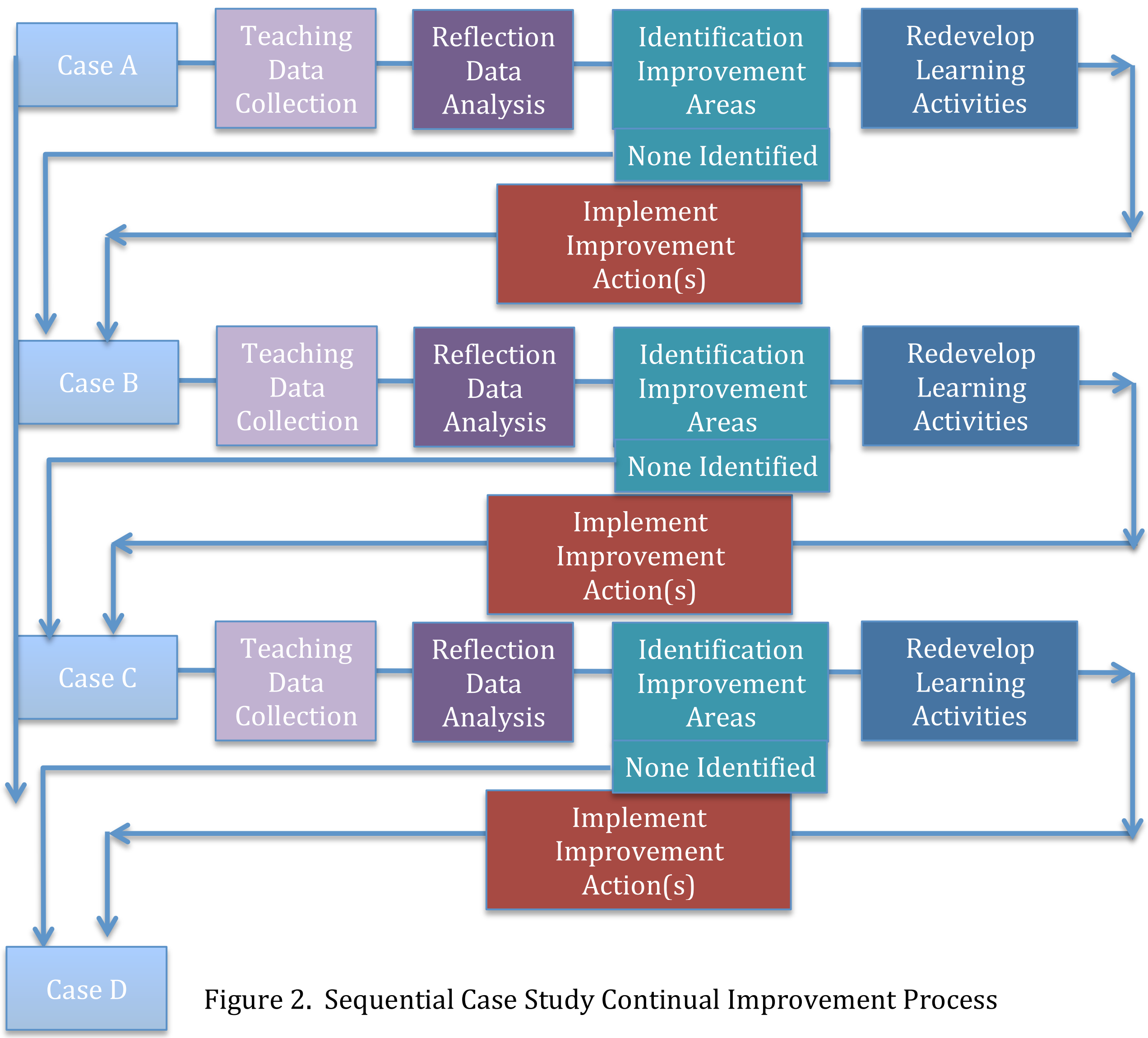

Figure 2. Sequential Case Study Continual Improvement Process

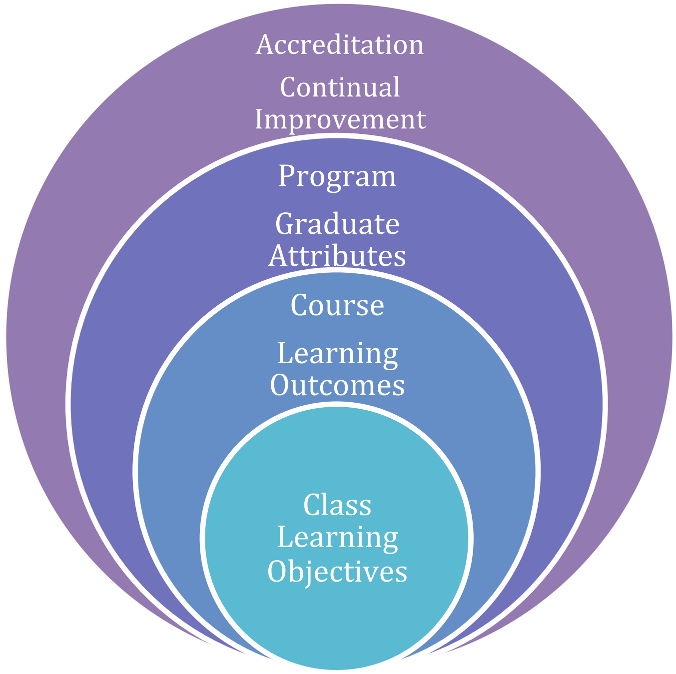

Figure 3. Outcomes Based Engineering Education Model Supporting Ongoing Quality and Relevance Improvement

included as a reflective learning activity (Jamieson, 2016). The skills evaluated were classified according to the CEAB graduate attributes and rated as no or introductory experience, developing, satisfactory, and mastered. The primary purpose of the pre course activity was team selection and development. The pre-post course comparison informed instructors of the student view of their skill development during the course. Comparative analysis identifies areas for improvement or justifications for the status quo. The analysis is consistent across time, cohorts, process design courses, and variations in the process design teaching team. Instructors evaluate the data generated during the course learning activities from a course and student team management perspective. This informs learning activity focus during an iteration of a course. Post course analysis focuses on identifying course improvement actions and possible program improvement actions based course reflection.

Case study data generation and assessment tools include student self-evaluations, peer and team evaluation and feedback tools, instructor evaluations, observations and reflections, and assessment of student results. These items provide data for both qualitative and quantitative assessment and inform ongoing aligned learning activity and assessment development consistent with the course and program objectives. A description of the data generating learning activities and assessments used for continual improvement are presented in Table 2. The continual improvement assessments are linked directly to the course learning outcomes, activities, and assessments and the data is be mapped to graduate attribute outcome assessments. As a result, the continual improvement data generation, analysis, and improvement activities have some variation between the two design courses. The common links are the activities used to develop team and leadership skills for students *and* instructors.

Table 2. Learning activities and assessments generating data for continual improvement			
Assessment Type (Case)	Description and Purpose	Frequency	Assessor / Data Type
Pre – Post Test Student Skill Self Assessment (Case A, B - Developed online tool)	Students self assess individual skills required for project teamwork as an input to team formation and developmental goal setting. The skills assessed are mapped to graduate attribute outcomes and the purpose is to identify areas where students view their GA development as weak. Instructors can examine the learning activities intended to support the GA outcome and identify improvement actions.	Twice per course	Individual Student / Quantitative
Peer and Team Evaluation (Case C - Changed tool)	ITP Metrics social comparison based peer and team evaluation. Monitors individual contribution and performance with feedback to individual students and the team. Also used to assess some team and individual graduate attribute indicators.	Three times per course	Individual Student / Quantitative
Peer Feedback (Case C - Included)	Anonymous written feedback to team members with the primary purpose of team and leadership development.	Three times per course	Individual Student/ Qualitative
Midterm and Final Exams (Case B - Online exams)	The midterm is an individual format with a follow up team exam using the same exam. Both exams assess students based on the application of their engineering knowledge and skills related to the graduate attributes.	Once each in one course.	Instructor / Quantitative
Instructor Teaching Evaluations	Course based comments can provide a source of qualitative data informing areas to target for development and improvement.	Once per course	Students / Qualitative
Draft Report Marking Discussion (Case D - Improved Marking Rubric)	Most draft reports are single marked, as the primary purpose of marking interim reports is to give students formative feedback. They are often completion grading or low stakes. The teaching team discusses observations made while marking and adjusts learning activity focus accordingly.	Twice per course	Instructors / Qualitative
Final report Marking (Improved Specifications Case A, B, C)	Reports are double marked by instructors. The first marker is the project advisor and the second marker is more distant from the team. Both markers give feedback comments to students. Marking is rubric based.	Once per course	Instructors/ Quantitative and Qualitative

Table 2. Learning activities and assessments generating data for continual improvement			
Assessment Type	Description and Purpose	Frequency	Assessor / Data Type
Report Marking Meetings (Case B, use in first course)	Marking is discussed and evaluated by the course teaching team for consistency between markers. Areas of concern are discussed and possible actions to address them. Marking comments are documented for feedback.	Twice per course	Instructors/ Qualitative
Design Project Poster Presentation (Case B, engaged external stakeholders)	Students present their design project work using a poster. Practicing engineers, faculty, staff, students, friends, and family with a diversity of perspectives are invited to the poster session. Students present their work and receive feedback from stakeholders on their project to incorporate in their final report. Poster judges provide feedback to instructors.	Once	Instructor Poster Judges Community of Practice/ Quantitative and Qualitative
Capstone Design Milestone Project Meetings (Ongoing)	Students present milestone project work to the industry advisor. Industry advisors act as clients and give feedback directly to the students on their project and progress. Students incorporate feedback in their work. Industry advisors provide their assessment of student preparedness to instructors.	Three meetings	Industry Advisor Community of Practice/ Quantitative and Qualitative
Capstone Project Meetings (prior to Case A)	Students meet with instructors weekly to monitor progress, ask, and answer questions. Students track project tasks, hours and resourcing then compare them to their project plan. Updates are handed in weekly.	Weekly	Instructor Students/ Quantitative and Qualitative
Post Course Instructor Meeting (Case B, added)	The process design teaching team is comprised of faculty and industry based instructors. Different teams may teach in a particular course during the year. This meeting collects feedback from all teaching team members.	Once per year	Instructors Community of Practice/ Qualitative

Continual Improvement Process Example: Leadership

Leadership is contextually situated in teamwork. The CEAB graduate attribute is stated as: "*An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting*". Effective teamwork and leadership were targeted for improvement actions as instructors noted team conflict reduces the time available for design tasks. Teams with process or relationship conflict states are less effective than teams experiencing only task conflict (O'Neil, 2018). An improvement action was identified and a learning activity was developed to teach conflict identification and management early (Jamieson, 2018). Formative activities are intended to develop and strengthen leadership in the context of student teamwork and intended to give students experiential opportunities to develop declarative, procedural, and conditional knowledge *practice* within a life long learning framework (Figure 4). Learning activities in the capstone design course build on learning activities in the introductory design course. These activities are intended to connect conceptual and procedural knowledge to leadership practice, develop skills, and *transferable* conditional knowledge.

Table 3 summarizes the leadership learning activities supported by teamwork in the process design courses, and the corresponding activity assessment in the continual improvement context. The activities follow an experiential path to transformational leadership development. Students learn how to set goals and/or demonstrate their ability to do so at the beginning of both courses. In the capstone course they are expected to monitor progress and manage deviations. Learning activities are team and project based. The working model for learning activities is individual preparation followed by team integration of individual contributions. Peer mentoring and teaching are encouraged within teams and between teams. The learning activities are set up to encourage discussion and recognize development with low stakes. Some assignments are set up as draft - instructor feedback - final copy - more feedback and linked to next assignment. This format allows the instructors to monitor progression, allows insight into individual and team development, and informs coaching. Written assignments produce continual improvement qualitative data assessment points allowing instructors to assess conceptual and procedural progress with respect to graduate attribute leadership outcomes. Leadership learning activity design is scaffolded, progressive (Jamieson, 2015), and intended to support student overall GA achievement.

Table 3. Learning activities developing team and leadership skills

Activity Type	Description (and Assessment)	Frequency	Assessor(s)
Pre – Post Test Student Self Assessment	Students self assess individual skills required for project teamwork. The skills assessed are mapped to graduate attribute outcomes. (Pre-post course comparison)	Twice per course	Individual Student Instructors
Self knowledge	Conflict Management Style Inventory ITP Metrics Instrument (not graded)	Once – first course	Individual Student
Self knowledge	Personality Inventory ITP Metrics Instrument (not graded)	Once – first course	Individual Student
Learning Module	Team Conflict Module – a workbook style individual learning activity to help students classify and manage conflict. (not graded)	Once – first course	Individual Student
Team SWOT Analysis	Team members share an individual strength and weakness of their choice with their team. The team develops a composite on this basis. This is translated to team opportunities and threats. (Formative)	Once – first course	Individual Team Instructor
Innovation Bonus Writing Assignment	Student teams review an aspect of leadership or innovation literature and formulate a hypothesis of how an idea could be applied to their teamwork and develop a framework to test their hypothesis during the term. (Rubric grading qualitative indicator)	Once - optional	Instructor

Table 3. Learning activities developing team and leadership skills.			
Activity Type	Description (and Assessment)	Frequency	Assessor(s)
Individual Goal Setting	Students evaluate their own performance in a design lab and set a SMART goal to improve their performance. (Completion grading and qualitative information)	Once – first course	Instructor
Team Development Plan	Based on the team skill composite, individual students identify and commit to two developmental goals that will improve their team skill matrix. (The development plan is graded for quality and completeness. Students assess goal achievement.)	Once per course	Teaching Assistants Instructors
Team Introduction	Team's introduce themselves and their individual goals for the course (completion)	Once per course	Instructors
Peer and Team Evaluations and Peer Feedback	Individuals assess their own and their peer's performances after milestone deliverables are completed. (Completion grading - allows for qualitative and quantitative assessment of leadership, teamwork, and accountability)	Three times per course	Individuals Teams Instructors
Leadership Assessment	Students have access to an optional ITP Metrics leadership assessment activity at the end of the capstone design course. (Activity is private. Completion rate is known.)	Once – optional capstone	Individual
Team Conflict Case Analysis	Teams analyze and discuss conflict cases to identify workplace and leadership characteristics. (Qualitative data - gives insight on student conceptual understanding)	Once – capstone	Teams Teaching Assistants
Team Charter	Teams develop a charter and identify leadership roles for each member, team values, norms, and expectations. (Qualitative data – developmental insight)	Once – capstone	Instructors
Team Reflection	After preparing individually, teams reflect on their collective performance using a rubric to identify improvement actions	Three times – capstone	Teams, TA Instructors
Regular Team Meetings	Teams meet regularly with their advisor. The meetings are used to monitor team development and health between milestone assessments. (formative – insight)	Weekly- both courses	Individuals Teams Instructors

The instructors share the course continual improvement model and the lifelong learning framework of a community of practice learning together with students. The instructors encourage students to be accountable, to have high expectations, and to commit to academic and personal goals in an experiential community environment characteristic of a quality education and life long learning development (Henton, 1996).

Continual Improvement Process Example: Innovation

Like leadership, innovation is difficult to measure on an exam. The continual improvement process is applied to learning activities intended to develop declarative, procedural and conditional knowledge with respect to innovation. The graduate attribute outcomes inform the vision and for the goal setting for learning activities.

Innovation is not an explicit CEAB graduate attribute. It is implicit. *"An **ability to design** solutions for complex, open-ended engineering problems and to design systems, components or processes…"* and *"An **ability to create**, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools…"* and *"…**synthesis of information** in order to reach valid conclusions"* describe innovation in the context of the CEAB graduate attributes. In the context of process design, iteration is integral to the design process and innovation is the result of iteration and collaboration. Steve Jobs, Bill Gates, Thomas Edison, and Elon Musk are thought of as innovators; all learned about failure and iterated with teams *over time* until innovation resulted. None were sole inventors. All worked in the context of teams. All were leaders (Catmull, 2014; Grant, 2016; Isaacson, 2014; Johnson, 2011; Johnson, 2014; Wilkinson, 2015).

Recognizing the end result of an innovation process is simpler than assessing the habit of innovative and creative thinking alternating with critical and evaluative thinking during the design process. A final design that is innovative will likely have a development path of twists and turns to produce a solution meeting the requirements within the constraints. Learning to be innovative requires conceptual knowledge (what, about) and procedural knowledge (how, when) as a foundation. The design process is inherently iterative and innovative. Conditional knowledge (why and when) and the ability to practice innovation both require understanding of metacognition. Learning activities are prepared explicitly to teach students about the design process, innovation, thinking, and learning strategies. Figure 4 illustrates the metacognitive cycles that underlie the iterative design process in the process design courses (Jamieson, 2018). Learning Moments, borrowed from the concept of a safety moment, are meant to support a learning culture. Innovation and learning are connected. Innovation learning activities remain diffuse in the design courses and depend on instructor and team interactions. Their development remains ongoing as part of the continual improvement process.

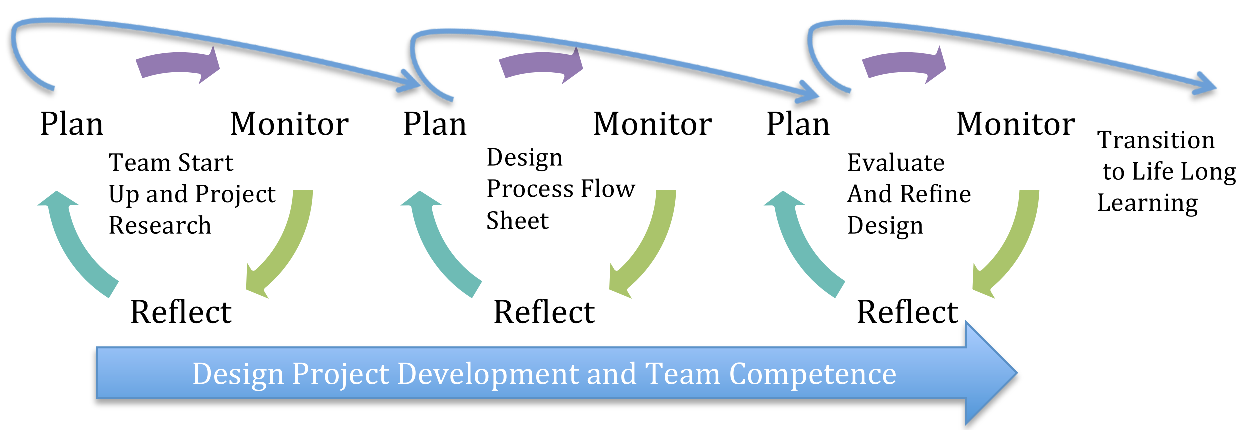

Figure 4. Design Course Metacognitive Cycles Progressing Team and Project Development

Conclusion

The successive mixed method case study format is used to answer the continual improvement question "*What needs to be improved (if anything) and what are the improvement actions?*" after each iteration of the introductory and capstone process design courses. The answers to these questions have led the instructors through key changes to the course structure, development of a strong team and leadership program integral to the design courses, the implementation of new continual improvement accreditation criteria at the course level, and have identified improvement actions for graduate attribute outcomes including team and leadership development. Close collaboration with industry (industrial advisors, design projects with relevance, real value propositions, and current design challenges) adds credibility to the concept of a community of practice, and the transitional nature of the process design courses. It also sets the stage for innovation (teaching and learning) as an integral part of process design. The continual improvement process presented in this contribution engages instructors, students, and industry partners in a community of practice intended to improve graduate attribute outcomes based on foundational elements supporting innovation and life long learning. Implicit and explicit CEAB graduate attributes are inherently challenging to measure. The continual improvement process has been an effective driver for targeting evidence based learning activity changes and justifying maintaining the status quo in areas where no improvement actions are identified.

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Appendix A:

Canadian Engineering Accreditation Board Continual Improvement Process Evaluation Rubric

3.2	Continual Improvement:	Accreditation Criteria and Procedures Description	Rating	Assessment Category Descriptors
	Improvement process	There must be processes in place that demonstrate that program outcomes are being assessed in the context of graduate attributes, and that the results are validated, analysed and applied to further development of the program.	A	Process (committees, annual cycle, authority, reporting) is in place AND process is adequately documented
			M	Process for continual improvement has some inadequate components AND/OR process documentation is limited
			U	Process for continual improvement is not in place AND/OR process is not adequately documented
	Stakeholder engagement	There must be demonstrated engagement of stakeholders both internal and external to the program in the continual improvement process.	A	Stakeholders broadly selected (e.g. internal: students, program faculty, engineering faculty; external: non-engineering faculty, alumni, engineering professionals, other professionals, employers, learned societies, etc.)
			M	Stakeholders narrowly selected (some internal and some representation) AND/OR stakeholder roles in the improvement process is inadequately demonstrated.
			U	Stakeholders insufficiently selected (e.g. only program faculty) AND/OR stakeholders are not specified
	Improvement actions	There must be a demonstration that the continual improvement process has led to consideration of specific actions corresponding to identifiable improvements in the program and/or its assessment process. **Note, if the evidence suggests no change is warranted, then no change is necessary.** ***This criterion does not apply to new programs.***	A	One or more program-level/process change action(s) implemented (**if change is necessary**) AND timelines and accountability for changes documented
			M	Program-level/process change action(s) implementation in progress AND/OR timelines and accountability for changes not yet assigned AND/OR rationale for decisions not to act yet to be developed.
			U	No program-level/process change actions implemented (**even though evidence suggested change is necessary**) AND/OR no timelines and accountability for changes assigned AND/OR no rationale for decisions developed.

Canadian Engineering Accreditation Board Graduate Attributes

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 teamwork: *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 analyze 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.*