Designing and Developing the Whole Engineer

by

Marnie V. Jamieson

A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Chemical Engineering

Department of Chemical and Materials Engineering

University of Alberta

Abstract

Our world is changing from social, technical, cultural, inclusivity, environmental, risk tolerance equity, and global economic perspectives. We are transitioning to different ways of knowing and working. The societal expectations of engineers and professional engineering are changing. These changes are already impacting professional engineering practice and teaching because it is engineers who interrogate complex contextual problems, frame them, and then develop, design and build solutions for local and global societies. What was acceptable ten years ago is no longer acceptable today. Projects previously approved and in progress have been cancelled or abandoned.

This thesis reflects the underlying tension between historical engineering education and engineering work paradigms and the rapidly evolving requirements for engineering education and engineering practice. Its goal is to contribute to ***the development of the whole engineer*** in a rapidly changing education, evaluation, and practice landscape, and to help engineering students transition to become engineers in training, prepared for the future. A multipronged design-based research approach, including qualitative and quantitative investigations, was adopted to improve teaching and learning effectiveness, content, scope, resiliency, and to substantiate the efficacy of the curriculum continuous improvement process (CIP) and teaching methods/approaches used and introduced as part of this work. In this work, it is accepted active learning, problem and project based learning, and communities of practice are effective at promoting deep and contextual learning as documented by others. It is accepted, based on prior work that blended learning provides a flexible course delivery mechanism and is neutral with respect to student performance.

A three-stage research plan was adopted to examine and enhance how a community of practice contributes to student development, the achievement of the Canadian Engineering Accreditation Board (CEAB) graduate attributes, and the development of an innovation ecosystem. By providing targeted direction to industrial participants in a process design course community of practice, it was possible to shift the focus of the community and its motivation for participation from benchmarking competence to innovation competence that supported student innovation and leadership capacity development. Research questions related to student engagement, satisfaction, innovation, metacognition, and leadership were raised and investigated. Outcomes from first-stage exploratory studies indicated incremental improvements and informed the construction of second-phase work examining where larger improvements might be made. The second phase concerned the development and application of a graduate attribute based theoretical framework used to identify key program focus areas, and the strategic application of learning theory to course and program design. The evolving identity of an engineer and engineering work were viewed through the lens of the CEAB graduate attribute assessment process and a

synthesis of engineering practice in the context of ontological, epistemological, and axiological perspectives. The third-stage examined the application and management of the continual improvement process strategy where areas for targeted improvement are identified, intervention strategies are planned, and the success of the strategies are monitored with respect to improved learning outcomes in a recursive metacognitive cycle.

A key outcome of the application of the developed theoretical framework is the inclusion of socio-technical knowledge, metacognitive and professional skill development alongside the development of core technical knowledge. Segregated non-contextual core technical knowledge is not readily applied by students or practitioners and the development of the graduate attributes relative to metacognition and professional practice are not easily achieved without the elements of design and engineering practice permeating core courses. The implementation of designed and aligned active engineering courses and programs, which leverage the learning paradigm (behaviorist, constructivist or situative) most useful for the achievement of particular learning outcomes is offered for consideration in building a new program or revising an existing program. This represents a shift in engineering education philosophy.

The implementation of a course and program continual improvement program is directly linked to the accreditation process, the graduate attribute outcomes, and the improvement of individual courses in the context of a holistic engineering program within a university. There are professional program accreditation outcomes that must be satisfied and university wide graduate attribute outcomes should support those required for the professional program but cannot usurp them. The process should be flexible and responsive enough to allow instructors to readily adapt the context of the core content to the current and future global milieu in which new engineering graduates will begin their engineering practice. It should facilitate the development of critical engineering practice skills such as engineering innovation, teamwork, leadership, and management. Engineering education should equip students for contributing to a sustainable future and not the past.

Preface

This thesis is an original work by Marnie V. Jamieson. Several of the chapters of this thesis are published conference proceedings or journal articles. The bibliographic and contribution details are presented below. The CTL blended learning research project, of which some work within this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, No. *Pro00048272*.

For all conference proceedings and journal articles co-authored by Marnie Jamieson and Dr. John Shaw: the identification and design of the research program, the collection of data, the analysis of the data, and the writing of the manuscript was completed by Marnie Jamieson. Dr. Shaw, as my supervisor, provided discussion, process guidance, and editorial assistance as the articles were published. This work is found in Chapters 3 and 4 and Appendices C and D as listed below.

For Chapter 5, this work was completed with Dr. John Donald as equal contributors. For Chapter 6, this work began as a term paper. Marnie Jamieson was the lead author and major contributor to the work. Dr. Lefsrud was a key writing and editing collaborator on this project as it progressed. Dr. Sattari contributed to the literature review, discussion, and editing. Dr. Donald provided review, discussion, and editing. For Chapter 7, Dr. Samira ElAtia led this work as part of the KIAS-Kule research grant titled ″Employability Attributes: Mapping the University′s Graduate Attributes to Faculty-Specific Professional Competencies and Standards″. Dr. Jason Carey, Marnie Jamieson, and Marcus Ivey were collaborators on this project. This trio mapped the Engineering graduate attributes to the University graduate attributes and Dr. Samira ElAtia, and Bashair Alibrahim completed the reverse mapping. The paper was co-written and edited with Dr. Samira ElAtia, Dr. Jason Carey, and Bashair Alibrahim with each making contributions to the research, literature review, method, mapping, writing, and editing under Dr. ElAtia′s leadership.

CH	Type	Title	Authors
3	Full Peer Review Journal	“**Teaching Engineering for a Changing Landscape**” *The Canadian Journal of Chemical Engineering*, 2019	Jamieson, M.V., Shaw, J.M.
4	Full Peer Review Journal	**“Teaching Engineering Innovation, Design, and Leadership Through a Community of Practice”** *Education for Chemical Engineers, 2020*	Jamieson, M.V., Shaw, J.M.
5	Full Peer Review Conference	**“Building the Engineering Mindset: Developing Leadership and Management Competencies in the Engineering Curriculum”** Canadian Engineering Education Association, Montreal, QB; June 17-22, 2020	Jamieson, M.V., Donald, J.R.
6	Full Peer Review Journal	**“Sustainable leadership and management of complex engineering systems: A team based structured case study approach.”** *Education for Chemical Engineers*, 2020, *35, pp.* 37–46.	Jamieson, M.V., Lefsrud, L.M., Sattari, F., Donald, J.R.

CH	Type	Title	Authors
7	Full Peer Review Journal	**“Intersecting Roadmaps: Resolving Tension Between Profession-Specific and University-Wide Graduate Attributes,”** *Canadian Journal of Higher Education - Revue canadienne d’enseignement supérieur*, (51) 1, pp. 71-98, 2021.	El Atia, S., Carey, J.P., Jamieson, M.V., Alibrahim, B., Ivey, M.
C	Full Peer Review Conference	“**A Continual Improvement Process for Teaching Leadership and Innovation Within a Community of Practice**”, Proc. 2019 American Society for Engineering Education; Tampa, Florida; June 16 – 19, 2019	Jamieson, M.V., Shaw, J.M.
D	Full Peer Review Conference	“**Learning to Learn: Defining an Engineering Learning Culture**”, Canadian Engineering Education Association (CEEA 2019) Conf., Paper 18, Ottawa, ON; June 9-12, 2019	Jamieson, M.V., Shaw, J.M.

Dedication

To

My grandparents and ancestors before them who worked with the land to survive;

my parents, Frank and Irene Vegessi;

my partner, Mark Jamieson;

my children, Melanie, Nathan, Matthew, Brandon, Mary and Megan;

my communities of practice in engineering, education, research, teaching,

engineering design, leadership, and management;

and

my teachers and my students throughout my life

- as all have taught me.

This work is dedicated to the achievement of technical, contextual, metacognitive, and professional knowledge in the context of lifelong learning while becoming and being an engineer.

Being an engineer has defined many aspects of who I am and
who I am has been intertwined with science, engineering, and care for the land
for as long as I can remember – even before I was officially an engineering student.

-M. V. Jamieson, May 2020.

"...Identity matters.
Engineering education provides a crucible
for becoming engineers..."
Tonso, 2014, p. 277

″Learning takes place in the minds of students and nowhere else, and the effectiveness of teachers lies in what they can induce students to do. The beginning of the design of any educational procedure is dreaming up experiences for students: things that we want students to do because these are the activities that will help them to learn this kind of information and skill.″

-Herbert Simon, 1998

″The people demand that knowledge shall not be the concern of scholars alone.

The uplifting of the whole people shall be its final goal.″

-Henry Marshall Tory, 1908

Acknowledgements

I would like to thank a number of people, who have helped me throughout the thesis:

My mother, who has listened and been supportive, as I have pursued my graduate education; and my children, who supported my need to further pursue both my education and career – even though it was a challenging time for us collectively on many fronts. I am proud of the adults they have grown up to be.

Dr. John M. Shaw, my colleague, my friend, and my thesis supervisor has continually provided support, guidance and encouragement from the inception of the blended learning project and has been my key partner in developing the capstone design course since 2010 and the formation of this thesis. Second, my teaching colleagues: Len Church, Frank Vagi, Wade Chute, Dr. Arno DeKlerk, Douglas Colborne, and Bill Pick, who were major and valued contributors to course development and very generous with their time for both the design courses and me. They have consistently been there to share the journey, the work, and the delight in seeing students transform. Third, our engineering design students, their willingness to try out our ideas, give us constructive and useful feedback, dig into their design projects and be directors of their own development. They continue to impress and encourage me. Thank you.

Dr. John Nychka, (Materials Engineering) and Dr. Norma Nocente, (Faculty of Education) were instrumental in guiding my development, my ongoing education in theory and application, and challenging my thinking along the way with difficult and thought-provoking questions.

Dr. Hani Heinen (Materials Engineering) who was always willing to chat about design, teaching design, and students learning design. His input and supportive discourse were most helpful.

Dr. Lianne Lefsrud (Chemical Engineering), Dr. Suzanne Kresta (Chemical Engineering, University of Saskatchewan), and Dr. Michél Perrier (Chemical Engineering, Polytechnique Montréal) all provided ongoing support and encouragement for learning, developing, and testing ideas for applying educational tools and concepts to engineering education along with their unique perspectives. I thank each of them for their ongoing friendship and mentorship.

Dr. Susan McCahan, Dr. Sylvie Doré, Dr. Jillian Seniuk Cicek, Lisa Romkey, and Robyn-Mae Paul (my CEEA-ACEG IEER collaborators and colleagues); and Dr. Cindy Rottmann and Dr. John Donald (my Engineering Leadership collaborators and colleagues), your support and friendship have meant everything to me. Thank you for being there for me and for many illuminating discussions.

Drs. Otto, Ryan, Wood, Lynch, and Mather for generally believing in me as an undergraduate student, their contributions to the U of A design course historical development and their support of active and problem based learning in Chemical Engineering from the very beginning.

Dr. Fraser Forbes, for ongoing support and encouragement to pursue my goals as I travelled the journey from sessional instructor to industrial professor to become the William and Elizabeth Magee Chair in Chemical Engineering Design and a teaching professor.

Dr. Jason Carey and Dr. Ania Ulrich, for ongoing support and encouragement.

I would also like to thank my many colleagues design professors, fundamental professors, education professors, engineering education researchers, collaborators, my graduate teaching assistants, and my co-op students. I have learned something from all of you that has helped shape my thinking, my teaching, and my research.

I also acknowledge the University of Alberta Provost's Office for funding the Blending Learning Award for the Capstone Design Course, the Department of Chemical Engineering for their continued and innovative support of engineering and design education, and the Faculty of Engineering for their overall support as we continue to meet and exceed the demands for educating engineers for the future.

University of Alberta Land Acknowledgment

The University of Alberta respectfully acknowledges that we are located on Treaty 6 territory, a traditional gathering place for diverse Indigenous peoples including the Cree, Blackfoot, Metis, Nakota Sioux, Iroquois, Dene, Ojibway/ Saulteaux/Anishinaabe, Inuit, and many others whose histories, languages, and cultures continue to influence our vibrant community.

L'Université de l'Alberta reconnaît respectueusement qu'elle est située sur les terres du Traité 6, lieu de rassemblement traditionnel pour de nombreux peuples autochtones dont les Cris, les PiedsNoirs, les Métis, les Sioux des Nakotas, les Iroquois, les Dénés, les Ojibwés/Saulteaux/Anichinabés, les Inuits et bien d'autres encore, dont les histoires, les langues et les cultures continuent d'influencer notre communauté si vivante.

I invite you to consider the ways in which you acknowledge the land where you currently sit – and invite you to remember that wherever you are sitting, whether it be somewhere in this place now called Canada, or somewhere across Turtle Island, or somewhere in other lands; that diverse Indigenous peoples inhabited and gathered in these places. (Provided by Dr. Florence Glanfield to acknowledge the land when gathering for online teaching and learning, 2020)

I invite you to remember we are all connected. Treaty 6 Territory is the homeland of the Papaschase and the Metis people. It was first signed on August 23, 1876 with additional signatures added until 1950. This territory is also the adopted home of the Galician, Bukovinian, and Ruthenian Slavic peasants who arrived from Ukraine and other Eastern European countries with very little other than the hope of a better life between 1896 and 1914. They came to make their home and their living with the land after an advertised invitation to immigrate from the Canadian Government. It was through their sacrifices and hard work that I was in a position to go to school as a child and continue on to higher education. I invite you to consider the outcomes for individuals and for people are not the sole result of meritorious work.

I am grateful for the opportunities I have had to bring me to this place and the people who have helped me to learn, grow, and become more open to the different ways of knowing and considering the world.

Table of Contents

List of Figures

List of Figures (continued)

List of Tables

Nomenclature, Glossary, and Publications

A list of abbreviations used in this work is provided below and a Glossary is provided in Appendix A. The Glossary includes my definition of terms based on the literature reviewed (A1.1) and frameworks used in this work, such as the CEAB Graduate Attributes (A1.2) and the UN Sustainable Development Goals (A1.9). A list of publications underlying this dissertation can be found in Appendix B.

Abbreviation	Description
ABET	Accreditation Board for Engineering and Technology, Inc. (United States)
AIChE PSM	American Institute of Chemical Engineers Process Safety Management
ADDIE	An Instructional Design Framework based on Analysis, Design, Development, Implementation, and Evaluation phases
ASEE	American Society for Engineering Education
CEEA-ACEG	Canadian Engineering Education Association – Association Canadienne de L'Éducation en Génie
CEAB	Canadian Engineering Accreditation Board
CEAB-GA	Canadian Engineering Accreditation Board Graduate Attributes
CIP	Continual Improvement Process
COP	Community of Practice
DBER	Discipline Based Education Research
DBR	Design Based Research (Education based methodology)
DEI	Diversity, Equity, and Inclusion
DRM	Design Research Methodology
DSR	Design Science Research
eClass	The Moodle eClass Learning Management System
EDI	Equity, Diversity, and Inclusion
EER	Engineering Education Research
EI	Emotional Intelligence
EL	Engineering Leadership

EM	Engineering Management
Engineer of 2020	"The Engineer of 2020: Visions of Engineering in the New Century," National Academy of Engineering (NAE) report 2004
EPC	Engineering Procurement and Construction
EPCM	Engineering Procurement Construction and Management
GA	Graduate Attributes
GAA	Graduate Attribute Assessment
GACIP	Graduate Attribute Continual Improvement Process
GPA	Grade Point Average: either based on or converted to the 4.0 scale
FoE	Faculty of Engineering
IEA	International Engineering Alliance
IRGC	International Risk Governance Council
ISD	Instructional System Design
IEER	Institute of Engineering Education Research
IRR	Internal Rate of Return
KSA	Knowledge Skills Attitudes
LMS	Learning Management System
NAE	(American) National Academy of Engineers
NRC	National Research Council (United States)
NSERC	Natural Science and Engineering Research Council (Canada)
PBL	Problem Based Learning
(D)PBL	(Design) Project Based Learning
PDF	Portable Document Format
PFD	Process Flow Diagram
P&ID	Piping and Instrument Diagram

Promax	Process Simulator, also known as BRE Promax
RBPSM	Risk Based Process Safety Management
SAM	Successive Approximation Method an ISD method based on a modification of ADDIE. Iterations of design are used prior to implementation
SDG	Sustainable Development Goals (also UN SDG)
SELM	Sustainable Engineering Leadership and Management
SLO	Social License to Operate
Symmetry	A process simulator, also known as VMG Sim
UGA	University Graduate Attributes
UN SDG	United Nations Sustainable Development Goals
U of A	University of Alberta

1. Introduction

Engineering work and engineering education are changing in response to global economic, environmental, social, and cultural transformations. Sustainability as a driver for change, the motivation for learning, and the impact of learning culture are addressed in this work. Resiliency and the future of engineering education are explored in the context of societal and cultural change and the embodiment of equity, diversity, and inclusion (EDI). The evolving societal and sustainability context for engineering and engineering work are examined with the current external and internal pressures on engineering programs to change rapidly. Each of these apparently diverse topics impact the development of the whole engineer and underpin the objectives and outline of this dissertation – appearing at the end of this chapter. An examination of the drivers of change, includes the Canadian Engineering Accreditation Board (CEAB) Graduate Attributes (Appendix A), the Washington Accord (IEA), the UN Sustainable Development Goals (Appendix A), and Risk Based Process Safety Management (Appendix A), and how we respond as engineers, as engineering educators, and as institutions to determine our collective future set the stage for this dissertation. Most of the chapters of this dissertation comprise self-contained publications (Appendix B is a listing of all work). The articles chosen for inclusion are summative expressions of completed work. Key developmental work is included in the appendices. The role of this chapter is to provide a common point of departure for the published articles included and to orient readers with a broader literature review and context. This chapter starts with an examination of definitions of engineering and engineering work to identify core elements of engineering and the implications for teaching engineering, and for learning to be an engineer. The background and history of engineering education is explored. Fundamental scientific and engineering knowledge development is then probed in the context of engineering design and practice – a central theme in this work. Engineering education and assessment are then interrogated in the context of developing engineering practice and a continual improvement process (Appendix C).

1.1 The Challenging Context of Engineering Education

Engineering education has been under scrutiny and revision since the mid 20th century (National Research Council, 1995). Questions regarding how engineers are educated, whether engineers are adequately prepared to work in industry and what it means to be an engineer have been perennial concerns peaking in the 1990s in the midst of the rapid spread of the Internet, environmental concerns, process safety management, automated drawing and process design tools, electronic communication, artificial intelligence, advanced process control, robotic mechanization, economic globalization, and the subsequent desire for enhanced professional engineering mobility. Engineering work was changing rapidly. The engineering graduate attributes were an outcome of global discussions on engineering, engineering work, the portability of engineering credentials, and who is qualified to do engineering work. These graduate attributes defined by the International Engineering Alliance (IEA) were the first attempt to define what was required to educate the whole engineer from socio-technical, cognitive, and professional perspectives.

The implementation of the graduate attributes (GA) as part of the Canadian accreditation process was slow. It took nearly 20 years for the GA to be introduced into the accreditation process in 2009 and another ten years to complete the first round of accreditation visits where graduate attribute assessment and continual improvement must be demonstrated. The implementation of a course level graduate attribute based continual improvement practice (GACIP) (CEAB, 2017 3.2.1) and what it should achieve are still key questions for design instructors who teach an experiential and pragmatic course with a multiplicity of possible outcomes for students and instructors depending on the course structure, design, assessments, and accompanying *implicit* theoretical and conceptual frameworks. Engineering program and curriculum development leading into design courses and graduate attribute assessment are ongoing discussions at engineering schools across Canada, and in fact globally. How sustainability will be addressed in existing engineering programs and engineering practice is a key consideration. The challenges of attracting and retaining personnel with diverse genders and ethnicities reflective of the composition of our society are ongoing. Empowering students to reflect on their learning, their ability to work as part of a diverse team, and their leadership development can be challenging in the context of course delivery and administration. Sharing course and program development expertise with university faculty in countries where programs are not yet accredited or developed to the point where accreditation is possible is a critical activity in the dissemination of knowledge and support of the UN SDGs globally. Engineering work is legally defined and regulated provincially in Canada. Most countries regulate engineering work, engineering education, and the admission to the profession. Engineering practice is complex and embraces more than just technical ability; engineering competence is based on qualifications *and* experience (APEGA, 2013). Engineering design, leadership, and management are core elements of engineering practice.

1.2 Engineering Practice and Definition

In order to understand how to ***teach*** engineering one must first understand ***what*** engineering is, ***how*** and ***why*** it is practiced as a profession. These declarative, procedural, and contextual knowledge elements of engineering are all required for professional practice. Engineering is creative and synthetic. Problems are analyzed often using a scientific lens, however the solutions are developed to meet requirements and fall within the prescribed constraints *as known at the time* of design development. Many definitions exist for what engineering is and how and why it is practiced as a profession. Some examples are presented and then analyzed below. For these definitions, the bold and italic emphases indicate the qualitative analysis coding for technical knowledge (**bold tags**), contextual cognitive task applications (*italic tags*) engineering supervision activity tags (***bold italic tags***). The underlined emphasis in the definitions illustrates the collective societal purpose and the constraints of engineering work.

> “Engineering is *creating, designing* **what can be**, but it is **constrained by nature**, by cost, by concerns of safety, reliability, environmental impact, manufacturability, maintainability, and many other such "ilities"” Wulf (1998, 2002)

> “The "practice of professional engineering" means any act of *planning, designing, composing, evaluating, advising, reporting,* ***directing or supervising*** that requires the *application* of **engineering principles** and that concerns the safeguarding of life, health, property, economic interests, the public welfare or the environment*, or* ***the managing of any such act***. In Canada, a licence is required to practise professional engineering. Engineering is constantly evolving and new areas of practice are always emerging.” (Engineers Canada, 2012)

> “Engineering *sets the stage* for anything. We train people to *embrace curiosity*. Teamwork works when there is trust. ...Professors, students and alumni have *played instrumental roles* in some of the most important **engineering discoveries** of our time. **Discovery**. It’s in our blood. It’s in our nature. It’s in our spirit. Engineering propels the world forward. Collectively we create history.” (Engineering at Alberta, Student View book Excerpt, 2020)

Legally, the Province of Alberta defines the practice of engineering as:

> (i) *reporting on, advising on, evaluating, designing, preparing* plans and specifications for or ***directing*** the construction, technical inspection, maintenance or operation of any structure, work or process
>
> > (A) that is aimed at the ***discovery, development*** or ***utilization*** **of matter, materials or energy** or in any other way **designed** for the use and convenience of humans, and
> >
> > (B) that requires in that *reporting, advising, evaluating, designing, preparation or* ***direction*** the ***professional application*** of the principles of **mathematics, chemistry, physics** or **any related applied subject**, or
>
> (ii) ***teaching*** **engineering** at a university

Engineering and Geoscience Professions Act, 2000, Section 1, pg. 8

Examination of the legal definition illuminates the firm connection of science, mathematics, and **technical knowledge** as the fundamental basis for the engineering design of systems and products with *the contextual cognitive tasks and* ***engineering supervision activities;*** inclusive of teaching, leadership, and management of engineering work, processes, and products that are to be used by society.

Engineering has deeply rooted social and societal connections having originated with military and civil societal objectives of increasing the wealth and security of a social group. As engineering disciplines and the structure of engineering work have evolved with scientific discoveries, technical advancements, and globalization there is an increased expectation of collaboration, telecommuting, virtual teams, increased cross-disciplinary interaction, diverse collaboration, project complexity and the requirements for contextual knowledge and professional skills have increased for engineers (Joyner, 2012).

> "Engineers no longer manage their daily tasks with plain substance expertise; instead they must be adept at communication, collaboration, networking, feedback provision and reception, teamwork, lifelong learning, and cultural understanding" (Lappalainen, 2009). (p. 123).

The above definitions of engineering and the CEAB graduate attributes (Appendix A) reflect the key role the technical knowledge base plays in the practice of engineering and in the education of an engineer. The definitions also indicate much more is required to be an engineer and to practice engineering There are implicit and explicit references to the changeable nature of engineering work and thus the requirements for designing and developing new engineers. Engineering education has traditionally included fundamental engineering and natural science knowledge as a key element. In addition, both the definitions of engineering and the graduate attributes reflect the socio-cultural contextual nature of engineering now and in the future as the structure of engineering work continues to evolve: "the *socio-cultural* dimensions that are becoming increasingly important as globalization intensifies the demands for flexible, socially adept and communicative engineering communities" (Lappalainen, 2009). The socio-cultural aspect of engineering education is often found in design course experiences, work placements, co-op experience, internships, study exchanges, engineering clubs, project and competition teams, complimentary studies and as an engineer in training where this aspect is an integral part of engineering work. Activities intended to increase socio-contextual elements in all years of a program are evident in the use of design spine program models where design courses are included in each year of an engineering program and traditional co-curricular activities are offered as integral program courses and elements or required aspects of the program. Examples of integrated approaches in Chemical Engineering curriculum redesigns have been implemented at Polytechnique Montréal (Perrier, 2005) and the University of Sydney (Gomes et al., 2006) where a problem based learning (PBL) approach has been implemented in core courses in addition to the project based design courses.

> "Success in the new work context requires engineers to have *both* strong disciplinary and inter-disciplinary knowledge along with tools, models and frameworks for analysis and synthesis *and* well-honed and continuously-improving EI (emotional intelligence) competencies." (Joyner et.al, 2012)

The above definitions of engineering also make it very clear the practice of applying thermodynamics and/or related fundamental subject areas contextually comprise the higher-level cognitive and affective domain tasks (*italic tags*) (Bloom, 1956) to create and communicate designs, complete evaluations, and advise. This elucidates the metacognitive requirement of engineering education – the ability to reflectively synthesize and evaluate technical knowledge along with socio-contextual information *with intent* to create or modify a functional design and then to communicate it to team members, stakeholders, and the public.

The fourth and last theme of engineering work is professional skill development. Technically elegant designs that are not communicated in a manner that secures social support for the implementation of the design are not built. In addition, designs must be developed and evaluated in the context of environmental and safety requirements and regulations. There is an increasing expectation for the development of professional skills in engineering education and the need for new pedagogical approaches to accomplish this development (Butun et al., 2009; Verzat et al., 2009; Crumpton-Young et al., 2010). The need for engineers to be able to communicate their ideas and work to diverse cross-functional teams and stakeholders has become a norm in engineering practice. Engineering leadership (EL) and engineering management programs, minors, certificates, and courses began to emerge in the late 1980s and have been gaining prominence since 2000 (Donald and Jamieson, 2022). The U of A was among the first to engage by offering an EL course in engineering safety and risk management in the Department of Chemical and Materials Engineering in 1988. Engineering entrepreneurship and entrepreneurial thinking are rapidly becoming a part of how instructors and students engage with engineering in both curricular and co-curricular activities. Interdisciplinary activities engaging business and engineering students have begun to emerge over the past two decades. Writing skill is a necessity. Ethics, equity, and professionalism are expected. Engineering leadership, project management, creativity, and innovation are highly desired. Engineering leadership enables the effective collaboration of cross-disciplinary teams to investigate and solve complex engineering problems in a manner that considers and balances the competing aspects of sustainability and societal impact while protecting the public and the public interest. Complex engineering problems may be system; process or product oriented; and may involve the design, management, operation, and/or decommissioning stages including recycling or remediation. As such, engineering leadership requires technical mastery and expertise in collaborative relationship management including the ability to synthesize and share a vision and influence others towards the realization of the vision. Engineering education must evolve to equip engineering students with a skillset to enable this effective collaboration in the context of the physical realization and operation of engineering systems, processes, or products recognizing competing sustainability requirements, economic realities and technical constraints.

1.3 Fundamental Knowledge and Engineering Practice

The need for fundamental technical knowledge in engineering education will find broad agreement. Whether there is time available to teach metacognitive, socio-contextual, and professional skills in core courses or as additional courses in an engineering program is where dissent might be found along with questions regarding what should be eliminated as everything is regarded as necessary, one can often find an argument for inclusion, and one worries about removing items from the curriculum. It is proposed that fundamental knowledge be taught in the context of developing engineering practice in core courses as well as in design courses. This method has been successfully employed in the chemical engineering program at Polytechnique Montréal (Perrier, 2005) and as part of the curriculum renewal at the University of Sydney (Gomes, 2006). Aalborg University also employs problem based learning (PBL) to incorporate contextual learning, specifically with respect to introducing sustainability (Guerra, 2016). Both PBL and integrated curricular design using inductive teaching and PBL are becoming more common in engineering programs. At Bucknell University, inductive teaching and problem-based learning are used to teach heat transfer (Prince et al., 2010). One key advantage of using inductive teaching strategies and problem-based learning is that they require students to learn to ask and answer questions. This strategy requires students to look for their own answers and to validate whether or not something makes sense. The use of active learning strategies is becoming more common at many institutions in North America (including the University of Alberta) and globally, outcomes-based learning is gaining momentum as engineering education is evolving towards educating the whole engineer and using a more student-centered approach.

Teaching and learning the fundamental knowledge of thermodynamics in the context of engineering practice and problems is addressed as an example. Thermodynamics underlies the engineering design of chemical products and processes, hydrocarbon production and processing, metallurgical process and product design, mechanical and electrical product and system design, environmental, municipal, and structural systems. All these design types interact with people and the environment and are subject to the laws of thermodynamics. The efficiency of the design determines the economic viability. (Although designs can be subsidized by policy and program offerings the subsidy must originate from some form of revenue generating activity or borrowing.) The determination of the state of the material being processed is critical to the function of the equipment being designed, the form of the design, and the energy input required to drive the process. This fundamental subject is key to understanding how designs interact with our world, states of matter, spontaneity of reactions and interactions and their maximum efficiency. Thermodynamics *in practice* is about *making sense* of a system; predicting its behavior and its boundary conditions at given temperatures, pressures, and volumes underlies design evaluation and plausibility. The practice of engineering with respect to thermodynamics happens when the knowledge is used to, create, evaluate, operate, and maintain process or product systems and related innovations. Our ability to guide students to practice thermodynamics and weave it into their practice of engineering while developing lifelong learning skills is a key step in educating effective engineers. Vigeant (2020) demonstrates this type of guidance as she enables students to apply thermodynamics to a designed or selected real life situation as a summative portfolio assignment in lieu of a final exam during the pandemic remote learning period. Thermodynamics is more than sets of transformable partial differential equations. The ability to manipulate the mathematical aspects allows us to create *and use* the necessary models and measurement tools to predict the state, reaction spontaneity, and energy requirements of a system in order to ensure design plausibility. The context of the model application, the validation, the fundamental aspects, and the communication of the engineering work are all equally necessary for plausible, efficient, and sustainable design.

1.4 Engineering Education and Assessment in Terms of Practice

Along with the requirement to understand what engineering is, how, and why engineering is practiced in order to teach engineering; one must also become familiar with educational theory and practice. According to Constructivist (education) Theory, learning is constructed within the existing framework of what is already "known" and accepted. John Dewey, Maria Montessori, Jean Piaget, and Lev Vygotsky elucidated the early core principles of this theory. Learners test their hypotheses through their interactions with new material regardless of how it is taught (Vygotsky, 1980). Learners bring their prior experiences with them and sometimes what is already known is "wrong" or inconsistent with new knowledge or the new depth of knowledge. Learners tend to keep their old knowledge framework and adjust it to accommodate the new learning (Mayer 1987). Sometimes this accommodation hinders further learning (McDermott, 1991). At times the partially correct understanding can be used as the basis for further learning, but when fundamental concepts are misunderstood this can interfere with subsequent learning (National Research Council, 1997).

Some learning experiences force students to confront misconceptions in their constructed framework while others allow students to achieve excellent grades while maintaining their conceptual deficiencies (NRC, 1997). Some learning experiences may have associated negative feelings which can distort perceptions, lead to false interpretations, undermine the will to persist, and interfere with the efficacy of reflective practice (Bormotova, 2011). Bain (2004) suggests students adopt learning behaviors based on their learning goals. These learning goals are often informed by course and program assessments and requirements. Using Bain's levels of learning, Table 1.1 is constructed with motivation, cognitive task assessment and characteristic activities that support the described levels of learning. Although constructive alignment appeals to our sense of fairness and logic in that students are aware of what the learning objectives are, the assessment is aligned with the learning objectives, and both inform the creation of learning activities either by the instructor, the students or by both; it is still assessment driven learning and one can still expect students to be motivated by passing the assessment. Rote learning, surface learning, and strategic learning will all be applied in order to pass the assessment, as passing the assessment is the barrier to achieving the goal of receiving the desired credential. Each of these strategies for learning does have a place and none are inherently 'good' or 'bad' strategies. Depending on the goals of the program and the degree granting institution, some of these strategies might be encouraged. For example, the rote learning of the multiplication tables was efficient, effective and it has served me well to this day. This is not the only way that I understand the multiplication tables but when I want to calculate quickly, I will use recall and not the cognitive understanding of the meaning of each of those tables and why the associative property works – I just want the answer. If I need to explain why and in what context this answer makes sense then I need to have learned more than just the memorized values. Likewise, engineers must be able to execute numerical solutions, program to solve problems, and use commercial software in order to predict outcomes, provide answers, and design solutions. In addition, engineers must determine if the solution produced is plausible and communicate how it makes sense and is within the design constraints and meets the design requirements. If contextual and professional practice competence are goals of the credential granting body, then alternate forms of student assessment may need to be considered to achieve this end.

In a situative community of practice learning environment (as detailed in Chapter 4) assessment is an ongoing process because mentoring and learning discussions are ongoing. The assessment is not necessarily high stakes at the midterm and/or at the final exams. The assessment might be the result of longer-term regular reflections of both the student and the instructor/mentor/guide on the progress of the student (and possibly the progress and development of the mentor as well). In addition, the types of learning activities may need to be varied and include rote learning, constructing learning, and legitimate practice opportunities. As explored in Appendix D, one learning theory perspective may not be adequate to address the learning needs for students who will need to be able to use the materials in a variety of contexts and situations after they graduate. As popular as constructive alignment has become in engineering education circles it may not be enough to create a learning culture that fully develops the graduate attributes in our students.

Vygotsky's Social Development Theory, including the zone of proximal development, underlies the sense making process. From the definitions of what an engineer is we can conclude that misconceptions in thermodynamics can have far reaching implications for the practice of engineering and by extension the society using and impacted by the designs produced, implemented, maintained, and operated by engineers. Sense making is a critical component to learning thermodynamics and then practicing thermodynamic applications at the heart of engineering. Sense making and reflection in action practice are Schön's "continual interweaving of thinking and doing" and Bain's "deep learning", which are necessary parts of engineering practice, education, identity, and the graduate attributes for investigation and design. In essence, sense making and reflection are the iterative and evaluative processes of engineering research and engineering design. What is the problem? What are the constraints? Will this work? Can we make this happen? What do we need to change to make it happen safely and efficiently? What else do we need to consider? What are the risks? I note that this sense making is often a critical part of the problem framing and conceptual design stage when the problem, the requirements, constraints and the potential solutions are developed and examined.

Sense making and reflection were also a necessary part of the exploratory phase of my research. As ideas about student graduate attribute development and competency were translated to learning activities and course improvements they were tested against *my* existing knowledge framework and beliefs. As the new knowledge was acquired my own framework had to be adjusted and at times completely reworked when inconsistencies arose. I learned students might be experiencing the same phenomena when they moved past strategic learning and this might take them out of their comfort zone. The exploratory phase paper "To Teach is to Learn" captures this understanding (peer reviewed conference paper, 2017). "Applying Metacognitive Strategies to Teaching Engineering Innovation, Design, and Leadership," (peer reviewed conference paper, 2017) and "Graduate Attribute Based Continuous Course Improvement in a Blended Learning Design Course – A Writing Seminar Case Study," (peer reviewed conference paper, 2018) describe how this understanding was applied to developing engineering practice in experiential design courses (Listed in Appendix B).

Table 1.1. Changing student learning behavior by changing expectations and constructing aligned activities

Type of learning behavior	**Motivation Description**	**Thinking Construction Cognitive task assessment**	**Characteristics of Constructed Activities to Support Learning**
Surface Learning	Learn enough to avoid failure "C's get Degrees" "I need to pass the test" "What do I need to do to pass?"	What does the *instructor* want me to do? (Base level) **Assessment Driven**	Examples Similar applications Reproduction of examples Recall Testing
Strategic Learning	Learn what is needed to get an A and do it! "I need a 4.0 – to get the best opportunities" "I need to do well"	What does the *instructor* want me to achieve? (Advanced level) **Assessment Driven**	Examples Varied application Anticipate connections Communication Application Testing
Deep Learning	Learning for mastery "I need to teach/use this stuff! I better get it right. " "I need this to do my work – it is *contextually meaningful*."	What do I need to learn/teach? How do I learn it? Why do I need to teach it? What is it useful for? How do I practice? How do I explain it? How does it fit in? **Practice Driven**	Peer teaching Research Team work Design Engineering Practice Relevant Topic Communicating Metacognition in action

The use of learning activities by students in a supportive environment where the learning objectives of a program are *consistent* with the required program assessments and outcomes are central to the theory of constructive alignment (Biggs, 1999; Hattie, 2009), to deep learning (Bain, 2004), and to reflective practice (Schon, 1987). In the context of practice, this is a key method of confronting misconceptions learners may bring with them to the engineering classroom or the design lab. These ideas are consistent with a situative community of practice where learners are given appropriate and legitimate opportunities to practice. They are also consistent with practicing engineers checking their work and looking for errors and misconceptions that might result in design failure and to lifelong learning. Biggs and Watkins (1996) have noted that application of rote learning may produce excellent results especially when combined with other learning strategies (Nield, 2007). Rote and behaviorist based learning strategies can be a necessary step in the learning process and possibly the most effective learning strategy depending on what the desired learning outcome is. Not every learning outcome is related to cognitive processing - some outcomes are related to the ability to execute a task or behavior. In Appendix D, this aspect of the graduate attributes is explored.

Students are often able to use algorithms to solve numerical problems without completely understanding the underlying scientific concept (NRC, 1997). The student's ability to solve these numerical problems could be classified as an example of rote learning. They have imitated what the instructor has shown them similar to how I memorized my multiplication tables. It could be classified as an example of the success of a behaviourist learning model. The student is able to perform (copy) the desired behaviour.

Asking students to explain the concepts and their solution as well as to apply the algorithm is a method to test for conceptual misunderstanding. It could also be viewed as the next (and necessary) stage of learning. Once the student is able to use the solution procedure, the learning objective and the assessment shifts from 'Can you produce it?' to 'Can you explain it?' Sense making is now required. Students must do this for themselves and instructors provide the structure for them to accomplish this task. This is analogous to the understanding I have constructed of the associative property and a variety of other neat things I have learned about multiplication facts. Knowledge constructions that allow me to validate and check my calculation results and explain and/or contextualize my answer. This step could be viewed as the success of constructivist learning theory.

Asking students to transport their knowledge to a new problem with new constraints, an open-ended problem, or a design problem with multiple solutions and real-world complications is the next level of learning. The practice of engineering and the practical use of thermodynamics are not typically as tidy as it might seem in an undergraduate thermodynamics textbook. In the textbook problems I can set constraints so that I can apply the model and manipulate the model so that I can use the variables that I can measure. I have come a long way from my multiplication tables but am I ready for the complexity of the real world yet? The next step in the learning process (and one that is typically left to the final year design courses) is to attempt to make sense of the theory when applying it to a complex problem that is not tidy. This step is not easily managed in large classes and it requires the instructor to model a process that is messy, has failures, takes longer than one anticipates to find an answer (solution), the first answer developed may not meet the requirements and the constraints, the model assumptions may not be consistent with the real world situation, a new approach might need to be developed, an approximation may need to be sought, and the answer may not be within an acceptable error. In other words, the process to develop plausible solutions is iterative and non-linear and often littered with solutions that won't work and/or don't meet the requirements and the constraints. Then there are the plausible solutions passing the first evaluation hurdles that might not last, cause harm, pose risk, and may not be efficient. The success of learning and the achievement of the learning objectives are now much less clear, but it is obvious that the rote learning and constructed knowledge frameworks are now being applied in the new situation and the sense making process with a new context is in progress. Contextual learning is in progress and students are evaluating and reflecting on the process. This step could be viewed as the success of situative learning theory and it is necessary for the student to transition to practice. Assessment of this type of learning is not easily done and often requires the student to write a report (or a thesis) to allow the examiner to understand their thought process, their application of their conceptual understanding, how the model was developed, the evidence they have for validity and their ability to explain their findings. Assessment is more formative and iterative as the learner and the assessor negotiate the contextual meaning and the relevance of the material to the learners professional practice (Soysal and Radmard, 2018) either within or with changing the learners pre-existing belief and knowledge system or philosophical paradigm to accommodate the new concepts, theories and/or applications. As the term and project draw to a close, the focus of the assessment becomes summative. How far did the learner(s) go towards accomplishing the set learning objectives to demonstrate their ability to effectively make sense of the fundamental knowledge base, use the design process, demonstrate their engineering ability and communicate what they did?

As systems have evolved in complexity and integration along with the societal and economic transitions accompanying the digital revolution engineering work has changed and the question of whether the status quo in engineering education is adequate has been heard around the world. The urgency for engineering education change was noted over twenty years ago and is summarized below:

> "…it will require radical rethinking of educational content and *process to reflect* the nature of new knowledge and the changing modes of its transmission, the globalization of technology, the changing nature of engineering jobs and career patterns, and the changing nature of the university itself." (NRC, 1995)

> "...engineering is changing. Indeed that change is what underlies the urgency that I feel for a change in engineering education. Growing global competition and the subsequent restructuring of industry, the shift from defense to civilian work, the use of new materials and biological processes, and the explosion of information technology -- both as part of the process of engineering and as part of its product -- have dramatically and irreversibly changed the practice of engineering. If anything, the pace of this change is accelerating." (William A. Wulf, ASEE Keynote 2002)

Radically rethinking the engineering educational processes requires the *intersection of fundamental knowledge with the practice of engineering* and an examination of how *developing the practice and the* *knowledge simultaneously* is possible. It frames the fundamental knowledge in a relevant framework that requires students, instructors, academic administrators, and the professional community of practice stakeholders to confront their beliefs (and misconceptions) about engineering, teaching, and learning and apply the sense making metacognitive process to engineering education. Educating engineers is a form of engineering practice and as with other forms of engineering practice it requires more than engineering science and technical competence. Schon describes a reflective practicum as "a practicum aimed at helping students acquire the kind of artistry essential to competence in the indeterminate zones of practice" (Schon, 1987, p.18). This aspect is further explored in Chapter 3 "Teaching Engineering for a Changing Landscape..." and Chapter 4 "Teaching Engineering Innovation, Design, and Leadership within a Community of Practice," as published in Education for Chemical Engineers (2020).

1.5 Sustainability and the Future of Engineering Education

Sustainability is currently driving changes to the economic systems and paradigms of our world. Sustainability is a systemic interdisciplinary problem that requires interdisciplinary system solutions. What is sustainability? Sustainability can be defined as the ability to maintain a specific practice over an extended period of time, with minimal long-term adverse consequences to *society* & *environment*[1]. A commonly accepted working definition of sustainable development first appeared in 1987 from the Brundlant commission: "Sustainable development meets the needs of the present, without compromising the ability of future generations to meet their own needs.[2]" Both of these definitions speak to the key elements of long term economic sustainability and evoke images of a cyclical material flow from design conception, to process or product use, to waste management, and finally reclamation with planned and accessible recycling to feedstock materials supporting a connected and economic circular system. Both also suggest that the long term health and safety of the society and the environment are key design requirements. Our processes and systems should support safe operation and limit the risk exposure to both society and the environment. Very few people would argue against sustainability as an objective, however, the definition of sustainability criteria, what sustainability looks like now and in the future, how best to achieve sustainability, and what the optimal pathway to sustainable development and system operation will all find vigorous debate and discussion. The above definitions of sustainability also support the premise engineering is not just a technical and objectively applied science profession but rather a technical social science profession, where practitioners must understand the *values* of the societal stakeholders and be able to apply science to solve complex problems. "Engineering is not "just applied science". To be sure our

---

[1] Andrews, G. C. *Canadian professional engineering and geoscience. Practice and ethics*, 4ed; Nelson Edu.: Toronto, 2009, p. 359.

[2] ibid

understanding of nature is one of the constraints we work under, but it is far from the only one, it is seldom the hardest one, and almost never the limiting one," (Wulf, 2002). An understanding of both objective *and* subjective perspectives is required to be able to synthesize design evaluation criteria, conceive the design options, complete the design evaluation, implement, build the design, and manage the operation or lifecycle of the design. Recognition that subjective societal and/ or cultural values influence engineers as individuals and as a profession is also a necessary step on the path to sustainability. These aspects are further explored in Chapter 5 in the 2020 peer reviewed conference paper "Building the Engineering Mindset: Developing Leadership and Management Competencies in the Engineering Curriculum"

What does sustainability mean for engineering education? What does it mean for engineering practice? How does engineering leadership respond to sustainability and how do we value sustainability as engineers? How does engineering management respond to the definition and evaluation of complex engineering systems design and operation? These questions are examined in Chapter 6 "Sustainable Leadership and Management of complex engineering systems: A team based structured case study approach," as published in Education for Chemical Engineers (Jamieson, 2021). How do we respond as engineering educators in a system that has traditionally responded very slowly in the past? What happens when rapid change is required? A recent rapid shift in engineering education is examined in "Keeping a Learning Community and Academic Integrity Intact after a Mid-Term Shift to Online Learning in Chemical Engineering Design During the COVID-19 Pandemic," as published in the Journal of Chemical Education (Jamieson, 2020). This rapid pivot to online and remote delivery suggests that we can change and we can change rapidly, however, the change must be a priority as this change requires significant time and focus.

Sustainable Engineering Leadership and Management (SELM) is about how we educate engineers today to get to where we want to be as a society in the future. In the middle of the last century, societal goals were centered on technological achievement and engineers delivered with space missions, air travel, better life through chemistry, and the energy to supply the current standard of living. It made sense to focus on technical development to achieve these historical aspirations. The techno-economic engineering project evaluation was the standard evaluation method until it was gradually displaced by triple bottom line[3] sustainability evaluation combined with demonstrating a net social benefit for the project currently in use. Societal goals have been shifting over the last seventy years towards global sustainability concerns, diversity, inclusivity, and equity. Social justice has called on engineering as a profession to demonstrate a more inclusive culture, curriculum, and practice. As the goals have shifted, the demands on engineers and

---

[3] Often technical feasibility combined with economic, environmental, and safety evaluations in a risk management framework.

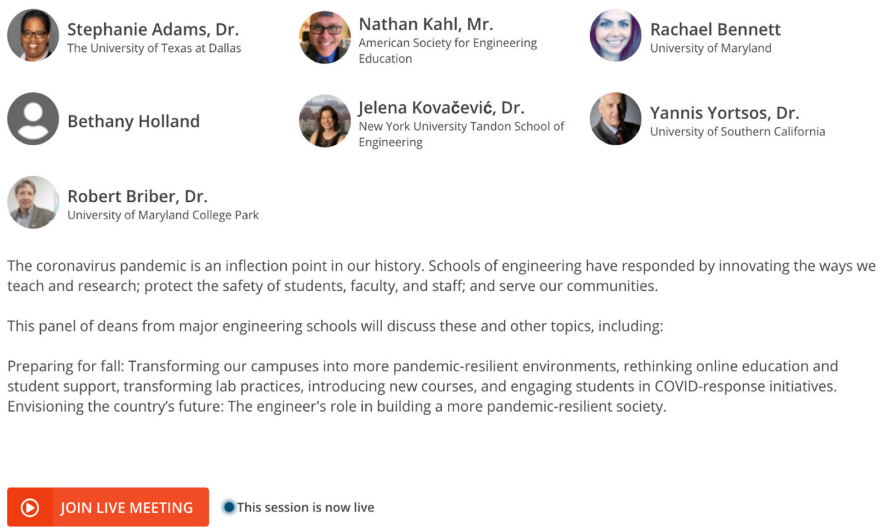
the organizations engineers typically work in have also been shifting. At one time we expected people to conform to the pre-existing culture of engineering and business organizations. This strategy is no longer enough and the culture needs to change to be more inclusive while maintaining technical standards and the protection of the public. How are we responding? How will we respond? How will our graduates respond?

The triple bottom line sustainability analysis of engineering projects has typically considered maximizing the internal rate of return (IRR) while staying within the environmental and occupational health and safety regulatory frameworks while managing or transferring risk away from the organization executing the project. The consideration of Net Social Benefit and Social License to Operate (SLO) in project evaluation and stakeholder engagement has recently become more common in both engineering education and practice in response to public stakeholder demands. Is it enough to shift to societal and environmental sustainability? How do we operationalize sustainability in engineering education?

"Society demands we create trustworthy graduates" – competence *and* character are the components of being a trusted profession (Yanis Yortsos, ASEE, 2020) "Engineering was a technical field without regard for creating whole humans – we need to move beyond this and pay attention to what our work means and the impact it has on society – we don't exist in a vacuum" (Jelena Kovacevic, ASEE, 2020).

"You can't be what you can't see..." (Robert Briber, ASEE, 2020). These recent comments during an ASEE panel discussion (Figure 1.1) suggest engineering education is still struggling to embrace sustainability and what it means to educate whole engineers. Engineering students need to "see" sustainability connected to engineering practice, the impacts of current practices, and have tools to evaluate the impacts. (Briber et al., 2020)

The ninth Canadian Engineering Accreditation Board (CEAB) graduate attribute (GA) embodies sustainability as previously defined and clearly elucidates societal and environmental impacts. "***Impact of engineering on society and the environment***: *An ability to analyze social and environmental aspects of engineering activities. Such*



Stephanie Adams, Dr.
The University of Texas at Dallas

Nathan Kahl, Mr.
American Society for Engineering Education

Rachael Bennett
University of Maryland

Bethany Holland

Jelena Kovačević, Dr.
New York University Tandon School of Engineering

Yannis Yortsos, Dr.
University of Southern California

Robert Briber, Dr.
University of Maryland College Park

The coronavirus pandemic is an inflection point in our history. Schools of engineering have responded by innovating the ways we teach and research; protect the safety of students, faculty, and staff; and serve our communities.

This panel of deans from major engineering schools will discuss these and other topics, including:

Preparing for fall: Transforming our campuses into more pandemic-resilient environments, rethinking online education and student support, transforming lab practices, introducing new courses, and engaging students in COVID-response initiatives.
Envisioning the country's future: The engineer's role in building a more pandemic-resilient society.

Figure 1.1. Panel at the ASEE 2020 Virtual Conference: "After COVID-19: The Role of Engineering Schools in the Post-Pandemic Era Featuring Engineering Deans" - Presented by the University of Maryland, Online, June 22, 2020

ability includes an understanding of the interactions that engineering has with the economic, <u>social</u>, health, safety, legal, and <u>cultural</u> aspects of society, the uncertainties in the prediction of such interactions; and the concepts of <u>sustainable design and development</u> and environmental stewardship." This vision requires operationalization by engineering educators and program leaders. The Washington Accord graduate attributes were introduced by the US and Canadian accrediting bodies ABET in 2004 and the CEAB in 2009. Both lists are similar. The ABET version of GA9 is "*The broad education necessary to understand the impact of engineering solutions in a <u>global</u>, economic, <u>environmental</u>, and <u>societal</u> context.*" In 2004, the National Academies of Engineering (NAE) defined the required characteristics for the Engineer of 2020 in order to maintain the global relevance of the American engineering profession. The Canadian Engineering Accreditation Board graduate attributes (CEAB-GA) and Engineer of 2020 characteristics are compared in Table 1.2 demonstrating significant overlap.

Table 1.2. Mapping The CEAB Graduate Attributes to the NAE Engineer of 2020

CEAB Graduate Attribute Keywords	Engineer of 2020 Characteristics
1. Knowledge base for engineering	--
2. Problem analysis	Strong Analytical Skills
3. Investigation	Practical Ingenuity
4. Design	Creativity
5. Use of engineering tools	Flexibility
6. Individual and teamwork	Leadership, Dynamism
7. Communication skills	Communication
8. Professionalism	Professionalism
9. Impact of engineering on society	Agility, Resilience
10. Ethics and equity	High Ethical Standards
11. Economics and project management	Business and Management
12. Lifelong Learning	Life-long Learning

There is general agreement on what an engineer should be and what they should be able to do. During the CEEA-ACEG 2017 conference, Dr. Greg Evans engaged participants in a workshop session entitled "Designing the Engineer of 2050" (Irving, 2017) where participants were encouraged to post their contributions on Twitter #CEEA17. Characteristics similar to those suggested in Table 1.2 emerged with some items that speak to the social connection of engineering: Humanity, cross-disciplinary, engineering philosophy, and connection to the community.

The workshop discussion provocation was "*What will society require from engineers in 2050 that is different from today?*" A response found online at #CEEA17 is shown in Figure 1.2 and exemplifies the societal and environmental sustainability themes of the workshop (Hassan, 2017). The questions remain regarding the processes to be used to develop our future engineers to respond to what society is asking from the engineering profession. How do we transition from where we are now to sustainable engineering, leadership, and management? Can we educate the whole engineer? How far do we still need to go? How will we get there? What does this look like in the engineering curriculum?

Liz Hassan @Liz_Hassan · Jun 7, 2017
Engineer of 2050 #ceea17

Figure 1.2. Twitter post from #CEEA17 and the Engineer of 2050

1.6 Resiliency and the Future of Engineering Education

Amid the disruptive changes we are experiencing during the COVID-19 pandemic public health measures, depressed fossil fuel prices due to oversupply, climate change confrontations, Truth and Reconciliation with Indigenous peoples, the Black Lives Matter social upheaval and protests rooted in demands for equity triggered by the 2020 murder of George Floyd while in custody; the potential economic consequences for nations, corporations, and individuals are significant. We are at a crossroads of crises and an opportunity to respond quickly as we rework engineering education for online delivery and redefine who our students are, where they are learning from, how and what they are being taught. What post secondary education and engineering education will look like post the current defining economic and social crises is a current topic of conversation at universities and conferences around the globe. An example panel is shown in Figure 1.1 and excerpts from the ASEE opening are summarized on the virtual conference website as follows:

" '*As engineers, we like to think our objectivity shields us from history, our culture, and current events, but this is not the case*,' ASEE's 2020-21 President Sheryl Sorby declared in her 2020 keynote speech: '*Let me begin by saying Black lives matter. Black engineers matter.*' Citing 50 years of diversity efforts that have yielded only marginal progress, she said, '*I think it's time we looked in a mirror and faced the facts—since we are not part of the solution, we are a large part of the problem.*' Change is urgently needed: '*if we do not transform our programs, we will become outmoded and may cease to exist,*'(Sorby, 2020). The past urgent calls for change are becoming critically urgent current calls for change. It is time to transform engineering education.

Instructors across faculties and universities all struggled with an over a weekend in March (2020) pivot to online learning and the general consensus is that "it actually didn't turn out that badly" (Jelena Kovacevic, ASEE, June 22, 2020). This is a critical observation. When it comes to including sustainability (socio-contextual), professional, and metacognitive topics, we can shift. It is possible. And we can shift rapidly – we can pivot. Universities incorporated longer-term online learning in anticipation of continued public health measures. Some courses may stay as online offerings or incorporate online delivery methods even after we are able to return to in person instruction. All courses were online from the Spring/Summer 2020 term through to the Spring/Summer 2021 terms in the Faculty of Engineering at the University of Alberta creating an opportunity for rethinking course design, content, delivery, and student engagement. As we shifted to online learning we had an opportunity to redevelop our course materials and further address sustainability, diversity, equity, inclusivity, how engineering students learn, how we teach them, the learning culture we create, and the future resilience and sustainability response of the profession. Change was urgently required when I was an undergraduate and an engineer in training. Like the adoption of the graduate attributes, change with respect to sustainability, equity, diversity and inclusivity has also been slow. It is now beyond urgently required. Will we take advantage of the opportunity to pivot?

1.7 Motivation and Research Objectives

Students learn from what they experience, what they think about, and what they do. The experiences engineering educators cultivate for their students impact students' emerging engineering identity and their developing engineering practice. The vision and the mission of engineering departments and faculties (or lack thereof) sets the direction and cohesiveness of the program provided to students and determines the degree of alignment with the direction of the society the engineering educators serve. The CEAB graduate attributes have been used in two accreditation cycles now and evidence of a continual improvement process is now part of the accreditation requirements. The graduate attributes provide a framework for the characteristics and abilities of an engineering graduate but they do not speak to how the graduate attributes are developed, measured, or the overall vision of what engineers do and contribute within a societal sustainability framework. This vision is a necessary but missing ingredient for engineering education as we often envision what engineers *are* from an education product perspective but less often from the perspective of '*What will society demand of engineers?*' and *what engineers will need to do* to achieve the societal objective of sustainability. In other words, we need to envision future engineering work in service of the needs of our global society now and in the future rather than what was needed in the past to ensure the wealth and security of a nation and prepare students for the shifting demands of society. As the need for change is urgent, we need to prepare them now as the future envisioned with the Washington Accord and the "The Engineer of 2020: Visions of Engineering in the New Century" is here.

The objectives for this work are to develop a model for engineering education in the future and provide illustrative tools that embody this model. Specifics and the relevant chapters or appendices are listed below:

- to develop and apply the theoretical and conceptual frameworks developed to teaching engineering for the changing world (Chapter 3, Appendices D and E);
- to examine the impact of the community of practice on innovation in the process design course pre and post blended learning(Chapter 4);
- to move towards educating the whole engineering practitioner by developing a foundation for technical, leadership, and management skills during the undergraduate degree (Chapter 5);
- to develop a framework for aligning undergraduate engineering education with the technical *and* socio-contextual demands of engineering practice creating a foundation for lifelong learning to support the career arc of engineers as engineering practitioners, leaders, and managers (Chapters 5 and 6);
- to connect sustainability to the work of engineers as practitioners, leaders, managers, and educators and examine the use of a structured case study to teach sustainability (Chapter 6);
- to examine the intersection of the CEAB-GA and the more generic University Graduate Attributes (UGA) and consider the integration of professional and institutional graduate attribute objectives. (Chapter 7; Appendix C)

1.8 Paper Based Dissertation Chapter Outline

In Chapter 1 the nature and breadth of engineering work is examined by analyzing engineering definitions for technical and socio-contextual items. Based on the study of engineering definitions, the initial four key concepts of fundamental knowledge, complementary knowledge, reflection, and "soft" skills, often seen in the graduate attribute and accreditation discourse and supported by a preliminary analysis of engineering work were initially proposed as the preliminary themes. From the textual analysis of engineering definitions the initial themes of engineering work and subsequently undergraduate education appear to be: *core technical knowledge, socio-contextual knowledge, metacognitive skills, and professional skills*. Chapter 2 outlines the structure of this thesis and the research study including the research questions; the ontological, epistemological, and axiological positions adopted; their alignment with the methodology and methods used in the study; who I am as a researcher; and the study context. Appendix C outlines the design of a graduate attribute based the continual improvement process for the design courses (with leadership and innovation examples) and the philosophical positioning of the work. This chapter is a full peer reviewed ASEE June 2019 conference paper: "A Continual Improvement Process for Teaching Leadership and Innovation Within a Community of Practice."

Guided by the structure elucidated in Chapter 1 to identify key data sources, the CEAB graduate attributes, the graduate attribute history, design course teaching practice, and interdisciplinary literature informed the inductive development of the conceptual framework is outlined in Appendix D with further details of the related graduate attribute studies in Appendix E.

Appendix D captures the philosophical alignment of three key learning theories, the development of a learning culture and an engineering education theoretical framework grounded in the graduate attributes as published in the CEEA-ACEG 2019 peer reviewed conference proceedings. In Appendix E the philosophical underpinnings of the graduate attributes are examined in the context of the associated learning theory and the conceptual framework development.

Appendix D, is based on a full peer reviewed CEEA-ACEG June 2019 conference paper “Learning to Learn: Defining an Engineering Learning Culture,” (Jamieson, 2019). The following studies are described:

- Study 1: Conceptual Framework Analysis (based on Jabareen, 2009)
- Study 2: Graduate Attribute Learning Theory Categorization Coding
- Study 3: Design Course Metacognitive Structure Mapping

In Study 1, a multi step process for conceptual and theoretical framework development is used to produce a conceptual framework for engineering education informed by the practice based CEAB graduate attributes. It includes a validation step where the framework is presented in multiple venues for validation and feedback. The interdisciplinary literature sources detailed in “Learning to Learn: Defining an Engineering Learning Culture” (Jamieson, 2019) are extensive as the graduate attributes are diverse, the work of an engineer is diverse, and the education of an engineer is complex and multi-faceted. Validation of the conceptual and theoretical frameworks as described in Appendix D is complete with positive and useful feedback obtained and integrated. After concept integration and resynthesis four key areas emerged: socio-contextual knowledge, core content (discipline) knowledge, metacognitive skills, and professional skills. The pre-post test graduate attribute student self-assessment constructs were used as the initial conceptual framework constructs and the ontological and epistemological orientation for each is presented in Appendix E along with further description of the graduate attributes and the development of continual improvement processes. A qualitative study to categorize the graduate attributes from a learning theory perspective (Appendix D, Study 2) was undertaken in order to understand if a particular approach might be required to enhance graduate attribute development. The nature of the graduate attributes is considered through a learning theory lens considering behaviorist, situative/pragmatist, and cognitivist characteristics. The third study in Appendix D examines and maps the metacognitive structure of a design course. The learning culture suggested by the developed engineering education and practice theoretical framework includes activities drawn from behaviorist/empiricist, cognitive/constructivist, and situative/pragmatic learning theories. Students need to learn the mechanics by memorizing, seeing examples, imitating and reproducing; make sense of the mechanics by thinking, applying, connecting, constructing; and finally contextually applying the mechanics in the context of legitimate practice, preferably in a community of practice. Appendix E transitions to applications of the theoretical framework to engineering education.

Chapter 3 “Teaching Engineering for a Changing Landscape” explores how metacognitive and lifelong learning skills can be taught in engineering courses, enable students to learn to learn, and shift from teacher centered to student centered approaches. This paper was published in the Canadian Journal of Chemical Engineering, November 2019. The impact of further developing a course level community of practice and incorporating innovation with the four themes identified above during the continual improvement process is summarized in Chapter 4 “Teaching Engineering Innovation, Design, and Leadership Through a Community of Practice” as published in Education for Chemical Engineers (ECE) (online May, 2020). This paper examines the evolution of the community of practice and the shift from benchmarking to innovation projects in the context of the transition to blended learning. The design course organizational structure is compared to the innovation dynamo framework.

Chapter 5 is a full peer reviewed CEEA-ACEG June 2020 Conference paper “Building the Engineering Mindset: Developing Leadership and Management Competencies in the Engineering Curriculum,” researched and written with Dr. John R. Donald (University of Guelph). A framework for further engaging engineering leadership and management development in the engineering undergraduate curriculum is presented building on the emerging four key areas of engineering education and practice: socio-contextual knowledge, core content (discipline) knowledge, metacognitive skills, and professional skills. The connection between the graduate attributes and engineering practice considering the career arc requirements of an engineer in an organization lead to the proposition that leadership and management skills are an integral part of engineering education. These principles have recently been applied to the first year design courses at both universities (Jamieson and Donald, 2021 CEEA) and were already employed in graduate engineering leadership and capstone engineering design courses at both universities.

Chapter 6, is a full peer reviewed paper published in Education for Chemical Engineers (online December 2020) “Sustainable leadership and management of complex engineering systems: A team based structured case study approach” written with Dr. Lianne Lefsrud, Dr. Fereshteh Sattari, and Dr. John R. Donald. The use of case studies and risk based process safety management to operationalize sustainability and the UN Sustainable Development Goals in graduate and undergraduate engineering programs is presented. Developing the CEAB-GA and operationalizing sustainability in the engineering curriculum by employing a structured case study approach and risk governance is proposed in this work. The case study approach could be used to study technical, leadership, and management topics (including ethics and equity) with respect to sustainability and connect with developing the four key areas elucidated in Chapter 1 and Appendices D and E at the graduate and undergraduate level in a variety of courses. Dr. Lefsrud currently employs case studies in an undergraduate/ graduate course in quantitative risk management and I have employed a structured case study approach to train undergraduate engineering and business students for case competitions and have developed this into an undergraduate interdisciplinary course.

Finally in Chapter 7, the evaluation of professional program graduate attributes, using the CEAB GA as the example, in the context of higher education performance and institutional graduate attribute evaluation is explored. "Intersecting Roadmaps: Resolving Tension Between Profession-Specific and University-Wide Graduate Attributes" is published in the Canadian Journal of Higher Education and is the result of an interdisciplinary research collaboration with Dr. Samira ElAtia, Dr. Jason Carey, Bashair Alibrahim, and Marcus Ivey spanning several years and investigating the complementarities and tensions between the CEAB-GA and the University Graduate Attributes. The institutional UGA are intended to be developed as a result of completing any program at the University of Alberta and have been in development for several years (Dew, 2013). The UGA were initially developed at the request of students interested in demonstrating their enhanced employability and readiness for the evolving world of work (Moghaddam, 2020).

This dissertation concludes with a general discussion of the key findings of this work and an outlook for engineering education and engineering educators. Chapter 8 is a summary discussion of the results of the work presented and Chapter 9 contains the conclusions. A glossary of terms used in the development of this thesis is presented in Appendix A. The definitions are derived from the literature and referenced accordingly.

References

American Society for Engineering Education (ASEE).1994. Engineering Education for a Changing World.

Association of Professional Engineers and Geoscientists of Alberta (APEGA). 2013. Guidelines for ethical practice. Section 2.1 Professions (pg. 2).

Bain, K., 2004. What the Best College Teachers Do. Cambridge, MA: Harvard University Press ISBN: 0-674-01325-5

Biggs, J., 1999. What the student does: teaching for enhanced learning. Higher Education and Development 18(1):57-75.

Biggs, J.B. (2003). *Teaching for Quality Learning at University: What the Student Does*. Buckingham; Philadelphia. Society for Research into Higher Education : Open University Press.

Biggs, J. B. (1996) Western Misperceptions of the Confucian-Heritage learning Culture. In: D.A. Watkins and J.B. Biggs, (Eds.) (1996) The Chinese Learner: Cultural, Contextual and Psychological Influences. Hong Kong, CERC and Melbourne: ACER. 45-68

Bloom, B., Englehart, M. Furst, E., Hill, W., & Krathwohl, D. 1956. Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain. New York, Toronto: Longmans, Green.

Briber, R., Kovacevic, J., Yortsos, Y., After COVID-19: The Role of Engineering Schools in the Post-Pandemic Era - Featuring Engineering Deans - in (moderators) Kahl, N., and Adams, S. ASEE, 2020

Bormotova, L. S., (2011). "A Qualitative Study of Metacognitive Reflection: The Beliefs, Attitudes and Reflective Practices of Developing Professional Educators". Theses and Dissertations (All). 434. http://knowledge.library.iup.edu/etd/434

Butun, E., Erkin, H.C., & Altintas, L. (2009). A new teamwork-based PBL problem design for electrical and electronic engineering education: A systems approach. *International Journal of Electrical Engineering Education, 45* (2), 110 – 120.

Canadian Engineering Accreditation Board (2017). *Canadian Engineering Accreditation Board: Accreditation Criteria and Procedures*. Ottawa: Canada. Canadian Council of Professional Engineers. Retrieved: https://engineerscanada.ca/sites/default/files/accreditation-criteria-procedures-2017.pdf

Canadian Engineering Accreditation Board (2018). *Continual Improvement Rubric v3.2*. Retrieved from https://engineerscanada.ca/accreditation/accreditation-resources

Canadian Engineering Accreditation Board (2019). *Accreditation Criteria and Procedure*. Ottawa: Canada. Canadian Council of Professional Engineers. Retrieved from https://engineerscanada.ca/sites/default/files/accreditation/Accreditation-Criteria-Procedures-2019.pdf

Canadian Engineering Accreditation Board (2018). Continual Improvement Rubric v3.2 https://engineerscanada.ca/accreditation/accreditation-resources [Accessed January 25, 2019]

Cole, J. 1996. The two cultures revisited. The Bridge 26(3&4):15-21.

Crumpton-Young, L. et al. (2010). Engineering leadership development programs: A look at what is needed and what is being done. *Journal of STEM Education, 11*(3&4), 10 – 21.

Dew, S., Csorba, E, Chelen, D, Yousefi, N., Andrews, N., & More, C. (2013). Graduate Attributes at the University of Alberta: A report of the Committee on the Learning Environment (CLE) Subcommittee on Attributes and Competencies. Retrieved from http://www.provost.ualberta.ca/en/~/media/provost/Documents/Information/GraduateAttributes.pdf

Donald, J. R., & Jamieson, M. V. (2022). Diversity in engineering leadership program designs. In M. R. Kendall & C. Rottmann (Eds.). *New Directions for Student Leadership: No. 173. Student leadership development in engineering* (pp. xx-yy). Wiley (In Press).

Engineering at Alberta (2020). Student View book, [Accessed May 15, 2020]

Engineers Canada (2012). Public guideline on the practice of engineering in Canada, Ottawa: Canadian Engineering Qualification Board. https://engineerscanada.ca/public-guideline-on-the-practice-of-engineering-in-canada#-the-engineers-canada-definition-of-the-practice-of-engineering

Engineering Deans Council and Corporate Roundtable. Washington, D.C.: ASEE

Engineering and Geoscience Professions Act. 2015. Section 1, p. 8 Queen's Printer, Alberta

Everding-Wustl, G. 2004. Students learn more if they'll need to teach others. Futurity. Retrieved from: http://www.futurity.org/learning-students-teaching-741342/

GACIP (2017). Summit Meeting, December 7, 2017, University of Toronto.

Gomes, V.G., Barton, G.W., Petrie, J.G., Romagnoli, J., Holt, P., Abbas, A., Cohen, B., Harris, A.T., Haynes, B.S., Langrish, T.A.G., Orellana, J., See, H.T., Valix, M., & White, D. (2006). Chemical Engineering Curriculum Renewal, *Education for Chemical Engineers*, *1*(1), 2006, Pages 116-125, ISSN 1749-7728, https://doi.org/10.1205/ece.06020.

Guerra, A. (2017). Integration of sustainability in engineering education: Why is PBL an answer? *International Journal of Sustainability in Higher Education, (18)* 3, pp. 436-454, 1467-6370

Hassan, L. (2017). Engineer of 2050 Twitter post #CEEA2017; CEEA 2017 Engineer of 2050 Workshop, Evans G. (moderator), Toronto : Twitter.

Hattie, J. 2009. Visible learning : a synthesis of over 800 meta-analyses relating to achievement. London; New York : Routledge.

Hattie, J. The Black Box of Tertiary Assessment: An Impending Revolution (2009). 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.

International Engineering Alliance. 2015. Best Practice in Accreditation of Engineering Programs: an Exemplar. IEA. http://www.ieagreements.org/

Jamieson, M.V., Donald, J.R., (2021). "Building the Engineering Mindset: Developing Sustainable Leadership and Management Competencies in First Year Engineering," Canadian Engineering Education Conference (CEEA-ACEG 2021) UPEI

Jamieson, M.V., Lefsrud, L.M., Sattari, F., Donald, John R. (2021). Sustainable Leadership and Management of complex engineering systems: A team based structured case study approach," as published in Education for Chemical Engineers, *Education for Chemical Engineers*

Jamieson, M.V. (2020) Keeping a Learning Community and Academic Integrity Intact after a Mid-Term Shift to Online Learning in Chemical Engineering Design During the COVID-19 Pandemic, ACS *Journal of Chemical Education*

Joyner, F.F., Mann, D.T.Y., & Harris, T. (2012). Engineering as a social activity: Preparing engineers to thrive in the changing world of work. *American Journal of Engineering Education*, 3(1), 67-81.

Lappalainen, P. (2009). Communication as part of the engineering skill set. *European Journal of Engineering Education, 34* (2), 123 – 129.

Moghaddam, Y. (2020). *The future of work : how artificial intelligence can augment human capabilities* (First edition.). Business Expert Press.

Mayer, R.E. (1987). Educational psychology: A cognitive approach. Scott Foresman & Co.

McDermott, L. (1991). Millikan lecture 1990: What we teach and what is learned - closing the gap. *American Journal of Physics*, 59, 301-315.

National Academy of Engineering 2004. *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10999.

National Academy of Engineering (NAE) (2004). The Engineer of 2020: Visions of Engineering in the New Century, Washington, DC: The National Academies Press. https://doi.org/10.17226/10999

National Research Council (NRC) (1995). Engineering Education: Designing an Adaptive System. Board on Engineering Education, Washington, D.C.: National Academy Press.

National Research Council (NRC) (1997). Science Teaching Reconsidered: A Handbook. Washington, DC: The National Academies Press. doi: 10.17226/5287.

National Science Foundation (NSF) (1995). Restructuring Engineering Education: A Focus on Change. Report of an NSF Workshop on Engineering Education, June 6-9, 1994. NSF 95-65. Arlington, Va.

Nield, K., (2007). Understanding the Chinese Learner: a Case Study Exploration of the Notion of the Hong Kong Chinese Learner as a Rote or Strategic Learner. Journal of Hospitality, Leisure, Sport and Tourism Education, 6(1), DOI:10.3794/johlste.61.131

Perrier, M., Bertrand, F., Dubois, C., Klvana, D., Legros, R. & Farand, P. (2005). Integrating Process Control and Unit Operations in a Single Core Course of the Chemical Engineering Curriculum, 2nd Canadian Design Engineering Network Conference, Kananaskis, Alberta.

Perrier, M., Bertrand, F., Dubois, C., Klvana, D., Legros, R. & Farand, P. (2005). A Case Study in Curriculum Integration of Core Courses in Chemical Engineering, ASEE Annual Conference, Portland, Oregon, Session 3613.

Prince, M.J., Vigeant, M.A.S., Nottis, K., (2010) A preliminary study on the effectiveness of inquiry-based activities for addressing misconceptions of undergraduate engineering students, *Education for Chemical Engineers* 4 (2), 29-41

Schon, D. (1987). Educating the reflective practitioner. Towards a new design for teaching and learning in the professions. San Francisco: Jossey-Bass.

Verzat, C., Byrne, J., & Fayolle, A. (2009). Tangling with spaghetti: Pedagogical lessons from games. *Academy of Management Learning & Education, 8*(3), 356 – 369.

Vigeant, M., (2020). A portfolio replacement for a traditional final exam in thermodynamics, *Education for Chemical Engineers*, 35(2021) p. 1–6

Vygotsky, L. S. 1980. Mind in society: The development of higher psychological processes. Harvard university press.

Wulf, W.A. (1998). The urgency of engineering education reform. The Bridge 28(1):15-21.

Wulf, W.A. (2002). The Urgency of Engineering Education Reform, ASEE Keynote Speech.

2. Study Design, Structure, Frameworks, and Methodology

In this chapter, I present the study design; the research questions; the structure of this study with respect to the ontological, epistemological, and axiological orientations; and the positioning of this work with respect to the literature and practice of teaching and learning (conceptual and theoretical frameworks). An aligned methodological orientation informs the design research method chosen to gather data, answer the research questions, and to design interventions or artefacts (Blessing and Chakrabarti, 2009). Figure 2.1 provides an overview of the research study development process and is a basis for CEEA-ACEG Institute for Engineering Education Research (IEER) workshops. It shows how the research paradigm, comprising ontology, epistemology, and axiology, align with the research question(s), theoretical and/or conceptual framework(s), the methodology and the methods selected. This process was adapted from previous work (Crotty, 1998; Patel, 2015) by the CEEA-ACEG IEER workshop development and facilitation team (alphabetically: S. Doré, M.V. Jamieson, S. McCahan, R. Paul, L. Romkey, J. Seniuk Cicek, 2020; 2021). As my personal philosophical paradigm (including my beliefs regarding ontology and epistemology) impacts my research questions, data collection and interpretation, and the methodology and methods selected for this study, I also examine who I am as a researcher in this chapter.

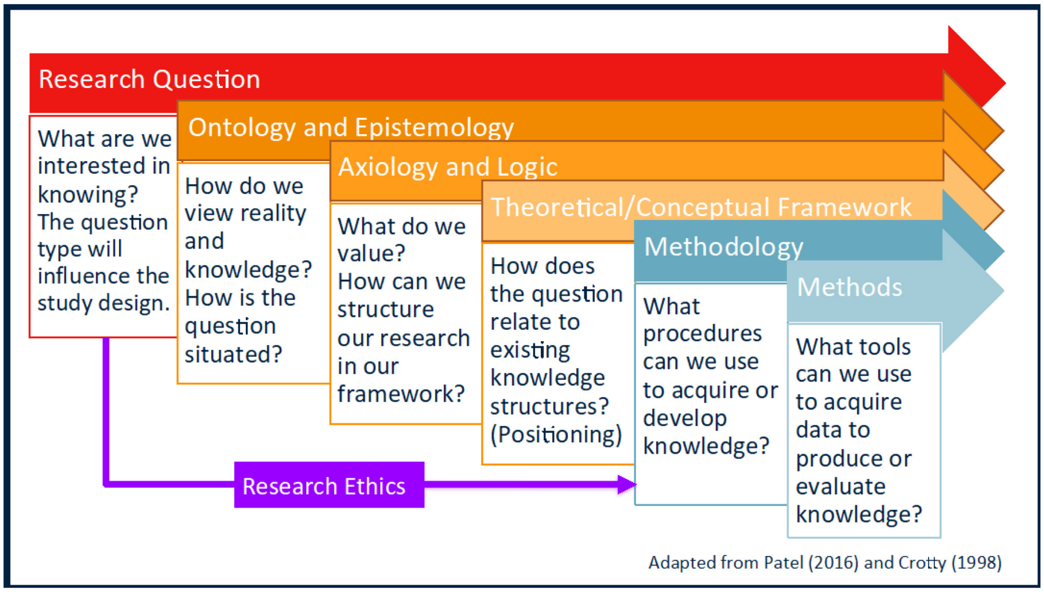


Figure 2.1. Research Study Design, CEEA-ACEG Institute for Engineering Education Research, July 2020.

Design Based Research (DBR) is the underlying structure of the work contained in this dissertation and my prior work. “DBR is a methodology designed by and for educators [who seek] to increase the impact, transfer, and translation of educational research into improved practice. In addition, it stresses the need for theory building and the development of design principles that guide, inform, and improve both practice and research in educational contexts.” (Anderson and Shattuck, 2012). DBR is typically the methodology found in education literature whereas Design Science Research (DSR) is typically found in engineering and computer science literatures. “DSR…is the scientific study and creation of artefacts as they are developed and used by people with the goal of solving practical problems of general interest,” (Johanesson and Perjons, 2014). A methodology referred to as Design Research Method (DRM) is found in the work of Blessing and Chakrabati (2009) and shown in Figure 2.2. The outputs of this method are the study goals, contextual problem understanding, solution and artefact design where the theory and/or understanding are applied, and the demonstration and the evaluation of the efficacy of the artefact. In design-based research methods two questions are asked for internal validity (Johannesson and Perjons, 2014):

- Demonstrate: How can the developed artefact be used to address the explicated problem in one case?
- Evaluate: How well does the artefact solve the problem and fulfil the defined goals?

Cohort grade performance outcomes were shown previously to be neutral for blended learning compared to face-to-face only curriculum delivery in a project-based design context from a statistical perspective (Jamieson, 2016). The need to follow up prescriptive recommendations to support further engagement and graduate attribute development of individual students and teams in future process design course iterations was also identified. The current study connects to this previous work at this prescriptive study stage. It begins with a follow up evaluation stage utilizing exploratory mixed methods research questions intended to evaluate the prescriptive recommendations synthesized in “An Application of Blended and Active Learning to Chemical Engineering Design Instruction” (Jamieson, 2016) and the design of a course based continual improvement process (described in Appendix C). It then

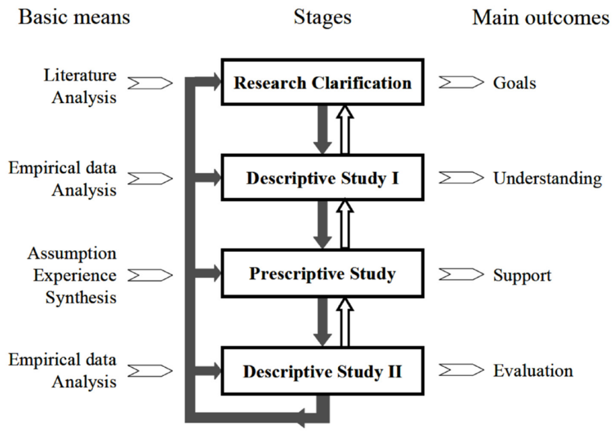


Figure 2.2. Design Research Methodology (DRM) Framework (Blessing and Chakrabati, 2009, p.15)

progresses from the specifics of the chemical engineering capstone design course through to more general engineering education questions and graduate attribute applications and artefacts.

2.1 Research Questions

The global objectives of this thesis are to ask questions and to develop curriculum improvements that better align design course learning activities and engineering program content with engineering graduate attributes, engineering practice, and incorporate innovation and sustainability into the engineering work and the engineering mindset of graduating engineers. A secondary objective of this work is to explore what might help more students achieve their potential at the performance level they desire.

The ontological and epistemic positions and assumptions underlying the graduate attributes and engineering practice are also of interest. During the initial exploratory and evaluative phase of this work questions related to iterative and incremental improvements of the process design course were raised. The exploratory research questions evaluated the efficacy of improvements arising from the initial work to enhance student achievement within the existing paradigm:

- Does continual improvement impact student satisfaction and engagement?
  - What is student engagement and satisfaction in blended learning?
  - What is the instructor experience in developing and implementing blended learning?
- Does a writing seminar or process with writing milestones and encouragement for early and ongoing writing improve the academic performance of students for their final design report?
  - What is the student view of the utility of writing instruction in a design course?
  - Where and how would writing instruction be beneficial (student view)?
- Can a bonus innovation leadership assignment and learning environment influence outcomes?
- Can innovation be encouraged and developed in a process design course?
  - What is an explicit model for innovation and leadership supported by a community of practice in a metacognitive learning environment?
  - Can the proposed design project types be influenced to produce innovation in a community of practice learning environment?

Although positive impacts were demonstrated quantitatively for these innovations and interventions identified in “An Application of Blended and Active Learning to Chemical Engineering Design Instruction” (Jamieson, 2016), the answers to these questions, published in CEEA-ACEG conference proceedings (Jamieson, 2017; 2018; 2019), were not entirely satisfactory. Other questions were also raised as a result of this exploratory work, including the ontological and epistemic roots of the current teaching and learning paradigm.

Questions remained about the generalizability of the work, how to develop a learning culture, and *how* to *change* the existing paradigm in engineering education. How to meaningfully address engineering sustainability, engineering leadership, engineering management, ethics, and lifelong learning (CEAB-GA 6-12) to better support societal demands for rapid changes in engineering practice were of interest. This led to deeper questions that required a different approach in order to answer them, and a different set of assumptions as to what counts as knowledge, evidence, and what is credible. These latter questions were outside of the experimental and quasi-experimental methodology that had typically been used in my work. The inductive design research questions investigated include:

- What is engineering work and practice? How is it connected to engineering education? (CH 1)
- What does a course based continual improvement process (CIP) design look like? A CEAB-GA based CIP? What is the ontological and epistemological orientation of such a process? Is there an impact on student achievement and experience? (APPX C)
- What defines an engineering learning culture? What type of learning environment might better support student graduate attribute development? What is a plausible general theoretical framework for the development of the CEAB graduate attributes and an engineering practice identity? (APPXs D&E)
- What are the ontological and epistemic roots of the engineering design practice skills and the CEAB graduate attributes? (APPX E)
- Can metacognitive cycles be mapped to the design course learning process? (CH 3 & APPX D) Can an innovation model be mapped to the design course learning process? (CH 4)
- Can reflective practice, effectuation thinking, innovation and sustainability transform Engineering Education? (CH 4, 5 & 6)
- How can sustainability and leadership, elements of engineering practice, be included in the undergraduate and graduate engineering programs? What tools can be used or developed to support this change? (CH 5 & 6)
- How does the Faculty of Engineering CIP align with the engineering graduate attributes and the University Graduate Attributes (UGA)? (CH 7)

2.2 Ontological and Epistemological Framework

The Ontological framework for this doctoral study is complex critical realism (Clark, 2008) as a variant of Critical Realism (Bhaskar, 1975) described in (Appendix C) "A Continual Improvement Process for Teaching Leadership and Innovation Within a Community of Practice" and further elucidated in (Appendix D) "Learning to Learn: Defining an Engineering Learning Culture". Critical Realism (Bhaskar, 1975; 2016) allows for individual subjective human interpretation of an objective independent reality or existence (Clark, 2008) separating ontology from epistemology. The distinction between complex and complicated made by Clark helps to elucidate why a stratified reality is necessary in healthcare research where the prediction of results in complicated systems is different than in complex systems. The trajectory of a rocket is complicated, but it can be predicted and controlled. Systems become complex when we begin to operate them or operate within them as additional layers of reality impact the system. The space program and the Challenger space shuttle represent a complex system. The Challenger disaster was not predicted in advance but it could be explained later. Engineering education, engineering research, engineering education research (EER), and the interaction of engineers with society after they have been educated and begin to practice in a variety of organizational structures and contexts is indeed a complex system. Engineers are trained to understand, predict and control things like the trajectory of the rocket, chemical reactions, the flow of electrons in the power grid. They also lead and manage the operation of space programs, process plants, power plants and systems including the societal, environmental, and regulatory interactions of those systems. In addition, professional engineers hire and mentor engineering graduates as they walk the path from engineers-in-training to professional engineers.

The objective existence of the natural world and real social structures such as governments, universities, engineering programs, capstone design courses, the CEAB-GA performance constructs, and continual improvement requirements are recognized as transcendent of the human mind along with their purpose and function in society (Egbo, 2005; Thorpe, 2019). They exist independently of our experience with them and are regarded as intransitive (Shipway, 2011). The subjective and interpretive epistemological stance of Critical Realism is invoked in order to recognize the subjective human experience with intransitive structures where the same result may not happen with similar intransitive structures. This transitive aspect enables researchers to ask and seek experiential and qualitative answers to questions regarding the individual design-student learning experience, motivation, engagement, satisfaction, and the development of graduate attributes; the design and implementation of the course and community of practice; and the application of the CEAB-GA to develop measurement indicators and a continual improvement process. In addition, like design, it allows for a range of answers and explanations. Transitive human social interactions enable the construction and negotiation of meaning. In order to understand the research questions at the intersection of objective and subjective ways of knowing, a mix of epistemic realism and relativism is required.

This creates a stratified view of reality and allows for different ways of knowing and experiencing. Figure 2.3 illustrates the three domains of real, actual, and empirical (Barnett, 2013; Thorpe, 2019) with items relevant to engineering education as examples. Critical Realism recognizes the fallibility of distinguishing the transitive from the intransitive and that science is a human activity directed at studying natural phenomena often for the purpose of applying what is learned to engineering work, designs, and systems, all human technical *and* social activities. From a chemical engineering process design

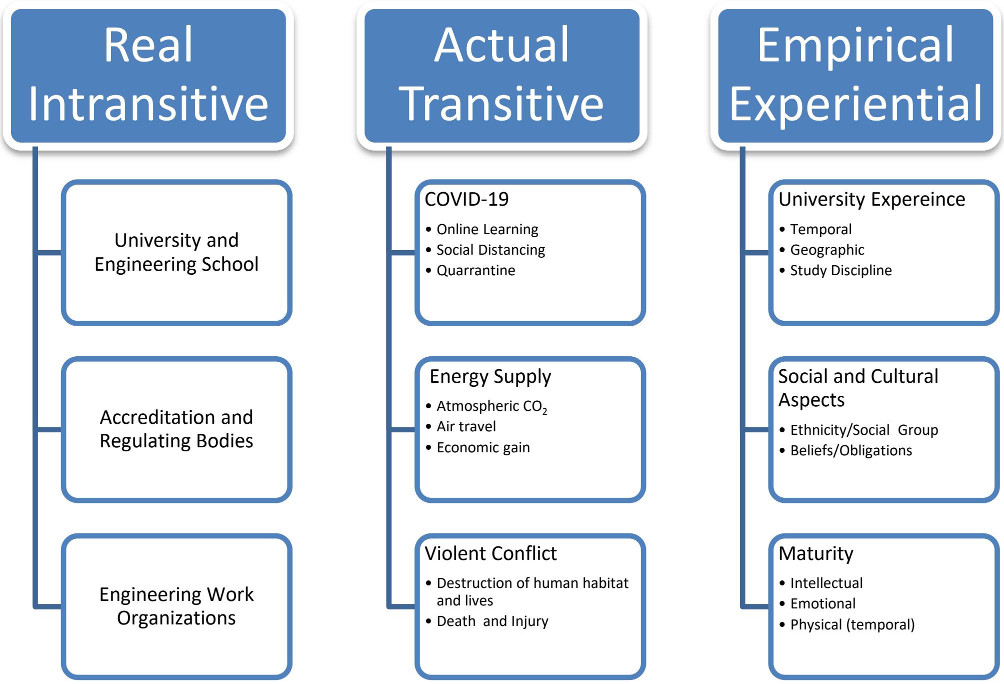


Figure 2.3. Engineering education and practice represented as a stratified or laminated ontological reality with three domains of real, actual, and empirical using the critical realist paradigm elements of intransitive, transitive, and experiential. (Barnett, 2013; Thorpe, 2019).

perspective, the intransitive structures are analogous to the vessels, the vessel design and arrangement, the process piping, the process control system and objectives. These items, once designed and assembled, belong to the real domain and are similarly classified as intransitive. Items corresponding to the actual domain are actual events that impact the real system, such as disturbances and control actions. Some are not predictable, some do not follow patterns, some are a result of the system design itself (i.e. reboiler steam condensation cycles where cascaded process temperature/ steam flow control is used), some may follow patterns and some may be predictable. Phenomena of the actual domain exist regardless of our knowledge or perception of them. Items in the empirical domain relate to the experience of the real and actual levels of reality. In our system process control example this would be analogous to corrosion in the piping, depending on the area of the piping one is examining the corrosion may be severe, or it may be mild and it may be the result of a single mechanism or several mechanisms. The operating experience of steam piping will be different than the experience of condensate piping or process piping. Our human experience and perception of the experience of other humans is limited to our awareness of their experience, whether that be in the present moment or their historical experience. Our human experience of the ‘natural’ phenomena described in the example above is also limited to our awareness of the system experience whether that be in the present moment or the historical experience of the system. For example, we may be aware that there is ongoing hydrogen embrittlement in the process system piping; we may even be monitoring it, performing maintenance replacements, etc. We will not necessarily be aware that a failure is imminent and may only become aware of the event after the failure and consequences have become an event in the actual domain. Our ability to know the experience of the system is limited to the tools we have to measure that reality *and* our interpretation of that reality.

It is important to note that intransitive items can and do change, even though they are relatively unchanging things. The Rocky Mountains were different in 1900 than they are in 2021. The Frank Slide (1903) at Turtle Mountain is an example of this type of change in an intransitive object in the natural world. The Frank slide itself would be a transitive or actual event, which occurred independent of human minds. The experience of the Frank Slide is empirical and would depend on one's temporal and geographic location, social and cultural factors, maturity at the time of the experience, and possibly other factors, perhaps the weather. The experience of a survivor is clearly different from that of one buried in the slide and varies again with the experience of the slide as one drives through the slide as a contemporary experience. The factors that impact the empirical or experiential can be studied and potentially controlled for in research and their impact on experience can be understood. Actual events may or may not be influenced by individual and/or collective decisions nor are they necessarily predicted. Inhabitants and miners were not aware of the imminent event yet the event still occurred. Was the slide on Turtle Mountain a result of mining activity or would the slide have occurred irrespective of the mining activity? This question was asked in the aftermath of the tragedy. The primary cause of the slide was later determined to be the unstable geological structure and mining activity was a secondary cause. The slope is still unstable and is monitored for movement. It is possible that another event may occur. The likelihood of another event is dependent on a multitude of natural and human factors, only some which may be predicted and controlled.

2.3 Axiological Alignment

The goal of this work is to develop a learning culture consistent with enabling the education of the whole engineer and a potential paradigm shift in engineering education to encompass the practices of sustainability and inclusivity in engineering. Building knowledge for action and participation are consistent with an emancipatory axiology. Critical realism embodies an emancipatory axiology (Bhaskar, 1975; Uppström, 2017; Thorpe, 2019) consistent with the transformative action of engineering education in general and more specifically with design science (Uppström, 2017) and educational leadership and management (Thorpe, 2020).

Engineering design, especially capstone design, is a bridge students cross to become engineers in training and to begin to practice engineering professionally. The nature of engineering education as it leads up to the capstone design courses is transformative. Students enter the undergraduate program as something other than an engineer and graduate with an engineering degree with the rights and privileges of an engineering degree. Students are transformed. They become engineers in training by developing an engineering identity through their experience in their engineering program. By the end of this experience students will have determined whether they identify with being an engineer, are still uncertain, or they do not. They will have formed opinions and developed beliefs about what is and is not possible, what sustainability means, and how we can or cannot influence the transitive and intransitive objects of our world.

Engineering education has an implicit set of values and ideals that inform the practice of engineering. These implicit values are transmitted by what we teach, how we teach it, and how we tell stories about past engineering designs and projects – the successes and the failures. In order to enable the transformation of engineering education we must recognize there is an implicit axiology in engineering education where technical and economic analyses have been privileged. For most engineers this is still regarded as a core aspect of design evaluation. The increasing importance of engineering safety, environmental stewardship, risk management, ethics, equity, wellness, and net social benefit beyond meeting the legal regulations highlights the axiological shift towards sustainable practice.

2.4 Theoretical Framework

A theory is a generalized statement of “interrelated concepts, definitions, and propositions that explain or predict events or situations by specifying relations among variables” (Glanz, 2008, p. 114) or the connections between or among phenomena within the limits of critical bounding assumptions that the theory explicitly makes (Gabriel, 2008). A theoretical or conceptual framework can be thought of as “the specific perspective, which a given researcher uses to explore, interpret or explain events or behaviour of the subjects or events they are studying” (Imenda, 2014).

In the context of this work, the application of the CEAB graduate attributes to course and program design is considered in the context of outcomes-based education. Outcomes based education is grounded in cognitive and constructivist learning theory (Hattie, 2009), which holds that students learn by constructing knowledge and meaning (Biggs, 1996) and continual improvement quality assurance ideas (Cornesky, 1993; Hattie, 2009)) which holds that measured student performance or attribute outcomes influence what institutions, administrators, instructors and course designers will do in the classroom. The motivation for such measures can be rooted in a variety of policy purposes and typically are initiated by regulatory or government stakeholders with an interest in the results of higher education related funding, budget constraints, economic productivity, and direction. At times, these performance or attribute outcomes are tied to funding and/or accreditation processes for a variety of purposes and as a result may encounter grass roots resistance in the implementation stage as demonstrated with the slow adoption of the CEAB graduate attributes in Canada.

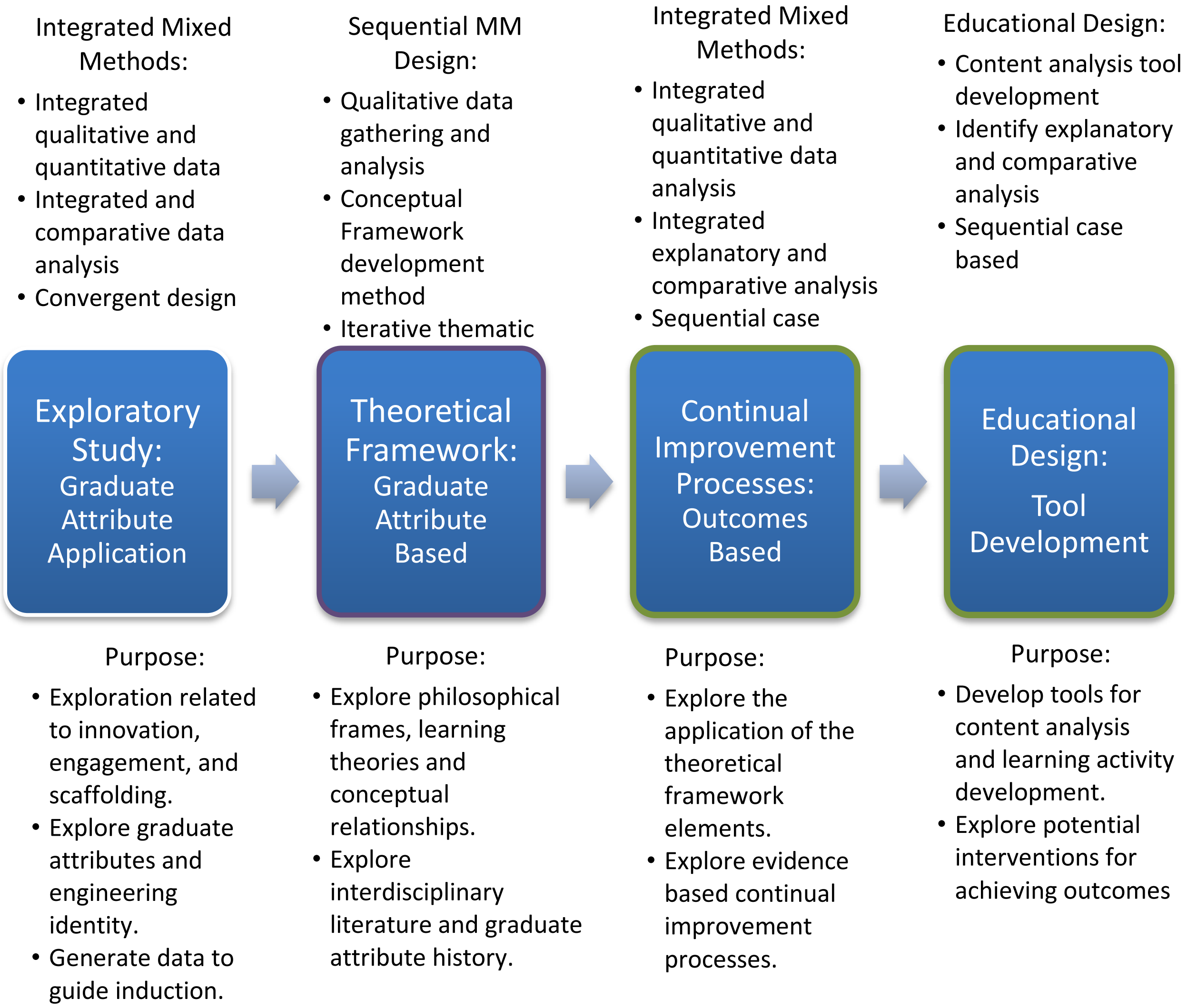
Here I investigate and design both processes and methods to develop and assess the CEAB graduate attributes in students participating in an engineering design course, generalize and connect the results obtained to engineering programs and position them more broadly in the context of engineering education and engineering education research in Canada. In order to facilitate the development of the whole engineer described by the graduate attributes and who is prepared to meet the complex sustainable development challenges we face, there is a need to understand what the graduate attributes are and what tools are necessary to develop them; what engineering practice is and how it relates to engineering education; how to measure graduate attributes and how they are connected to student development and engineering practice. A goal of this work is to develop a conceptual framework based on the graduate attributes and the literature and a generalized theoretical framework describing engineering education that can be used for evolving engineering education. These frameworks are developed by integrating and synthesizing concepts from the literature, experience, and practice using a grounded theory method within the design-based research methodology and inform the later development of transformative tools, processes, and recommendations.

2.5 Methodology

Design based research is the methodology chosen for this research as it is aligned with the phenomena being investigated: engineering design, engineering design education, and more broadly engineering education. It is also aligned with the creation of design tools, processes, and artefacts (interventions) to support a paradigm shift in engineering education towards producing graduates prepared for engineering practice in a world demanding a sustainable and inclusive practice of engineering. The approach adopted, from specific and pilot scale to more general and large-scale change in engineering education, is well aligned with the design research methodology (DRM) framework - an accepted and valid methodology in engineering (Blessing and Chakrabarti, 2009).

2.6 Methods

The mixed methods study design (Creswell, 2015), summarized in Figure 2.4, has three research phases. The first phase utilizes concurrent mixed methods studies to retrospectively evaluate design course improvements synthesized from prior work. The second phase describes the development of a generalized engineering education theoretical framework aligned with engineering practice and the engineering graduate attributes to support a learning culture and implementation of an innovation-based community of practice. The third phase describes the design of the graduate attribute based continual improvement process and iterative case-based design course evaluation. The final phase develops generalized tools for incorporating sustainable engineering leadership and management into the undergraduate curriculum and operationalizing sustainability into engineering education and practice.



Integrated Mixed Methods:
- Integrated qualitative and quantitative data
- Integrated and comparative data analysis
- Convergent design

Exploratory Study: Graduate Attribute Application

Purpose:
- Exploration related to innovation, engagement, and scaffolding.
- Explore graduate attributes and engineering identity.
- Generate data to guide induction.

Sequential MM Design:
- Qualitative data gathering and analysis
- Conceptual Framework development method
- Iterative thematic

Theoretical Framework: Graduate Attribute Based

Purpose:
- Explore philosophical frames, learning theories and conceptual relationships.
- Explore interdisciplinary literature and graduate attribute history.

Integrated Mixed Methods:
- Integrated qualitative and quantitative data analysis
- Integrated explanatory and comparative analysis
- Sequential case

Continual Improvement Processes: Outcomes Based

Purpose:
- Explore the application of the theoretical framework elements.
- Explore evidence based continual improvement processes.

Educational Design:
- Content analysis tool development
- Identify explanatory and comparative analysis
- Sequential case based

Educational Design: Tool Development

Purpose:
- Develop tools for content analysis and learning activity development.
- Explore potential interventions for achieving outcomes

Figure 2.4 Overall Mixed Method Design Summary

In the first phase, exploratory mixed methods were used to evaluate course improvements identified after the initial blended learning pilot and subsequent post course instructor reflections. Interventions and scaffolding aimed at improving the design of the blended learning course and developing graduate attribute competencies were evaluated, and themes underlying graduate attribute outcomes-based engineering education emerged. Student and instructor satisfaction and engagement were measured and reported in a mixed method study (Jamieson, 2017), metacognitive learning strategies were explored (Jamieson, 2017), the efficacy of a writing seminar was considered (Jamieson, 2018) and the course application of an innovation dynamo model was analyzed (Jamieson, 2018). The results of this phase have been published as outlined in Appendix B. These exploratory studies informed Phase 2 - the inductive development of an engineering education theoretical framework and Phase 3 - the course level and program level continual improvement process. A grounded theory approach based on an analysis of the graduate attributes in the context of learning theory was used to develop a conceptual framework and then generalize it to the broader categories of the theoretical framework. The validated and generalized engineering education and practice theoretical framework can be used in content development and analysis, as a basis for a continual improvement process, and learning culture development. The third phase comprised the development and application of the continual improvement process to be employed for subsequent iterations of the design course. This phase also included the resulting development of course improvements and tools that could be used in the next iterations of the course and elsewhere in the program. “Teaching Engineering for a Changing Landscape,” a summary paper applying the theoretical framework to metacognitive content development is published in The Canadian Journal of Chemical Engineering and presented in Chapter 3. The development of learning moments to support learning culture development and student engagement with learning and how to learn is presented in this paper. The conceptual and theoretical framework development is presented in more detail in Appendices D and E.

2.7 My Personal Interest in the Study and Who I am as a Researcher

I am a chemical process engineer who has worked in a variety of operations, environmental, leadership, process control, failure analysis, loss management, and design roles for the first ten years of my career and then worked part time as a consultant for the next ten. I became a process design instructor and content developer at the University of Alberta in 2009 and have taught process design since then. I began managing the project development and content development and delivery for the process design courses in 2012. I have worked with the same core teaching team since 2012 to develop the process design program and align the program with the CEAB graduate attributes. In 2014, I began researching in engineering education.

I believe that almost all students who enter the engineering program have the potential and capacity to become capable engineers in training. The engineering graduate attributes describe a general engineering identity (the whole engineer) and the design courses help students to transform from engineering students to engineers in training because they require students to use their knowledge to justify and evaluate solutions for open ended and ill-defined problems and then communicate the designed solution. I strongly support sustainable design, engineering leadership, risk management, engineering management, and continuous improvement. These practices have been a part of my career from early on and were taught to me by engineers *who mentored me* after I completed my undergraduate degree and to a large extent by lifelong learning and continuing professional development processes. I also believe that sometimes a disruptive change must occur to address a systemic issue in order to overcome the resistance to change. For example, the rise of process safety management science was a necessary disruption setting us on our path towards sustainability.

In addition to being an engineer - I am a teacher, researcher, lifelong learner, mother, mentor, skier, hiker, and enthusiastic participant in making connections using epistemic cognitive, metacognitive, and cognitive activities. I like to understand how philosophies, motivations, concepts, ideas, systems, and real-life processes and equipment fit together; how they work, how they are related, and why they are or are not connected along with the resulting impacts of operations, perceptions, and misperceptions. I first began learning about blended learning and engineering education research in 2014 when our teaching team won a blended learning award. I first became interested in helping students achieve their goals at the performance level they desire (typically A's and B's) when I realized the vast majority of students put in the requisite effort but not all achieve satisfactory or mastery results even though it is my belief that all are capable and intelligent. *Something was missing for them and I wanted to find out what it was*. One of the objectives of this work is to explore what might help more students achieve their potential at the performance level they desire.

I came from a positivist realistic objective engineering science paradigm and learned to embrace a relativist subjective paradigm to answer research questions using mixed methods and a pragmatic approach. To me quantitative methods measuring graduate attributes and constructs give the research structure and qualitative methods allow us to add the necessary insight to the subjective human experience. We can then begin to answer some of the research questions that lead to the creation of a more effective learning environment more quickly by better informing our CIP choices. I have come home to the philosophical perspective of complex critical realism (Clark, 2008). The paradigm framing this work is one of a mind independent world with mind dependent perceivers. I continue to be significantly influenced by the construct that learning happens as the result of what the student does and only what the student does. The teacher can only *influence* what the student does by providing an *effective* learning environment to challenge and motivate the student (attributed to Herb Simon, 2001).

> "Learning takes place in the minds of students and nowhere else, and the effectiveness of teachers lies in what they can induce students to do. The beginning of the design of any educational procedure is dreaming up experiences for students: things that we want students to do because these are the activities that will help them to learn this kind of information and skill." (Simon, 1998)

What the student experiences, what the student does, and what the student thinks about all contribute to the intellectual, cognitive, affective, and social development of the student. The students, the teacher, the academic administration, and the professional community of practice stakeholders all have a responsibility to deliberately create the learning culture of a classroom and an institution. Although this is a shared responsibility, the teacher has the influential and leadership role in the classroom to create and sustain a positive learning culture with consideration to sustainability and DEI. The academic administration has the leadership role and responsibility to create and maintain the institutional vision, structure, and framework so that it *supports and encourages the instructor* and *facilitates* the growth and development of a positive and active learning culture *everywhere* in the institution.

2.8 Study Context

The CEAB GA assessment was introduced in the 2012 accreditation cycle at the University of Alberta. Accredited programs were expected to map the graduate attributes to course learning outcomes, assess and report on achievement progress in the next accreditation cycle. As a part of this effort, the chemical engineering capstone design course was converted to a blended learning course in 2015. Jamieson (2015; 2016) investigated the historical evolution of the chemical process design courses, the design and implementation of the blended course in the context of the CEAB graduate attributes, the academic outcomes of the blended learning course design and suggested improvements for future iterations. Students participating in the previous lecture-based course and the first blended iteration of the course had similar academic outcomes (Jamieson, 2015). Topics to target for ongoing design course improvement were identified (reflection, writing, stakeholder communication, teamwork, and leadership development) in the context of improved graduate attribute competency. These topics are addressed as part of an ongoing continual improvement process and discipline-based education research (DBER) program. My list of publications is in Appendix B. Fourth year students typically take the capstone process design course just prior to graduation. The course enrolment fluctuates between 110 and 180 students.

References:

Anderson, T. and Shattuck, J., (2012). Design-Based Research: A Decade of Progress in Education Research? Educational Researcher, Vol. 41, No. 1, pp. 16–25, DOI: 10.3102/0013189X11428813

Barnett, R., (2013). Imagining the University. Abingdon: Routledge.

Bhaskar, R. (1975). A realist theory of science. London: Verso.

Bhaskar, R., (2016). Enlightened Common Sense, the Philosophy of Critical Realism, edited by Mervyn Hartwig. London: Routledge.

Biggs, J. B. (1996) Western Misperceptions of the Confucian-Heritage learning Culture. In: D.A. Watkins and J.B. Biggs, (Eds.) (1996) The Chinese Learner: Cultural, Contextual and Psychological Influences. Hong Kong, CERC and Melbourne: ACER. 45-68.

Biggs, J.B. (2003). *Teaching for Quality Learning at University: What the Student Does*. Buckingham; Philadelphia. Society for Research into Higher Education : Open University Press.

Blessing and Chakrabarti (2009). DRM, A Design Methodology. Springer : London

Clark, A.M., Lissel, S.L., Davis, C. (2008). Complex Critical Realism: Tenets and Application in Nursing Research *Advances in Nursing Science*, 31(4), pp. E67-E79.

Cornesky, R. A., Lind, J. (1993).The Quality Professor: Implementing TQM in the Classroom, Magna Publications Inc., Madison.

Creswell, J.W. (2015). A concise introduction to mixed methods research. Sage Publications.

Crotty, M., (1998). Foundations of Social Research: Meaning and Perspective in the Research Process. London; Thousand Oaks, Calif.: Sage Publications.

Egbo, Benedicta. (2005). “Critical Realism and Transformative Research in Educational Administration.” McGill Journal of Education 40 (2): 267–284.

Gabriel, A. (2008). The meaning of theory. Sociological Theory, 26, 173 – 199.

Glanz, K. (2008). Health behavior and health education: theory, research, and practice. San Francisco: Jossey-Bass Inc.

Hattie, J. The Black Box of Tertiary Assessment: An Impending Revolution (2009). 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.

Imenda, S., (2014). “Is There a Conceptual Difference between Theoretical and Conceptual Frameworks?” J Soc Sci, 38(2): 185-195 (2014)

Irving, T., (2017). Designing the engineer of 2050: Canadian engineering educators to meet in Toronto. University of Toronto Engineering News, https://news.engineering.utoronto.ca/designing-engineer-2050-canadian-engineering-educators-meet-toronto/

Jamieson, M.V., (2016). “Application of Blended and Active Learning to Chemical Engineering Design Instruction”, University of Alberta

Jamieson, M.V., and Shaw, J.M. (2017). Applications of peer teaching and deep learning in engineering education course design. *Proceedings of the 7th International Conference on Mechanics and*

Materials in Design Albufeira/Portugal 11-15 June 2017. Editors J.F. Silva Gomes and S.A. Meguid. Publ. INEGI/FEUP.

Jamieson, M.V., and Shaw, J.M. (2017). Applying metacognitive strategies to teaching engineering innovation, design, and leadership. *Proc. 2017 Canadian Engineering Education Conference (CEEA17)*, G. Evans (ed)(Toronto, Ontario; 4-7 June 2017), Paper 045.

Jamieson, M.V., Shaw, J.M., (2018). Graduate attribute based continuous improvement in a blended learning engineering design course – a writing seminar case study. *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) (Vancouver, British Columbia; 3-6 June 2018), Paper 77.

Jamieson, M.V., Shaw, J.M., (2016). Pre and Post Course Student Self Assessment of CEAB Graduate Attributes - A Tool for Outcomes Assessment, Student Skill and Course Improvement. Proc. 2016 Canadian Engineering Education Association (CEEA16) Conf. Paper 037; Dalhousie University; June 19 – 22, 2016

Jamieson, M.V., Shaw, J.M., "Student and Instructor Satisfaction and Engagement with Blended Learning in Chemical Engineering Design", Proc. 2017 Canadian Engineering Education Association (CEEA17) Conf. Paper 040; University of Toronto; June 4 – 7, 2017

Jamieson, M.V., Shaw, J.M., (2018). Teaching Engineering Innovation, Design, and Leadership within a Community of Practice. *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) (Vancouver, British Columbia; 3-6 June 2018), Paper 113.

Jamieson, M.V., Church, L., Vagi, F., Pick,W., Onuczko, T., Nychka, J., Nocente, N., Shaw, J.M. (2015). The University of Alberta chemical engineering capstone design course goes flipped! Proc. 2015 Canadian Engineering Education Conf. (CEEA15),

Johanesson and Perjons, (2014). An Introduction to Design Science. Springer: London. Ch 1, p. 1-18.

Kivunja, C. (2018). Distinguishing between Theory, Theoretical Framework, and Conceptual Framework: A Systematic Review of Lessons from the Field. International Journal of Higher Education 7(6)

Nield, K., (2007). Understanding the Chinese Learner: a Case Study Exploration of the Notion of the Hong Kong Chinese Learner as a Rote or Strategic Learner. Journal of Hospitality, Leisure, Sport and Tourism Education, 6(1), DOI:10.3794/johlste.61.131

Patel, S., (2015). *The research paradigm – methodology, epistemology and ontology – explained in simple language*. Retrieved from: http://salmapatel.co.uk/academia/the-research-paradigm-methodology-epistemology-and-ontology-explained-in-simple-language/

Shipway, B., (2011). A Critical Realist Perspective of Education. London: Routledge.

Simon, H.A. (1998). What we know about learning. *Journal of Engineering Education* 87(4) Wash. D.C.

Soysal ,Y., & Radmard, S., (2018) Social negotiations of meanings and changes in the beliefs of prospective teachers: A Vygotskian perspective, Educational Studies, 44:1, 57-80, DOI: 10.1080/03055698.2017.1345676

Thorpe, A., (2020) Why has critical realism not been used more in educational leadership and management research? A critical realist exploration, Journal of Critical Realism, 19:1, 29-44, DOI: 10.1080/14767430.2019.1682813

Uppström, E., (2017). Re-Visiting IS Design Science Artifacts: Making a Case for Critical Realism, Proceedings of the 50th Hawaii International Conference on System Sciences

3. Teaching Engineering For A Changing Landscape (*Canadian Journal of Chemical Engineering*, 2019)

TEACHING ENGINEERING FOR A CHANGING LANDSCAPE (Published July 8, 2019)

Marnie V. Jamieson[1(*)] and John M. Shaw[1]
[1]Department of Chemical and Materials Engineering (CME), University of Alberta, Edmonton, Canada
(*)*Email:* mvjamies@ualberta.ca and jmshaw@ualberta.ca

ABSTRACT

Engineering educators face a rapidly changing, and ever more challenging world. Rapidly evolving industry demands, accreditation agencies, and students themselves are calling for an engineering education with integrated multidisciplinary design knowledge, leadership, communication, business, education, entrepreneurship, sustainability and lifelong learning explicitly included in their undergraduate programs. Students still need the core content knowledge of thermodynamics, mass, energy, and momentum balances and fluxes. They also need integrated socio contextual knowledge to evaluate a design for sustainability and demonstrate a net positive social benefit. There is only so much time available in an undergraduate program and learning takes time. These challenges are driving changes to both what and how we teach our students to integrate broader competencies and enhance engineering student graduate attribute achievement.

A framework for engineering education includes fundamental and socio-contextual knowledge integrated with metacognitive and professional skill development. This contribution provides practical ideas for how to infuse these dimensions into courses, support developing engineering practice and deepen student engagement with their courses.

Keywords: learning culture, innovation, teamwork, leadership, sustainable design, capstone design courses, graduate attributes, continual course improvement, metacognitive skill, professional development

INTRODUCTION

The relative achievement of graduate attributes (GA), by engineering undergraduate students, depends on multiple factors including prior student experiences, their metacognitive and professional skills, their engagement and the learning effort they expend, the quality and quantity of their fundamental and socio-contextual knowledge bases.[21,23,24,27,37,41] Analysis of graduate attribute outcomes for an engineering course within an engineering program necessitates examining a complex system.[4] Complex systems[7,8] may have a range of short term and long-term outcomes. They are characterized by multiple interacting factors where generalized formulas have limited applicability and where doing the same thing twice does not necessarily result in the same outcome. Students in a program may all graduate but almost certainly won't attain the same levels of achievement for graduate attributes.[6] The proposed engineering education and practice framework[22] (Figures 3.1 and 3.2) coupled with the continual course improvement method advocated in this work can be used to improve and to develop engineering science and design course content and to support learning.[18] The conceptual framework in Figure 3.2 was developed from an interdisciplinary literature review, including the graduate attribute literature, with the goal of developing a generalized theoretical framework identifying key engineering education components (Figure 3.1). The latter can also be thought of as a model for designing or redesigning engineering courses and programs and as a high-level evaluation tool for existing course and program content with respect to continual improvement and perhaps to better inform GA measurement indicator selection.

A case based integrated mixed methods design is used in this work to examine course and student outcomes, to identify *improvement actions* for subsequent iterations, and to demonstrate student attribute achievement. The method is briefly presented here and builds on elements of previously proposed methods to improve student outcomes in higher education such as scholarly teaching,[37] total quality management,[9] and teaching for effective learning.[12,42] A more detailed elaboration of the theoretical framework development and continual improvement process application is provided elsewhere.[18,22] The engineering education and practice framework was developed using qualitative analyses of interdisciplinary and graduate attribute literature[22] and the ongoing use of a continual improvement process.[18-27] The framework provides general guidance on the key types of learning experiences required and the continual improvement process is used to more effectively target course improvements needed for students to excel. It can help guide a plan for short and long term course and program development.

DEVELOPING A LEARNING CULTURE

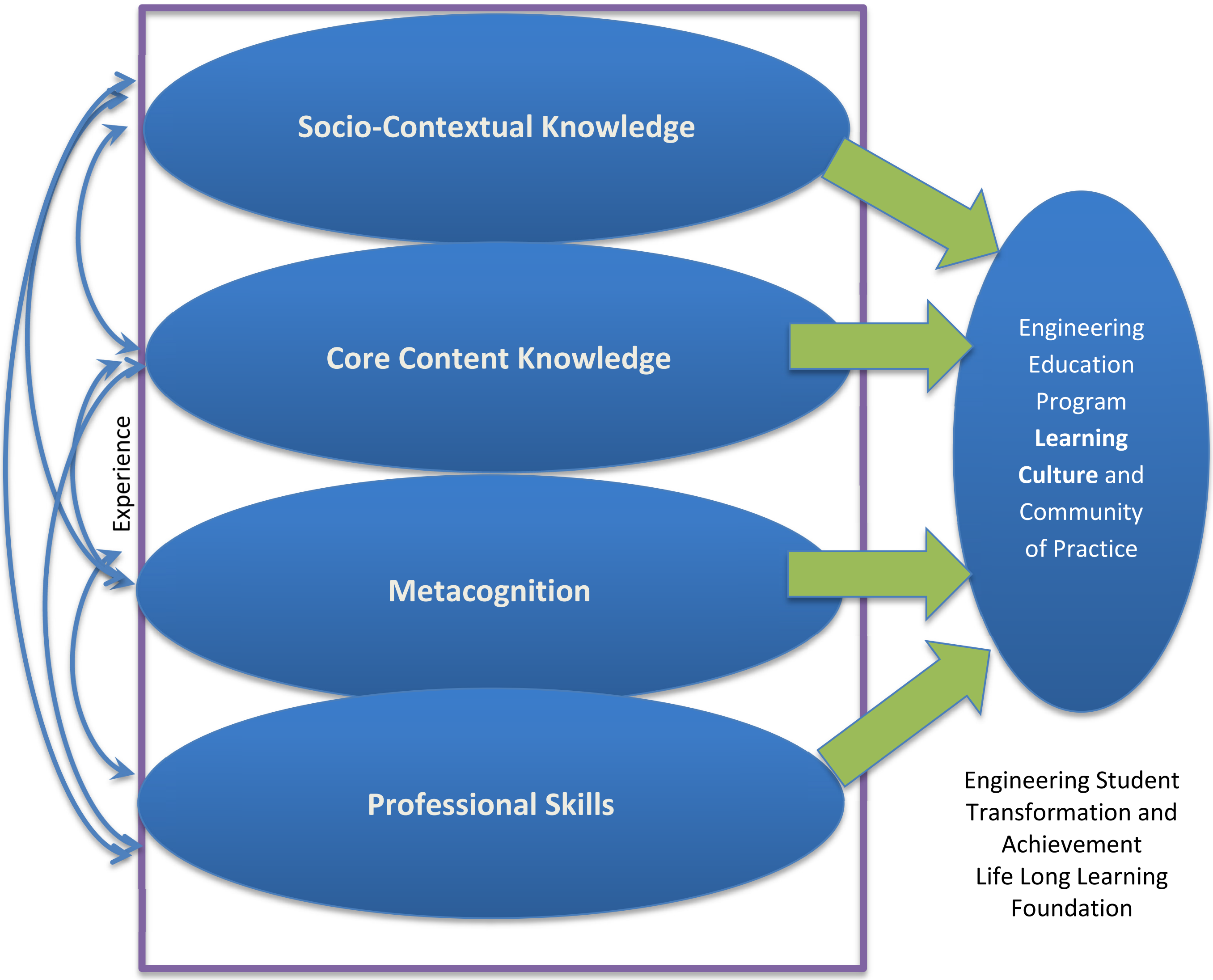
- *What defines an engineering learning culture? Why is it relevant?* An engineering program is a complex system.[21,22,41] Instructors *and* students change from iteration to iteration as they are learning, responding, and reflecting. Students and student cohorts can be influenced by previous

---

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

> work experience, class size, teammates, course sequencing, extra curricular activities, life experience, performance in prior related courses, different instructors may teach the same prerequisite courses, economic factors, and perceived career opportunities, etc. The list of possible confounding factors is Self Regulation Connections with the Learning Process

long. This observation lends support to the idea that students experience our design courses uniquely even though there is a common “reality” for all students.[7,8] Instructors are also subject to their own learning, experiences, and metacognitive processes as they develop and deliver instructional material. Beliefs,



Themes of Engineering Practice and Identity

Figure 3.1. Generalized Engineering Education and Practice Theoretical Framework

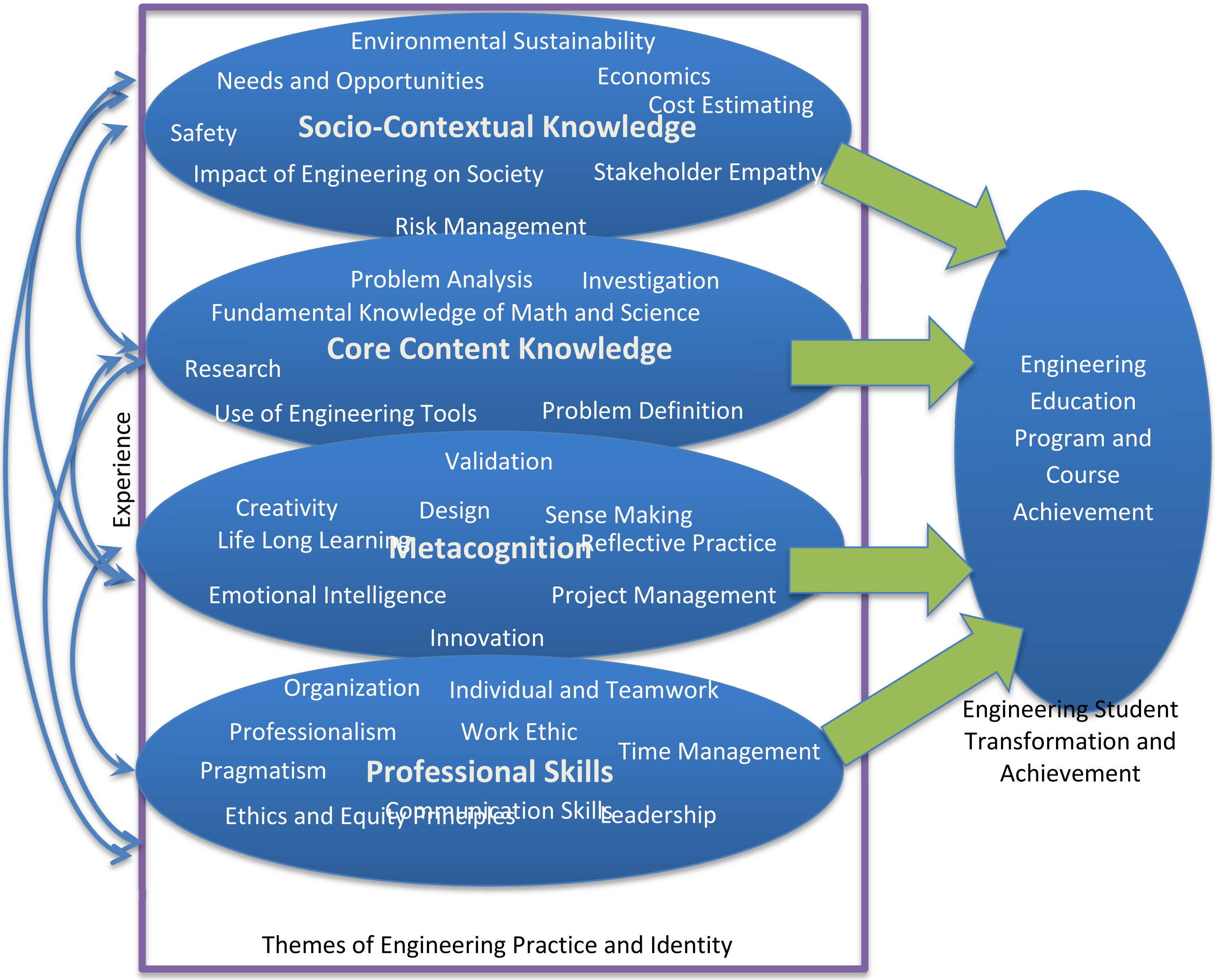


Figure 3.2. Underlying Engineering Education and Practice Conceptual Framework

perceptions, and values regarding learning and the nature of intelligence underlie the preparation of course materials and the ensuing student approaches to learning.[1,2,3,4,10,13,30,32,43] Learning is influenced by the beliefs and values of both students and instructors regarding intelligence,[10,11,17,32,40] motivation,[10,11,17,24,32,35,36,40] and self-efficacy.[5,10,11,17,32,38,34] Learning how to learn is an engineering graduate attribute[5,22,28,29-31,33,38,39,41] and a learning culture attribute[2,18-21,22,25,32,34]. Actively engaging students with *effective tools for learning* and a growth mindset[10,11,17] aids students at all levels as they negotiate the challenges of open-ended complex engineering science and design processes associated with engineering practice. Metacognitive skill development can have a significant impact on students' success.[12,32,34,42] Metacognitive strategies tend to develop self-awareness, self-control, and self-regulation and enable students to learn how to learn.[34,42,43] Key strategies to consider are summarized and referenced with resources in Table 3.1.

TABLE 3.1 Key Metacognitive Strategies for Engineering Students[12,18-27,32,34,41,42,43]

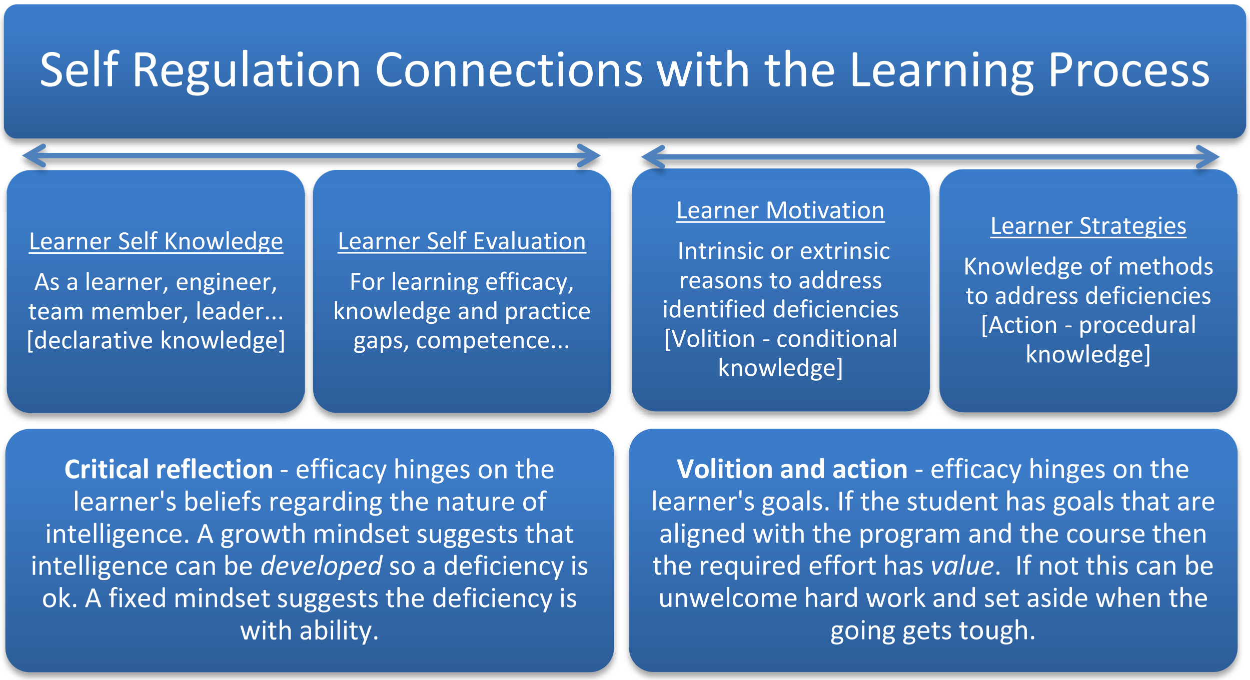
Metacognitive Strategy	**Description**
Identification and Awareness of Knowledge Gaps[12,19,20,21,23,27,32,34,42,43]	Being able to identify what one knows and what one doesn't know about a topic allows for research and learning to begin.
Planning and Organization[20,21,25,24,26,32, 34, 41,42]	Students must learn how to plan, monitor, and evaluate short and long-term tasks. Writing and thinking about tasks are required.
Generating Questions[19,24,25,27,32,34,42]	Asking questions helps students identify what they do and do not know. They must identify knowns and unknowns to learn. It cannot be done for them.
Conscious Control of Processing[18,19,22,24,32, 34,42,43]	Being able to identify different types of knowledge (declarative, procedural, conditional) allows for conscious control of processing of knowledge.
Consequence Analysis[12,20,22,24,32,34,41]	Evaluating a choice or a strategy to determine the expected consequence(s) of actions or behaviour(s) with the potential ramifications develops causal contextual relationships.
Setting and Pursuing Goals[23,25,26,32,34,41,42,43]	Goal setting provides motivation and accountability in learning and in engineering.
Self Evaluation and Monitoring[19,20,21,23,24,26, 32,34,42,43]	Self-evaluation with respect to goal progress, achievement, knowledge, cognitive, and emotional regulation.
Peer Teaching or Imagining Teaching[12,27, 32,42]	When students need to teach or explain something to their peers, it helps them develop their own knowledge and identifies knowledge gaps along with relationship skills.
Making Their Own Notes and Writing[12,19,21,27,32,34,42]	Done while reading material, listening in class, solving problems. When students make summary notes they put the content into their own words and

	process it.
Preview and Review[19,27,32,34,42]	Previewing lecture material in advance and reviewing it after gives students an opportunity to determine what they know and don't know and to generate questions.
Working in Pairs and Teams[12,19,20,25,26,27,34]	Requires students to develop skills and plan. Students must be able to defend their thinking and methodologies to their teammates.
Problem solve – without an example[12,25,27, 32,34]	Creating an exam question or solving a problem without a step by step example allows students to find their knowledge gaps and then do something about it i.e. research, ask questions, analyze, synthesize, etc.

LEARNING MOMENTS

When will I have time to develop a learning culture or teach about metacognition? Learning Moments are fast and effective. They can be a single slide or a handout designed to provoke learner engagement with metacognition and to communicate that learning is a priority. Metacognitive skills are higher level thinking processes engineers use to determine when to use certain procedures, transfer between contexts, determine if a model is applicable to a new situation, evaluate a design and determine whether something makes sense.[2,5,15,16,32,34,35,38-40] Practicing engineers may find this to be second nature. Engineering students are still learning how to do it. Reflection and asking questions are also metacognitive skills.[2,3,4,13,14,32,34,38-40,41,43] When we encourage students to reflect on their learning strategies and the efficacy of those strategies we are teaching them how to be engineers.[22,41]

A more detailed discussion of learning moments and their creation is a topic of a future study. A Learning Moment to facilitate discussion or reflection is illustrated in Figure 3.3. In this example we ask learners to examine the broader context of their work and to ask why something is or is not valid. For example, what type of knowledge is self-evaluation? When we require engineering students to ask questions and consider why something is valid or works in a certain way we are encouraging the development of conditional knowledge. Declarative (*what, about*), procedural (*how, when*), and conditional (*why, when, where*) knowledge examination is necessary for the development of contextual engineering skills. Providing students with learning objectives tells them about the declarative knowledge we expect them to know along with the learning goals. Examples and models they can follow provide them insight into procedural knowledge. Asking them to use their knowledge in a new context gives students practice with conditional knowledge.[4,27-30] Learning is better if we don't save conditional knowledge applications for the exam. Student confidence is developed when they learn about conditional knowledge and how to practice prior to a summative exam - perhaps in a low stakes formative assignment or learning activity. Including learning moments with learning objectives at the beginning of a class can teach students more about how to learn *and* how to transfer their learning to new contexts during class. Learning moments are like safety moments. They help students *and* instructors connect to the priority task of learning together.



Self Regulation Connections with the Learning Process

Learner Self Knowledge

As a learner, engineer, team member, leader... [declarative knowledge]

Learner Self Evaluation

For learning efficacy, knowledge and practice gaps, competence...

Learner Motivation

Intrinsic or extrinsic reasons to address identified deficiencies [Volition - conditional knowledge]

Learner Strategies

Knowledge of methods to address deficiencies [Action - procedural knowledge]

Critical reflection - efficacy hinges on the learner's beliefs regarding the nature of intelligence. A growth mindset suggests that intelligence can be *developed* so a deficiency is ok. A fixed mindset suggests the deficiency is with ability.

Volition and action - efficacy hinges on the learner's goals. If the student has goals that are aligned with the program and the course then the required effort has *value*. If not this can be unwelcome hard work and set aside when the going gets tough.

Figure 3.3 – Learning Moment Example Slide or Handout – Ask learners what they think.

CONTINUAL IMPROVEMENT PROCESS

The overall objective of a continual improvement process,[18] illustrated in Figure 3.4, is the continual identification of improvement actions or to demonstrate the adequacy of the status quo *over time*.

Improvement actions are targeted to enhance the learning culture and graduate attribute development from an outcome based assessment perspective. Evidence based improvement actions can target course or program level refinements and should be supported by an analysis of outcomes at the course level. The method used to identify the improvement actions should include multiple perspectives and engage stakeholders, including learners, teachers, academic program administrators, and engineering practitioners. This approach considers the wider context of program and practice objectives and continuity. Is the program progressive and does it support engineering practice? If no improvement actions are identified the status quo can be justified - based on an outcome-based evidence assessment. Scholarly teaching[37] advocates for the evaluation and ongoing improvement of teaching practices. This continual improvement process is more closely aligned with the scholarship of teaching and learning and advocates for graduate attribute achievement, learning, and teaching evaluation to inform improvement actions. Example cases can be found in previous work.[18,20,21, 23,24,25]

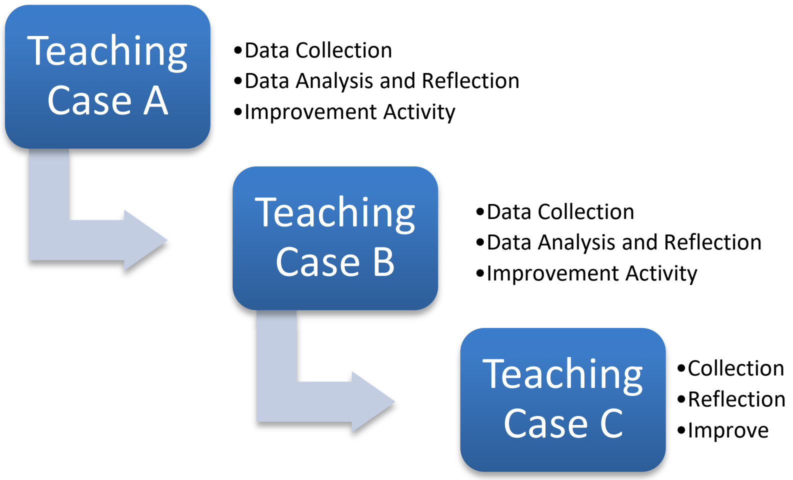


Fig. 3.4 – Sequential Case Based Integrated Mixed Method Design for Continual Improvement [18]
© ASEE 2019 M.V. Jamieson, J.M. Shaw, "A Continual Improvement Process for Teaching Leadership and Innovation within a Community of Practice," ASEE Annual Conference Proceedings, American Society for Engineering Education, Tampa, 16-19 June 2019.

SUMMARY

The engineering education and practice frameworks, described in this contribution, generalize key themes of engineering education. These frameworks can be used to help guide students to develop contextual and practice skills across the graduate attributes enabling more advanced graduate attribute achievement on completion of their engineering program. Successful program and design course curriculum development also support lifelong learning and professional practice roles for engineers as their careers develop.

Beliefs, perceptions and values regarding learning shape the culture of a classroom and a program of study. Accountability, engagement, recognition, motivation, appreciation, credibility, and continual improvement are key elements of a functional learning culture. Learning moments are a concise way to make learning to learn a relevant part of each session and encourage student reflection and metacognition. Encouraging metacognitive experiences and strategies can help students learn how to learn and deepen their engagement with the applications of course materials, and the contextualization of engineering and design problems.

REFERENCES

[1] A. A. Jensen, X. Du, M. Kirkebæk. Teaching and Learning Culture: Negotiating the Context, Sense Publishers, Rotterdam, **2013**.

[2] L.S. Bormotova, A Qualitative Study of Metacognitive Reflection: The Beliefs, Attitudes and Reflective Practices of Developing Professional Educators, PhD Thesis, Indiana University of Pennsylvania, **2011**.

[3] D. Boud, R. Keogh, D. Walker, Using Experience For Learning, SRHE, University Press, Michigan, **1993**.

[4] D. Boud, R. Keogh, D. Walker, Reflection, Turning Experience into Learning, Kogan Page, London, **1985**.

[5] A. Brown, “Metacognition, Executive Control, Self Control, and Other Mysterious Mechanisms,” in Metacognition, Motivation and Understanding, F. Weinert, R. Kluwe Eds., Erlbaum, Hillsdale, NJ, **1987**, p. 65-116.

[6] Canadian Engineering Accreditation Board, “Canadian Engineering Accreditation Board: Accreditation Criteria and Procedures,” Engineers Canada, **2016**, accessed June 20, 2018, https://engineerscanada.ca.

[7] A. M. Clark, S. L. Lissel, C. Davis, Complex Critical Realism, Adv. Nurs. Sci. **2008**, *31*(*4*), E67.

[8] A. M. Clark, T. G. Briffa, L. Thirsk, L. Neubeck, J. Redfern, BMJ **2012**, *345*(7888), 25.

[9] R. A. Cornesky, J. Lind, The Quality Professor: Implementing TQM in the Classroom, Magna Publications Inc., Madison, **1993**.

[10] C. S. Dweck, Self-theories: Their Role in Motivation, Personality and Development, Taylor and Francis, Philadelphia, **1999**.

[11] J. Ehrlinger, A. L. Mitchum, C. S. Dweck, *J. Exp. Psychol.* **2016**, *63*, 94.

[12] R. M. Felder, R. Brent, Teaching and Learning STEM a Practical Guide, Jossey-Bass, San Francisco, **2016**.

[13] D. R. Garrison, J. B. Arbaugh, *Internet High. Educ*. **2007**, *10*, 157.

[14] D. R. Garrison, M. Cleveland-Innes, AJDE **2005**, *19*(*3*), 133.

[15] J. Greeno, A. Collins, L. Resnick, "Cognition and Learning," in Handbook of Educational Psychology, R. Calfee, D. Berliner Eds., MacMillan, New York, **1996**, pp. 15–46.

[16] L. M. Guglielmino, Development of the Self-directed Learning Readiness Scale, PhD Thesis, University of Georgia, **1977**.

[17] K. Haimovitz, C. S. Dweck, *Child Dev.* **2017**, *88*(*6*) 1849.

[18] M. V. Jamieson, J. M. Shaw, "A Continual Improvement Process for Teaching Leadership and Innovation within a Community of Practice," ASEE Annual Conference & Exposition, American Society for Engineering Education, Tampa, 16-19 June **2019**.

[19] M. V. Jamieson, J. M. Shaw, "Applying Metacognitive Strategies to Teaching Engineering Innovation, Design, and Leadership," CEEA Annual Conference, Canadian Engineering Education Association, Toronto, 4-7 June **2017**.

[20] M. V. Jamieson, J. M. Shaw, "CATME vs. ITP Metrics-Which one should I choose?" ASEE Annual Conference & Exposition, American Society for Engineering Education, Salt Lake City, 24-27 June **2018**.

[21] M. V. Jamieson, J. M. Shaw, "Graduate Attribute Based Continuous Improvement in a Blended Learning Engineering Design Course – a Writing Seminar Case Study," CEEA Annual Conference, Canadian Engineering Education Association, Vancouver, 3-6 June **2018**.

[22] M. V. Jamieson, J. M. Shaw, "Learning to Learn: Defining an Engineering Learning Culture", CEEA Annual Conference, Canadian Engineering Education Association, Ottawa, 9-12 June **2019**.

[23] M. V. Jamieson, J. M. Shaw, "Pre and Post Course Students Self-assessment of CEAB Graduate Attributes…Outcomes Assessment, Student Skill and Course Improvement," CEEA Conference, Canadian Engineering Education Association, Dalhousie, 19-22 June **2016**.

[24] M. V. Jamieson, J. M. Shaw, "Student and Instructor Satisfaction and Engagement with Blended Learning in Chemical Engineering Design," CEEA Annual Conference, Canadian Engineering Education Association, Toronto, 4-7 June **2017**.

[25] M. V. Jamieson, J. M. Shaw, "Teaching Engineering Innovation, Design, and Leadership within a Community of Practice," CEEA Annual Conference, Canadian Engineering Education Association, Vancouver, 3-6 June **2018**.

[26] M. V. Jamieson, L. Church, F. Vagi, W. Pick, T. Onuczko, J. Nychka, N. Nocente, J. M. Shaw, "The Univ. of Alberta Chemical Engineering Capstone Design Course Goes Flipped!" CEEA Conference, Canadian Engineering Education Association, Hamilton, 31 May-3 June **2015**.

[27] M. V. Jamieson, L. Goettler, A. Liu, J. M. Shaw, “To Teach is to Learn: Student and Instructor Perspectives on Assignment Development as a Springboard to Deep Learning,” CDIO International Conference, CDIO, Calgary, 18-22 June **2017**.

[28] A. Johri, B. M. Olds, *JEE* **2011**, *100*(*1*), 151.

[29] F. F. Joyner, D. T. Y. Mann, T. Harris, *AJEE* **2012**, *3*(*1*), 67.

[30] J. Lave, E. Wenger, Situated learning: Legitimate Peripheral Participation, Cambridge University Press, Cambridge, **1991**.

[31] P. Lavoie, C. Michaud, M. Bélisle, L. Boyer, E. Gosselin, M. Grondin, C. Larue, S. Lavoie, J. Pepin, *J. Adv. Nurs.* **2018**, *74*, 239.

[32] S. Y. McGuire, S. McGuire, Teach Students How to Learn, Stylus Publishing, paperback, **2015**.

[33] T. A. O'Neill, A. Deacon, N. L. Larson, G. C. Hoffart, R. W. Brennan, M. Eggermont, W. Rosehart, *Learn. Individ. Differ.* **2015**, *39*, 124.

[34] E. Papaleontiou-Louca, Metacognition and Theory of Mind*,* Cambridge Scholars, Newcastle, **2008**.

[35] P. R. Pintrich, “The Role of Goal Orientation in Self-Regulated Learning,” in Handbook of Self-Regulation M. Boekaerts, P. P. Pintrich, M. Zeidner Eds., Academic, San Diego, **2000**, pp. 451–502.

[36] A. Rattan, C. Good, C. S. Dweck, *J. Exp. Soc. Psychol.* **2012**, *48*(*3*), 731.

[37] L. Richlin, “Scholarly Teaching and the Scholarship of Teaching,” in Scholarship revisited: Perspectives on the scholarship of teaching and learning C. Kremer Ed., Jossey-Bass, San Francisco, **2001**, pp. 57–68.

[38] D. Schon, Educating the Reflective Practitioner: Towards a New Design for Teaching and Learning in the Professions, Jossey-Bass, San Francisco, **1987**.

[39] D. Schon, The Reflective Practitioner: How Professionals Think in Action, Basic Books, New York, **1983**.

[40] D. A. Schunk, Learning Theories an Educational Perspective, 6th ed., Pearson, Boston, **2012**.

[41] G. Stubley, “Thinking About Learning – Inferences From How We Support Curriculum Design,” CEEA Annual Conference, Canadian Engineering Education Association, Vancouver, 3-6 June **2018**.

[42] M. D. Svinicki, W. J. McKeachie, McKeachie’s Teaching Tips: Strategies, Research, and Theory for College and University Teachers, Cengage Learning, Wadsworth, **2014**.

[43] G. P. Thomas, “The Metacognitive Science Teacher: A statement for enhanced teacher cognition and pedagogy,” in Contemporary Science Teaching Approaches: Promoting Conceptual Understanding in Science F. Ornek, I. Saleh Eds., Information Age, Charlotte, **2012**, pp. 29-53.

4. Engineering Innovation, Design, and Leadership Through a Community of Practice (*Education for Chemical Engineers* 2020)

This paper originated as a conference paper during the exploratory research phase of my work. It appears below as the latest manuscript, the preprint version of the accepted April 2020 paper for ECE.

Engineering Innovation, Design, and Leadership Through a Community of Practice

Marnie V. Jamieson and John M. Shaw
Department of Chemical and Materials Engineering, Faculty of Engineering, University of Alberta
mvjamies@ualberta.ca and jmshaw@ualberta.ca

Abstract *– Instructors with a diverse mix of industrial and academic experience teach our process design courses. The instructors work in close collaboration with working professional engineers including industrial technical specialists, entrepreneurs, and academic colleagues with an industrial focus. We prepare unique process design projects and advise student teams collectively. Many of the industry advisors are long-term contributors and over time some have become instructors for the design course. Our community of practice offers students a window on engineering design practice and innovation as they transition to the professional community. This paper explores how a community of practice contributes to student development, the achievement of the Canadian Engineering Accreditation Board (CEAB) graduate attributes, and the development of an innovation ecosystem. By providing targeted direction to industrial participants in a process design course community of practice, we show that the focus of the community and their motivation for participation can be shifted over time from benchmarking competence to innovation competence that also supports student innovation and leadership capacity development.*

Keywords: Community of Practice, Graduate Attributes, Design, Capstone, Student, Self, Outcomes, Course, Assessment, Communication, Innovation, Leadership, Blended Learning

1. INTRODUCTION

Undergraduate student intellectual development is progressive [11,33]. This development is required to support student achievement of the Canadian Engineering Accreditation Board graduate attributes (CEAB GA) [5] and student attainment of the associated capstone design course learning outcomes [18,19,21]. The performance of capstone design tasks is linked to the CEAB GA and requires students to have developed cognitive *and* affective domain skills at all levels of Bloom's taxonomy [4,18,19,21]. The global course learning outcomes are mapped to the twelve CEAB GA in Table 4.1. These outcomes include technical and professional competences including communication, leadership, self-direction, self-management, and introspection as life-long learners. Students are given opportunities to plan their work, develop competences and skills and then to reflect on their achievement as course deliverables are prepared. There are three structured metacognitive cycles in the course design of approximately four weeks each as illustrated in Figure 4.1. During each cycle students are given feedback and are required to perform self and team assessments co-incident with the delivery of a project solution proposal (deliverable 1) early in the term, the mass and energy balances for the proposed solution (deliverable 2) after the course midpoint, and the submission of a final report (deliverable 3) at the end of the term. After completing these milestone deliverables, students reflect on the quality of their design work, their schedule progression, their role, and their organizational success. They then adjust their plans for the next phase of their course work and the beginning of their careers. Individual and team performance peer evaluations [32] are completed and followed by team review using a team performance reflection rubric. This course structure arose over time as a result of instructor reflection on the types of questions posed and issues most frequently encountered by students during the capstone design course and was in place five years prior to the blended learning implementation. Many of the questions indicated that students had developed standard problem-solving techniques characteristic of the third level of Bloom's cognitive task classification but were still developing higher-level cognitive and affective domain task and open-ended problem-solving abilities. We redesigned the capstone course and learning materials to support student cognitive and affective development at higher levels of Bloom's taxonomy including analysis, synthesis, evaluation, and creation. A flipped and blended learning course delivery format was adopted as elaborated elsewhere [18,21,24]. Additional course and design project innovation strategies were developed and employed concurrently with the blended learning course design to enhance student development of an engineering practice mindset alongside innovation and leadership skills.

Table 4.1. Global Capstone Design Learning Objectives Mapped to the CEAB Graduate Attributes

Course Global Learning Objective	Related CEAB Graduate Attributes
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 (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.	3, 4, 5, 9
Inculcate life-long learning and teamwork 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

Development of higher-level cognitive and affective skills and abilities is best achieved through deliberate integration of student intellectual and cognitive development within engineering undergraduate curricula. Their inclusion enhances student performance and can be realized by directly supporting the creation and implementation of relevant learning activities [1,2,3,4,12,19,21,23,24,26]. Teaching leadership alongside process and product innovative design can be accomplished by constructing learning activities [5,12,14,18,19,24,] in an experiential learning spiral [16] embedded in a contextual and supportive course structure using a situative learning framework [29] and/or a community of practice [9,13,15,24,37]. In this contribution we combine these threads from the literature to illustrate the use of an integrated community of practice, comprising individual students, student teams, instructors, and industrial advisors for the development of innovation and leadership skills within the context of a capstone design course. The impact is demonstrated by the scope and nature of design projects that are now successfully addressed by students in the redeveloped capstone design course.

CEAB graduate attributes are not explicit regarding innovation or leadership, but at a minimum, they are implicit in the design, engineering tools, communication, and impact on society performance criteria. In order for engineering students to learn about these implicit attributes and practice innovation and leadership, we set out to create a learning environment to support this goal including activities, assessments, and feedback within a community of practice. We posed the questions: *How can innovation and leadership skills be taught to students in design courses?* and *How can a situative learning* *environment, supported in a community of practice, infuse students with an innovative spirit and leadership capacity*?

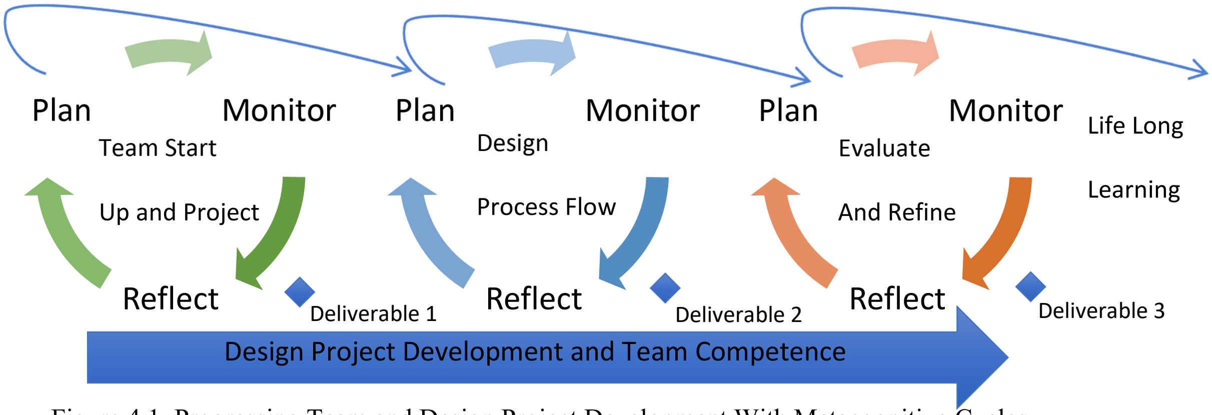


Figure 4.1. Progressing Team and Design Project Development With Metacognitive Cycles.

1.1 Motivation

Innovation, design, and leadership skillsets are sought after in new engineering graduates and practitioners alike. The CEAB includes design, professionalism, and the ability to work as a leader on a team, as key engineering graduate attributes. Including innovation and leadership development activities in undergraduate engineering programs of study is challenging at the course level and for engineering programs due to over all time constraints and the already ambitious learning outcomes for individual courses. However, their inclusion is necessary if the design, operational, and decommissioning needs associated with global and complex engineered systems now and in the future are to be met.

1.2 Literature Review

Student development and learning can be enhanced with metacognitive strategies, feedback, engagement, and spaced practice [14,23]. Including these strategies throughout a program of study increases the use of ongoing spaced skill practice and introduces students to the technical and professional skill integration required to meet CEAB graduate attribute performance criteria earlier in their program of study. Cognitive learning frameworks [12,19,26] support student knowledge acquisition and help students connect concepts in active learning environments [3,12,18,26]. Students who develop self-conscious management of the learning process (metacognition) often perform better than those who do not [12,28]. Intellectual and professional development require more than cognitive development [6,7,9,23,37,40]. A situative learning framework including student activities such as collaborative learning, leadership, task planning, and work strategy implementation combined with iterative design processes can lead to metacognitive regulation functions [23]. A recursive learning cycle or spiral [8,11,14,16] where reflection leads to targeted practice further develops technical, design, team, and leadership skills that transfer to new circumstances [19, 23, 24]. The capstone design course structure, Figure 4.1, incorporates each of these features.

1.3 Capstone Design Course Structure Description

Before the course begins, students complete a personal and team based skills and knowledge assessment. Individual and team strengths and weaknesses are identified and the teams prepare a development plan to address their specific needs during the term. For example, students are required to take on a leadership role either related to specific deliverable activities or related to the organization of the team as a whole related to specific needs. Formative and summative assessments coincident with each deliverable provide students with an opportunity to learn from their experiences and to apply their learning ahead of subsequent deliverable deadlines. For example, draft copies of deliverable (1) are assessed by the instructor working most closely with a team. Formative feedback is provided before teams submit this deliverable for summative assessment by the instructors and before students receive additional feedback from the industrial advisor who proposed the project at their first project meeting. Industrial advisors act as clients and provide feedback to teams based on the solution the students have proposed. After the meeting, students are then required to complete personal and team reflections to assess the efficacy of their strategies and levels of achievement vis-à-vis the CEAB GA. They then have an opportunity to make changes for the subsequent cycles.

Innovation processes [10,17,35] and effectuation thinking [35,36] can be introduced into a design course [24] structured in this way. This type of contextual learning, described by Lave [29] and Greeno, Collins & Resnick [12] leads to a *strengthening of the practices of a community* because learners are offered legitimate opportunities to participate [29]. Innovation requires thinking processes, goal setting, and strategies [8,19,24,35,36,39] including effectuation thinking [35,36,39]. Effectuation describes a thinking process used when there is uncertainty and imagined solutions must be developed from the available means and within sets of constraints. The practice of innovation requires a situation where the development of imagined ends is necessary [8,24,49]. Learning innovation appears to require legitimate participation in a community of practice where innovation is needed. Thus, student participation in a community of practice ought to afford opportunities for them to develop innovation and leadership capabilities as suggested by the

CEAB GA performance criteria [9,15,24,27]. A deliberate effort is made to develop projects that require legitimate participation and to shift the project framing towards innovation and efficiency in order to provide opportunities for students to address design from sustainability and net social benefit perspectives. Regardless of the project framing, all design teams complete economic, safety, environmental, and net social benefit evaluations of their proposed design.

1.4 Community of Practice Description

Unique process design projects contributed by industrial and entrepreneurial sponsors change or are adapted from year to year, reflecting shifts in industrial focus and markets, as well as outcomes realized by student teams in prior iterations of the design course. These inputs foster and sustain an innovation ecosystem [25] by providing a venue to create and assess potential innovations. Design students are exposed to new methods and ideas. Industrial partners are engaged with new perspectives. The final design report evaluation criteria are performance based and do not change from year to year. However, incoming student populations and their learning needs do change from year to year. In the spirit of continuous improvement, the capstone design course is evaluated following each iteration [20] to improve course objective achievement and to better align the course objectives with the CEAB GA. It is in this context that we endeavor to incubate and improve innovation, engineering design, and leadership skills among the students [24]. This lead us to the questions: *How can we incorporate innovation into our capstone design community of practice and can we determine if we are cultivating an environment where students are encouraged to practice and improve their innovation skillset?*

1.5 Innovation and Leadership in our Community of Practice

The role and importance of a community of practice in the development and strengthening of students' design, innovation, and leadership skillsets in the practice of engineering is often overlooked. In the past, curriculum preparation and course instruction have focused on the development of the engineering knowledge base as the core goal of undergraduate engineering education. In this work, we explore the inclusion of innovation in design courses via alliances with industrial and engineering communities, including our university research community, to form a longitudinal community of practice. Committed practicing engineers contribute projects and *participate* in the innovation process with students in their roles as invested clients and advisors. Student teams explore new industrial opportunities, value propositions, commercialization concepts, redesign, improvement, and start-up opportunities across a variety of industries. Proposed design projects are classified as benchmark, efficiency, or innovative projects depending on the level of creativity required for solution generation. A benchmark project comprises the design of a standard process plant with known technology at proven rates. An efficiency project requires a design perspective change to address sustainability. An innovation project is a project that requires a new and non-standard solution to meet the objectives. Students select their project from the available projects each year. The projects are not labeled as benchmark, innovation, or efficiency projects. Students select projects on the basis of their interest in the project, the industrial sponsor, the academic advisor, or a combination of interests. Students with diverse abilities and backgrounds select all three types of project.

2.0 EXPERIENTIAL LEARNING IN A SITUATIVE FRAMEWORK

Undergraduate engineering curricula should provide ample opportunities for students to learn, practice, and demonstrate development of CEAB graduate attributes. In addition, planned opportunities for feedback on both technical and professional task performance combined with active reflection on their progress is required. This teaches students how to identify their strengths, their weaknesses, and to target their next steps to continue to learn and to develop effectively. The "*ability to work as an effective team member or leader"* does not simply 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. The same could be said of becoming an effective innovator or designer. Further, changing only the method of assessment to one that provides for performance demonstration without providing the opportunity to develop a skill with feedback is equally ineffective. The embedded nature of the learning space within a community of practice and the larger innovation ecosystem is situative [8,12,17,18,25,26,28] in nature and Situativity Theory [12,26,29] is the framework and context for this study and capstone course design.

The construction of learning by students in an environment where the learning objectives of a program of study are consistent with the required assessments and outcomes are central to the theory of constructive alignment [3,12]. Learning about learning, thinking, and reflective strategies introduces students to and teaches them about team, design, and innovation processes [1,2,12,19,23,34]. A blended and active learning environment engages students in processes and encourages reflection and sense making [18,19]. A community of practice provides mentors and models of the innovation process and an environment for students to be introduced to engineering design, innovation, and leadership skills where they develop and practice these skills. These framework conditions are depicted in Figure 4.2.

To date, student feedback has provided continual improvement suggestions for enhancing skills such as technical reading, technical writing, and process or product design problem resolution earlier in their program of study. Working in teams earlier and more frequently in their program of study, on goal-oriented tasks, was also cited as potentially advantageous to developing required skills for the capstone design course. These student suggestions reflect a desire for earlier learning experiences that would help them develop skills related to the practice of engineering and not just the knowledge for engineering. Students typically have not suggested further development of their leadership or innovation skillsets but sometimes struggle with teamwork. When we helped students develop better team and leadership skills, fewer conflict and equity issues were encountered [19]. The intended learning outcome of the pedagogical intervention, described here, was to give students *opportunities to practice* being leaders, to be creative, and to become innovative contributors to open ended capstone design projects.

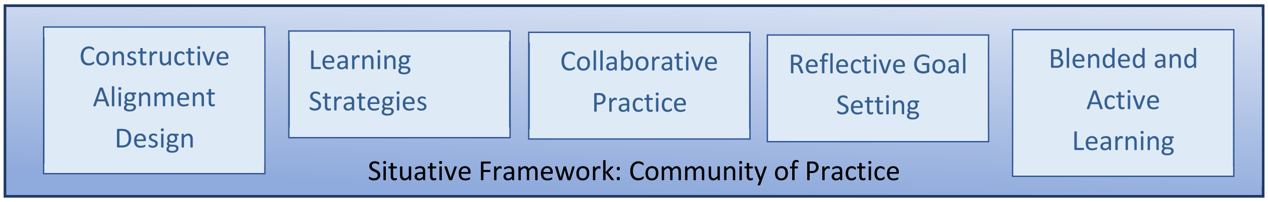


Figure 4.2. Experiential learning environment for capstone design supporting design, innovation and leadership development in a community of practice.

3.0 METHOD

The OSLO Manual [31] innovation map, rehearsed in Figure 4.3, illustrates factors necessary for innovation. The design course community of practice structure can be superimposed on the more general OSLO innovation policy map also shown in Figure 4.3. Measures of innovation opportunity include the presence or absence of transfer factors that ease the diffusion of information and ideas such as: technological gatekeepers; informal linkages among firms and regulatory and research agencies; international links. This framework is compared to the capstone process design course community of practice environment where for engineering design, innovation can be more narrowly defined and can be measured based on objective improvement in the performance of a process or a product [31]. Schumpeter [38] suggests “radical” innovations shape big changes in the world, whereas “incremental” innovations fill in the process of change continuously. Process innovation, new to an industry, is one of the key drivers for economic change [30,31] and can be either radical or incremental.

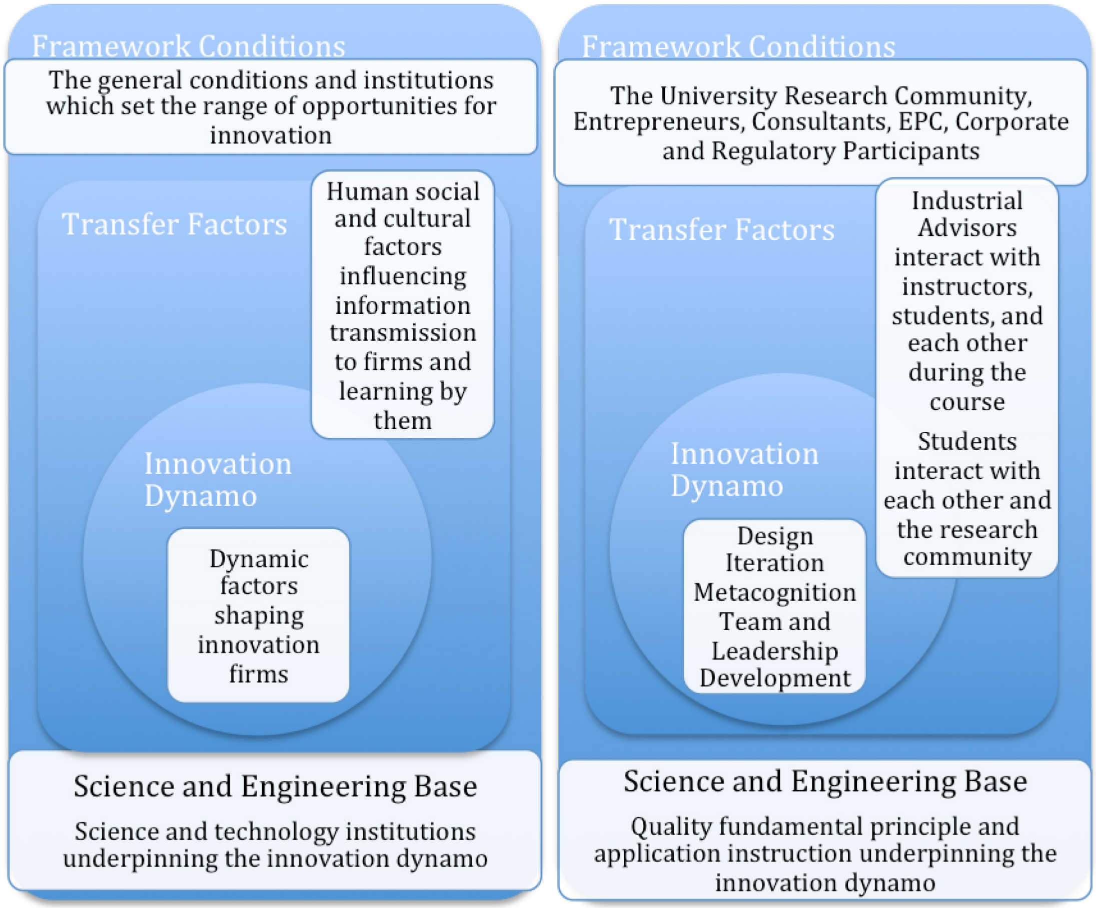


Figure 4.3. Innovation Policy Map – OSLO (left) and Mapping of the factors and conditions to the capstone design community of practice structure (right).

Projects proposed by members of the community of practice are classified here as: *innovation*, if the project requires a process innovation to complete a design; *efficiency*, if the project requires a comparison or incremental improvement; or *benchmark*, if the process design is based on completing an already operating design. Our measure of innovation in the course includes the number of design projects that produce either a process or a product innovation, that propose an innovative process, that capture R&D in the design, or offer a fresh perspective on an old problem. The degree of innovation demonstrated in student design reports is not evaluated in this analysis. Examples of *innovation* projects include pre FEED (Front End Engineering Design) level conceptual designs for a pilot, demonstration or full-scale process from R&D or a process patent, and new technology options for established processes. *Efficiency* projects include comparisons for incremental improvement or for modification of existing facilities to improve efficiencies or to modify production rates. *Benchmarking* projects include pre FEED level designs of standard technologies already in commercial use. While not captured in this analysis, design reports submitted by students may include product or process innovations irrespective of proposed project classification.

4.0 RESULTS AND DISCUSSION

Capstone project descriptions were collected over a twelve-year period. The number of student teams per year ranged from 22-30, depending class size. While some content and delivery details are changed following each iteration using a continual improvement process [20], the study period was divided into two halves. The introduction of blended learning was the most significant content and delivery method change in the data set and is highlighted in this way. Industrial advisor proposed capstone process design projects are classified in Figure 4.4. Twenty-five to thirty-five projects are proposed annually as shown in Table 4.1. The changes in the percentage of projects requiring process innovation over time is complex and reflects changes in the business needs of the community of practice and the selection of new advisors from different industrial sectors. Both lead to shifts in the composition and focus of the community of practice. For example, prior to the study period, two instructors (one from industry and one from academia) taught the course and managed the project proposal process with a largely corporate industry advisor base focused on

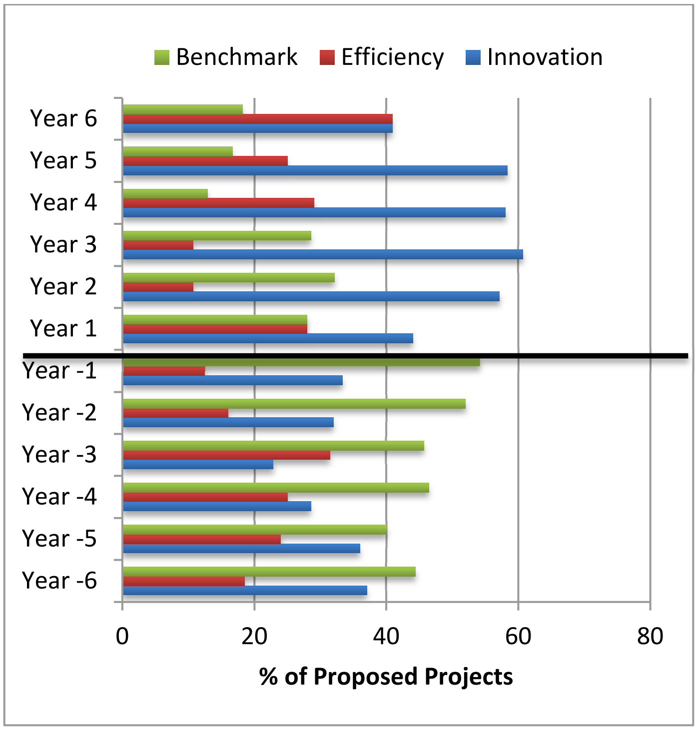


Figure 4.4. Project classification by year (pre and post introduction of blended learning).

Table 4.2. Annual Number of Proposed Projects

Year	Proposed Projects	Advisor Classification	
		Returning	New
Year 6	22	17	13
Year 5	24	18	10
Year 4	31	22	10
Year 3	28	19	9
Year 2	28	20	8
Year 1	25	16	9
Year -1	24	12	12
Year -2	25	17	8
Year -3	35	18	17
Year -4	28	14	14
Year -5	25	15	10
Year -6	27	14	13

oil and gas ventures. Many advisors were interested in evaluating potential recruits. *Benchmark* projects were common and were more easily assessed by both instructors, who guided up to twelve teams each. About five years prior to blended learning, the format of the course changed from informal mentorship to an organizational structure reflective of an engineering firm and the number of instructors increased to three (two from industry). At this time rubric grading and double marking of the reports by the academic advisor working with the team and one at arms length were introduced. Just prior to implementing blended learning, there were four instructors and since there have been five instructors with more diverse industry experience and skills. The increase in the number of instructors over time reflects both the growing enrolment and the purposeful intensification of resources in design education including more instructors with industrial experience. The role of the instructors has evolved toward coaching, guiding, and managing students as engineers in training i.e.: toward resembling an early work assignment context.

The status of industrial advisors as new or returning is presented in Figure 4.5. An advisor is categorized as returning if they have participated in the capstone course previously. Some returning advisors elect to advise two student teams. Conversely, advisors may propose multiple projects but are only able to advise one team. Most, but not all, of the proposed projects are selected by student teams. Returning advisors often invite new advisors to join them in advising student teams. New advisors often return to advise teams during subsequent iterations of the course. Since the adoption of the blended learning course format [18,19,21] and the introduction of online meetings industrial advisors from remote locations more readily supplement local advisors diversifying the industry sectors from where projects are offered and providing the course with an international context.

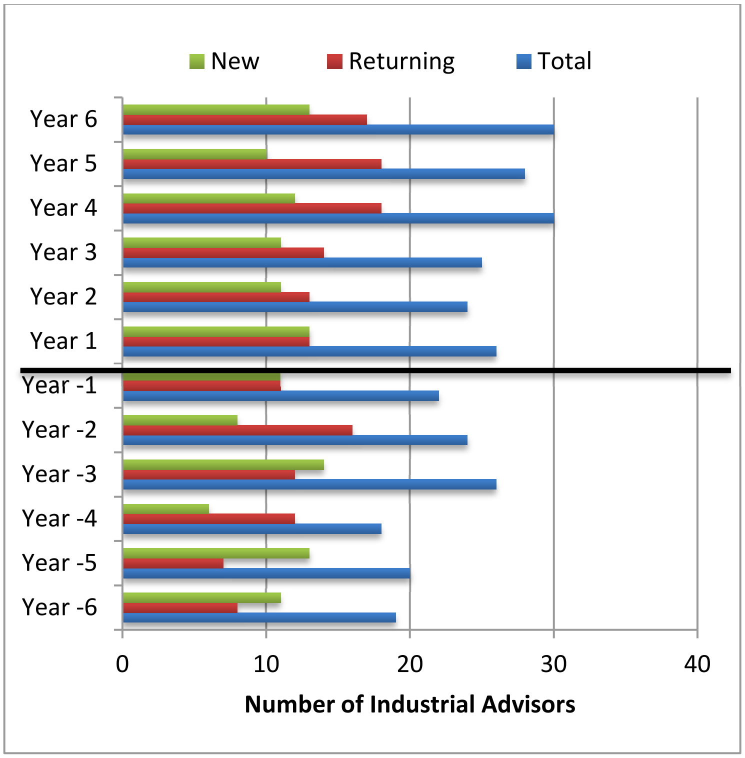


Figure 4.5. Industrial Advisor Classification by year (pre and post introduction of blended learning).

The number of projects proposed by new and returning advisors is also shown in Table 4.2. Prior to blended learning *benchmark* or *efficiency* projects dominated. The percentage of proposed projects requiring an innovative response has increased sharply post blended learning, for new advisors, and during the second iteration, for returning advisors, as shown in Figures 7.6 and 7.7. While this change is due in part to changing economic circumstances, the change in the course structure from a lecture based project course to a blended learning project course (freeing classroom time for student-student and student instruction interaction), the introduction of activities and evaluation methodologies fostering learning in innovation and leadership, and the increase in the number of instructors have all enabled the support of more projects requiring process innovation. *Innovation* projects require more instructor *and* industry

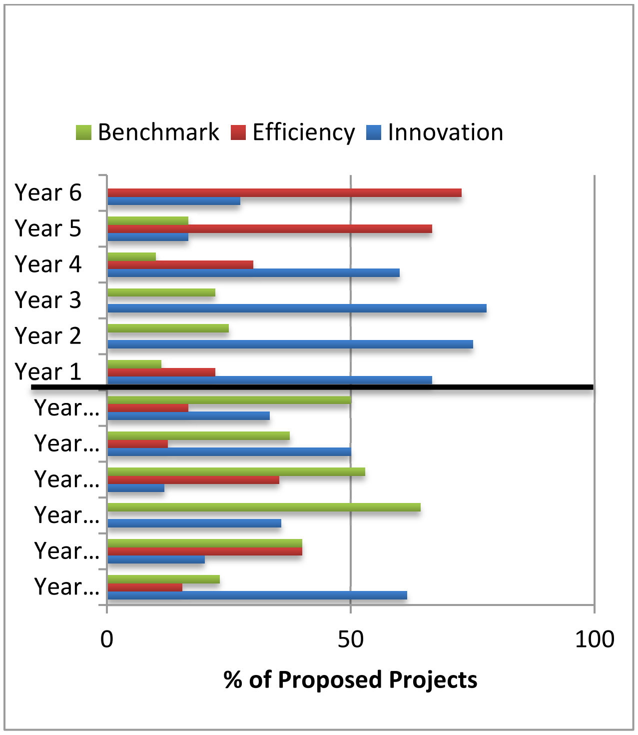


Figure 4.6. Classification of Projects Proposed by New Industrial Advisors by year.

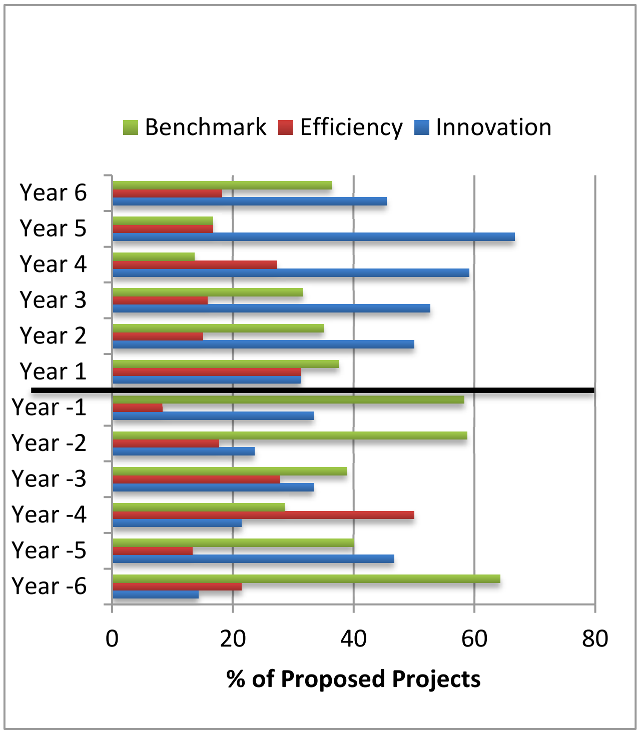


Figure 4.7. Classification of Projects Proposed by Returning Industrial Advisors by year.

advisor support than *benchmark* projects. Blended learning changed the dynamics of the instructor student and student-student interactions, the engagement of the students with their industry advisors, and with their design projects. These coincident shifts all enhanced transfer factors and the *innovation dynamo* [30,31] in the process design community of practice. The key factors contributing to the innovation dynamo of the OSLO innovation map (Figure 4.3), in general, include innovation process capacity, skilled employees, alliances, and innovation options. In the capstone design course, the *innovation dynamo* comprises the student teams, teaching assistants, academic and industrial advisors and the course structure that fosters learning and targeted skill development. Teams use metacognitive cycles as shown in Figure 4.1 to reflect on their overall performance monthly and on their learning performance weekly. Performance is directly tied to the CEAB graduate attributes. The capstone design course transfer factors are expressed as the formal and informal linkages between industrial advisors, the university research community, and the student design teams. The industrial advisors include representatives from regulatory, entrepreneurial, research and innovation, consulting, oil and petrochemical processing, and engineering, procurement, and construction (EPC) sectors, drawn from local, national, and international engineering communities. This diversity facilitates the mobility of new ideas. In addition, the project development process includes ongoing interaction between the course instructors and the industrial advisors prior to and during the capstone design course. Both industrial and academic advisors act as technological gatekeepers by keeping abreast of new developments and seeking out new connections and opportunities for the community. The community of practice values trust and it is regulated with intellectual property agreements where appropriate. Reworking and redeveloping projects to achieve better results over time also supports innovation and is a part of the business development cycle managed by the course instructors.

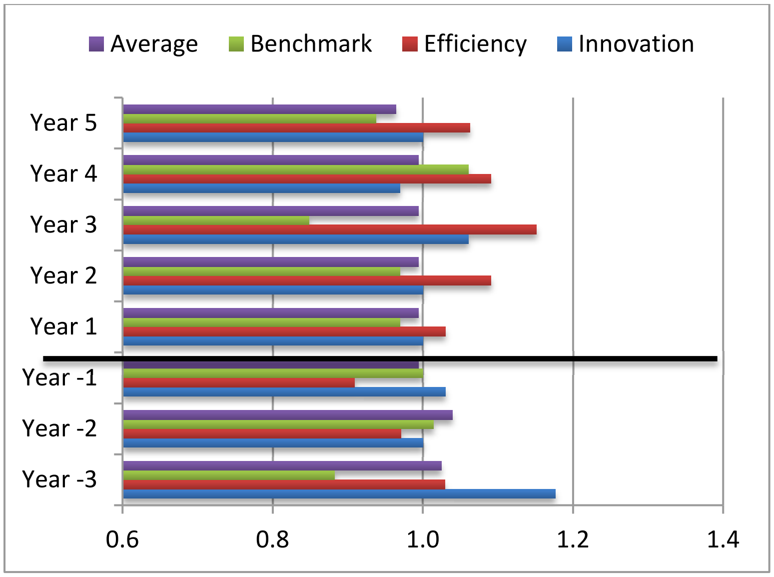


Figure 4.8. Normalized performance by project classification pre and post blended learning.

Interpreting student performance by project type must be done with care. Students do not choose projects on this basis nor is the number of each type of project the same from year to year. In addition, students may be more or less innovative regardless of the project type. Project grading is rubric based aligned with course objectives and not evaluated on innovation. Students start the course with diverse abilities and experiences and their achievement of course objectives has a distribution. It is possible to be innovative with a lower relative performance with respect to the course outcomes as aligned with the CEAB graduate attributes (Table 4.1). The normalized performance for benchmark, efficiency and innovation coded projects are reported in Figure 4.8. Performance is normalized utilizing the class average for the iteration year of the course. Moreover, the class average has remained constant after double marking was introduced prior to blended learning implementation. It is important to note innovation projects comprised a smaller number of projects prior to blended learning implementation (Figure 4.5). Post blended learning, there were considerably more innovation projects in absolute and percentage terms. With these caveats in mind, the data demonstrate students tackling projects requiring innovation or efficiency are not disadvantaged with respect to academic performance. These findings are similar to the grade performance evaluations of the blended learning implementation [18]. Further, providing appropriate scaffolding, leveraging in class time with experienced instructors, supporting team and leadership development, and intentionally shifting towards innovation with intrinsically more difficult projects and more rigorous sustainability evaluations, it is clear that most students can address innovation or efficiency sustainable design type projects, without incurring academic penalty. Student learning is deepened and broadened, and their satisfaction is not negatively impacted.

Students typically appreciate the current course structure and their comments reflect positive affective belonging in the community as evidenced by example comments below. More detailed analysis of student satisfaction and engagement post blended learning is reported elsewhere [22].

"*I learned a lot from this course, and especially from the advisor asking you to think by yourself, because it used to be: 'I'll tell you this, and you'll tell me that', but this time it was: 'you tell me what you think, or what's the option you have to accomplish this design' And that made me very motivated*" (Student).

"*Learning in that environment was actually really interesting, because some of the other students could have an insight that another may not, and a lot of the co-op students have worked in different areas, and when we talked about pumps or heat exchangers, they knew about them more than some of the traditional students. So, it was really nice to share the experiences and to start learning from other people, and start collaborating with them*" (Student)

5.0 CONCLUSIONS

Our study shows that teaching engineering innovation, design, and leadership through a community of practice is feasible and desirable. Successful integration of innovation and leadership education and skill development is nurtured by strong academic leadership in an experiential organizational structure where leadership and innovation are modeled. Strategic and incremental changes on how design courses are taught are required. Switching from a lecture to a blended learning content delivery format permits more intensive interaction between student teams and instructors and can be scaled by including additional instructors. By increasing the diversity of and providing targeted direction to industrial participants in a process design course community of practice, the focus of the community and their motivation for participation can be shifted over time from *benchmarking* competence to *innovation* competence that supports student innovation and leadership capacity development. The adoption of an organizational structure reflective of an engineering firm within a cross sectional and longitudinal community of practice facilitates the development of a situated learning experience with the student design team as an *innovation dynamo*. Increasing the number of instructors, particularly those with significant industrial experience, provides an opportunity to further strengthen students design, leadership, learning and development satisfaction, and their innovation skills within a community of practice. In such environments, student teams are able to tackle intrinsically more challenging projects, which better prepare them for future career development – without negatively impacting their satisfaction or incurring an academic penalty vis-à-vis student teams tackling inherently less demanding projects.

Acknowledgements

The design course redevelopment was funded by the Provost's Office (University of Alberta). The CTL blended learning research project, of which this research is a part, received research ethics approval from the University of Alberta Research Ethics Board, No. *Pro00048272*. The authors acknowledge with thanks the support given by our community of practice – our students, our teaching team, our research community, and our industry participants.

REFERENCES

[1] Ken Bain, *What the Best College Teachers Do.* Cambridge, Mass.: Harvard University Press 2004. {ISBN: 9780674013254}

[2] John C. Bean, *Engaging Ideas: The Professor's Guide to Integrating Writing, Critical Thinking, and Active Learning in the Classroom*. 2nd ed. Jossey Bass : San Francisco, 360 p. 2011. {ISBN: 978-0-470-53294-4}

[3] John Biggs, What the student does: teaching for enhanced learning, Higher Education Research and Development 18(1): p. 57-75, 1999.

[4] Benjamin S. Bloom, Max D. Englehart, Edward J. Furst, Walker H. Hill, & David R. Krathwohl Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain. New York, Toronto: Longmans, Green 1956.

[5] Canadian Engineering Accreditation Board, "Canadian Engineering Accreditation Board: Accreditation Criteria and Procedures", Ottawa: Canadian Council of Professional Engineers, 2014. Accessed June 20, 2015.

[6] David Yun Dai & Robert J. Sternberg, "Beyond Cognitivism: Toward an Integrated Understanding of Intellectual Functioning and Development," (Introduction) In David Yun Dai & Robert J. Sternberg (Eds.), Motivation, Emotion, and Cognition: Integrative Perspectives on Intellectual Functioning and Development (pp. 1–38). Routledge, 2004.

[7] Lori Donath, Roxanne Spray, Nancy S. Thompson, Elisabeth M. Alford, Nadia Craig, & Michael A. Matthews, "Characterizing Discourse Among Undergraduate Researchers in an Inquiry-Based Community of Practice." *Journal of Engineering Education* 2005, p 403–417.

[8] Peter Drucker, "The Discipline of Innovation," *Harvard Business Review*, 1985.

[9] Nicky Eshtiaghi, Shanthi Robertson, Georgia Warren-Myers “Good practice groundwork: Managing initial meetings with higher degree research students.” *Education for Chemical Engineers* Volume 7 (2012) e196–e202

[10]Marc Graham, Alex Slocum, & Richardo Moreno Sanchez, “Teaching High School Students and College Freshmen Product Development by Deterministic Design With PREP.” *Journal of Mechanical Design* 2007, Volume 129 p. 677-681 DOI: 10.1115/1.2722334

[11] Ann Gribbin, “Design and Critical Thinking: Applying Perry’s Theory of Intellectual Development to Foundational Design Instruction”. *Proceedings of the 19th National Conference on Beginning Student Design* (Southern Illinois University Carbondale), 2003.

[12] James G. Greeno, Allan. M. Collins, & Lauren B. Resnick, Cognition and Learning. In R. Calfee & D. Berliner (Eds.), *Handbook of educational psychology (*pp. 15–46). New York, NY: MacMillan, 1996.

[13] Karri M. Haena, D. Raj Ramanb, Elena Polushc, &Mari Kemisd, “Training the next generation of creative, innovative andadaptive scientists and engineers: The NSF Engineering Research Center for Biorenewable Chemicals (CBiRC) Research Experience for Undergraduates.” *Education for Chemical Engineers* Volume 7 (2012) e230–e240.

[14] John Hattie, “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, 2009.

[15] Bill Hewitt, Moray Kidd, Robin Smith & Stephen Wearne, “Developing a virtual engineering management community.” *European Journal of Engineering Education*, 41:2, 220-230, DOI: 10.1080/03043797.2015.1056098

[16] Mary Henton, *Adventure in the Classroom: Using Adventure to Strengthen Learning and Build a Community of Life-long Learners*. Dubuque, Iowa: Kendall/Hunt. (1996).

[17] Teruaki Ito, Tetsuo Ichikawa, Nevan C. Hanumara, & Alexander H. Slocum, “Teaching Creativity in Design Through Project-Based Learning in a Collaborative Distributed Educational Setting.” In: Schaefer D. (eds) Cloud-Based Design and Manufacturing (CBDM). Springer, Cham, 2014.

[18] Marnie V. Jamieson, “Application of Blended and Active Learning to Chemical Engineering Design Instruction”, University of Alberta (2016)

[19] Marnie V. Jamieson and John M. Shaw, “Applying metacognitive strategies to teaching engineering innovation, design, and leadership,” in *Proc. 2017 Canadian Engineering Education Conf.* (*CEEA17*), G. Evans (ed)(Toronto, Ontario; 4-7 June 2017), Paper 045

[20] Marnie V. Jamieson & John M. Shaw, “A continual improvement process for teaching leadership and innovation within a community of practice,” *Proceedings of The American Society for Engineering Education Conference*, *(ASEE19)*, Tampa, Florida; 16-19 June 2019.

[21] Marnie V. Jamieson & John M. Shaw, “Pre and Post Course students self assessment of CEAB Graduate Attributes – A Tool for Outcomes Assessment, Student Skill and Course Improvement,” Proc. 2016 Canadian Engineering Education Association (CEEA16) Conf. Paper 037 Dalhousie University; June 19 – 22, 2016.

[22] Marnie V. Jamieson and John M. Shaw, “Student and Instructor Satisfaction and Engagement with Blended Learning in Chemical Engineering Design”, *Proc. 2017 Canadian Engineering Education Association (CEEA17)* Conf. Paper 040; University of Toronto; June 4 – 7, 2017

[23] Marnie V. Jamieson & John M. Shaw, "Teaching Engineering for a Changing Landscape" *Canadian Journal of Chemical Engineering; Nov 2019;* 97; 11; p2870-p2875

[24] Marnie V. Jamieson & John M. Shaw, "Teaching Engineering Innovation, Design, and Leadership within a Community of Practice," in *Proc. 2018 Canadian Engineering Education Conf.* (*CEEA18*), P. Ostafichuk (ed)(Vancouver, BC; 3-6 June 2018), Paper 113.

[25] Steve Johnson, *Where Good Ideas Come From: The Natural History of Innovation*, Riverhead Trade, 2011. Chapter 1: "Reef, City, Web: Darwin's paradox"

[26] Aditya Johri & Barbara M. Olds, "Situated Engineering Learning: Bridging Engineering Education Research and the Learning Sciences." *Journal of Engineering Education*, *100*(1), 151-185 2011.

[27] Lydia Kavanagh & Caroline Crosthwaite, Triple-objective team mentoring Achieving Learning Objectives with Chemical Engineering Students." *Education for Chemical Engineers*, Trans IChemE, Part D, Volume 2, 2007.

[28] Alice Y. Kolb & David A. Kolb, The Learning Way: Meta-cognitive Aspects of Experiential Learning. *Simulation & Gaming*, *40*(3), 297-327 2009.

[29] Jean Lave & Etienne Wenger, Situated learning: Legitimate peripheral participation. Cambridge, UK: Cambridge University Press. 1991.

[30] Stéphane Lhuillery, Julio Raffo, and Intan Hamdan-Livramento, Economic Research Working Paper No. 31, Measuring Creativity: Learning from Innovation Measurement. WIPO World Intellectual Property Organization, Geneva, 2016.

[31] *Oslo manual. [electronic resource] : guidelines for collecting and interpreting technological innovation data*. n.p.: Paris : Organisation for Economic Co-operation and Development : Statistical Office of the European Communities, 2005., 2005. *University of Alberta Library*, EBSCO*host* (accessed Feb. 11, 2018).

[32] Tom A. O'Neill, Nicole Larson, J. Smith, Magda Donia, C. Deng, William Rosehart, & Robert Brennan, Introducing a scalable peer feedback system for learning teams. *Assessment & Evaluation in Higher Education, 44,* 848-862 2019.

[33] William G. Perry (1970). Forms of Intellectual and Ethical Development in the College Years: a scheme." Holt, Reinhart and Winston, Inc. New York.

[34] Lauren B. Resnick, & Leopold E. Klopfer, (Eds.) *Toward the Thinking Curriculum: Current Cognitive Research*, 1989. Alexandria, VA: Association for Supervision and Curriculum Development.

[35] Saras D. Sarasvathy & Sankaran Venkataraman, "What Makes Entrepreneurs Entrepreneurial?" 2001. http://www.effectuation.org/paper/what-makes-entrepreneurs-entrepreneurial

[36] Saras D. Sarasvathy & Sankaran Venkataraman, "Entrepreneurship as Method: Open Questions for an Entrepreneurial Future," **Entrepreneurship Theory and Practice**. 35, No. 1: p. 113-135.

[37] William J. Schell, Bryce E. Hughes & Brett Tallman, "Exploring the conflict between engineering identity and leadership," in *Proc. 2018 Canadian Engineering Education Conf.* (*CEEA18*), P. Ostafichuk (ed)(Vancouver, BC; 3-6 June 2018), Paper 157

[38] Joseph Schumpeter, The Theory of Economic Development, Harvard University Press, Cambridge, Massachusetts 1934.

[39] Amy Wilkinson, *The Creator's Code*, Simon & Schuster: New York, NY, 2015.

[40] Barry J. Zimmerman & Dale H. Schunk, "Self-Regulating Intellectual Processes and Outcomes: A Social Cognitive Perspective," In David Yun Dai & Robert J. Sternberg (Eds.), Motivation, Emotion, and Cognition: Integrative Perspectives on Intellectual Functioning and Development (pp. 323–349). Routledge, 2004.

5. Building the Engineering Mindset: Developing Leadership and Management Competencies in the Engineering Curriculum (*CEEA-ACEG*, 2020)

Proceedings of the 2020 Canadian Engineering Education Association (CEEA-ACEG20) Conference
Full Peer Reviewed Paper

Marnie Jamieson[1] *and John Donald*[2]
[1]*Department of Chemical and Materials Engineering, University of Alberta*
[2]*School of Engineering, University of Guelph*
Author E-mail: mvjamies@ualberta.ca and jrdonald@uoguelph.ca

Abstract – *In this paper we explore building the engineering mindset from the perspective of developing exceptional leadership and management competencies to guide and support the traditional technical competencies that are the primary focus of undergraduate engineering programs. A knowledge base for engineering, science, and design is developed throughout most engineering programs. Math and science are carefully scaffolded from first year engineering to ensure technical competence by graduation. We ask the questions: "How are leadership and management related to engineering work and design?" and "Can we develop a framework to guide the development of leadership and management skills in the engineering curriculum?" We argue leadership and management are integral to the engineering mindset and necessary to address the complex engineering problems society faces. There is discord between the responsibility of the engineer and the decision-making authority for engineering projects. This dissonance often results in engineers being technically accountable for their designs yet lacking the authority to make decisions with respect to the construction, commissioning, and operation of their designs. To address this gap, we suggest leadership and management training be carefully scaffolded in the same manner that technical competence has been stewarded in engineering programs and propose a framework to do so.*

Keywords: Engineering, Mindsets, Design, Leadership, Management, Programs, Graduate Attributes, Learning, Outcomes, Authority, Responsibility, Accountability

5.1.0 Introduction

A mindset is a set of attitudes, beliefs and experiences framing a way of thinking and interpreting information [1]. **An Engineering Mindset** is built on the core belief that solutions to human problems can be designed within the constraints of science, economics, environment, and safety risk management. If the solution can't be found within the bounds of known technology then research and innovation may provide a path forward. In addition, a mindset is "a proper understanding of a method's use" in context and within constraints [2]. In this paper we explore building the engineering mindset from the perspective of concurrently developing leadership and management skills with core technical and design skills as the engineering skillset during the undergraduate program. Technical competence is developed throughout most engineering programs and is at the core of the identity of an engineer. It is who we are but is not the only item that defines an engineering mindset or engineering practice. To design solutions an engineer must have developed empathy for the people who will either be served by the design or will use the designed object. The engineer must understand what the user values and desires in the system or the object, what is plausible, and how to research and develop the design options. The engineer must understand the context of the design use and the consequences of the use of the design. The engineer will then work with a variety of disciplines to effect the design of the system or the object within sustainability and regulatory constraints. These tasks require a variety of Bloom's cognitive, affective, and psychomotor domain skills including innovation, creativity, evaluation, empathy, and influence.

5.1.1 Motivation

The motivation for this paper is to present a contextual framework to scaffold engineering leadership and management in the undergraduate engineering curriculum while maintaining the technical competence of our graduates. Designing within technical constraints is one aspect of a successful *sustainable* engineering design. The design must also be operated or marketed within environmental regulations, safety, and economic constraints. The operation must be managed within these sustainability regulations and constraints for the cradle to grave life cycle of the design and preferably support a circular economy. As product development and design operation are typically done in organizations, they require ongoing engineering leadership and management grounded in technical competence. Both are at the core of engineering practice and identity. Increasingly, there are calls for engineers to be more actively involved to influence and steward the impacts of technology on society, by contributing in areas such as policy development, politics, and advocacy [3, 4].

The administrative and resource burden for teaching engineering design, leadership, and management is high. There is a cost associated with the intensive work required to develop, mentor, and assess engineering students to become engineering leaders, designers, and managers. This cost may be a barrier that reinforces the tendency to maintain less resource intensive instructional methods and focus on fundamentals and engineering science.

5.1.2 The Engineering Practice Gap

Graduating engineers are technically competent, but sometimes lack communication and professional skills fundamental to successful engineering practice [5, 6]. The need for strong non-technical skills is also identified by the Canadian Engineering Accreditation Board (CEAB) with a majority of the twelve Graduate Attributes focusing on non-technical skills such as communication, team work, ethics and life long learning [7]. Finally, after graduation, there may be dissonance between the responsibility of the engineer and the organizational decision-making authority for engineering projects. This discord may result in engineers being responsible for their design work yet lacking the authority to make decisions with respect to the construction, commissioning, and operation of their designs [8]. This may be compounded by a lack of influence and leadership skill development. To address this disconnect engineering graduates must become comfortable taking leadership roles in implementing and managing the impacts of engineering designs from economic, environmental, and safety perspectives. In addition there is a role for engineers in the public policy and legislative forums with respect to the management and regulation of complex engineered systems. Currently, engineers are underrepresented in Parliament at a time where their skills and knowledge are needed [3,4] to support sustainability.

To prepare engineering graduates to better negotiate the dissonance between responsibility and authority and become more influential in decision-making surrounding complex designs, we suggest leadership and management concepts be delivered as core content. Concurrent development of professional, leadership, and managerial competence to the same degree as technical competence could help close this gap for engineering graduates. Leadership and management can act as a frame for positioning the development of the underlying non-technical Graduate Attributes in a way that maps to engineering professional practice.

Using the engineering practitioner lens instead of the engineering scientist view, we examine the requirements to practice engineering for program graduates. Our key research and development questions are: "*How are leadership and management related to engineering work and design?*" and "*Can we develop a framework to guide the development of leadership and management skills in the engineering curriculum?'*

5.1.3 Leadership Management Development Matrix

A Leadership-Management Development Matrix (LMDM) has been developed by the authors to provide a framework for identifying and scaffolding leadership and managerial skills within the engineering curriculum. The LMDM framework considers the leadership levels and expanding spheres of influence of self, team, organization and society based on principles of both Transformational Leadership [9,10] and the skills approach to leadership [11,12]. We also relate underlying skills such as communication, self-regulation and empathy to typical organizational roles in engineering practice (e.g., skilled worker, team leader, project manager, organizational leader, societal leader). The lens of a flexible management model [13] is used to frame the shifting societal expectations of organizations.

The proposed LMDM is demonstrated by its application to a typical exercise in an engineering design course. Graduate Attribute indicators are reviewed and then mapped to the underlying skills. Graduate attribute scaffolding in the curriculum and the supporting leadership and management skills are considered in the context of attribute development.

The LMDM is proposed as a mechanism for identifying and assessing non-technical skill progression through the engineering curriculum and relating these skills to engineering practice. Ultimately the authors hope that it can serve as a framework to help engineering programs develop and assess undergraduate curriculum and learning activities that bring the awareness and practice of the non-technical engineering skills to the same level and rigour as technical skills. This will provide engineering graduates with the base skills to become leaders and stewards of technology in society that reaches beyond the technical aspects of their training.

The LMDM was formulated by mapping the development of leadership and management skills to the career arc of engineering work and engineering design. The objective is to support the development of the whole engineer. We hope to facilitate a broader shift to a more wholistic perspective of engineering education

5.2.0 Literature Review/Background

5.2.1 The Definition of Engineering Work

Engineering work and oversight are typically completed by professional engineers:

“The "practice of professional engineering" means any act of *planning, designing, composing, evaluating, advising, reporting, directing or supervising* that requires the *application* of engineering principles and that concerns the safeguarding of life, health, property, economic interests, the public welfare or the environment*, or the managing of any such act*. In Canada, a licence is required to practise professional engineering. Engineering is constantly evolving and new areas of practice are always emerging.” [14]

Engineering is a self-governing profession and is regulated provincially in Canada. Legally, the Province of Alberta defines the practice of engineering as:

“(i) *reporting on, advising on, evaluating, designing, preparing* plans and specifications for or *directing* the construction, technical inspection, maintenance or operation of any structure, work or process

(A) that is aimed at the ***discovery, development*** or ***utilization*** **of matter, materials or energy** or in any other way **designed** for the use and convenience of humans, and

(B) that requires in that *reporting, advising, evaluating, designing, preparation or direction* the ***professional application*** of the principles of **mathematics, chemistry, physics** or **any related applied subject**, or

(ii) teaching engineering at a university"

Engineering and Geoscience Professions Act, Section 1, pg. 8 [15]

Examination of this last definition (bold emphasis ours) illuminates the firm connection of science, mathematics, and technical knowledge as the fundamental basis for the engineering design of systems and products *to be used by society* in part (A). The underlined emphasis in the above definitions illustrates the social nature and context of engineering work. Engineering has typically served the needs and wants of people with an implicit business motivation. Engineering has historically been a blend of the application of specialized scientific knowledge to useful applications with a business aspect [16]. As the structure of engineering work has evolved with globalization there is an increased expectation of collaboration, telecommuting, virtual teams, increased multi disciplinary diverse collaboration and project complexity hence the requirements for professional (and contextual) skills have increased for engineers [17].

"Engineers no longer manage their daily task with plain substance expertise; instead they must be adept at communication, collaboration, networking, feedback provision and reception, teamwork, lifelong learning, and cultural understanding" [18] (p. 123).

Finally this definition in section (i) draws our attention to "*directing* the construction, technical inspection, maintenance or operation;" in other words, the management of the "structure, work or process;" and by implication, the *leadership* of the people involved in these tasks. Although the legal definition of what engineering is does not describe the social responsibility of an engineer both APEGA and Engineers Canada are clear that engineering is concerned with "the safeguarding of life, health, property, economic interests, the public welfare or the environment*, or the managing of any such act*." It is at the core of the profession.

"The Definition has sufficient breadth so that it applies to all phases of engineering endeavour, including feasibility studies, designing or planning, operations, and decommissioning. That is to say, engineering is not only the design, planning, and supervision of construction of a process plant such as a petroleum refinery, but it also includes supervision of the operation, ongoing maintenance, and modifications of such a facility, as well as its eventual decommissioning.” [14]

Engineering work clearly requires fundamental scientific knowledge and skills, professional skills, contextual skills, the ability to appropriately select and competently apply those skills in a variety of situations [19].

5.2.2 Impact of Engineering Beyond the Technical

The growing alignment of Engineering Education with Engineering Practice is clearly set out in the CEAB graduate attributes. Canadian Engineering programs are embracing graduate attribute development and honouring a commitment to engineering fundamental knowledge [20], [21]. Technical/scientific background is part of the engineering identity and so is the professional practice component. Even as the graduate attributes are helping to shape engineering education, the engineering community recognizes there are systemic issues that require resolution to address the complex global problems and risks posed by our technological and consumer driven world. The primary goal of the Engineering Change Lab is to deepen our understanding of engineering and to unlock the potential of engineering by taking action to address systemic challenges [11]. The National Council of Deans of Engineering and Applied Sciences (NCDEAS) are focussing on the UN Sustainable development goals and how we will incorporate these goals in engineering programs [22]. The CDIO syllabus model explicitly encompasses technical, cognitive, procedural engineering knowledge and skills embedded in personal, professional and interpersonal skill development [23]. Professional and contextual skill development in undergraduate and practicing engineers is widely recognized as a necessity for the interdisciplinary and collaborative work needed for complex system and the product lifecycle design.

5.2.3 Leadership-Management Development

In practice, engineers apply management-leadership spectrum skills, either explicitly or implicitly. Success in the workplace as an individual contributor is often dependent on technical competence and managerial skills. Further progression requires leadership skills and abilities [10]. Historically, leadership was viewed as a “linear progression from great management performance, but in fact, it is a new course of study”[10]. The skills required to manage tasks and work within managerial systems are somewhat different from those required to lead people to accomplish tasks within a system.

Several management and leadership development frameworks are available to position the scaffolding of personal and professional skills within the engineering curriculum. For example, Transformational leadership [9] identifies how leaders can engage followers to reach high levels of motivation, morality and performance often with change to a new paradigm as an end objective. The skills approach to leadership [11] and the capability model of leadership [12] identify specific skills and/or knowledge required for leadership. Katz [11] categorizes the skills from a technical, human, and conceptual perspective where technical and management skills are viewed as more important early in a career; while the importance of conceptual skills increases as responsibility increases and human skills maintain their importance across domains. The skills and capability models focus on developmental needs to make effective leadership possible rather than on leadership behaviour. The skill category descriptions for both models are similar. Mumford et al. characterize the underlying individual abilities supporting leadership skill development as: motivation, personality, and cognitive ability. Mumford categorizes leadership competencies as: knowledge skills (technical), problem solving skills (conceptual), and social judgement skills (human) [12]. The knowledge category includes the facts and the organizational structure or the expert schema suggesting technical skills are not less important but rather they have been used to an extent as to develop expertise. The manner in which this expertise is utilized may shift [24]. In the transformational leadership model [10], leadership and management skills are identified and both are required to shift an organization or a team to a new way of thinking and doing. Hacker & Roberts [10] identify creativity, vision, empowerment, and community building as the leadership characteristics required for break through change. The management characteristics are identified as performance, analytical, energetic, and administrative. This describes how transformational leaders (and managers) apply their developed skills and knowledge to effect change in their domain of influence.

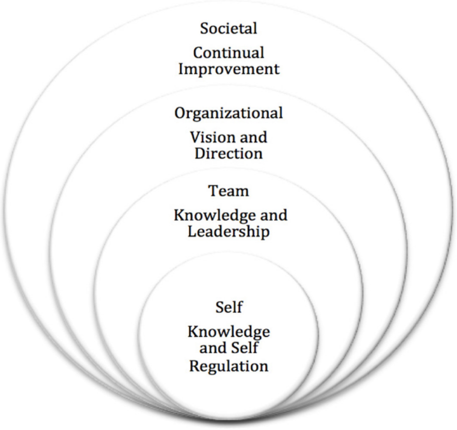


Figure. 5.1. Leadership Domains of Influence

Common to many leadership models, including the capabilities and transformational models, is the idea that leadership starts with a need to understand and manage your own knowledge and skills and then grow to be able to lead and manage at larger scales of influence. For our LMDM we represent this increasing circle of leadership influence as "Domains of Influence", from self, through team, to organization, and to society as illustrated in Figure 5.1. These models and concepts form the framework for leadership activity development in the engineering curriculum. In the proposed LMDM, the skills required for self-leadership and followership are a foundation for the skills required for team leadership, organizational leadership, and societal leadership.

The management model is based on Birkinshaw's [22, 23] continuum of traditional and alternative principles illustrated in Figure 5.2. Historically organizations were formed for an industrial or business purpose and often resemble the characteristics on the left side of the continuum yet the societal expectations of organizations are shifting towards the right hand side of the continuum. Societal expectations initially shifted from economic growth to sustainable development and more recently, they are shifting towards a socially responsible model with respect for all human needs reflecting the UN sustainable development goals. Birkinshaw's management model framework best captures this tension. It also informs the framework for developing learning activities directed at addressing this shift and supporting skill development for engineering work in the future.

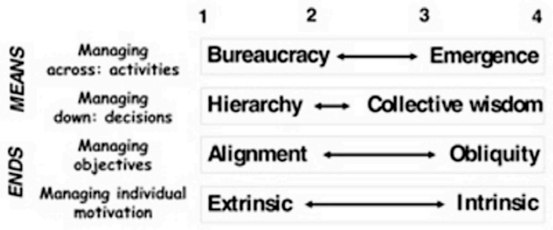


Figure 5.2. Management Model Framework (Birkinshaw [13])
https://creativecommons.org/licenses/by-nc-sa/3.0/ Used with attribution and no changes.

5.3.0 Method: LMDM Development

Organizations within society exist for a purpose and they exist in a wide variety of sizes. Their purpose may be to govern, to regulate, to do business, to influence, to educate, to protect, to serve or to care for people. Management is what humans do to plan and coordinate tasks to achieve objectives within constraints. This may be in the context of self or organizational management. One can manage the self, a team, a business unit, a collection of units, an organization, or a collection of organizations. Inter-organizational cooperative resource management, legislative, regulatory framework, and policy management are examples of societal objective management. As in leadership, the management skills required for self-management and individual performance form the foundation for the skills required to manage larger organizational units.

The literature review captures the importance of leadership and management skills and the need for engineers to master these non-technical skills to be effective in driving change towards sustainable solutions to complex engineering problems. Figure 5.3 captures some of the specific characteristics and nature of these leadership and management skills, indicating the overlapping character of both.

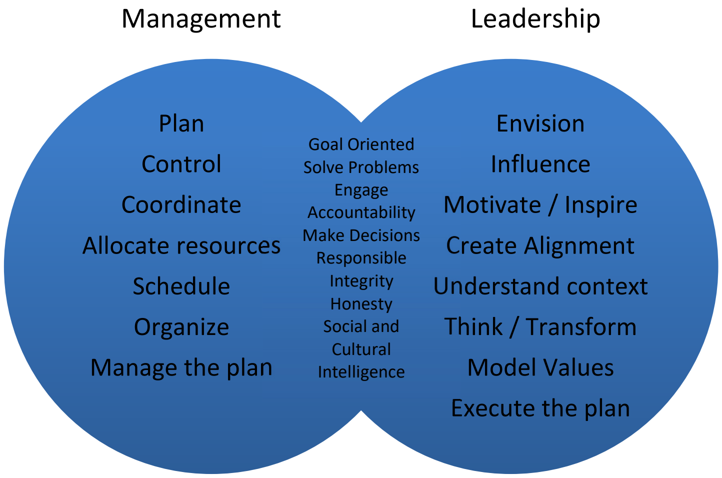


Figure 5.3. Management Leadership Development Skills Venn Diagram

The societal call for a paradigm shift in the design and management of engineering systems towards a more sustainable reality informed the leadership and management model selection. In turn, these models influenced the skills, roles, and finally the engineering mindset to be developed in a university program. To create the LMDM, we first considered the required skills and developmental levels for an engineer over the course of a career beginning with individual contribution. Next we examined the team, organization, and societal levels and began to identify relevant management and leadership skills for an individual to execute the role in the context of sustainable engineering leadership and management of complex designs and systems. Last we considered the related graduate attribute foundation for each development level, and the progression of the skill development through each of the levels. We assumed a graduating engineer requires an applied competence in the full complement of CEAB graduate attributes.

To position the development of leadership and management skills within the undergraduate engineering curriculum to support a societal transition to sustainable design and development, a change in how engineers steward technology at the organizational and societal levels is required. To this end, we have incorporated the concepts of transformational leadership [9], the skills/ capability approach [12] and the management model framework [25] to create a Leadership-Management Development Matrix (LMDM).

The LMDM, shown in Table 5.1, represents leadership development at the four progressive domains of influence from self, through team, to organization, and finally, to society. At each level, the matrix is aligned with a typical positional management role that can be associated with a leadership development level. Progressive organizational roles encompass and build upon the foundational skill domains of prior roles.

In addition to leadership and management skills, we felt it important to articulate skills in both the cognitive and the affective (behavioral) domains. Developing cognitive and affective regulation (metacognition) underlies the development of leadership and management skill and ability. For each leadership level and corresponding management role, the LMDM describes the nature of each of the four relevant non-technical skill domains: namely cognition, behavior, management, and leadership. This can aid our understanding of how we might scaffold non-technical skills in the curriculum as they relate to the career arc leadership and management development of engineers. For each of the leadership-management development levels, we can identify skills, the skill level required, and relate these to the Graduate Attributes set out by accrediting bodies. The LMDM also identifies the timing (years) within the undergraduate curriculum where the skills could be typically developed and applied. Two dimensions that underlie the LMDM are: one, the program level outcome requirements, which can be represented by the 12 CEAB graduate attributes [7]; and two, the depth and complexity of the of the learning content level, which can be represented by the CEAB definitions of introduced (I), developed (D), and applied (A) [19]. At the introductory level students begin to learn and apply concepts. At the developing level, students "*begin to probe more deeply... and deepen their exploration into concepts*." At this level, students realize there is complexity, different levels of organization, and analysis. At the applied level, students are developing insights and working with the knowledge in a very different way. They "*explore deeply...and experience controversies, debate and uncertainties...An advanced student can be expected to relate material contextually, to synthesize, integrate and achieve fresh insights."* [26]

All twelve graduate attributes, both technical and non-technical, influence the engineering leadership and management competencies in all leadership domains and management roles for engineering work. At the self and team leadership development levels, the emphasis is toward the technical attributes, communication, and teamwork. Technical skills are important in a leader early on to establish technical credibility with ones peer group and followers. Progressing to the organizational and societal leadership development levels, the emphasis shifts more to graduate attributes 6 through 12 and increased emphasis on contextual aspects. Although the relative importance shifts, technical competence is still necessary for

Table 5.1 – Leadership-Management Development Matrix (LMDM)

Leadership Development Level (Domain of Influence)	Management (Positional) Level	Non-technical Skill Domains (1. Cognition 2. Behaviour 3. Management 4. Leadership)	Skills
Society GA: 1-12 (A) Years 4 to 5	Thought Leader Inter Organization Manager Regulatory or Governing Body Director	Role: Thought Leader/Inter Org, Manager/Director 1. Integrative/ Interdisciplinary/Cultural cognitive processing (i.e. complex design processes or broad management interactions) a. Code/ standard development (collective experience /cognition) 2. Inter-organizational network relational-regulation/Social Intelligence (even more distant)/Cultural intelligence (broadly defined – both disciplinary and societal) 3. National and international policy development, environmental, safety, educational management. Across society and organizations. 4. Societal Leadership (Values, economics, freedom, education, individual vs collective)	Creativity /Vision Creating value - insight Community Builder Management and leadership (self +) Listening skills Empathy Metacognitive skills, Self-regulation
Organization (n>20) GA: 1-12 (A) Years 3 to 4	CxO Dept. Manager	Role: CxO/Org. Manager 1. Integrative/ Interdisciplinary cognitive processing (e.g. complex design, procurement, and operational processes including interdepartmental management) 2. Interdepartmental network relational-regulation/Social Intelligence (more distant) 3. Business integration with societal demands and expectations, client management, Project, Process-management 4. Organizational Leadership (vision, mission, values)	Same as above Contextual differences with similar skills sets in problem solving, social judgment, and knowledge schema categories
Team(n<20, typical 5) GA: 1-12 (D) Years 2 to 4	Team Leader Project Manager	Role: Team Leader 1. Group cognitive processing (e.g. design processes) 2. Relational-regulation/Social Intelligence (adaptive ways of management within relationship) 3. Team-management, inter team collaboration management, resources, schedule, etc. 4. Team leadership (vision, mission, values). Organizational alignment (vision, mission, values, priorities) Note: As the domain of influence expands foundational skills continue to develop and are more deeply explored and applied. Hence the I, D, A labeling with the role progression.	Connections and problem solving– with others and ideas. Administration Leadership Listening skills Empathy Metacognitive skills (performer) Self-regulation
Self (n=1) GA: 1- 12 (I) Years 1 to 2	Individual Contributor	Role: Individual (Follower, self leader, self manager) 1. Metacognition (think, transfer knowledge to other domains) 2. Self-regulation/ Emotional Intelligence (behave as individual) 3. Self-management (goals, plans, actions, tasks) 4. Self-leadership (vision, mission, values). Adoption of team schedule, goals, vision mission and values	Metacognitive skills (performer), Self-regulation Technical analytical competency Ability to learn

CEAB Graduate Attributes

1. *A knowledge base for engineering*
2. *Problem analysis*
3. *Investigation*
4. *Design*
5. *Use of engineering tools*
6. Individual and teamwork
7. Communication skills
8. Professionalism
9. Impact of engineering on society and environment
10. Ethics and equity
11. Economics and project management
12. Life-long learning

engineering leadership and management. In addition, some technical attributes such as problem analysis will expand to include other models or frameworks of analysis outside of the traditional engineering approach. Similarly, student competence development within the curriculum, from I through D to A, will generally follow progressive spheres of leadership influence and complexity from self to society in the life long learning context. Student exploration depth increases and then transitions to ongoing professional development.

5.4.0 Results: Application in the Engineering Curriculum

The LMDM presented in Table 5.1 can be used as a framework for engineering faculty and educational developers to explicitly map non-technical skills into the engineering curriculum in a way that relates engineering leadership and management practice from an introductory application of self through to applied applications in society. This parallel positioning of technical and non-technical skill development meaningful to engineering practice addresses a disconnected view that non-technical graduate attributes and skills are something apart from fundamentals or engineering science.

Utilizing the LMDM in developing engineering curriculum repositions the approach to developing non-technical graduate attributes. Instead of starting with the graduate attribute in isolation, the attribute and skill level can be contextually positioned within the need for engineering leadership and management in engineering practice. This repositioning can aid instructors when thinking about professional GA development in technical courses, potentially facilitating a move beyond the assignment of isolated problem sets into multifaceted learning activities such as case studies. It also strengthens the positioning of the activities within design courses in a way that can be explicitly related to practice (i.e., you are not just improving your communication skills, you are improving your ability to lead and manage in practice).

As an illustrative example, most engineering programs have design courses where students must work in teams on open ended projects delivering the results of their design and evaluation work as final reports, presentations and/or poster sessions. In these presentations, the assessment of the work is often done with rubrics that are positioned in the context of CEAB graduate attributes. For example, “Cohesiveness of Team” could be related to GA 6 – Individual & Team Work skills; and the dialogue during the presentation could be related to GA 7 – Communication skills. Rubrics for these skills tend to stand alone from the actual framing within engineering practice. For example, a strong performance in the team aspect might be phrased “All members contributed to the presentation and Q&A session;” and a strong performance in Communication might be phrased as “Clear, complete, thoughtful order to presentation;" and/or "Formulates thorough concluding statements in the context of the problem and design." While these statements may provide information for evaluation and GA assessment, the connection to the broader picture of engineering practice can be lost. Looking to the LMDM framework, an instructor can position these non-technical elements within practice. For example, if the final report is presented in the context of a report to a supervisor, the communication skills assessment could sit within the Team/Project Manager Leadership-Management Domain; whereas if positioned as a presentation to a client, it might fit within the Organizational/ Department Manager leadership-management domain; and a presentation session to stakeholders and professional members might be classified in the societal leadership/management domain. Providing practice context gives the exercise relevance beyond the rubric focus on an independent graduate attribute and moves to the realm of practical experience. Positioning relative to the LMDM also provides a mechanism for instructors and educational developers to think more intentionally about the educational outcomes relative to professional practice.

This is a simple example, but our goal is to enrich engineering education with a supportive method for intentional scaffolding of the contextual and professional aspects of engineering practice into the engineering curriculum. Used across a program, the LMDM could help to identify gaps in practical experiences and enable better planning for student development ahead of the capstone design courses while supporting a more wholistic approach. An approach that supports the transformation of the engineering program to one that enables engineering practice and empowers students to develop a sustainable engineering mindset and skillset with the ability to steward technology sustainability at the personal, team, organizational, societal and global levels.

5.5.0 Conclusions and Future Work

As the impact of engineering and business on society and our world continues to escalate, there are calls for the engineering profession to increase its focus on technology stewardship and to drive sustainable solutions. Also, calls to increase engineering influence beyond the technical to transform our economies with sustainable solutions. Engineering education will need to transform to empower sustainability and build both mindset and skillset capacity in graduating engineers to address current and future demands. Consequently, it is equally important to capture the non-technical skills in the curriculum and value them in parallel with technical skills. This can be challenging, as the direct connection of technical engineering skills to engineering research and practice is readily apparent to faculty and students. Not so apparent, is how the requisite non-technical skills connect to the curriculum beyond design courses.

A Leadership-Management Development Matrix has been created to help both faculty and students envision how the non-technical skills are also foundational to professional practice. By relating the non-technical skills to engineering practice through the lens of leadership and management, the LMDM attempts to position these skills in a way that encourages learning activities in the context of engineering practice and its impact on society. The scaffold follows the leadership-management trajectories that flow from responsibilities to self, to team, to organization, and to society. Beyond the leadership and management components, the LMDM can be grounded in assessment through the CEAB graduate attributes. A simple example has been provided to demonstrate the application of the model.

This work represents a preliminary view of how to position the relevance of non-technical skills in a way that integrates its relevance within the leadership and management domains of engineering practice. In future work we plan to map the leadership management skills more explicitly and provide further examples of how the LMDM can help engineering educators develop whole engineers who bring skills beyond the technical to engineering practice and consequently the development and stewardship of sustainable engineering solutions.

Acknowledgements

This work was inspired by interaction with many engineering educators at the Canadian Engineering Education Association Conferences and in particular, those that have participated in the National Initiative on Capacity Building and Knowledge Creation for Engineering Leadership (NICKEL) conferences from 2016 through 2019. The authors would like to thank individuals who shared workshop materials and other resources related to the development of the whole engineer. These experiences, along with our engineering teaching, research, and practice experience have all formed and contributed to our thinking.

References

[1] L. Bosman and S. Fernhaber, *Teaching the Entrepreneurial Mindset to Engineers*. Cham: Springer, 2018.

[2] M. M. Andreasen, C.T. Hansen, and P. Cash, *Conceptual Design Interpretations, Mindset and Models*. Cham: Springer, 2015.

[3] H. Brown and B. Keidan, “ONTARIO ENGINEERS FIND THEIR PLACE IN THE HOUSE OF COMMONS,” *Engineering Dimensions*, no. 5, p. 33, 2015.

[4] T. Duever, “Ryerson University holds inaugural engineering conference,” *Construction Canada*, p. NEWS, 31-Mar-2015.

[5] K. Smith, “A Classroom Experience That Builds the Top Skills Employers Want,” *Manag. Teach. Rev.*, vol. 1, no. 2, pp. 73–78, 2016, doi: 10.1177/2379298116633870.

[6] C. Kivunja, “Teaching students to learn and to work well with 21st century skills: Unpacking the career and life skills domain of the new learning paradigm,” *Int. J. High. Educ.*, vol. 4, no. 1, pp. 4–11, 2015, doi: 10.5430/ijhe.v4n1p1.

[7] "2019 Accreditation Criteria and Procedures," Nov. 2019.

[8] P. A. Vesilind, *Engineering Peace and Justice The Responsibility of Engineers to Society*. Cham: Springer, 2010.

[9] J. M.Burns, *Leadership*, 1st ed. New York: Harper & Row, 1978.

[10] S. Hacker and T. Roberts, *Transformational Leadership : Creating Organizations of Meaning*. Milwaukee, Wisconsin: ASQ Quality Press, 2003.

[11] R. L. Katz, "Skills of an effective administrator," *Harv. Bus. Rev.*, vol. 33, no. 1, pp. 33–42, 1955.

[12] M. D. Mumford, S. J. Zaccaro, F. D. Harding, T. O. Jacobs, and E. A. Fleishman, "Leadership skills for a changing world: Solving complex social problems.," *Leadersh. Q.*, (11), no. 1, pp. 12–23, 2000.

[13] J. M. Birkinshaw, *What is your Management Model?*, 02-Sep-2010.: https://www.managementexchange.com/blog/what-your-management-model.

[14] Engineers Canada, "Public guideline on the practice of engineering in Canada | Engineers Canada," *Engineers Canada*, Feb-2012.: https://engineerscanada.ca/publications/public-guideline-on-the-practice-of-engineering-in-canada..

[15] Engineering and Geoscience Professions Act, "Engineering and Geoscience Professions Act. (2015). Section 1, p. 8." Queen's Printer, 2015.

[16] P. Meiksins, "The 'Revolt of the Engineers' Reconsidered," *Technol. Cult.*, vol. 29, no. 2, pp. 219–246, 1988, doi: 10.2307/3105524.

[17] F. F. Joyner, D. T. Y. Mann, and T. Harris, "Engineering as a social activity: Preparing engineers to thrive in the changing world of work.," *Am. J. Eng. Educ.*, vol. 3, no. 1, pp. 67–81, 2012.

[18] p. Lappalainen, "Communication as part of the engineering skill set.," *Uropean J. Eng. Educ.*, vol. 34, no. 2, pp. 123–129, 2009.

[19] M. V. Jamieson and J. M. Shaw, "Teaching engineering for a changing landscape," *Can. J. Chem. Eng.*, vol. 97, no. 11, pp. 2870–2875, 2019, doi: https://doi.org/10.1002/cjce.23626.

[20] A. Parker, E. Watson, M. Ivey, and J. P. Carey, "Approaches to graduate attributes and continual improvement processes in faculties of engineering across Canada: A narrative review of the literature," in *Proc. 2019 Canadian Engineering Education Association (CEEA-ACEG19) Conference*, Ottawa, ON, 2019.

[21] J. Kaup and B. Frank, "EGAD National Snapshot Survey: Change Progress and Improvement," in *Proc. 2016 Can Eng Education Association (CEEA16) Conf.*, Dalhousie, NS, 2016.

[22] M. Wells, "Realizing the potential of Canadian engineers to change the world | The Star," 2019. [Online]. Available: https://www.thestar.com/opinion/contributors/2019/12/31/realizing-the-potential-of-canadian-engineers-to-change-the-world.html?

[23] E. F. Crawley, J. Malmqvist, S. Östlund, D. R. Brodeur, and K. Edström, *Rethinking Engineering Education - The CDIO Approach*. Cham: Springer International Publishing, 2014.

[24] P. G. Northouse, *Leadership Theory and Practice Ch 3 Skills Approach*, 8th ed. Sage, 2018.

[25] J. M. Birkinshaw, *Becoming a better boss: why good management is so difficult*. San Francisco, CA: Jossey-Bass, A Wiley Brand, 2013, 2013.

[26] Canadian Engineering Accreditation Board, "A Guide to Outcomes-based Criteria: for Visiting Team-Chairs and Program Visitors, version 1.25." Engineers Canada, 01-Mar-2015.

6. Sustainable Engineering Leadership and Management of Complex Engineering Systems (*Education for Chemical Engineers*, Online December 2020)

This paper began as a term paper assignment for a *Quantitative Risk Management* graduate course. It was submitted as an abstract with Dr. L. Lefsrud for the ASEE 2020 conference with the intent of further developing it after the course into a conference paper. As the paper was further developed we invited two additional authors, Drs. F. Sattari and J. Donald to join us as the work began to intersect with other projects. The full ASEE paper was peer reviewed, accepted, and presented by Marnie Jamieson at the virtual conference in June 2020. This resulted in an invitation to submit a manuscript to Education for Chemical Engineers (ECE) for a special issue: Process Safety in Chemical Engineering Education and Training. The paper included here is the version of the manuscript accepted for publication.

Sustainable Leadership and Management of Complex Engineering Systems: A team Based Structured Case Study Approach

Marnie Jamieson[1], Lianne Lefsrud[1], Feresheteh Sattari[1], John Donald[2]
[1]Department of Chemical and Materials Engineering, University of Alberta
[2] School of Engineering, University of Guelph

Abstract

Engineering leadership and management consider the organizational aspects of the development and operation of complex designs in a sustainable manner. Safety and risk management are key elements in sustainable design, operation, and management of engineering projects (Crowl & Louvar, 2019). Recognizing that a safety culture does not develop on its own, but is a product of management's intent and consistent reinforcement (Fleming et al., 2018; IAEA, 1986), case studies help students to understand and reflect on the leadership values and management beliefs that can lead to sustainability, inherently safer designs, and a supportive organizational culture. Using case studies to connect incident stories to engineering safety, culture, and risk management can help students examine the enacted values, underlying values, assumptions, and beliefs that may contribute to major incidents (Guldenmund, 2000; Kerin, 2018; Shallcross, 2013b). Further, the education of engineers as empowered leaders who understand the implications of their own underlying values, assumptions, and beliefs and their subsequent connection to the sustainable design and operation of complex systems enhances societal sustainability. This paper proposes a case study analysis structure developed to connect the role of the underlying values, ethics, assumptions, and beliefs of people who lead, manage, and work in complex engineering projects towards the enactment of a sustainability culture or a safety culture or both. The proposed case study structure reinforces engineering education outcomes, the United Nations sustainable development goals, and Risk Based Process Safety (RBPS) management in order to further develop technical and professional skills in undergraduate and graduate students better preparing them for their future roles in a world demanding sustainable solutions.

1. INTRODUCTION

Sustainable engineering leadership and management considers the organizational aspects of the development and operation of complex designs in a manner consistent with sustainability principles (Jamieson & Donald, 2020). Safety and risk management are key elements in sustainable design, operation, and management of engineering projects (Crowl & Louvar, 2019). The engineering programs at many universities list process safety as a program objective and a few include it as either a core or elective stand alone course in their program but more often it is included in existing courses (Amaya-Gómez, 2019). Recognizing that a safety culture does not develop on its own, but is a product of management's intent and consistent reinforcement (Fleming et al., 2018; IAEA, 1986), case studies may help students to understand and reflect on the leadership values and management beliefs that can lead to sustainability, inherently safer designs, and a supportive organizational culture. Using case studies to connect incident stories to engineering safety, culture, and risk management can help students examine the enacted values, underlying values, assumptions, and beliefs that may contribute to major incidents (Guldenmund, 2000; Kerin, 2018; Shallcross, 2013b). Further, the education of engineers as empowered leaders who understand the implications of their own underlying values, assumptions, and beliefs and their subsequent connection to the sustainable design and operation of complex systems enhances societal sustainable development. We propose a case study analysis structure developed to connect the role of the underlying values, ethics, assumptions, and beliefs of people who lead, manage, and work in complex engineering projects towards the enactment of a sustainability culture or a safety culture or preferably both. The proposed case study structure reinforces and integrates engineering education outcomes, the United Nations sustainable development goals (UNSDG), and Risk Based Process Safety (RBPS) management in order to further develop requisite technical and professional skills in undergraduate and graduate students better preparing them for their future roles in a world demanding sustainable solutions.

1.1 Motivation

Engineering education must equip graduates with an understanding of the role of engineering in society and the complex interactions of engineering designs with the environment, people, organizations, and society (Jamieson & Shaw, 2019) aligned with the 2030 UN Agenda for Sustainable Development (UN, 2015, 2020). Further, engineering and project management are being influenced by artificial intelligence, climate change, work methods (including COVID-19 impacts), and the location of emerging economic growth centers (PMI, 2019, 2020a; Wellingtone, 2020). Currently, only 50 to 55% of projects are completed on time and on budget with almost 50% experiencing scope creep (PMI, 2017) with these factors being exacerbated in companies with limited commitment to core project management skills (PMI, 2019, 2020b). To meet these new challenges and current schedule/scope/budget issues, stakeholder engagement, risk management, and planning are the most useful and easiest to embed in project management processes by practicing professionals (Wellingtone, 2020). In addition, process safety incidents are still occurring globally at a rate similar to past decades; process safety culture deficiency is the leading cause with emergency preparedness and mechanical integrity tied for second place (Bhusari et al., 2020). In sum, these complex emerging and existing challenges affect how we operationalize 'sustainable leadership' for engineering management.

To create educational programs to equip engineers for this complex environment, program accrediting bodies, such as the Canadian Engineering Accreditation Board (CEAB) and the Accrediting Board for Engineering Technology (ABET), have introduced a broad array of technical and non-technical outcome-based graduate attributes (ABET, 2019; Engineers Canada, 2018). Process safety education is a necessary part of engineering education and can be integrated into the technical and fundamental core curriculum (Dixon & Kohlbrand, 2015). In this paper, we argue that sustainable design and sustainable operation of complex systems requires specialized technical engineering knowledge and skills **combined with** engineering leadership and management skills in the organizational context. This requires that programs develop integrated learning activities across these graduate attributes, which can be challenging given an already hectic curriculum. In addition, despite the inclusion of process safety from an accreditation perspective the inclusion of process safety material may be limited by program constraints and the availability of process safety management professors (Amaya-Gómez, 2019). We further argue that employing integrative case-based learning activities can be an effective and efficient mechanism to effectively fulfill educational requirements across the engineering graduate attributes and support ongoing fundamental technical skill development. Finally, to provide a basis for constructing case study learning activities, we define a structured case study model demonstrably grounded in the key frameworks of sustainability, safety and risk management.

1.2 Engineering Leadership and Management Connections

Historically, engineering leadership curricula tend to use more experiential approaches, while business school leadership curricula tend to take a case study approach (Klassen & Donald, 2018). We propose that mixing experiential approaches and case studies supports student learning with respect to practice and context of complex system engineering design, management, and sustainability. Many engineering projects are designed, operated, and decommissioned in a context with potentially conflicting business motivations, social orders, and power structures that cause variance between technical intentions (what is designed) and organizational action (what is implemented) (Stackhouse & Stewart, 2017). With years of technical design training, engineering graduates can be confused by such inconsistencies. Sometimes they are left wondering: Why is a design not being used as intended? or why is a design or process issue not being corrected? Understanding how and why engineering projects may not be implemented or operated as designed is integral for engineering students to successfully recognize and respond to contextual challenges. To overcome these drawbacks, case studies are particularly well suited to the study of organizational decision-making. For example, understanding the social, market, and regulatory context of organizations and to examine the impact of social order and power, which can frustrate technical decision-making processes (Suddaby & Lefsrud, 2010). Case studies are a subset of problem-based learning (PBL) (Duch et al., 2001) and have been foundational to undergraduate curriculum transformation in medicine (Allen et al., 2011). There is significant evidence that PBL is effective (Allen et al., 2011; Duch et al., 2001; Mandeville & Stoner, 2015) and is a recommended method to incorporate and support sustainability and a move to a more wholistic educational paradigm that promotes a systems thinking approach (Guerra & Smink, 2019).

Incident case studies are a more specific PBL approach, which are typically used to develop student presentation skills (Crowl & Louvar, 2019) and incident recall (Shallcross, 2013a;b). However, these may also lead students to oversimplify the situation and conclude that the incident may have been easily foreseen and thus avoided had one decision been changed (hindsight bias). To fully understand the context of the incident, it is important for a student to consider not just the technical viewpoint, but also the leadership and management context in which decisions are made. This can provide insight beyond the technical into how engineers can influence a culture of safety and sustainability within their organizations. Ideally this equips and empowers engineers to better understand and enact their professional responsibilities ensuring that protection of the public is paramount.

2. BACKGROUND

Engineering work and systems are multidimensional thus engineering education is required to develop engineers' ability to take on engineering, management, and leadership roles. As engineering education has evolved, new methods for developing engineers have been proposed yet gaps still exist. Important aspects are: 1) understanding the roles of engineers in society and sustainability objectives, 2) redefining the role of engineering education to better support societal objectives, including protection of the public, and 3) the benefits of further implementing integrative active learning strategies like case studies. All of these aspects underlie and support sustainable development.

2.1 The Engineering Role in Organizations and Society

The design and operation of a complex system requires engineering work and engineering oversight as key inputs (Engineers Canada, 2012). Engineers do not design or operate complex systems on their own or outside a regulatory framework. Rather, complex systems are operated by corporate entities within a government regulatory framework that considers economic, environmental, and safety implications with respect to society as a whole. In other words, engineers are subject to the formal and informal interaction dynamics of bureaucracy and institutions (Blau, 1964; Suddaby & Lefsrud, 2010). Engineers' roles and responsibilities are typically embedded, most often as organizational employees, in these business and technical aspects (Meiksins, 1988). Depending on their organizational position and role, engineers may or may not have direct input into the formal organizational structure of the firm, the definition of the roles and responsibilities of positions within the organization, or the allocation of resources. As a result, the same individual may not hold decision-making authority and design/operation responsibility. The Challenger explosion (Vaughan, 1996), Brumadinho dam collapse (Santamarina et al., 2019) and many other incidents (Cooke & Rohleder, 2006) resulted from a misalignment of decision-making authority and design/operation responsibility.

Corporations and regulatory entities are typically large institutionalized organizations and include non-engineering individuals who have diverse skills, beliefs, values, and motivations for their work. They may or may not have professional obligations as engineers do – yet they may be in positions of influence or authority with ability to impact decision-making and potentially the employment status of engineers. This contributes to the captive nature of the engineering profession from both a practical and intellectual perspective (Johnston et al., 1996) where organizations motivated by business objectives dictate the problems to be addressed and the terms of the acceptable solutions (Goldman, 1990), often in terms of the profitability of the venture within regulatory framework and constructs. Aspects not typically covered in an undergraduate engineering program leaving graduates underprepared to manage the organizational realities of engineering work.

Organizational realities include the requirements for group cross coordination and management systems, respecting regulatory constraints, and maintaining the safety of the society hosting the complex system for their collective net benefit. Their collective assumptions, beliefs, values, experience, communication and management systems define the culture (Guldenmund, 2000) of the operating or regulatory entity. Professional Engineers are ethically obligated to consider the impact of their work on society as a whole (APEGA, Belanger & Pupulin, 2004). Their responsibility to the public and subsequently to sustainable development principles is their paramount ethical precept. Yet, besides a misalignment of authority and responsibility, engineers may be separated from the people whom their work and decisions impact (Meiksins, 1988; Rulifson, 2019). Further, the organizational structure and culture of an entity may not support this obligation, if the collective assumptions, beliefs, and values are inconsistent with engineering ethics.

Engineering graduates must be better prepared and supported in order to negotiate this complex organizational and societal landscape while supporting sustainable development, as their responsibility to the public demands it. Sustainability encompasses technical feasibility supported by economic, environmental, and safety objectives, regulations, and risk management. “Sustainable development ... meets the needs of the present, without compromising the ability of future generations to meet their own needs,” Brundtland Commission (Andrews, 2009, p. 359). There are competing priorities in the sustainable design, operation, and decommissioning of complex systems and they must be managed considering societal perceptions (Gehman et al., 2017) and at times the global community as a whole with respect to present and future needs and more recently, while considering and addressing inequities of the past (Sterling & Landmann, 2011).

2.2 The Evolving Role of Engineering Education

To fulfill our role in organizations and society, engineering education has evolved from applied science roots to include engineering design and more recently engineering leadership, engineering safety and risk management. Design became a component of the chemical engineering curriculum at the University of Alberta in the middle of the 20th century (Faculty of Engineering Calendar, 1955) and has since evolved to support the early professional development of engineering students (Jamieson, 2016; Jamieson & Shaw, 2020) as the definition of engineering work has evolved (IEA, 2013). Engineering design is now a central and core component of accredited engineering programs, typically taught as an immersive, experiential, and open-ended problem-based course, generally in teams. Engineering education embraces outcome-based engineering graduate attributes (ABET, 2019; Engineers Canada, 2018; IChemE, 2017; IEA, 2013) and additional facets of professional practice, such as engineering leadership and risk management (an undergraduate requirement at the University of Alberta), are becoming more prominent in the learning activities and characteristics of engineering programs (Amaya-Gómez, 2019; Anderson et al., 2018; ASEE Workshop report, 2014; Danielson, 2014; Norval, 2015b).

Social responsibility aspects of professional practice have been developing in parallel (Belanger & Pupulin, 2004). The design of learning activities to support the skills of professional practice must include contextual and situational elements for students to gain practice in the application of the specialized knowledge of the engineering profession to the complex problems they will face during their careers and empathy for the social, cultural, and life cycle impacts of the solutions they propose (ASEE Workshop report, 2014; Matthews et al., 2017). The legal expectation of providing adequate occupational and process safety training to students and workers is increasing (Norval, 2015b). These responsibilities and their navigation in organizational structures can be directly connected to case study learning activities, as engineering students review the management and leadership implications of engineering decision-making processes with such incidents.

2.3 Case Studies in the Engineering Education Curriculum

Case studies are used as an analysis and research method to understand the relationships between theoretical constructs and practical applications in many fields including nursing, medicine, business, law, management, leadership, engineering and organizational studies (Wiebe et al., 2010). The use of the case study method has found instructional value in sectors such as business, law, and policy, owing to a host of benefits this method provides. Chief among these benefits, case studies offer students a practical avenue to explore creative and innovative applications of the technical and organizational principles. In a similar vein, engineering students can be exposed to incident case studies focussing on root cause analysis of accidents and system safety failures. Reviewing and reading incident case studies can empower engineers to recognize the role and importance of human error/failure in engineering design and the influence of engineering activities on society (Condoor, 2004). The investigation of incident case studies is a vital component of the engineering profession and is particularly critical in engineering education (Saleh & Pendley, 2012) for understanding past failures and incidents. It can help students identify predictive indicators, evoke constant vigilance in monitoring those indicators, develop inherently safer technologies, and understand systemic and logistical issues.

The real-life nature of case studies engages cognitive, affective, and behavioural learning (Kolb, 1984) — dimensions that instructors and educators may not be able to tap into through conventional teaching methods and curricula. Case studies, along with problem and project based learning, are an active learning approach that brings the technical, contextual, metacognitive, and professional skill aspects of engineering practice into the classroom. Therefore, the inclusion of case studies into the teaching and learning experience is likely to have a constructive and lasting effect on students' mindset and skillset. This outcome touches upon a significant component of education beyond the utilitarian model that includes the development of genius, innovation, and a zone of patience and contemplation in the university (Faust, 2010) to prepare engineering students as agents of change (Saleh & Pendley, 2012; Swuste & Arnoldy, 2003) for continual improvement and sustainable development. Furthermore, by developing the cognitive, affective, and behavioural abilities of engineering students, the case study method enables graduates to focus on the bigger picture — aspects beyond technical considerations — and to work safety measures and sustainability implications into their decision-making, regardless of their role in industry, be it in a design, operational, or a managerial capacity (Hale & deKroes, 1997). This development of a sustainable engineering leadership and management mindset may begin to address the ongoing societal failure to fix identified deficiencies that contribute to critical loss incidents and operational problems. (Saylan & Blumstein, 2011; Stackhouse & Stewart, 2017).

Eisenhardt (1989) reemphasized the need to enforce case study-based learning in engineering education, noting that the learning outcomes from case study research may range from development of ideas, and frameworks, to postulations, or mid-range theory, owing to the richly descriptive nature of case studies. Another advantage is the concurrent opportunity to focus on the ethics component of engineering education. Many incident case studies include a moral or ethical dilemma. Asking students to recognize a dilemma and seek resolution can bring a positive impact on moral reasoning and incorporate technical, communication, and teamwork skills (Wilson, 2013). In addition, as an active learning approach, case studies require students to rework open-ended problems from a fundamental perspective reinforcing their technical abilities and placing technical skills in the context of real world engineering work and practice. In conclusion, discussion and analysis of incident case studies as a part of the engineering curriculum attends to two integrated themes that an engineering program is founded upon – the appropriate application of technical knowledge and skills, for example, safety principles (safety by design); and the integration of professional and contextual knowledge and skills, for example, the organizational and societal contributions to system causation and prevention.

2.4 Developing an Integrative Framework for Engineering Education, Sustainability, and Risk Management Consistent with Graduate Attributes

To design engineering program learning activities and experiences, including case based activities, consistent with achieving the engineering graduate attributes and the emerging development of a sustainability culture, we investigate the integration of three frameworks:

- the CEAB Graduate Attribute framework (Engineers Canada, 2018) (Appendix A1.2),

- the United Nations (UN) Sustainable development framework (UN Sustainable Development Summit, 2015) (Appendix A1.9, Appendix E, Section 5.3.4), and
- the Risk Based Process Safety (RBPS) management framework (AIChE CCPS, 2007; Crowl & Louvar, 2019) (Appendix A1.10, Appendix E, Section 5.3.4).

These all suggest that education, continual improvement, and lifelong learning practices underlie the long-term success of sustainable development, engineering, engineering education, engineering safety and risk management. In addition, they are consistent with professional practice societal obligations.

There is significant intersection between these frameworks in the design, construction, operation, maintenance, and decommissioning of complex engineering systems in the service of society. Sustainability balances social, economic, and environmental goals, while risk management and process safety offer approaches to quantify, evaluate, and trade-off the associated social, economic, and environmental risks. To prepare for their future roles, engineering students need: exposure to identifying hazards and failures (Haluik, 2016; Norval, 2015b) in the workplace and in complex system design and management systems (Crowl & Louvar, 2019; Mkpat et al., 2018); to develop skills consistent with the expectations of the engineering graduate attributes; to create and support designs consistent with the UN sustainable development goals; and to be able to evaluate new and existing designs with a risk management process. The integration of engineering leadership with sustainable development principles and undergraduate engineering education equips future engineers with the skills and tools to better address our global challenges (i.e. clean water and sanitation; affordable and clean energy; industry, innovation and infrastructure; etc.).

From this intersection, we develop a case analysis structure to examine the technical, business, and human aspects of significant incidents from the perspective of students' learning and instructors' teaching. The case analysis structure leverages experiential contextual learning activities by combining team and problem based open-ended work and incident case studies. The use of both learning and teaching perspectives in a case study supports peer teaching as a learning tool in the broader context of engineering education and practice (Jamieson et al., 2017). This structure reinforces that engineering is not just the positivist application of science to serve business goals (Johnston et al., 1996), but that we serve and protect the public and, thus must also consider the consequences of our designs and actions more broadly. The achievement of the engineering graduate attributes requires the development of fundamental technical and contextual knowledge concurrently with professional and metacognitive skills (Jamieson & Shaw, 2019). The achievement of sustainable development requires an engineering management system. Engineering Safety and Risk Management (ESRM) is already employed and considers many of the facets of sustainable development. ESRM may be congruent with the UN sustainable development goals. If so, this allows for the rapid inclusion of sustainable development principles and goals into structured incident case studies and the engineering education curriculum.

3. METHOD

First the intersection of risk management, sustainable development and engineering education outcomes was examined. Next, engineering education outcomes were examined in the context of comparing the CEAB graduate attributes to the Accreditation Board for Engineering and Technology (ABET) student outcomes both before and after the ABET revisions. Then, the International Risk Governance Council (IRGC) risk governance framework (Appendix A1.11) and the CCPS RBPS structure were compared. The foundational blocks of the CCPS RBPS management structure were mapped to the (IRGC) risk governance framework. The IRGC framework was adapted to reflect the objectives of the learning process. Our adaptation of the framework process reflects the process required to prepare students to contemplate the UN SD goals in the context of engineering leadership and risk management while delivering the CEAB graduate attributes. The UN SD Goals and the CEAB graduate attributes were mapped to steps two to five of the adapted process. Step one of the process, cross cutting aspects, reflects the integrative and experiential nature of engineering design and practice. Last, the structured case study is built using the adapted process as a guide to facilitate the classroom experience of engineering practice situations.

3.1 Mapping the Framework Intersections to Engineering Education and Practice

As complex engineered systems are designed, constructed, operated, and maintained by groups of people (organizations); leadership, policies, procedures, management systems and regulatory frameworks are required to ensure a business remains sustainable and the interests of societies are served. The intersection of the UN Sustainable Development Goals framework and the Risk Based Process Safety Management framework were investigated by mapping common elements. For example, Sustainability as defined by the UN Sustainable Development Goals framework (UN Sustainable Development Summit, 2015) includes profitable operation (SD Goals 8 & 9), which map to the RBPSM *Manage Risk* category; environmental regulatory stewardship (SD Goals 6, 13, 14, &15) map to elements in *Commit to Process Safety*; and safe operation of the system with regard to the safety of individuals, the community, the society; and the global environment (SD Goals 9, 11, &12) map to the *Understand Hazards and Risk Category*. To meet these sustainability requirements corporations, regulators, engineers, and engineering graduates require a broad cross section of skills beyond their core technical competency and capabilities to negotiate the sustainable design and operation of complex systems within society and our global environment (Engineers Canada, 2018; IEA, 2013; APEGA: Belanger & Pupulin, 2004). We summarize mapping the intersection of CEAB graduate attributes (GA) and UN SDGs with the RBPSM framework at the bottom of Figure 6.1 and include further mapping data in the supplementary material.

3.2 Mapping the Graduate Attributes and Student Outcomes

The Canadian Engineering Accreditation Board (CEAB) Graduate Attributes (GA) (Engineers Canada, 2018), the US Accreditation Board for Engineering and Technology (ABET) Student Outcomes (ABET, 2019) and the International Engineering Alliance (IEA) description of an engineer's work (IEA, 2013) demonstrate the breadth of the education required to negotiate the complex interrelationships of engineering designs and systems with the people who build, operate, maintain, decommission, and benefit from the designs and systems. As ABET accredits national and international programs, the CEAB graduate attributes and the ABET student outcomes were also mapped as part of the process. This mapping, included in the supplemental material, indicates excellent agreement between the CEAB graduate attributes and the ABET student outcomes. These engineering attributes and outcomes are similarly reflected in the literature of global accrediting bodies. The Institution of Chemical Engineers (IChemE) graduate attributes strongly reflect process safety education requirements (IChemE, 2017) and our mapping suggests a strong correlation between the risk based process safety management elements with the CEAB graduate attributes (see Figure 6.1). This observation is noted for global accreditation related student outcomes (Amaya-Gómez, 2019) and supported by the longer term argument that risk management is necessary for all engineers (Amyotte & McCutcheon, 2006).

Strong technical and fundamental skills are a core aspect of engineering and are necessary for engineering work (CEAB Graduate Attribute 1). Analysis of the graduate attributes indicate that graduating and practicing engineers require core technical, contextual, metacognitive, and professional skills (Jamieson & Shaw, 2019) to satisfy the remainder of the graduate attributes. Strong professional skills including leadership, management, and organizational skills are a core aspect of engineering work and a key component of engineering safety and risk management (Graduate Attributes 6,7,8,9,10,11,12). The intersection of the UN SDGs and the CEAB graduate attributes is also clear and the sustainable development goals can provide a framework for engineering education and for practicing professionals as they execute their roles in the context of global sustainability and uphold their responsibility to protect the public.

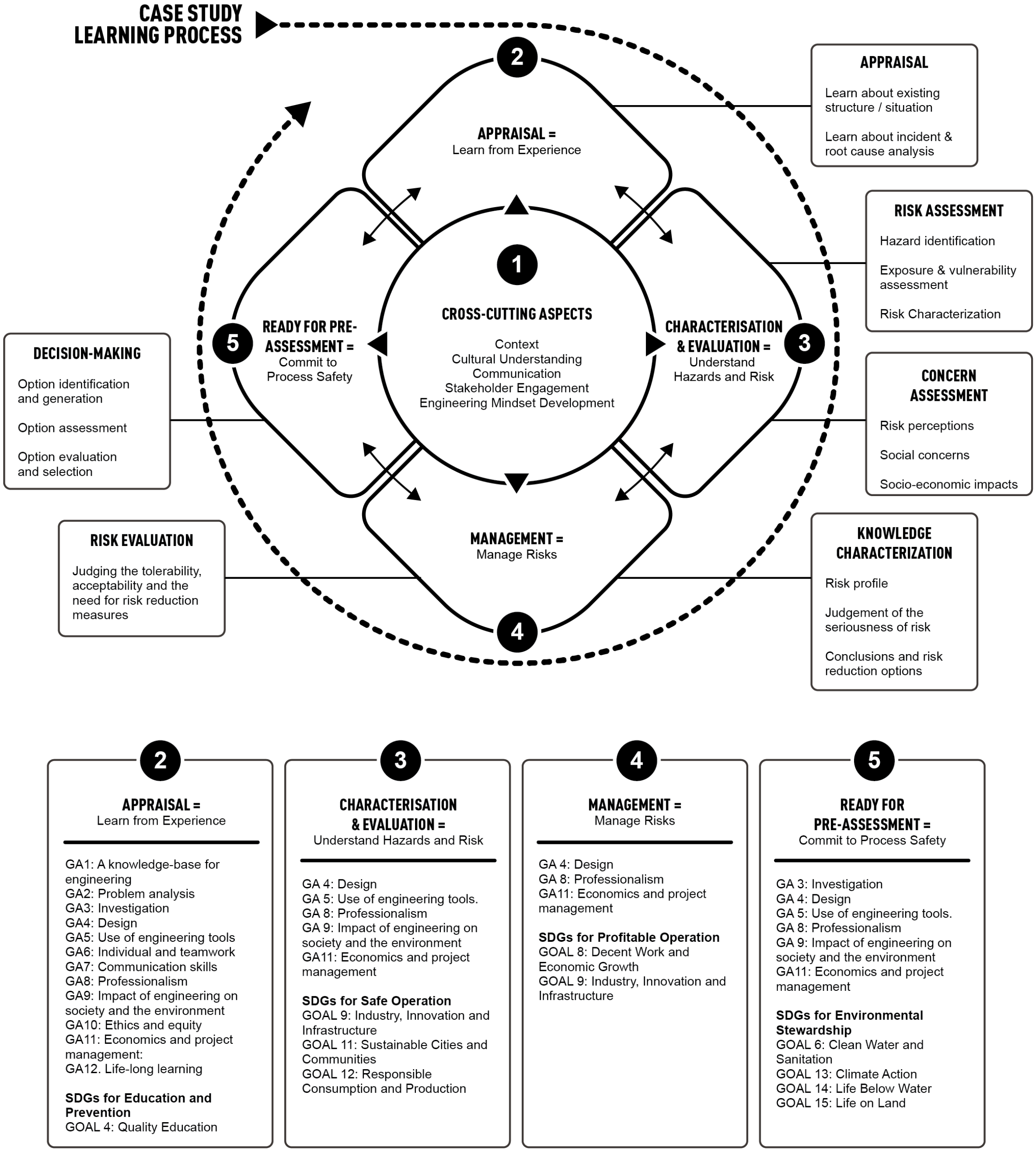


Figure 6.1. RBPS Management mapped to the IRGC risk governance framework and adapted_(IRGC, 2017; Schweizer & Renn, 2019) to the structured case study approach demonstrating the intersections of the UN Sustainable Developing Goals (SDGs) and CEAB Graduate Attributes (GA) with risk management objectives. (M. Jamieson et al., 2020)

Case studies make these connections real, to engineering students by: demonstrating the consequences of failures, role-modeling how engineers learn from failures, illustrating how that learning is integrated into the codes and standards of practice, and showing how organizational roles and management processes and procedures influence engineering work and operations. Case study learning activities can also support professional skill development by giving students the opportunity to connect the variety of engineering organizational roles, with service to society and professional responsibility, in a sustainability context. In addition, RBPSM, an existing and already in service engineering management system, could be used to rapidly operationalize sustainable development goals in engineering work and projects because of the intersection observed between both RBPSM and the UN SDG's and the CEAB graduate attributes.

3.3 Mapping Risk Based Process Safety Management to the IRGC Framework

The twenty elements of Risk Based Process Safety (RBPS) management (AIChE CCPS, 2007) fall into four categories: *commitment to process safety, understand hazards and risk, manage risk*, and *learn from experience*, arrayed as a circular process at the top of Figure 6.1 (following Schweizer & Renn, 2019). The RBPSM categories map directly to the four components of the IRGC risk governance framework (IRGC, 2017). "For any incident, experience has shown that *many of the 20 elements RBPS are involved*. Incidents almost always stem from a *failure of the management system*. Thus, by improving the management system, incidents can be significantly reduced" (Crowl & Louvar, 2019). By improving design, operation, and management systems deficiencies, the root causes are addressed and best practices incorporated into the organization reducing process safety incidents. The RBPS management framework is an aspect of sustainability as defined by the UN sustainability framework (Blum et al., 2017; Moldavska & Welo, 2019). An element of RBPS management is incident investigation and the application of the learning to prevent future incidents – precisely the purpose and intent of utilizing either case histories or incident case studies as a learning activity for engineering students. The UN sustainability and RBPS management frameworks intersect with the CEAB engineering education outcomes based graduate attributes in the role of an engineer to contextually apply scientific principles for the benefit of society, typically in organizations and institutions.

In sum, the framework intersection is detailed at the bottom of Figure 6.1 and the relationship of the RBPS management foundational blocks to the International Risk Governance Council (IRGC) risk governance adaptable framework (IRGC, n.d.) for complex, uncertain, and/or ambiguous issues (IRGC, 2017; Renn, 2006; Schweizer & Renn, 2019) is illustrated at the top of the diagram. These elements are then rearranged to structure the circular case study learning process (dashed line, with number showing alignments), consistent with the learning objective of preparing students for engineering practice in complex and ambiguous situations.

4. RESULTS: Supporting Process Safety Culture and Sustainable Development

A process safety culture is defined as a positive environment where employees at all levels are committed to process safety. This starts at the highest levels of the organization and is shared by all. Process safety leaders nurture this process (Crowl & Louvar, 2019). Key educational aspects of the RBPS management system are learning from incident experience, training, hazard identification, and developing process safety competency. Incident case studies integrate the educational aspects of the process safety management categories and may contribute to developing process safety competency (Shallcross, 2013b; 2013a). As a learning activity, incident case studies can support the development of the engineering graduate attributes and enhance the UN Sustainable Development Goals while reducing the risk of industrial activities to individuals and communities by raising the level of process safety competency in graduating engineers. By increasing the number of individuals with process safety competency within our society the overall ability of the society to manage risk and better address life cycle issues in a sustainability context improves (Pittman et al., 2015).

For the purpose of this paper a broad definition of process safety is considered. It includes chemical process safety and process systems safety with respect to the systems that surround the design, construction, operation, maintenance, and disposal of complex engineering designs used by society or to produce products for societal consumption. Although companies with a mature safety culture tend to have a higher market value than those that do not (Farell & Gallagher, 2015), society itself tends to bear the cost of corporations who operate with a less developed or non-existent corporate safety culture because of the far reaching and significant consequences of process safety events. Examples in this category of high societal consequence incidents include memorable disasters such as Bhopal, Lac Mégantic, MGPI Processing, BP Texas City, and most recently the Port of Beirut, Lebanon. In addition, these incidents may negatively affect the public perceptions of engineering as a profession (Crowl & Louvar, 2019; Pittman et al., 2015) and the organizations engineers lead, manage and belong to (Gehman et al., 2017). In some cases, such as Bhopal, Lac Mégantic, and the Port of Beirut, the incidents may also negatively impact national and international public perceptions of regulatory bodies and governments entrusted with protecting the public. The ability to rapidly operationalize sustainable development in a risk governance framework and better equip graduating engineers may have long term positive consequences on both the engineering profession and society.

5. RESULTS: Team-Based Structured Incident Case Study Method

Case studies are used as a method to understand the relationships between theoretical constructs, practical application of process safety management systems and design, and contextual concepts to prevent incidents (Norval, 2015a; Shallcross, 2013a). It is proposed the use of team-based incident case studies in undergraduate and graduate engineering courses may be useful in further developing technical, professional, contextual, and metacognitive skills for students in the same manner that case studies are useful in business programs. The case study structure is crucial to avoid hindsight bias (Kerin, 2018) and to ensure learning is integrated over the technical and professional domains. In course design practice, select case studies with content directly linked to the global course learning objectives and aligned with assessments. Table 6.1 describes the connections between the RBPS management educational elements selected from each of the five categories of the IRGC risk governance framework (IRGC, 2017), their relationship to the UN sustainable development (SD) goals, and engineering education in the overall context of contributing process safety competency and expertise to society.

Engaging students in a learning activity where they discover the unfolding incident from the perspective of the people involved in or impacted by the incident prior to taking the perspective of an investigator can demonstrate the complexity of incident causation. The incident investigation perspective provides clarity and the analysis of the case with engineering tools provides the perspective for developing preventative recommendations. Considering retrospective prevention and the technical analyses required to support this step shifts the student perspective to that of the engineering practitioner. In keeping with this lens, the root cause analysis of the incident broadens the view to include the engineering leadership and management aspects of complex design and system operation. The final step is to reflect on the values and beliefs to develop recommendations to address the underlying root causes, inadequate management structures, and/or misalignment with societal beliefs. By challenges to students' way of knowing about themselves and their interactions with and consequences on others and the world – the case study has the potential to become a lesson in leadership. As students work in teams to develop and present a case study there are opportunities for applying the risk management process and discussion to support holistic student development and include sustainability discourse.

The following outlines the proposed team-based incident case study structure, summarized in Figure 6.1 and Table 6.1:

- Part 1 Cross cutting aspects: Introduction and background of the incident itself – look at the incident from the perspective of the people involved just prior to the incident. What does the incident look like from their perspective? How does it feel to be in their shoes as the incident unfolds? What are the sustainability issues? Consider economic, human, and environmental.
- Part 2 Appraisal=Learn from Experience: Incident description – what were the immediate initiating events? Proximal contributors? Contributing factors? Key decision points?
- Part 3 Characterization and Evaluation=Understand Hazards and Risk: Retrospective prevention – Identification of hazards that led to the incident. From the incident description, was the hazard identified and if so what was put in place to mitigate the hazard? Were they prioritized? What could have been put in place? How does this connect to the theory of hazard identification, inherently safer design, environmental protection, sustainable development, and risk management?
- Part 4 Manage=Manage Risk: Causal Analysis – Identification of management contributors, the design contributors (ineffective layers of protection), safety culture, root cause(s), enacted values (how it really is), and the underlying values, assumptions, and beliefs of the people and the organization. This includes the use of appropriate engineering tools to use to identify the hazards, management issues, and controls for incident prevention.
- Part 5 Ready for Pre-Assessment=Commit to Process Safety: Summary - Resulting recommendations to prevent or mitigate incidents in the future. Lessons learned? How should things be done differently? Where were the blind spots? What are the engineering leadership implications? What are the management system implications? Are there regulatory and policy implications? How will corrections be implemented? Students are preparing to commit to process safety and sustainable development principles.

In summary, a structured team based incident case study requires students to confront the incident from a complex perspective and engage with the engineering tools used to identify hazards, consequences, and risks used in practice to prevent incidents using the plan/do/check/act (PDCA) cycle. Incident case studies afford opportunities for students to engage in redesign, release modeling, procedural analysis, layers of protection analysis, and emergency response planning while they examine the leadership, management, societal, and ethical implications of the incident. The case

Table 6.1. Incident Case Study Structure Aligned with the RBPS Management and the CEAB Graduate Attribute Frameworks Supporting the UN Sustainable Development Goals in the context of Engineering Education. (M. Jamieson et al., 2020)

RBPS Foundation	Cross Cutting Aspects (Part 1)	Learn from Experience (Part 2)	Understand Hazards & Risks (Part 3)	Manage Risk (Part 4)	Commit to Process Safety (Part 5)
RBPS Key Element(s)	Context: Workforce Involvement, Process Safety Information, Conduct of Operations & Management Review	Incident Investigations, Auditing, Continuous Improvement	Hazard Identification and Risk Analysis	Training, Safe Work, Management of Change, Emergency Management	Process Safety Competency and Process Safety Culture
Broad Educational Purpose	Supports balanced professional and technical mindset development. (Goals 1-5, 10, 12, 16, 17)	Identify incident root causes for corrective action to prevent future incidents. (Goals 4, 8, 9 &11)	Ensure society can identify process and personal hazards and differentiate risk levels. (SD Goals 4+)	Practical instruction in job and engineering task requirements (UN SD Goals 4+)	Ensure society has the required process safety skills. (Supports all UN SD Goals)
Relevant Associated Activities	Training to increase contextual and stakeholder awareness.	Conduct and manage incident investigations and actions.	Develop or implement methods to identify hazards and assess risk.	Develop, deliver, and oversee process safety training.	Training to increase society members' level of competency.
Team Based Structured Incident Case Study Method (Learning Activity Alignment)					
Case Study Learning Objective	Develop empathy for the people involved in the incident. No one wants to be a part of or injured in an incident!	Develop skills to report on an incident and use lateral thinking to extend to other safety contexts and implications.	Use PHA methods to identify hazards and assess risk. Analyze the incident causes. Connect to leadership and management.	Connect the context of the incident with proactive use of the risk engineering and management systems and tools.	Identify the path forward for continual improvement of engineering system management.
Case Study Activity	Background of the incident.	Incident description including root cause	Pre incident hazard identification	Management contributor analysis	Conclusions and Recommendations
Lens	The people on the front line.	The incident investigator	The incident investigator	An objective observer	An objective observer
Key inquiry question.	What was the framework they had to work within to do their jobs?	What are the initiating and underlying events? Aggravating factors?	What were the hazards – known and unknown – that led to the incident?	What needs to be changed for safer process management of the system?	What needs to be done to improve sustainability objectives?
Connection to practice	CEAB GA: 1, 2, 4, 6, 7, 8, 9, 12	CEAB GA: 2, 3, 5, 6, 7, 8, 9, 10	CEAB GA: 1, 3, 5, 6, 7, 8, 9, 10, 11	CEAB GA: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	CEAB GA: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 , 11, 12

study experience with reflection can lead to an examination of their personal values and beliefs about engineering, sustainability, and their responsibilities in the context of engineering practice, leadership, and management.

Lac Mégantic and MGPI Processing were both used as the basis for the structured case analysis, from a recent graduate course in quantitative risk analysis. An initial set of slides was developed for both incidents and students worked in a team to further analyze the case from a variety of perspectives using appropriate engineering tools they selected. The first section tells the story of the incident and attempts to put the students in a place where they can discover how the incident may have happened. At MGPI an unsupervised truck driver hooked up to an unlocked connection not realizing there were two unlocked connections. For Lac Mégantic, the train engineer set the brakes as per usual not realizing the circumstances would change dramatically as a result of the engine failure and fire. The context of the incidents, the stakeholders, and the culture of the organizations involved are considered. The second section describes the investigated design and the operation of the design. For MGPI, the connections were examined, as were the operational procedures and reactive chemicals. For Lac Mégantic, the design of the track, the brakes, the safety instrumented system, and the operating procedures were examined. The primary goal is to investigate and learn from the experience of the incident. For the third section, hazards and risks are described. For the MGPI case, modelling of the release was examined critically as was their emergency preparedness with respect to reactive chemicals. For Lac Mégantic, a root cause analysis exposed the management and human factors that led to the incident. Hazard identification, technical analysis and modeling to support risk based investigation of potential consequences were followed up with mitigation and risk reduction strategies in this section. For the fourth section, manage risk, both studies investigated how the management of the operation contributed to the incident and what could be done differently. This leads naturally to a discussion of management actions, responsibility, ethics, sustainability, and the consequences resulting from the incident for society, for the frontline personnel, and for management. In addition, part four provides a venue to discuss that safety standards and design codes are frequently updated, often as a result of incidents and their analysis and recommendations. It is critical for chemical engineers to continue to refresh their understanding of safety throughout their career as part of their commitment to lifelong learning and professional practice requirements. Part five presents the conclusions regarding the lessons learned, whether recommendations were appropriate, and whether or not the causal factors have been adequately addressed to prevent future incidents. This section can produce discussion and questions regarding engineering leadership and management with respect to the incident and in the future. It can also raise questions about the structure of societal institutions, for example, leadership being guided by quarterly earning reports and the impact this has on decision making. Resources for case studies are discussed in the supplementary resources (Appendix A1.12). In addition, the incident cases students presented are included. Materials for these incidents are accessible.

6. CONCLUSIONS

The role of an engineer in organizations and society involves the development and operation of complex and sustainable systems. The engineering graduate attributes, the UN sustainability development goals, and the RBPS management frameworks encompass these aspects of engineering work and intersect to provide context for developing case studies to help students understand and develop the knowledge skills and attitudes to navigate the complexity of implementing sustainable engineering systems. The sustainability development goals can be operationalized via risk based process safety management frameworks and tied to the CEAB engineering education outcomes. We develop a structured method for using case studies that leverages these recognized frameworks to connect engineering students to the technical, leadership, management, and societal viewpoints required in engineering practice. By introducing this sustainable leadership management layer to a case study approach, students will begin to develop skills to effectively lead and manage complex engineering work.

Structured incident case study learning activities that concurrently develop sustainability, leadership, management, and technical skills in the context of complex system failures allow engineering students opportunities to explore connections between the resulting incidents and the enacted values, the underlying values, the assumptions, and the beliefs that contributed to the incident while exploring safety and sustainability cultures in a meaningful way. In turn, this supports the development of technical, professional, contextual, and metacognitive skills for engineering students in a manner that can be scaffolded and introduced at all stages of their development. A list of resources to help instructors get started or enrich their case study use in core and elective courses is included at the end of the supplementary materials (Appendix A1.12).

Acknowledgements

This research was funded by the University of Alberta Faculty of Engineering, the William and Elizabeth Magee Chair in Chemical Process Design, and the following research grants: SSHRC PDG 890-

2017-0015 Enhancing Regulatory Effectiveness and Corporate Performance and NSERC COVDI-2020-06431 and RGPIN-2018-05170 Developing a Safety Management Systems (SMS) Model. The authors acknowledge with thanks the support given by our community of practice – our students, our teaching team, our research community, and our industry participants.

REFERENCES

ABET. (2019). *Criteria for Accrediting Engineering Programs, 2019 – 2020 | ABET*. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/

AIChE CCPS. (2007). *Guidelines for risk based process safety*. AIChE. https://www.aiche.org/ccps/resources/certified-process-safety-professional/resources

Allen, D. E., Donham, R. S., & Bernhardt, S. A. (2011). Problem-based learning. *New Directions for Teaching and Learning*, *2011*(128), 21–29. https://doi.org/10.1002/tl.465

Amaya-Gómez, R. (2019). Process safety part of the engineering education DNA. *Education for Chemical Engineers*, 11.

Amyotte, P. R., & McCutcheon, D. J. (2006). *Risk Management—An Area of Knowledge for all Engineers. Technical Report. Discussion paper prepared for Canadian Council ofProfessional Engineers.* https://engineerscanada.ca/sites/default/files/risk_management_paper_eng.pdf

Anderson, N., Watson, E., Cocchio, J., Li, L., & Lefsrud, L. (2018). Fostering "Soft-Skill" Graduate Attribute Development using Multifaceted Instructional Strategies in an Undergraduate Engineering Course. *Journal of Online Engineering Education*, *9*(1), 1–11.

Andrews, G. C. (2009). *Canadian professional engineering and geoscience, Practice and ethics.* (4th ed.). Nelson Edu.

ASEE Workshop report, M. (2014). *Transforming Undergraduate Education in Engineering Phase I: Synthesizing and Integrating Industry Perspectives*. ASEE. https://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf

Belanger, R., & Pupulin, R. (2004). *APEGA Concepts of Professionalism 2004*. APEGA. https://www.apega.ca/docs/default-source/pdfs/professionalism.pdf?sfvrsn=ca3d5769_2

Bhusari, A., Goh, A., Ai, H., Sathanapally, S., Jalal, M., & Mentzer, R. A. (2020). Process safety incidents across 14 industries. *Process Safety Progress*, *n/a*(n/a), e12158. https://doi.org/10.1002/prs.12158

Blau, P. M. (1964). *Exchange and power in social life.* Wiley.

Blum, C., Bunke, D., Hungsberg, M., Roelofs, E., Joas, A., Joas, R., ..., & Stolzenburg, H. C. (2017). The concept of sustainable chemistry: Key drivers for the transition towards sustainable development. *Sustainable Chemistry and Pharmacy*, *5*, 94–104.

Condoor, S. (2004). *Importance of teaching the history of technology*. 34th ASEE/IEEE Frontiers in Education Conference.

Cooke, D. L., & Rohleder, T. R. (2006). Learning from incidents: From normal accidents to high reliability. *System Dynamics Review*, *22*(3), 213–239.

Crowl, D. A., & Louvar, J. F. (2019). *Chemical process safety: Fundamentals with applications /* (Fourth edition.). Pearson.

Danielson, Vi. (2014, June 9). Raising the safety bar An interview with Syncrude veteran and safety guru Gord Winkel. *CIM Magazine*.

Dixon, D. J., & Kohlbrand, H. T. (2015). Lending industrial experience through reactive hazard examples in university safety instruction. *Process Safety Progress*, *34*(4), 360–367. https://doi.org/10.1002/prs.11785

Duch, B. J., Groh, S. E., & Allen, D. E. (2001). *The power of problem-based learning: A practical "how to" for teaching undergraduate courses in any discipline* (1st ed.). Stylus Pub. http://site.ebrary.com/id/11170657

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *Academy of Management Review*, *14*(4), 535–550.

Engineers Canada. (2012, February). *Public guideline on the practice of engineering in Canada | Engineers Canada*. Engineers Canada. https://engineerscanada.ca/publications/public-guideline-on-the-practice-of-engineering-in-canada

Engineers Canada. (2018). *Graduate Attribute and Continual Improvement rubric*. Engineers Canada Accreditation Resources. https://engineerscanada.ca/accreditation/accreditation-resources

Faculty of Engineering. (1955). *Calendar of the Faculty of Engineering 1955—56*. Univeristy of Alberta.

Farell, M., & Gallagher, R. (2015). *Journal of Risk and Insurance*, *82*(3), 625–657.

Faust, D. G. (2010, June 30). *The role of the university in a changing world.* Royal Irish academy, Dublin, Ireland.

Fleming, M., Harvey, K., & Cregan, B. (2018). Safety culture research and practice: A review of 30 years of research collaboration. *Journal of Applied Biobehavioral Research*, *23*(4), e12155.

Gehman, J., Lefsrud, L. M., & Fast, S. (2017). Social license to operate: Legitimacy by another name?(New Frontiers). *Canadian Public Administration*, *2*, 293.

Goldman, S. L. (1990). Philosophy, Engineering and Western Culture. In P. T. Durbin (Ed.), *Broad and Narrow Interpretations of Philosophy of Technology*. Kluwer.

Guerra, A., & Smink, C. K. (2019). Students' Perspectives on Sustainability. In W. Leal Filho (Ed.), *Encyclopedia of Sustainability in Higher Education* (pp. 1–9). Springer International Publishing. https://doi.org/10.1007/978-3-319-63951-2_32-1

Guldenmund, F. W. (2000). The nature of safety culture: A review of theory and research. *Safety Science*, *34*(1), 215–257. https://doi.org/10.1016/S0925-7535(00)00014-X

Hale, A., & deKroes, J. (1997). System in safety 10 years of the chair in safety science at the Delft University of Technology. *Safety Science*, *26*(1), 3–19.

Haluik, A. (2016). Risk perception and decision making in hazard analysis: Improving safety for the next generation of electrical workers. *2016 IEEE IAS Electrical Safety Workshop (ESW)*, 1–8. https://doi.org/10.1109/ESW.2016.7499712

IAEA. (1986). *Summary report on the post accident review meeting on the Chernobyl accident. Safety SERIES No 75 INSAG 1, Rep.* International Atomic Energy Agency (IAEA), Vienna.

IChemE. (2017). *Accreditation of Chemical Engineering Progammes. A Guide forHigher Education Providers and Assessors. Technical Report.* Institution ofChemical Engineers.

IEA. (2013). *Graduate Attributes and Professional Competencies Version 3: 21 June 2013*. International Engineering Alliance (IEA). https://www.ieagreements.org/assets/Uploads/Documents/Policy/Graduate-Attributes-and-Professional-Competencies.pdf

IRGC. (n.d.). IRGC Risk Governance Framework. *IRGC*. Retrieved February 2, 2020, from https://irgc.org/risk-governance/irgc-risk-governance-framework/

IRGC. (2017). *Introduction of the IRGC Risk Governance Framework, Revised version*. International Risk Governance Council. https://irgc.org/risk-governance/irgc-risk-governance-framework/

Jamieson, M., & Donald, J. (2020). Building the Enigneering Mindset: Developing leadership and management competencies in the engineering curriculum. *Proceedings of the Canadian Engineering Education Association (CEEA)*. https://doi.org/10.24908/pceea.vi0.14129

Jamieson, M., Lefsrud, L., Sattari, F., & Donald, J. (2020). Engineering Safety and Risk Management: A Structured Case Study Approach to Investigating Chemical Process Safety. *2020 ASEE Virtual Annual Conference Content Access Proceedings*, 34558. https://doi.org/10.18260/1-2--34558

Jamieson, M. V. (2016). *Application of Blended and Active Learning to Chemical Engineering Design Instruction, 2015 MSc Thesis*. University of Alberta.

Jamieson, M. V., Goettler, L., Liu, A., & Shaw, J. M. (2017). To teach is to learn: Student and instructor perspectives on assignment development as a springboard to deep learning. *Proceedings of the 13th International CDIO Conference*. CDIO, University of Calgary.

Jamieson, M. V., & Shaw, J. M. (2020). Teaching engineering innovation, design, and leadership through a community of practice. *Education for Chemical Engineers*, *31*, 54–61. https://doi.org/10.1016/j.ece.2020.04.001

Jamieson, M. V., & Shaw, J. M. (2019). Learning to learn: Defining an engineering learning culture. *Proc. 2019 Canadian Engineering Education Conference (CEEA18), D. (Ed.)*, *2019*.

Johnston, S., Lee, A., McGregor, H., & Society for Philosophy and Technology. (1996). Engineering as Captive Discourse. *Society for Philosophy and Technology Quarterly Electronic Journal*, *1*(3), 128–136. https://doi.org/10.5840/techne199613/413

Kerin, T. (2018). Accounting for hindsight bias: Improving learning through interactive case studies. *Loss Prevention Bulletin*, *264*, 17–20.

Klassen, M., & Donald, J. (2018). Using an Academic Plan Model to Analyze Canadian Engineering Leadership Curriculum. *Proceedings of the Canadian Engineering Education Association (CEEA)*. https://doi.org/10.24908/pceea.v0i0.12981

Kolb, D. (1984). *Experiential learning: Experience as the source of learning and development.* Prentice Hall.

Mandeville, D., & Stoner, M. (2015). Assessing the Effect of Problem-Based Learning on Undergraduate Student Learning in Biomechanics. *Journal of College Science Teaching*, *45*(1), 66–75. JSTOR.

Matthews, M., Longo, A., & Ryland, A. (2017). *Transforming Undergraduate Education in Engineering Phase II Insights from Tomorrow's Engineers Workshop Report*. ASEE. https://www.asee.org/documents/publications/reports/2017TUEEPhase2.pdf

Meiksins, P. (1988). The "Revolt of the Engineers" Reconsidered. *Technology and Culture*, *29*(2), 219–246. JSTOR. https://doi.org/10.2307/3105524

Mkpat, E., Reiners, G., & Cozzani, V. (2018). Process safety education: A literature review. *Journal of Loss Preverntion in the Process Industries*, *54*, 18–27.

Moldavska, A., & Welo, T. (2019). A Holistic approach to corporate sustainability assessment: Incorporating sustainable development goals into sustainable manufacturing performance evaluation. *Journal of Manufacturing Systems*, *50*, 53–68.

Norval, G. (2015a). Aspects Of Changing The Safety Culture In Today's Universities. *The Canadian Journal of Chemical Engineering*, *93*. https://doi.org/10.1002/cjce.22184

Norval, G. (2015b). Introduction to health and safety responsibilities. *Proceedings of the Canadian Engineering Education Association*. https://doi.org/10.24908/pceea.v0i0.5863

Pittman, W., Mentzer, R., & Mannan, M. S. (2015). Communicating costs and benefits of the chemical industry and chemical technology to society. *Journal of Loss Prevention in the Process Industries*, *35*, 59–64. https://doi.org/10.1016/j.jlp.2015.03.020

PMI. (2017). *Success Rates Rise Transforming the hihg cost of low performance*. https://www.pmi.org/-/media/pmi/documents/public/pdf/learning/thought-leadership/pulse/pulse-of-the-profession-2017.pdf

PMI. (2019). *The Future of Work: Leading the Way with PMTQ*. https://www.pmi.org/-/media/pmi/documents/public/pdf/learning/thought-leadership/pulse/pulse-of-the-profession-2019.pdf?sc_lang_temp=en

PMI. (2020a). *PMI 2020 Signposts report*. https://www.pmi.org/-/media/pmi/documents/public/pdf/learning/thought-leadership/pmi-signposts-2020.pdf?v=80eb681d-96b7-48ee-b0f9-a3753d8889b3

PMI. (2020b). *Pulse of the Profession (2020) | PMI*. https://www.pmi.org/learning/library/forging-future-focused-culture-11908

Renn, O. (2006). Risk governance—Towards an integrative appraoch (white paper). *IRGC Scientific and Technical Council*, 157.

Rulifson, Greg, B., Angela. (2019). Learning Social Responsibility: Evolutions of Undergraduate Students' Predicted Engineering Futures. *International Journal of Engineering Education*, *35*(2), 572–584.

Saleh, J. H., & Pendley, C. C. (2012). From learning from accidents to teaching about accident causation and prevention: Multidisciplinary education and safety literacy for all engineering students. *Reliability Engineering and System Safety*, *99*, 105–113.

Santamarina, J. C., Torres-Cruz, L. A., & Bachus, R. C. (2019). Why coal ash and tailings dam disasters occur. *Science*, *364*(6440), 526–528.

Saylan, C., & Blumstein, D. (2011). *The Failure of Environmental Education (And How We Can Fix It)*. University of California Press. https://login.ezproxy.library.ualberta.ca/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=e000xna&AN=367503&site=eds-live&scope=site

Schweizer, P.-J., & Renn, O. (2019). Governance of systemic risks for disaster prevention and mitigation. *Disaster Prevention and Management: An International Journal*, *28*(6), 854–866. https://doi.org/10.1108/DPM-09-2019-0282

Shallcross, D. C. (2013a). Safety education through case study presentations. *Education for Chemical Engineers*, *8*(1), e12–e30. https://doi.org/10.1016/j.ece.2012.10.002

Shallcross, D. C. (2013b). Using concept maps to assess learning of safety case studies – The Piper Alpha disaster. *Education for Chemical Engineers*, *8*(1), e1–e11. https://doi.org/10.1016/j.ece.2013.02.001

Stackhouse, M. R. D., & Stewart, R. (2017). Failing to Fix What is Found: Risk Accommodation in the Oil and Gas Industry. *Risk Analysis: An International Journal*, *37*(1), 130–146.

Sterling, L., & Landmann, P. (2011). The Duty to Consult Aboriginal Peoples-Government Approaches to Unresolved Issues. In D. A. Wright & A. M. Dodek (Eds.), *Public Law at the McLachlin Court: The First Decade* (pp. 235–244). http://www.cba.org/cba/cle/PDF/Constit09_Sterling_paper.pdf

Suddaby, R., & Lefsrud, L. (2010). Institutional Theory. Old and New. In E. Wiebe, G. Durepos, & A. J. Mills (Eds.), *Encyclopedia of Case Study Research* (pp. 464–473). Sage Publications.

Swuste, P., & Arnoldy, F. (2003). The safety adviser/manager as agent of organisational change: A new challenge to expert training. *Safety Science*, *41*(1), 15–27.

UN. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development | Department of Economic and Social Affairs*. https://sdgs.un.org/2030agenda

UN. (2020, nd accessed). *THE 17 GOALS | Department of Economic and Social Affairs*. https://sdgs.un.org/goals

UN Sustainable Development Summit. (2015). *UN Sustainable Development Goals*. UN. https://sustainabledevelopment.un.org/sdgs

Vaughan, D. (1996). *The Challenger launch decision: Risky technology, culture, and deviance at NASA.* University of Chicago press.

Wellingtone. (2020). *The-State-of-Project-Management-Report-2020-Wellingtone.pdf.* https://wellingtone.co.uk/wp-content/uploads/2020/06/The-State-of-Project-Management-Report-2020-Wellingtone.pdf

Wiebe, E., Durepos, G., & Mills, A. J. (Eds.). (2010). *Encyclopedia of Case Study Research*. Sage Publications. https://web-b-ebscohost-com.login.ezproxy.library.ualberta.ca/ehost/ebookviewer/ebook/bmxlYmtfXzQ3NDI2NF9fQU41?sid=b8b3312a-02af-483e-aab2-5ab66df99f2d@pdc-v-sessmgr03&vid=0&format=EB&rid=1

Wilson, W. R. (2013). Using the Chernobyl Incident to Teach Engineering Ethics. *Science and Engineering Ethics*, *19*(2), 625–640.

7. Intersecting Roadmaps (Canadian Journal of Higher Education, 2021)

The Canadian Journal of Higher Education/La Revue Canadienne d'Enseignement

This paper was published in CJHE on April 29, 2021. This paper is the result of interdisciplinary research collaboration between the authors. This paper was written collaboratively with each author significantly contributing to the research and the writing.

INTERSECTING ROADMAPS: RESOLVING TENSION BETWEEN PROFESSION-SPECIFIC AND UNIVERSITY-WIDE GRADUATE ATTRIBUTES

Samira El Atia[1], Jason Carey[2], Marnie V. Jamieson[2], Bashair Alibrahim[1], Marcus Ivery[2]

[1]Campus St. Jean, University of Alberta; [2]Facutly of Engineering, University of Alberta

https://journals.sfu.ca/cjhe/index.php/cjhe/article/view/188781/186465

Abstract

Can we map university-wide graduate attributes to specific program requirements? Can we develop and manage an integrated assessment process? In this article, we present a seven-month long project where we attempted to map generic university graduate attributes (UGAs) to required engineering program graduate attributes in a large Canadian research institution. The purpose of the project was to explore the intersection of the UGAs with engineering graduate attributes, evaluate the accreditation process, develop a mapping process, and examine management strategies for assessing both sets of graduate attributes, all the while keeping the continual improvement process attractive to students, instructors, and administrators. Using a modified dialectical inquiry, two groups worked on the mapping process: one from engineering, the other from social sciences (Education and Arts), to ensure objectivity of comparison. Both forward and backward mapping took place. Results demonstrated that, although generic, UGAs may not necessarily capture specific professional program graduate attributes. The study also highlighted the need for more revisions and updates of UGAs by including various stakeholders who can substantially contribute to the implementation and assessment of UGAs.

Keywords: graduate attributes, engineering education, professional attributes, mapping, learning outcomes

Résumé

Peut-on associer des compétences transversales universitaires, d'ordre général et générique, à des exigences et compétences essentielles propres à un programme de formation particulier? Peut-on mettre au point et gérer un processus cohérent et uni d'évaluation des deux types de compétences au sein du même établissement postsecondaire? Dans cet article, nous présentons un projet qui a duré sept mois et dans lequel nous avons tenté de mettre en correspondance les compétences transversales universitaires et les compétences essentielles requises dans le programme d'ingénierie d'un établissement canadien. Le but de ce projet était d'explorer l'intersection des compétences transversales et de celles requises des diplômés en génie et d'évaluer le processus d'agrément du programme de génie. En gardant en vue l'idée de garder le processus d'amélioration continue attrayant pour les étudiants, les enseignants et les administrateurs du programme, nous visions à mettre au point un processus de schématisation/modélisation pour déterminer des stratégies de gestion afin d'évaluer les deux ensembles de compétences. En utilisant une enquête dialectique, deux équipes se sont penchées sur le travail de schématisation/modélisation : l'une du domaine de l'ingénierie, l'autre de celui des sciences sociales (éducation et arts), afin d'assurer l'objectivité de l'étude comparative. Une schématisation inversée a eu lieu. Les résultats démontrent que, bien que génériques, les compétences transversales universitaires ne capturent pas nécessairement les compétences essentielles particulières aux programmes professionnels. L'étude a également mis en évidence le besoin de réviser et de mettre à jour les compétences transversales universitaires en incluant des parties prenantes qui peuvent contribuer substantiellement à leur mise en œuvre et à leur évaluation.

Mots clés : compétences transversales, pédagogie du génie, compétences professionnelles, schématisation, résultats d'apprentissage

Introduction

At higher education institutions in Canada, professional engineering programs are accredited by the Canadian Engineering Accreditation Board (CEAB). The aim of the accreditation process is to ensure each student graduating from an accredited engineering program meets the profession's minimum knowledge and skills development required by the principal stakeholders of their education; namely, the profession, society, educational institutions, employers, and graduates themselves. Similar to other professions, such as medicine and law, the governing bodies require strict development and assessment of field-specific technical knowledge, skills, and abilities (Committee on the Accreditation of Canadian Medical Schools [CACMS], 2019; Federation of Law Societies of Canada Standards, 2018; CEAB, 2019). Non-professional university programs do not require an accredited quality assurance assessment of students, programs, and instructor qualifications; however, from employability and career decision-making perspectives, students desire to understand and define the competencies developed as a result of their university experience regardless of the discipline of study (Dew et al., 2013).

To this end, the University of Alberta identified and published a set of seven student attributes to reflect graduate characteristics and the values of the university believed to be developed as a result of course work and extracurricular activities (Dew et al., 2013). The recommended implementation path and assessment of the student attributes was to be accomplished by program planners and instructors. An obstacle to implementation is the perception of whether or not these attributes are linked to program objectives, are developed and/or addressed in the curriculum, would be linked to the curriculum, and could hence be assessed by instructors (Kanuka & Cowley, 2017). The implementation of UGAs as a set of outcomes acquired by students in higher education is a complex, multifaceted project. It requires cooperation and collaboration on many levels, spanning from the classroom and course level, to the program and department level, to the interdisciplinary and administrative levels, and beyond academia to include the multiple stakeholders invested in qualified university graduates, including potential employers, communities of practice, and accreditation and regulatory bodies. It is a complex process that is challenging to undertake (Hamou-Lhadj et al., 2015; Harris et al., 2011; Kaupp et al., 2012; Kaupp & Frank, 2016; Oliver & Jorre de St. Jorre, 2018; Parker et al., 2019; Sepheri, 2013; Stiver, 2011; Watson et al., 2018[5]) given the various and diverse stakeholders involved as shown in Figure 7.1.

Each professional accrediting body may use different terminology to define what competencies graduates must meet. For example, the Committee on the Accreditation of Canadian Medical Schools (CACMS, 2019) defines in its lexicon, medical education program objectives, which are defined as "statements of what medical students are expected to be able to do at the end of the educational program i.e., exit or graduate level competencies" (p. iv). The Federation of Law Societies of Canada Standards (2018) calls them *skill competencies*. In the Canadian engineering education field, these abilities are called *graduate attributes* (CEAB, 2019); they are demonstrated through institution level-specific and measurable indicators mapped to course learning outcomes (Ivey et al., 2017, 2018). In each of these professions,

---

[5] Parker et al. (2019) provide a comprehensive summary of the Canadian engineering graduate attribute literature from 2010 to 2017.

graduates are required to demonstrate knowledge and skills specific to the profession (e.g., engineering design, clinical skills, knowledge of case law) and skills that are often common (e.g., lifelong learning, communications, ethics). A complete review of accreditation bodies and processes is outside of the scope of this article, but there is clearly significant overlap in professional requirements.

Figure 7.1: Stakeholders and Graduate Attributes

The language used to describe the professional competencies is very different, which underpins the need for a process to map competencies in different fields when implementing and administering a set of graduate attributes relevant to all university graduates, especially those in professional programs governed by accreditation requirements. In this article, we examine the intersection of two sets of graduate attributes at the Faculty of Engineering, University of Alberta: the professional engineering graduate attributes, and the university graduate attributes for the purposes of implementation and administration in a faculty of one university. In engineering, assessment of graduate attributes is part of the required continual improvement process (CIP), a framework each program must develop. There are 12 engineering graduate attributes (GAs) related to student performance of engineering work that must be demonstrated at different levels of ability prior to graduating.

The Faculty of Engineering, University of Alberta framework has been detailed extensively (Parker et al., 2019; Ivey et al., 2018; Watson et al., 2018; Ivey et al., 2017). The seven university graduate attributes are related to skills, characteristics, and values. The necessity for students to demonstrate these attributes is linked to post-graduation marketability and the idea that a university education provides preparation to contribute to the public good (Bendixen & Jacobsen, 2017) rather than demonstrated competence for entry into a profession. Implementation has been slow in professional programs as accreditation-related graduate attribute assessment is already in place and the correspondence of the sets of professional and university graduate attributes is not obvious. In addition, the actual assessment of the UGAs is viewed as an obstacle by academics (Ipperciel & ElAtia, 2014; Kanuka & Cowley, 2017; Maguire & Gibbs, 2013). In non-professional and professional programs alike, there are challenges in implementation as academics do not share common conceptions of student attributes, how they are developed, or the core achievements of higher education.

Prior Research on Implementing GAs

Since the 1989 Washington Accord (International Engineering Alliance [IEA], 2015), engineering education programs accredited by signatories, such as CEAB and the American Accreditation Board for Engineering and Technology (ABET), are recognized as academically equivalent to support international mobility for professional engineers. In 2009, the Washington Accord accrediting bodies introduced the engineering graduate competency-based outcomes as part of the accreditation process (Easa, 2013; Frank et al., 2011; Gopakumar et al., 2013; Stiver et al., 2010). Subsequently, engineering programs began grappling with how these graduate attributes would become a part of the accreditation process with limited direction from the Canadian Engineering Accreditation Board or Washington Accord signatories. Engineering schools began implementing processes to review curriculum and map the graduate attributes to curriculum content, develop assessment criteria, and then measure graduate achievement of these attributes. Gradually, the 12 CEAB graduate attributes[6] and the associated CIP (IEA[7], 2015) have become a significant part of the accreditation process in Canada (CEAB, 2017, 2018; Kaupp & Frank, 2016). The CEAB Graduate Attributes (CEAB-GAs) have driven changes to the accreditation process, program level assessment, and highlighted the need for a university culture that supports the scholarship of teaching and learning at program and course levels as part of the CIP (Doré, 2019; Jamieson & Shaw, 2019b; Meikleham et al.,

---

[6] In this paper and to avoid confusion, we will refer to the general University Graduate Attributes as (UGAs), and we will refer to the Canadian Engineering Accreditation Board attributes as CEAB-GAs.

[7] The International Engineering Alliance (IEA) is a non-profit organization that establishes and enforces international standards for engineering education to ensure quality and mobility.

2018; Parker et al., 2019). The development of the Washington Accord graduate attributes took nearly a decade (Stiver, 2011; Parker et al., 2019), another decade passed before they were introduced into the Canadian accreditation process (Parker et al., 2019), and it is expected to take another two accreditation cycles for full integration of the graduate attribute continual improvement process (GACIP).

Since 2014, engineering programs in Canada are required to report graduate attribute achievement and demonstrate the use of a CIP to identify program improvement opportunities or justify the status quo (CEAB, 2018) as part of the accreditation process (CEAB, 2017). In Canadian universities, the implementation of the CEAB-GAs framework for assessing the quality of engineering education and graduates is mandated by the national accreditation board and supported by provincial regulators. Consequently, academic program administrators and instructors in engineering faculties are working toward meaningful implementation of these attributes within their curriculum (i.e., Kaupp & Frank, 2016), developing management strategies (i.e., Parker et al., 2019), and writing about their ongoing progress and struggles, including the Engineering Graduate Attribute Development (EGAD) program inaugurated by several Canadian universities[8]. In addition, some engineering schools associated with the Conceive, Design, Implement, Operate (CDIO) program have investigated how the CEAB accreditation requirements map to CDIO[9] program standards and syllabus (Cloutier et al., 2012; Meikleham et al., 2018; Platanitis & Pop-Iliev, 2011) in order to better manage student and program assessment for two purposes; namely, accreditation and post-graduation marketability.

Parallel to this—and triggered by a growing dissatisfaction with higher education outcomes for university graduates (Arum & Roska, 2010), such as job opportunities and graduates' readiness for the job market—the need for a valid and longitudinal assessment that serves the needs of all higher education stakeholders comes to light. University-wide Graduate Attributes (UGAs) are presented as global learning outcomes for students, acquired during their education; they set criteria to assess the transformative influence of higher education on graduates and may link assessment to quality assurance and continual

---

[8] Queen's University, the University of Calgary, UBC, the University of Toronto, Dalhousie, and the University of Guelph (Frank et al., 2011; Kaupp et al., 2012; Kaupp & Frank, 2016; Stiver et al., 2010; Stiver, 2011), Ryerson University (Easa, 2013; Salustri & Neumann, 2016; Shehata & Schwartz, 2015), Concordia University (Gopakumar et al., 2013; Hamou-Lhadj et al., 2015), the University of Manitoba (Seniuk-Cicek et al., 2014; Sepheri, 2013), the University of Alberta (Dew et al., 2013; ElAtia & Ipperciel, 2015a, 2015b; ElAtia et al., 2016; ElAtia et al., 2020; Ivey, 2017; Ivey et al., 2018; Parker et al., 2019; Watson et al., 2018), the University of Victoria (Gwyn, 2016, 2017; Gwyn & Gupta, 2015), and Memorial University (Spracklin-Reid & Fisher, 2012, 2014).

[9] It is worth noting that other engineering schools manage more than one set of Graduate Attributes.

improvement, enhancing accountability of post-secondary institutions (French et al., 2014; Treleaven & Voola, 2008), especially in the eyes of funders. The UGA model comprises competency-based assessment criteria "which structures learning around competencies defined as fundamental for successful performance" (Stoffle & Pryor, 1980, p. 55). O'Donnell et al. (2017) identify two directions of transferable skill and attribute (TSA) development progression: a vertical progression enabling students to operate within their academic field of study and a horizontal skill development progression that crosses academic disciplines and enables students to "operate successfully within a variety of employment settings" (O'Donnell et al., 2017, p. 21). A goal for professional and non-professional programs is to develop both discipline-specific and generic professional competencies to foster flexibility and resilience in the face of a changing world.

The process of integrating the UGA model into university professional programs requires integrating this more horizontal transferable skill progression (addressing employability and transformative experience) with discipline-specific and professional program requirements such as the CEAB-GA, which address discipline competencies, and quality assurance accreditation. As graduates of different professional programs are expected to master skills related to their practical domain, these skills may or may not overlap with the UGAs (Harris et al., 2011; Stiver, 2011).

In order to ensure an effective implementation of a continual improvement program and aligned assessment of graduate attributes, engineering program and curriculum designers now integrate course level learning outcomes mapped to the CEAB graduate attributes and linked to the overall program objectives (Ivey, 2017; Watson, 2018; Kaupp, 2016). Work and co-op experience, capstone design projects, internships, and extra and co-curricular activities may be included as contributing factors to graduate attribute development (Salustri, 2017; Shehata, 2015; Gwyn, 2015 & 2017;Jamieson 2016a). The subsequent integration of the UGAs into this process requires the examination of overlap and divergence of the two sets of graduate attributes and the management of the assessment and continual improvement processes.

The implementation of the UGAs is still evolving and a shared understanding of what the UGAs are and how to implement them is still developing (Kanuka and Crowley, 2017). Administrative questions with respect to coordinated implementation with accredited programs are currently being investigated. This paper reflects on the outcomes of the process of mapping the UGAs to the CEAB-GAs within the Faculty of Engineering (F of E) at the University of Alberta (U of A). In addition to the mapping outcomes, the study highlights the methodology of mapping the graduate attributes to distinguish the overlaps and divergences between the two sets of graduate assessment criteria in order to implement the UGAs in a professional program.

Theoretical Frameworks Guiding the Study

As illustrated above, the body of literature on student attributes regarding their higher education purpose, their developmental goals, and their implementation goals are diverse. To guide our work, O'Donnell et al.'s (2017) description of discipline (vertical) and cross-discipline (horizontal) TSA frames the developmental goals of the GA. For the implementation goals Maguire and Gibbs' pragmatic definition of quality assurance best describes the CEAB-GA: "Quality has no intrinsic link with what higher education is; it is simply a measure of how well, effective or efficient an institution is in providing the benefits it claims for itself and its stakeholders" (Maguire & Gibbs, 2013, p. 44). The UGAs are better described by the definition presented: "This definition extends beyond the needs of the institutions and includes societal, economic and political dimensions of what can be taken as higher education" (Maguire & Gibbs, 2013, p. 44). In order to include the UGAs within the Faculty of Engineering GA assessment process for accreditation, an understanding of the congruence and divergence of the two sets of GAs is required. Regarding the overall purpose of student attributes in higher education, we propose a stakeholder framework as noted in Figure 7.1 to recognize the diverse interests in this process.

Dialectical approach to mapping

We employed a dialectical approach to mapping the UGAs to the CEAB-GAs. In mathematics, mapping is synonymous with transformation and is defined as "any prescribed way of assigning to each object in one *set* [emphasis added] a particular object in another (or the same) set" (Osserman, 2006, para. 2). In this project, we embarked on a structured qualitative approach to carrying out the mapping process between two sets of graduate attributes from the university: one is mandated by an accreditation body, while the other is more of a guide to generically define what students acquire in a university beyond the classroom experience.

Using Dialectical Inquiry (DI), we proceeded to the mapping process within a qualitative research methodology. Berniker and McNabb (2006) define DI as "a useful structured qualitative research method for studying organizational sense making processes as they are understood by participants. … Its focus is on the content and meaning of models and theories in use" (pp. 644–645)

Dialectical Inquiry (DI) requires debate and building arguments by experts on a subject or matter that requires opposite views. Hence, we organized our DI through an adapted Hegelian model of: thesis, antithesis, synthesis. We approach both sets of graduate attributes, the university, and the CEAB as thesis and antithesis, and the mapping process was the final synthesis of both forward mapping (thesis) from CEAB to UGA, and backward mapping (synthesis) from UGA to CEAB. The final results that contributed to the mathematical range is the synthesis of our work. Our aim was to answer these questions: Are the CEAB and UGAs equivalent/overlapping? And how can we read these similarities and/or dissimilarities within the wider scope of quality assurance in higher education?

Back in 1969, Mason found utility of the dialectical modeling for effective decision support system: the constructive debate between experts leads to better outcomes—a synthesis of new ideas and findings. The mapping process that we undertook was directly founded on this model for decision making.

Research Design

The overarching objective of this interdisciplinary study at the U of A is to advance the scholarship in understanding, use, implementation, and management of related graduate attribute competency-based continual improvement processes. This article addresses the following questions:

- What are the challenges of aligning the UGAs with program-specific requirements (the CEAB-GAs in our case study) to facilitate efficient implementation?
- How does mapping for implementation contribute to evolving the UGAs as a universal assessment criterion to include vertical and horizontal TSA development aspects?
- How does the dialectical method of one-to-many and many-to-one relationship expose the blindsided areas in the UGAs and in any assessment criteria in general?

The aim of this study is to identify the main areas of divergence between the two GA assessment models, along with identifying the main challenges of the actual enactment of the UGAs in curriculum design more broadly. The outcomes of this article will be valuable to those who seek to integrate UGAs with professional practice programs governed by external graduate attributes. This model is proposed for use in different faculties and disciplines and toward a cross-disciplinary standardization of the UGAs assessment process.

Case Description: Integration of the CEAB-GA and UGA Management Systems

The initial development of two separate systems to assess graduate attributes for engineering undergraduate students was identified as redundant, overlapping, an undue burden for both students and instructors, and potentially difficult to manage by program administration. The UGAs are structured as knowledge, skills, and attitudes (KSA) indications of the attribute and were intended to demonstrate student and program quality assessment of higher education programs. From a preliminary review, the CEAB graduate attributes and those of the U of A did not match as listed in Table 7.1. From a professional program perspective, the priority of the Faculty of Engineering is to maintain accreditation, meet the governing body's requirements, and train undergraduate students to ensure the safety of the public whom engineers serve; notwithstanding U of A requirements for demonstrating graduate competencies.

Accreditation and Graduate Attribute Implementation in Engineering Programs

The accreditation process of engineering undergraduate programs is multifaceted. Competency-based assessment, curriculum content, and quality inputs are seen as complementary aspects of a program and its accreditation. If an institution can deploy resources for collaborative implementation at the administrative, program, and course level, a cultural shift that explicitly makes learning a priority can happen. Students, instructors, administrators, and stakeholders must recognize the value in the implementation and believe that developing the graduate attributes is a worthwhile activity for the graduate attributes to become *embedded* at the program and course levels (Hamou-Lhadj et al., 2015; Jamieson, 2016b, 2018a, 2019a; Kaupp & Frank, 2016; Oliver & Jorre de St. Jorre, 2018; Parker et al., 2019).

Table 7.1: University and CEAB graduate attributes

UGA (7)	CEAB-GA (12)
1. Ethical Responsibility (ER)	1. Knowledge base in engineering (KB)
2. Scholarship (SC)	2. Problem analysis (PA)
3. Critical Thinking (CT)	3. Investigation (IN)
4. Communication (CM)	4. Design (DE)
5. Collaboration (CL)	5. Use of Engineering tools (ET)
6. Creativity (CR)	6. Individual and team work (TW)
7. Confidence (CF)	7. Communication skills (CS)
	8. Professionalism (PR)
	9. Impact of engineering on society and environment (IS)
	10. Ethics and equity (EE)
	11. Economics and project Management (EP)
	12. Lifelong learning (LL)

To achieve the objective of embedding the UGAs into the course and program levels of the curriculum, three levels of implementation and cultural change are targeted. The first is the institutional level, where a collaborative administrative team allocates resources, develops an implementation vision, and executes a strategy to support a learning-focused team that develops and monitors the implementation process as shown in Figure 7.2. At this level, a collaborative effort aimed at integrating the goals of the professional program(s) and the university graduation requirements is required. The second is a program-level approach that focuses on mapping the graduate attributes to the curriculum, the developmental trajectory of the graduate attributes on the learning pathway (Meikleham et al., 2018) over the program years, and integrating the goals of the professional program and the university graduation requirements into the program and course objectives. The third level targets specific course design coordinated with the developmental trajectory of the graduate attributes on the learning path for the program. Figure 7.3 shows an integrated approach to managing CEAB-GA implementation and continual improvement at the program and course levels focusing on constructivist and outcome-based learning approaches (Hattie, 2009). Course instructors can embed GAs at the course level given an institutional learning culture, but the learning trajectories must be managed at the program level across multiple courses that allow the student to progress on a learning pathway that scaffolds graduate attribute development through the program progression.

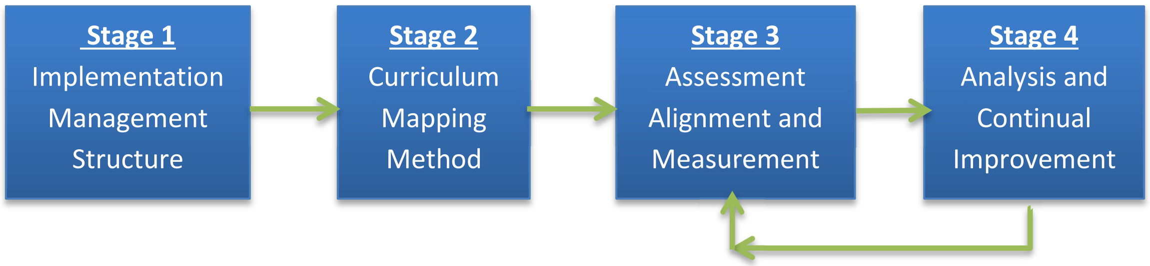


Figure 7.2: **Graduate Attributes Implementation Stages**

The initial institutional level work done at the U of A in the Faculty of Engineering to implement a management structure for the CEAB-GA is discussed in this case. At the time of investigating how UGA integration might occur, the U of A, Faculty of Engineering had already developed a management structure, mapped the curriculum, and was starting to move into Stage 3 as described in Figure 7.2. This study identified the first step toward integration as mapping the UGAs to the CEAB-GAs to outline the overlap as well as the divergence between the two frameworks, and potentially provide a management strategy to reduce assessment loading at the program and course levels while satisfying the professional program requirements and the university requirements concurrently.

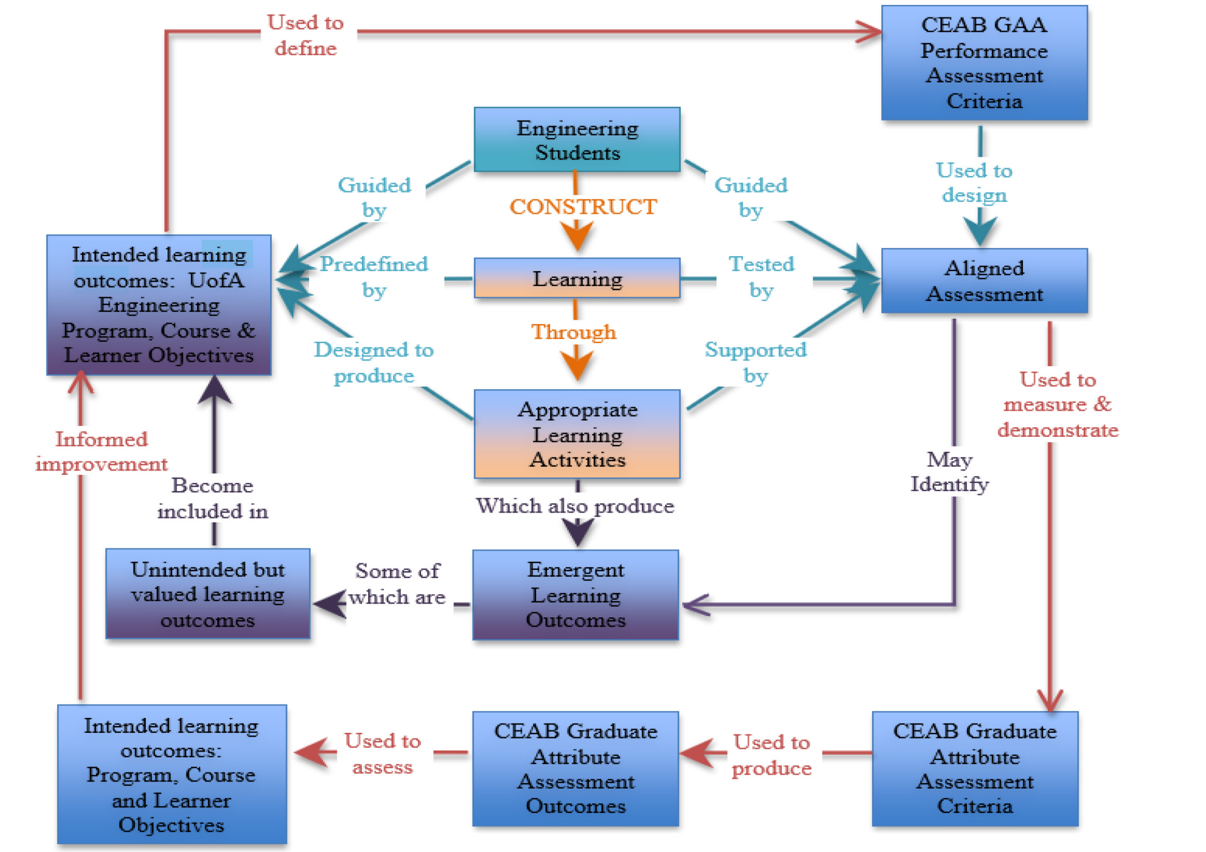
Developing the CEAB-GA Management Structure

In accordance with the internationally agreed-upon Washington Accord (IEA 2015), accreditation of Canadian engineering undergraduate programs requires students demonstrate a satisfactory level of competence commensurate with the professional expectations of an engineer in training at the time of graduation (CEAB, 2017). The development of these competencies should progress over the course of the engineering program. The CEAB-GAs are structured as competency or performance-based outcomes (Hattie, 2009) and intended to assure graduate and program quality. The U of A, Faculty of Engineering assessment model includes aspects, indicators, and measurements for each of the CEAB-GA. The 12 CEAB graduate attributes listed in Table 7.2 are defined in the Appendix A1.2.

For the U of A, Faculty of Engineering GACIP management process, a hierarchy was developed for each CEAB-GA as shown in Figure 7.4. For each of the 12 CEAB-GAs, the faculty academic planning committee identified a number of *aspects* (sub-attributes) that elaborated or characterized that CEAB-GA to provide a better understanding of how many different dimensions had to be considered and assessed within the curriculum. The aspects developed for the engineering programs are presented in the Appendix A1.5, where the mechanical engineering program is used as the example. With exceptions of CEAB-GA (1), Knowledge Base for Engineering, and CEAB-GA (5), Engineering Tools, which were largely discipline-specific, a common set was developed for all engineering programs at the U of A. This supported the deployment of a standardized management approach across the different engineering programs. For each aspect, at least one indicator was identified. These indicators describe some assessable skill and/or ability that an engineering student can demonstrate developmental competency in. The total number of indicators for all U of A engineering programs ranges from 82 to 90, depending on the program. In our programs, the number of indicators per graduate attribute ranges from four to 19. In mechanical engineering there are 82 indicators. Those highlighted in grey are discipline-specific. With this level of detail, mapping the U of A graduate attributes to the Faculty of Engineering CEAB-GA sub attributes was possible.

University Mandated Graduate Attributes at the University of Alberta

In 2007, the U of A’s Sub-Committee (Dew, 2013) on Graduate Attributes identified and developed indicators for the following seven competencies/profiles as graduating attributes of its students: ethical



<u>Figure 7.3</u>: Continual improvement process algorithm for the University of Alberta[10]

responsibility, scholarship, critical thinking, communication, collaboration, creativity, and confidence. The development of the UGAs and subsequent work of the Sub-Committee on Graduate Attributes was an initiative led by students from the Students' union representing various faculties, with advice and supervision by faculty members under the direct coordination of the Center for Teaching and Learning (CTL). The ultimate goal of these groups is a specific interest in identifying the attributes that students acquire during their university education that go beyond the classroom and the scholarship of the subject. The work was linked directly to employability attributes (i.e., these students wanted to identify what soft skills they acquire during their university overall experience that prepare them for the workplace). After

---

[10] Engineering program and course design using the CEAB-GA competency-based performance criteria in a continual improvement feedback process utilizing a curriculum design process concept map (Hattie, 2009) and illustrating constructive alignment (Biggs, 1996). Diagram Jamieson, (2016).

two years of work, the Sub-Committee on Graduate Attributes published its seven university attributes and their sub-indicators as guidelines for all university programs (Dew et al., 2013).

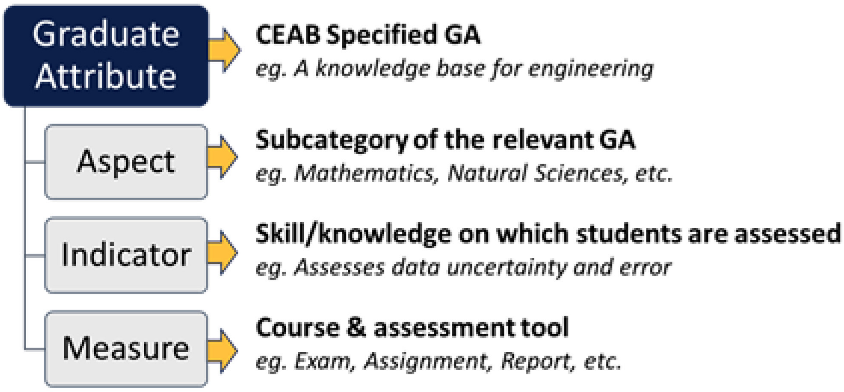


Figure 7.4: Graduate Attribute Hierarchy (CEAB, 2017)

Being notoriously difficult to implement and assess (Barrie, 2006; Drummond et al., 1998), typically because of their abstract and non-homogenous nature (Bennett et al., 1999; Green et al., 2009; Taylor et al., 2012), the integration of the UGAs has yet to gain traction campus-wide among instructors[11]. Previously, we devised a criteria-based model for assessing UGAs (Ipperciel & ElAtia, 2014). This model is founded on the understanding of UGAs as knowledge, skills, and attitudes, which allows us to integrate UGAs of a different nature. The model is also built around the notion that UGAs need to be "interpreted" as praxis-oriented, with can-do statements. These two measures allow for a subsequent and crucial step prior to the operationalization of the UGAs: the development of rubric scales for assessment. Following this first step, a readily implementable and practical UGAs assessment platform was developed (ElAtia et al., 2016; ElAtia & Ipperciel, 2017). The main objective is to have an implementation of the conceptualized model to establish an assessment procedure that accounts for the needs, interests, and concerns of the main GA stakeholders (i.e., students and instructors). This similar and parallel development of the university graduate attribute KSAs and praxis orientation and the CEAB-GA aspect and indicator development allowed for the possibility of mapping. This project proposes to implement an integrated assessment platform for both UGAs and CEAB-GAs for the Faculty of Engineering to determine to what extent both are addressed and acquired in the program.

---

[11] UGAs are widely supported by students and student unions within the university. The majority of the resistance to the integration of the UGAs comes from university professors.

Mixed Method Mapping Process for the UGAs to the CEAB-GAs

The mapping exercise was performed by two teams. The first group was composed of three members of the Faculty of Engineering, all of whom are subject-matter experts familiar with the CEAB-GAs and their assessment within the context of an engineering program. The second group was composed of two external members who were extensively researching the assessment and implementation of the UGAs. In this way, the teams are complementary and can have an objective, arms-length evaluation of the process. Both teams worked on mapping the two sets of attributes presented in Table 7.1 using the sub-attributes of both sets. A sequential mixed methods study design was utilized. A qualitative exploratory mapping study was followed by a quantitative aggregation of the mapping results. Integration of the qualitative and quantitative study results was completed as part of the interpretation of the results and presented in the results and analysis section.

For each of the 12 CEAB-GAs, the Faculty of Engineering had previously defined a list of sub-attributes, which constitute the key aspects of each graduate attribute. For each one of these sub-attributes, indicators had also been defined, which describe what a student must do to show competency in the attribute. Where possible, indicators were common across all nine engineering programs in the faculty; but where necessary, program-specific indicators were used. When assessing students, performance was rated on a 4-level scale based on a descriptive rubric consistent with accreditation standards.

Similarly, each of the seven UGAs have four sub-attributes associated with them. During the work to develop a criteria-based model for assessing UGAs, specific interpretations in the form of can-do statements were developed for each sub-attribute, along with descriptive rubrics for a 5-level rating scale to describe relative levels of attribute acquisition (ElAtia & Ipperciel, 2015a). The structure of these statements bears a close resemblance to the indicators and assessment rubrics written for the engineering sub-attributes and CEAB-GAs.

To map the UGAs to the CEAB-GAs, each Faculty of Engineering indicator was compared to the list of can-do statements and associated rubrics used to describe the University sub-attributes. Each team worked independently and then collaboratively in a group to compare analyses. Related sub-attributes and can-do statements were linked to the indicator in question as shown for example in Table 7.2. If appropriate, a single university sub-attribute could be assigned to multiple different Faculty of Engineering indicators, and multiple university sub-attributes could be linked to a single Faculty of Engineering indicator. If none of the can-do statements were appropriate, the indicator mapping was left blank.

The three steps in the mapping process were as follows. First, the preparatory phase: This phase consisted of various meetings. The first meeting was informative. In contrast, the purpose of the second meeting was a team calibration retreat of two days where various a groups representing Faculty of Engineering met to discuss their program, their involvement with their program-specific requirements and the UGAs, and the challenges they face to the implementation of these. The third meeting was to draft a working document and identify the working group and subgroup, as well as tasks for individual members. Second, the qualitative analysis phase: Individual and group analyses were conducted. Initially, two groups were established: one group carried the mapping from CEAB to UGAs, and the other group was tasked to do the mapping of UGAs to CEAB. Each individual in each group conducted independent mapping exercises; then, all the individual met afterwards to discuss a standard setting for each of the mapping of the attributes. Once the work of each group was finalized (Matrix), the two groups met to compare results of the mapping exercise. Third, the quantitative analysis phase: each subgroup within the groups analyzed their results and provided the analysis to the other members; aggregate tables were created and discrepancies amongst evaluators were discussed. A standard setting process was carried out to ensure the final reports of each group met all members' evaluations. Both convergences and divergences were documented. Finally, the debriefing and integration phase: Final mapping tables and aggregate analysis were shared and comparisons amongst groups were carried out. Final adjustments to the mapping were done.

Results and Analysis

When performing the mapping, all Faculty-wide indicators were mapped first, followed by any program-specific indicators. In total, 187 engineering indicators were mapped to the 28 University sub-attributes. Of the engineering indicators, 72 were common to all programs, and 115 were program-specific across the nine programs. Mapping the CEAB-GAs to the UGAs produced a table for each CEAB-GA linking CEAB-GA Faculty of Engineering indicators to corresponding UGA sub attributes. As a representative example, CEAB-GA Ethics and Equity was selected. Ethics and Equity intersected with two UGAs, Ethical Responsibility and Collaboration, as demonstrated in Table 7.3. The Faculty of Engineering indicators for Ethics and Equity were matched to the UGA sub-attributes. For example, consider the U of A indicator for the CEAB-GA Ethics and Equity: *Feels confident in ability to address ethical dilemmas,* which is measured by a survey question at program entrance and exit. The U of A engineering programs provide a variety of learning activities and courses intended to develop student ability to address ethical dilemmas including design, ethics, safety, and risk management. This indicator and measurement for Ethics and Equity encompassed the Ethical Responsibility sub-attributes of global citizenship, community engagement, social and environmental awareness, and professionalism.

Table 7.2: University and CEAB graduate attributes mapping example

CEAB-GA #10: Ethics and Equity		
Faculty of Engineering		**University**
Sub-attribute	**Indicator**	**Sub-attribute (*Can-do statement*)**
Awareness of Ethical Issues	Feels confident in ability to address ethical dilemmas	1a. Global citizenship *(Can consider issues from a global perspective)* 1b. Community engagement *(Can consider issues from the perspective of their impact on the community)* 1c. Social and environmental awareness *(Can adopt the perspective of the public good and take into consideration our embeddedness within society and nature)* 1d. Professionalism *(Is willing to meet the level of expertise and deontological expectations of her intended profession)*
Code of Ethics	Identifies provisions of the APEGA Code of Ethics	1d. Professionalism *(Is willing to meet the level of expertise and deontological expectations of her intended profession)*
Makes Ethical Choices	Makes ethical choices in complex situations	1a. Global citizenship *(Can consider issues from a global perspective)* 1b. Community engagement *(Can consider issues from the perspective of their impact on the community)* 1c. Social and environmental awareness *(Can adopt the perspective of the public good and take into consideration our embeddedness within society and nature)* 1d. Professionalism *(Is willing to meet the level of expertise and deontological expectations of her intended profession)*
Awareness of Equity Issues	Identifies situations containing equity issues	5a. Openness to diversity *(Can engage with a diversity of people (in terms of race, religion, cultures, classes, sex orientation and appearance)*
Awareness of Equity Issues	Is aware of provisions within the Alberta Human Rights, Citizenship and Multiculturalism Act	5a. Openness to diversity *(Can engage with a diversity of people (in terms of race, religion, cultures, classes, sex orientation and appearance)*
Awareness of Equity Issues	Feels confident in ability to address equity	5a. Openness to diversity *(Can engage with a diversity of people (in terms of race, religion, cultures, classes, sex orientation and appearance)*

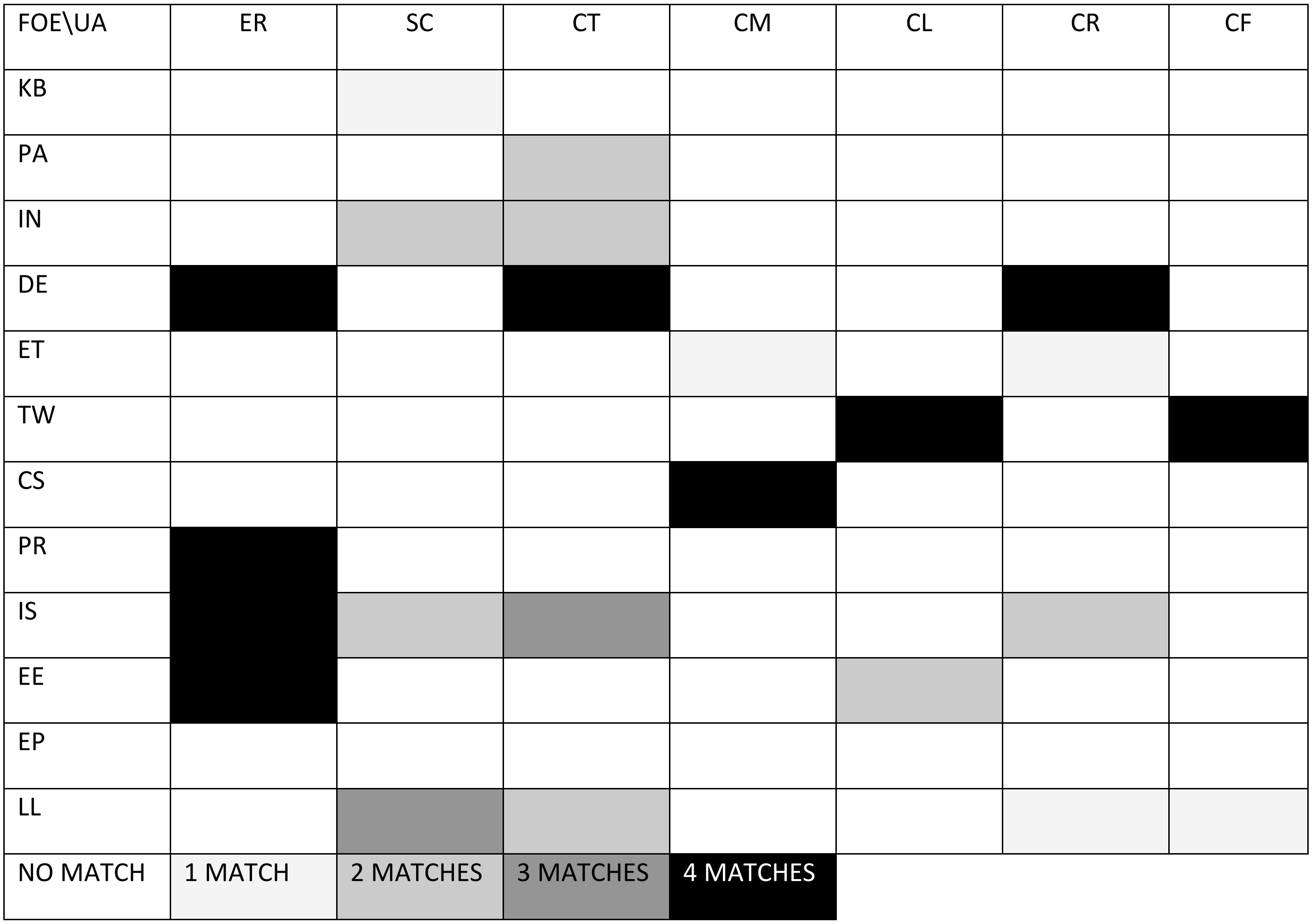
Mapping results between CEAB-GAs and UGAs are summarized as an intensity map in Figure 7.5. The scale of the mapping ranges from white, meaning no overlap, to black, meaning that the four indicators of the UGAs are fully mapped within one CEAB-GA. It is important to note that this does not indicate that the reverse is always true; not all of the indicators of a CEAB-GA are mapped to one or more UGA. This is especially true when considering the Design CEAB-GA (4), which three UGA indicators map into completely. There are a number of aspects in the Design CEAB-GA (4) that extend well beyond that of the Ethical Responsibility, Critical Thinking, and Creativity UGA sub-attributes.

The following were the key findings resulting from the GA mapping exercise:

First, there is little in the UGAs that relates to the CEAB-GA for "Knowledge Base," as evidenced by the single match indicated in Figure 7.5. The only link found was related to the UGAs for "Scholarship," of which only a single sub-attribute was able to be mapped. This finding was not surprising, as the UGAs framework was designed to be broad in order to encompass all university programs, whereas the indicators defined for the "Knowledge Base" CEAB-GA tend to be targeted toward highly discipline-specific knowledge.

It was found that no UGAs explicitly dealt with the use of tools to accomplish a task, which led to limited mapping opportunities with the "Use of Engineering Tools" CEAB-GA. One UGAs sub-attribute from each of CM and CR were mapped, but neither UGA could be fully aligned. This is an important omission from the UGAs that should be addressed. The ability to use modern tools is a key part of their university experience, for example word processing, which could apply to all, or in some disciplines a focus on specific tools, for example, musical instruments, artistic tools, and intravenous injections. This aspect is shared by students of all faculties and should be valued by the University.

Another important oversight observed was that none of the UGAs considered time management, economics, project management, or financial literacy (employability TSA). As a result, there was nothing that could be mapped to the "Economics and Project Management" CEAB-GA. It can easily be argued that these attributes are vital to all university graduates, who will require knowledge and skills in economics and project management in both their personal and professional lives, and that an additional UGA should be added to reflect this. In the case of the medical association requirements (CACMS, 2019), time management in handling patients is included for example, however, there was no such equivalent in Law (FLSC, 2018), but one should expect that lawyers have sound project and time management and budgeting skills. In many cases, medicine and law are secondary degrees, and these skills are acquired prior and expected to be demonstrated by the graduates. Engineering and most other undergraduate programs on campuses are direct entry from high school programs. The UGA “Communication: Multilingualism” has been interpreted during this mapping process to include computer languages and technical drawings. These are important languages used to accomplish tasks and communicate ideas within an engineering context.



FOE\UA	ER	SC	CT	CM	CL	CR	CF
KB		░					
PA			▒				
IN		▒	▒				
DE	█		█			█	
ET				░		░	
TW					█		█
CS				█			
PR	█						
IS	█	▒	▓			▒	
EE	█				▒		
EP							
LL		▓	▒			░	░
NO MATCH	░ 1 MATCH	▒ 2 MATCHES	▓ 3 MATCHES	█ 4 MATCHES			

Figure 7.5: Intensity Map of the Overall overlap in CEAB-GAs and UGAs. (Table 7.1 lists all GA acronyms with CEAB (A1.2) and UGA (A1.6) descriptions found in Appendix A.

The CEAB does recognize language courses (such as French, Spanish, etc.) and they count as complementary studies courses, however being multi- or bilingual is not a requirement to complete an undergraduate engineering degree. As such, there could be no link to multilingualism in a more conventional sense. However, it should be noted that multilingualism will not be an engineering learning outcome or indicator in communication skills. Allowing students to make their own choice of complementary studies course is an important principle of the programs, while programming language skills are inherent to the professional skills.

An ancillary benefit of the mapping process was that it allowed the Engineering group the opportunity to further reflect upon and refine the current CEAB-GA Aspects and Indicators being used for assessment. As a result, a number of potential improvements to the list of aspects and indicators were identified and recorded for future consideration and implementation by the affected engineering programs.

Discussion

During this process, it became evident that, for the successful implementation of the UGAs, certain elements are important for consideration. Training is important for all individuals involved in the mapping process. Stakeholder perspectives must be taken into consideration during the process. The Matrix model (in group, between groups) process (Osserman, 2020) is useful to ensure that all perspectives are met. To ensure validity and objectivity, it is important to have two sets of evaluators to meet those goals: those heavily involved with the programs (validity), and those at arm's length that can be neutral to the process (objectivity).

The mapping process was primarily qualitative in nature, followed by a tabulation amongst the five reviewers in the research team, to better understand the degree of divergence and overlap of the two sets of attributes. As the CEAB-GAs are part of the Canadian accreditation process and developed via international agreement they are not subject to adaptation by a single university. The processes to change the CEAB-GA institution-specified sub-attributes, indicators, and assessments are subject to revision by the U of A Faculty of Engineering and could be revised as part of the GACIP process. The UGAs were specified by the U of A and as such could be revised by the University. In addition, the can-do statements may also be revised as part of a CIP. This does allow for some tailoring and integration of sub-attributes and can-do statements at the institution level to reduce the divergence of the two sets of graduate attributes as they are embedded in the courses of a program.

It was noted that the UGAs did not cover some of the items that the CEAB-GAs did, and that the process used to develop the CEAB-GAs and introduce them into the accreditation process was lengthy. While the UGAs present a wider, more flexible frame of transferable skills (demonstrated by the fact that the mapping team was able to often map one UGA with a few GEAB-GAs), program-specific GAs target professionally oriented knowledge and skills. Thus, while the UGAs contribute to the overall vision for a university graduate as a global citizen, program-specific GAs ensure their functionality in their future profession. Moreover, the UGAs present a set of transferable skills that are applicable across programs and disciplines, while program-specific GAs combine some transferable skills that are applicable to a wide variety of disciplines, in addition to technical program requirements. These requirements might not find their analogue in, or may even be resisted by, other programs. A good example to this would be the attribute of problem solving, which is a basic requirement to programs across the scientific disciplines, but may not be a necessity for all arts programs. According to Oliver and Jorre de St. Jorre (2018), the most specified Australian university-level graduate attributes were: global citizenship, written and oral communication, critical thinking, problem solving, information literacy, and the ability to work independently. Of these items, the CEAB-GAs would address all of them explicitly at the graduate attribute description level with the exception of global citizenship, which is implicit in ethics and equity. Engineering leadership and management programs have been developing across Canada over the last 10 years, suggesting this aspect is a part of engineering education and work (Jamieson & Donald, 2020). The mapping analysis also suggests the UGAs continual improvement processes may need to consider including time management, economics, project management, problem solving, independent work, and financial literacy as part of the can-do statements or perhaps adding another attribute. Oliver and Jorre de St. Jorre (2018) note many of these items are seen as necessary by employers and are categorized in their work as *Independence* or *Employability* skills (work under pressure, be flexible in the workplace, meet deadlines, understand business/organization, leadership, management skills, take responsibility for personal professional development, demonstrate initiative). Oliver and Jorre de St. Jorre's main points are that (a) UGAs should be thought of and incorporated during the course development process, and (b) they should be communicated to students early and regularly, which will provide a better understanding, implementation, and achievement of the UGAs. Students should understand what the goals are for higher education and they should see how the courses they are taking help them make progress to that end.

O'Donnell et al. (2017) provides a list of transferable skills and attributes including: knowledge and understanding, ethical and professional understandings, computer-based skills, written and oral communications, adaptability and flexibility, time management and organizational skills, management and leadership, teamwork and interpersonal skills, information literacy skills, problem solving, research skills, and synthesis/creativity. While this list would find significant overlap with the CEAB-GA definitions, it would overlap less with the UGAs, again suggesting further study. This seems to indicate inclusion of these items in the UGAs and that creatively thinking about what the graduates will need in the future would better position them as an employability tool for graduates in a rapidly changing world. Further, it could support the role of the UGAs as providing a sense of who students could become after engaging in a university education, how they will benefit from this engagement, and what they will be able to contribute to society. UGAs should speak to and demonstrate the transformative nature of higher education. This model engages students with knowledge on the basis of who they are and the complex or wicked problems before us. It moves higher education beyond being student-centred or knowledge-centred to focus on the relations between students and knowledge (Ashwin, 2020) and the communities and world they live in.

As the employment of the dialectical method to map out the UGAs to program specific GAs offers a lucid critique to each set of graduate attributes, it also brings to light the importance of the coexistence of the two sets, as each one of them contributes to a different aspect of higher education outcomes; the UGAs and program-specific GAs each ensure the graduates' competence at different skills, both as employable global citizens as well as professionals. The overlap in the mapping process also brings to light the possibility of reducing program-specific requirements to the aspects that do not map out to the general UGAs to avoid redundancy.

Conclusion and Recommendations

The mapping process carried out for this project was a timely and illuminating task. The constructive debate during the dialectical mapping process and result interpretation led to a synthesis of new ideas regarding graduate attributes, their measurement, their use, their integration, and their implementation in professional and general university programs, as well as in the larger university context. During the exercise, it became evident that a continual improvement process for the graduate attributes is essential to embed the attributes at the program and course level. This process should include further constructive debate among stakeholders regarding the characteristics of higher education graduates, the measurement of such characteristics, and the use of such measures as metrics for institutional funding determinants and employability criteria. If the graduate attributes are to be used as a means to set institutional goals for student development and achievement, the attributes should be reflective of the discipline and institutional identity of the graduates, and not solely of the employability characteristics or funding metrics. For professional programs like engineering, this may be reflected in the requirements for the practice of the profession. For more generalized degree programs this may be more challenging to elucidate but necessary to determine the appropriate set of graduate attributes reflective of student development requirements. Consideration should be given to professional identity of graduates and their intellectual development including cognitive, affective, social, and psychomotor development. The purpose of higher education should be reflected in the graduate attributes and their measurement and not merely be a measure of the institution's ability to produce graduates with the current employability characteristics or funder metrics. The study also highlighted the need for more revisions and updates of UGAs by including various stakeholders who can substantially contribute to the implementation and assessment of UGAs.

There are two further and important items for consideration: it would be of utmost importance for the validity of the mapping process to include instructor and student feedback. The success of the graduate attributes lies in the adoption of the vision of what attributes a program graduate should have by both the instructors and the students. Without a shared vision of the goals of the program and courses within the program implementation of the graduate attributes, their measurement, and their contribution to shaping student development, will be hollow. Second, the university central administration must have an active role in the mapping process to inform and ensure a concrete implementation of the UGAs in programs consistent with goals of the institution, as well as lead implementation buy-in. Unless these stakeholder groups are actively involved, any attempts to truly demonstrate student and institutional achievement of the UGAs will remain elusive.

Thus far, the implication of this study is the generic UGAs, which will not be sufficient to encompass all programs within a university institution, especially those of a professional nature and that require federal and/or provincial accreditations. In such situations, program administrators must first abide by the accrediting body requirements. A concern arises regarding an excessive program administrative burden with the implementation and assessment of several sets of graduating attributes that is inconsistent with the drive to reduce costs. This project concludes that all graduating attributes must be implemented within discipline-specific frameworks to ensure there is sufficient disciplinary knowledge, consistency, and limited redundancy, which serves to ensure the implementation of a meaningful continual improvement process.

References

Arum, R. & Roska J (2010). *Academically Adrift: Limited learning on College Campuses*. Chicago, IL. Univesity of Chicago Press.

Ashwin, P. (2020). Transforming university education: A manifesto. Bloomsbury Academic.

Barrie, S. C. (2006). Understanding what we mean by generic attributes of graduates. *Higher Education, 51,* 215-241. https://doi.org/10.1007/s10734-004-6384-7

Bendixen, C., & Jacobsen, J. C. (2017). Nullifying quality: The marketisation of higher education. *Quality in Higher Education*, *23*(1), 20–34. https://doi.org/10.1080/13538322.2017.1294406

Bennett, N., Dunne, E., & Carre, C. (1999). Patterns of core generic skill provision in higher education. *Higher Education, 37*, 71–93. https://doi.org/10.1023/A:1003451727126

Berniker, E., & McNabb, D. E. (2006). Dialectical inquiry: A structured qualitative research method . *The Qualitative Report*, *11*(4), 643–664. https://nsuworks.nova.edu/tqr/vol11/iss4/2

Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher Education, 32*, 1-18.

Biggs, J. B., & Tang, C. (2003). *Teaching for quality learning at university: What the student does* (2nd ed.). Society for Research into Higher Education & Open University Press.

Canadian Engineering Accreditation Board. (2017). *Canadian Engineering Accreditation Board: Accreditation criteria and procedures*. Canadian Council of Professional Engineers. https://engineerscanada.ca/sites/default/files/accreditation-criteria-procedures-2017.pdf

Canadian Engineering Accreditation Board. (2018). *Continual improvement rubric v3.2*. https://engineerscanada.ca/accreditation/accreditation-resources

Canadian Engineering Accreditation Board. (2019). *Accreditation criteria and procedure*. Canadian Council of Professional Engineers. https://engineerscanada.ca/sites/default/files/accreditation/Accreditation-Criteria-Procedures-2019.pdf

Cloutier, G., Hugo, R., & Sellens, R. (2011, June 20–23). *Mapping the relationship between the CDIO syllabus and the CEAB graduate attributes: An update* [Paper presentation]. Proceedings of the 7th International CDIO Conference, Denmark, Copenhagen. https://www.researchgate.net/publication/228403384_Mapping_the_Relationship_Between_the_CDIO_Syllabus_and_the_2008_CEAB_Graduate_Attributes

http://www.cdio.org/files/document/file/b4-cloutier2011ceabcanada.pdf

Committee on Accreditation of Canadian Medical Schools. (2019). *Standards for accreditation of medical education programs leading to the M.D. degree*. https://cacms-cafmc.ca/sites/default/files/documents/CACMS_Standards_and_Elements_-_AY_2019-2020.pdf

Dew, S., Csorba, E., Chelen, D., Yousefi, N., Andrews, N., & More, C. (2013). *Graduate attributes at the University of Alberta: A report of the Committee on the Learning Environment (CLE) Subcommittee on Attributes and Competencies*. http://www.provost.ualberta.ca/en/~/media/provost/Documents/Information/GraduateAttributes.pdf

Doré, S., Terriault, P., Belleau, C. (2019). Gathering the voice of students for accreditation purposes through their definition of "Engineer" *Proceedings of the Canadian Engineering Education (CEEA) Conference June 3-6, 2019*, *Ottawa, ON,* 1–7.
DOI: https://doi.org/10.24908/pceea.vi0.13715

Drummond, I., Nixon, I., & Wiltshire, J. (1998). Personal transferrable skills in higher education: The problems of implementing good practice. *Quality Assurance in Education, 6*(1), 44–58. https://doi.org/10.1108/09684889810200359

Easa, S. M. (2013). Framework and guidelines for graduate attribute assessment in engineering education. *Canadian Journal of Civil Engineering*, *40*(6), 547–556. https://doi.org/10.1139/cjce-2012-0485

Engineering Graduate Attribute Development. (2018). GACIP summit meeting 2018: *Aggregating data*. https://egad.engineering.queensu.ca/?page_id=4291

ElAtia, S., & Ipperciel, D. (2015a). At the intersection of computer sciences and online education: Fundamental consideration in MOOCs education. *Queen's University Educational Letter*, *11*(2). https://educ.queensu.ca/sites/webpublish.queensu.ca.educwww/files/files/Community/ed_letter_spring_2015.pdf

ElAtia, S., & Ippeciel, D. (2015b). Towards a 21st century competency-based model of higher education: The pragmatics of accountability. *International Journal of Advances in Education*, *1*(1), 5–13.

https://www.semanticscholar.org/paper/Towards-a-21st-Century-Competency-Based-Model-of-of-ElAtia-Ipperciel/242c0c748d4f9164b0992391f863a9d950bb205a

ElAtia, S., & Ippeciel, D. (2017). Graduate Attributes Assessment Program: At the Intersection of Teaching and Learning. *Word Conference on Online learning*, Toronto, October 2017

ElAtia, S., Ipperciel, D., Bakhshinategh, B., Zaiane, O. R., & Thibaudeau, P. (2020). Graduate attribute assessment program. *The International Journal of Information and Learning Technology, 38*(1), 117–134. https://doi.org/10.1108/IJILT-03-2020-0025

ElAtia, S., Ipperciel, D., & Zaiane, O. R. (2016). *Data mining and learning analytics: Applications in educational research*. Wiley & Sons.

Federation of Law Societies of Canada. (2018). *National requirement.* https://flsc.ca/wp-content/uploads/2018/01/National-Requirement-Jan-2018-FIN.pdf

Frank, B., McCahan, S., Watts, K. C., Fostaty-Young, S., Ostafichuk, P., Wolf, P., & Saleh, N. (2011). Engineering graduate attribute development (EGAD) project. In *Conference Proceedings of the Second Annual Conference of the Canadian Engineering Education Association (CEEA) – June 6-8, 2011.* https://doi.org/10.24908/pceea.v0i0.3566

French, E., Summers, J., Kinash, S., Lawson, R., Taylor, T., Herbert, J., Fallshaw, E., & Hall, C. (2014). The practice of quality in assuring learning in higher education. *Quality in Higher Education*, *20*(1), 24–43. https://doi.org/10.1080/13538322.2014.889432

Gopakumar, G., Dysart-Gale, D., & Ali Akgunduz, A. (2013). Creating faculty buy in: Leadership challenges in implementing CEAB graduate attributes. *Proceedings of the Canadian Engineering Education Association Conference- École Polytechnique de Montréal June 2013*, 1–5. https://doi.org/10.24908/pceea.v0i0.4850

Green, W., Hammer, S., & Star, C. (2009). Facing up to the challenge: Why is it so hard to develop graduate attributes? *Higher Education Research & Development, 28*(1), 17–20. https://doi.org/10.1080/07294360802444339

Gwyn, M. (2016). Incorporating employer and student assessments into a graduate attribute assessment plan. *Proceedings of the Canadian Engineering Education Association (CEEA) Conference- Dalhousie University June 19-22, 2016*, 1–5. http://web.uvic.ca/~mgwyn/CEEA2016/Gwyn.pdf

Gwyn, M. (2017). Finding the gaps: The development of a network for graduate attribute professionals. *Proceedings of the Canadian Engineering Education Association (CEEA) Conference- June 4-7, 2017 University of Toronto,* 1–4. https://ojs.library.queensu.ca/index.php/PCEEA/article/view/10302

Gwyn, M. L., & Gupta, R., (2015). Co-op employer evaluations of the graduate attributes: A comparison of two approaches. *Proceedings of the Canadian Engineering Education (CEEA) Conference- McMaster University May 31-June 3, 2015*, 1–5. https://doi.org/10.24908/pceea.v0i0.5788

Hamou-Lhadj, A., Lynch, W., & Akgunduz, A., (2015). COGAF: A management framework for graduate attribute assessment. *Proceedings of the Canadian Engineering Education (CEEA) Conference- McMaster University May 31-June 3, 2015*, 1–6. https://doi.org/10.24908/pceea.v0i0.5762

Harris, J., Steele, A., & Russell, D. (2011). Progress on defining the CEAB attributes at Carleton University. *Proceedings of the 2nd Annual CEEA Conference: Memorial University, St. John's, Newfoundland, June 6-8, 2011,* 1–5. https://doi.org/10.24908/pceea.v0i0.3628

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). Ako Aotearoa.

International Engineering Alliance. (2015). *A history of the International Engineering Alliance and its constituent agreements: Toward global engineering education and professional competence standards.* http://www.ieagreements.org/assets/Uploads/Documents/History/IEA-History-1.1-Final.pdf

Ipperciel, D., & ElAtia, S. (2014). Assessing graduate attributes: Building a criteria-based competency model. *The International Journal of Higher Education*, *3*(3), 27–39. https://doi.org/10.5430/ijhe.v3n3p27

Ivey, M., Dew, S., Mandal, M., Mohamed, Y., Nychka, J. A., Raboud, D. & Carey, J. P. (2017). Using post course assessments to involve instructors in the continuous improvement process. *Proceedings of the Canadian Engineering Education Association (CEEA) Conference- June 4-7, 2017 University of Toronto.* https://doi.org/10.24908/pceea.v0i0.9519

Ivey, M., Mohamed, Y., Musilek, P., Raboud, D., Rajendran, A., & Carey, J. P. (2018). Using a common course syllabus as part of the quality control loop and accreditation data collection process. *Proceedings of the Canadian Engineering Education (CEEA) Conference June 3-6, 2018, Vancouver, BC,* 1–7. https://doi.org/10.24908/pceea.v0i0.12983

Jamieson, M. V. (2016a). *Application of blended and active learning to chemical engineering design instruction* [M.Sc.thesis]. University of Alberta.

Jamieson M. V., & Donald, J. R. (2020). Building the engineering mindset: Developing leadership and management competencies in the engineering curriculum. *Proceedings of the Canadian Engineering Education Association (CEEA) Conference*. https://doi.org/10.24908/pceea.vi0.14129

Jamieson, M. V., & Shaw, J. M. (2016b). Pre and post course student self-assessment of CEAB graduate attributes - A tool for outcomes assessment, student skill and course improvement. *Proceedings of the Canadian Engineering Education Association (CEEA) Conference- Dalhousie University June 19-22, 2016,* 1–8. https://doi.org/10.24908/pceea.v0i0.6497

Jamieson, M. V., & Shaw, J. M. (2018a). Graduate attribute based continuous improvement in a blended learning engineering design course – a writing seminar case study. *Proceedings of the Canadian Engineering Education Association (CEEA) Conference June 3-6*, *2018 Vancouver BC*, 1–7. https://doi.org/10.24908/pceea.v0i0.13022

Jamieson, M. V., & Shaw, J. M. (2018b). Teaching engineering innovation, design, and leadership within a community of practice. *Proceedings of the Canadian Engineering Education Association (CEEA) Conference June 3-6*, *2018 Vancouver BC*, 1–7. https://doi.org/10.24908/pceea.v0i0.9531

Jamieson, M. V., & Shaw, J. M. (2019a). A continual improvement process for teaching leadership and innovation in a community of practice. *Proceedings of The American Society for Engineering Education Annual Conference & Exposition*, *Tampa, Florida,* 1–23. https://pdfs.semanticscholar.org/89f6/0638ff8bb8b2c85e43936cc594cd6c357f0d.pdf

Jamieson, M. V., & Shaw, J. M. (2019b). Learning to learn: Defining an engineering learning culture. *Proceedings of the Canadian Engineering Education Association (CEEA-ACEG) Conference June 8-12 Ottawa Ontario,*1–12. https://doi.org/10.24908/pceea.vi0.13707

Kanuka, H., & Cowley, S. (2017). Graduand student attributes: A Canadian case. *The Canadian Journal of Higher Education, 47*(1), 61–79. https://doi.org/10.47678/cjhe.v47i1.186485

Kaupp, J., & Frank, B. (2016). EGAD National snapshot survey: Change, progress and improvement. *Proceedings of the Canadian Engineering Education Association (CEEA) Conference – Dalhousie University June 19-22, 2016,* 1–12. https://doi.org/10.24908/pceea.v0i0.6503

Kaupp, J., Frank, B., Brenman, R., McCahan, S., Narayanan, L., Ostafichuk, P., Sepehri, N., & Watts, K. C. (2012). A comparison of institutional approaches to CEAB graduate attributes requirements.

Proceedings of the Canadian Engineering Education Association Conference. University of Manitoba June 17-20, 2012, 1–7. https://doi.org/10.24908/pceea.v0i0.4642

Maguire, K., & Gibbs, P. (2013). Exploring the notion of quality in quality higher education assessment in a collaborative future. *Quality in Higher Education*, *19*(1), 41–55. https://doi.org/10.1080/13538322.2013.774220

Mason, R. (1969). A Dialectical Approach to Strategic Planning. *Management Science*. Vol 15, No.8, pp. 403-414

Meikleham, A., Brennan, R., & Hugo, R. (2018). Utilizing the CDIO syllabus to reveal CEAB graduate attribute pathways in a mechanical engineering curriculum. *Proceedings of the Canadian Engineering Education Association (CEEA) Conference June 3-6*, *2018 Vancouver BC,* 1–2. https://doi.org/10.24908/pceea.v0i0.12988

O'Donnell, P., Rakhshani, B., Rae, A., & Smith, R. (2017). The adaptable graduate. In C. Normand & L. Anderson (Eds.), *Graduate attributes in higher education: Attitudes on attributes from across the disciplines* (pp. 19–38). Routledge.

Oliver, B. (2013). Graduate attributes as a focus for institution-wide curriculum renewal: Innovations and challenges. *Higher Education Research & Development*, *32*(3), 450–463.

Oliver, B., & Jorre de St. Jorre, T., (2018). Graduate attributes for 2020 and beyond: recommendations for Australian higher education providers. *Higher Education Research & Development*, *37*(4), 821–836. https://doi.org/10.1080/07294360.2018.1446415

Osserman, R. (2006). Mapping. *Encyclopædia Britannica.* https://www.britannica.com/science/mapping

Parker, A. M., Watson, E., Ivey, M., Carey, J. P. (2019). Approaches to graduate attribute and continual improvement processes in faculties of engineering across Canada: a narrative review of the literature. *Proceedings of the Canadian Engineering Education Association (CEEA-ACEG) Conference June 8-12 Ottawa Ontario*. https://doi.org/10.24908/pceea.vi0.13736

Platanitis, G., & Pop-Iliev, R. (2011). Does program compliance with CDIO warrant automatic compliance with CEAB accreditation criteria for 2014? *Proceedings of the 2nd Annual CEEA Conference: Memorial University, St. John's, Newfoundland, June 6-8, 2011.* https://doi.org/10.24908/pceea.v0i0.3597

Salustri, F. A., & Neumann, W. P. (2016). Providing a uniform design experience in an undergraduate mechanical engineering program. *Proceedings of the Canadian Engineering Education Association (CEEA) Conference- Dalhousie University June 19-22, 2016.* https://www.researchgate.net/publication/313891202_Providing_a_Uniform_Design_Experience_in_an_Undergraduate_Mechanical_Engineering_Program

Seniuk Cicek, J., Ingram, S., Sepehri, N., Burak, J. P., Labossiere, P., Mann, D., Ruth, D., Parker, A., Ferens, K., Godavari, N., Oleszkiewicz, J., & Topping, A. (2014). Rubrics as a vehicle to define the twelve CEAB graduate attributes, determine graduate competencies, and develop a common language for engineering stakeholders. *Proceedings of the Canadian Engineering Education Association Conference University of Calgary. June 8-11, 2014,* 1–7. https://doi.org/10.24908/pceea.v0i0.5876

Sepehri, N., Kinsner, W., Burak, J. P., Shafai, C., Annakkage, U., Mann, D., Kuhn, D., Shalaby, A., Alfaro, M., Morrison, J., Ferens, K., Birouk, M., Labossiere, P., Torchia, M., & Beddoes, J. (2013). The process of continual improvement of engineering programs at the University of Manitoba: Now and next. *Proceedings of the Canadian Engineering Education Association Conference- École Polytechnique de Montréal June 2013*. https://ojs.library.queensu.ca/index.php/PCEEA/article/view/4901

Shehata, M. H., & Schwartz, M. (2015). Co-curricular activities and their role in supporting experiential learning. *Proceedings of the Canadian Engineering Education (CEEA) Conference- McMaster University May 31-June 3, 2015,* 1–5. https://doi.org/10.24908/pceea.v0i0.5791

Spracklin-Reid, D., & Fisher, A. (2012). Course-based learning outcomes as the foundation for assessment of graduate attributes. *Proceedings of the Canadian Engineering Education Association Conference. University of Manitoba June 17-20, 2012*, 1–4. https://doi.org/10.24908/pceea.v0i0.4928

Spracklin-Reid, D., & Fisher, A. (2014). Curriculum mapping in engineering education: Linking attributes, outcomes, and assessments. *Proceedings of the Canadian Engineering Education Association Conference University of Calgary. June 8-11, 2014,* 1. https://doi.org/10.24908/pceea.v0i0.5897

Stiver, W. (2011). CEAB's graduate attributes and Ontario's UUDLEs. *Proceedings of the 2nd Annual CEEA Conference: Memorial University, St. John's, Newfoundland, June 6-8, 2011,* 1–5. https://doi.org/10.24908/pceea.v0i0.3605

Stiver, W., Bradford, A., Chang, S., Farahbakhsh, K., Lubitz, D., Ryks, J., van Heyst, B., Zhou, H., & Zytner, R. (2010). Engineering graduate attributes – Investigation. *Proceedings of the 1st CEEA Conference: Queen's University Kingston, Ontario June 7-9, 2010*, 1–5. https://doi.org/10.24908/pceea.v0i0.3143

Stoffle, C. J., & Pryor, J. M. (1980). Competency-based education and library instruction. *Library Trends, 29*(1), 55–67. https://www.researchgate.net/publication/306283368_Competency_Based_Education_and_Library_Instruction

Lawson, R., Taylor, T., Herbert, J., Fallshaw, E., French, E., Hall, C., Kinash, S., & Summers, J. (2012). Strategies to engage academics in assuring graduate attributes. *Eighth International Conference on Education (ICE 2012): Educational Leadership & Management, 5-7 Jul 2012*, *Samos, Greece*.

Treleaven, L., & Voola, R. (2008). Integrating the development of graduate attributes through constructive alignment. *Journal of Marketing Education, 30*(2), 160–173. https://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ801781&site=eds-live&scope=site

Watson, E., Ivey, M., Mohamed, Y., Musilek, P., Raboud, D., Rajendran, A., & Carey, J. P. (2018). Building a culture that values learning outcomes as an integral part of effective program development - one faculty's example. *Proceedings of the Canadian Engineering Education Association (CEEA) Conference June 3-6*, *2018 Vancouver BC*, 1–4. https://doi.org/10.24908/pceea.v0i0.12979

8. Outcomes and Significance

The IEA Washington Accord has been a powerful influence on the mobility of engineers and engineering work and consequently on the direction of engineering education for university graduates globally. The outcomes based graduate attribute strategy could be a powerful tool to drive change in engineering education and movement towards the education of the whole engineer or it could be a powerful tool to disrupt the ability of a university engineering education program to respond to local societal needs and development, depending on who has control of the outcomes, whether control is centralized or localized, and who controls the process developed for revising outcomes.

On November 19, 2020, Engineers Canada published a webpage and reported: "In November 2019, the IEA established a working group with the World Federation of Engineering Organizations (WFEO) and UNESCO to update the GAPC framework," (Engineers Canada, 2020). "The working group has been consulting with IEA members on six main areas of change:

- **Accommodate future needs of engineering professionals and the profession:** strengthen the required attributes on teamwork, communication, ethics, sustainability.
- **Emerging technologies:** incorporate digital learning, active work experience, lifelong learning.
- **Emerging and future engineering disciplines and practice areas:** while retaining discipline independent approach, enhance the skills on data sciences, other sciences, life-long learning.
- **Incorporate the UN's Sustainable Development Goals:** when developing solutions, consider the technical, environment, social, cultural, economic, financial, and global responsibility impacts.
- **Diversity and inclusion:** include these considerations within ways of working in teams and within systems of communication, compliance, environment, and legal.
- **Intellectual agility, creativity, and innovation:** emphasize critical thinking and innovative processes in design and development of solutions." – Engineers Canada, 2020

An IEA update to the graduate attributes was issued on June 21, 2021, signalling that graduate attributes can be updated. Thus, accreditation process administrators should expect GA updates in their graduate attribute process. Neither the timeline nor the process for regular updates is clear. However, ABET student outcomes changed recently, as described in Appendix E. The need for graduate attribute change management at the international, national, institutional, and program level is apparent.

A continual improvement and adaptive process, as described in Appendix C, is analogous to how industrial facilities are optimized. A target outcome is specified by the graduate attributes. There must be a feedback loop, where the current state is compared to the target state and the deviation is directionally managed. When graduate attributes change, it is akin to an operational set point change for a critical variable in an industrial process. For a process operation change of that magnitude, one would consult with stakeholders and ensure agreement and approval from those responsible and accountable for the consequences of the change prior to implementing the change. Risk would be assessed and managed. Currently feedback appears to be missing. In addition, engineers in practice learn from failures and incidents. This aspect also appears to be missing in the graduate attribute update. A feedback loop in the form of a consultative stakeholder input process is necessary (Chapter 7) for meaningful implementation of graduate attribute changes as is a feedback loop based on failure and incident analysis. The development of graduate attributes becomes a part of teaching practice as described in Chapters 4, 5 and 6 rather than an external imposition likely to encounter resistance. In addition to stakeholder concerns, the timeline for GA changes must be considered in terms of the high administrative workload and cost to institutions, as well as the need to inform, and engage instructors, programs, and institutions.

8.1 Tension and Resistance to change in Engineering Education

The tension between what is needed for an engineer to enter graduate school from a knowledge content perspective and what is needed for an engineer to enter an international industrial work setting and begin practicing is clear and has been a key driver for engineering education reform in spite of the counter arguments of not enough time and nothing can be omitted from curricula (Chapter 1). The increasing pressure to address societal and environmental sustainability while educating the whole engineer as elucidated by the engineering graduate attributes adds to this tension (Chapter 6) as the current energy source disruption proceeds. Considering the academic success of all students admitted to engineering programs (and not just those who have already developed their metacognitive and professional skills) by addressing concerns holistically may reduce this tension (Chapter 3). The application of the key areas of the proposed theoretical framework (Appendix D) to content throughout an undergraduate engineering program may address this issue and facilitate development of graduate attribute competencies. For example, communication skills developed during undergraduate engineering programs are often viewed as underdeveloped by engineering employers (Donnell, 2011). In light of Canadian engineering schools significant efforts to develop capstone, cornerstone, and design spine courses to address the CEAB graduate attributes, the disconnect between the skill set employers believe new graduates need and the skills new graduates possess has narrowed (Parsons, 2016). A study of the new graduates and professional engineers perceptions of graduate attribute competencies and requirements identified gaps between the competencies and requirements for new engineers for most of the graduate attributes except the first one – knowledge base (Petkau, 2015). At the University of Manitoba, CEAB-GAs where both graduates and practicing professionals note the largest gaps between new graduate competencies and requirements are: communication, teamwork, professionalism, the impact of engineering, ethics, economics, project management, and life-long learning (Petkau, 2015). New graduates saw themselves as more competent in problem solving, investigation, and design than their supervisors did (Petkau, 2015) but both agreed new graduates typically met the initial requirements in these areas. Given the focus on these aspects in the undergraduate curriculum this is an interesting finding and perhaps this focus contributes to giving students the impression they are more skilled than their supervisors perceive.

A historical perspective of the need for socially conscious engineers with contextual knowledge was examined along with the typical complimentary elective mix of Canadian universities finding typical electives are business, economics, communications, and ethics related (Donald et.al, 2015) but often not integrated. Most Canadian engineering programs have elements intended to develop their graduates' knowledge base in complementary studies. The value initially placed on complimentary studies by students tends to be lower earlier in their program (Donald et.al, 2015) suggesting that initially students are not presented with how complementary studies are integrated with engineering work. Students may not even realize what engineering work is until late in their undergraduate program. This problem may be addressed with the general engineering education and practice theoretical framework (Chapter 6; Appendices D and E) for course content analysis and to describe engineering practice to first and subsequent year engineering students. The inclusion and rapid operationalization of sustainability in engineering education programs is overdue (Chapters 5 and 6). The NAE's 2004 report, "The Engineer of 2020: Visions of Engineering in the New Century," presented forward-looking goals for the engineering profession in 2020, including the challenges, opportunities, and global context within which engineers would work. Importantly, the report stated that engineering "must (1) agree on an exciting vision for its future; (2) transform engineering education to help achieve the vision; (3) build a clear image of the new roles for engineers, including as broad-based technology leaders, in the mind of the public and prospective students who can replenish and improve the talent base of an aging engineering workforce; (4) accommodate innovative developments from non-engineering fields; and (5) find ways to focus the energies of the different disciplines of engineering toward common goals." The report also defined a set of skills and capabilities that would be needed by those future engineers, including both professional and technical skills. As seen in Chapter 1 these skills are similar to the graduate attributes. The visionary timeframe for this report has come with limited progress toward transformative change in many engineering programs. Although there appears to be momentum building, the question still remains as to whether systemic issues will be addressed and societal and engineering transformation to a sustainable paradigm will be effected. Questions remain regarding the institutional and instructor commitments to implementing effective teaching practices and contextual based learning, instructor development, and credit for teaching development (Felder, et al., 2000a,b). Research on the efficacy of contextual learning (Felder et al, 2000b) such as problem based learning (Yew & Goh, 2016) and communities of practice (Kai & Mun, 2016) have been well documented. The generalized theoretical framework presented in this work demonstrates engineering practice is not just theoretical. To effectively teach students contextually, techniques such as cooperative learning, inductive teaching, problem based learning, and case studies have been effectively used in engineering (Felder et al, 2000b) and other academic disciplines (Yew & Goh, 2016; Kai & Mun, 2016).

Resistance to implementing a system that drives the outcomes of university programs from outside of the university is somewhat warranted because the feedback loop from institutions and signatory accreditation bodies to graduate attribute evolution is not yet clear. At this time, a formal feedback loop with input from students, instructors, programs, universities, regulators, and signatories (Chapter 7) into the graduate attribute revision process does not yet appear to be in place. There is a forward path for the prescriptive implementation of the graduate attributes to inform program decisions for accreditation processes and there is room for programs to develop processes around the current graduate attributes (Appendix C). At many institutions there is a feedback loop to program development and GACIP provides a pathway to the CEAB for feedback on the accreditation process itself (Chapter 7). However, a path for feedback as elucidated in Figure 7.3 to provide input to the IEA on the global version of the graduate attributes is less clear. As engineering work changes and the societal demand for the profession to support the UN Sustainable Development Goals and address the Engineering Grand Challenges increases, a graduate attribute implementation question remains – who is driving the outcomes and what is the process for input to change for the outcomes? This is a critical question that must be addressed for engineering practice and engineering education. Engineering educators are stakeholders in this process.

Protection of the public and the public interest is not a single conception. Public interest globally is not necessarily the same as public interest nationally, within smaller districts, or municipally. In the past, engineers have been criticized for being a tool of industry or capitalism. Without asking and developing answers for these important questions and developing a more transparent process for changes to the graduate attributes, we risk becoming a tool for someone else's agenda rather than protecting the public and the public interest. There is value in the independent operation of higher education institutions apart from political and industrial control and this is a critical aspect to consider in the global development of outcomes-based processes. Checks and balances are a necessary part of system design. A feedback pathway for input to graduate attribute revision balances the prescriptive nature of outcomes based education where the outcomes are being defined external to the program administration. Without a feedback pathway, the ability to regulate the system is lost and responsibility and accountability are disconnected from control. This is a problem often seen in engineering management systems (Chapter 6) and may result in conflict between professional and organizational responsibilities. The implementation of the University Graduate Attributes (Chapter 7) appears to suffer from a similar problem of resistance to prescriptive outcomes with incomplete stakeholder input. This is a significant problem with UGA implementation (Chapter 7).

8.2 Addressing Systemic Issues in Engineering Education

The gap between engineering education program content and the socio-contextual nature of engineering practice is not the sole result of an ontological and epistemic mismatch between the reality of engineering practice and education programs (Chapter 2; Appendices D and E). The work of developing a conceptual framework and resulting theoretical framework grounded in the outcomes-based graduate attributes, engineering practice, and the education literature suggests an ontological and epistemic position aligned with critical realism better describes engineering work and education than the traditional positivist one often found in engineering science research and graduate work and permeating the undergraduate core content courses (Chapters 3, 4 and 5). Although this mismatch may be a barrier to the transformation of engineering education of the whole engineer it is not the *only* barrier. University structures can be somewhat inflexible when it comes to change, especially given the high workload and expectations of both research and teaching. For many instructors who are balancing a demanding workload this is an unwelcome addition and resistance to the additional workload presents in addition to the resistance to external control and the tension between preparing students for graduate work and practice already described. Recently the online transition to remote learning because of the COVID-19 pandemic has stretched most students, instructors, and institutions even though it ‘didn’t turn out that badly’, (Kovacevic, 2020). The management of the graduate attribute process along with program and curriculum improvement can be time consuming and frustrating. How we evaluate and value the work of faculty (research and teaching stream) and the value we place upon different types of contributions sets the agenda for what is accomplished. In addition, the attention we focus on engineering education research and development from a national funding perspective speaks volumes about the priority, relative value and esteem that engineering education transformation and international competitiveness holds. In the US, engineering education is liberally funded by the NSF and recognized as critical to meeting the goals of the 2004 NAE Engineer of 2020 report quoted above. In Canada, engineering education research is not funded by NSERC and at times it appears to be intentionally marginalized by research funding agencies by explicit exclusion from possible sources of funding. These are critical barriers to the development of strong, sustainable and innovative Canadian engineering programs that support the technical and the social aspects of engineering. Change requires work and work requires funding. This type of research work is not easily monetized external to funding agencies. However, it is critical to meet the UN Sustainable Development Goals and support economic transitions.

The challenge of continuing to bridge the gaps between the graduate attribute expectations for new grads and their competencies in the socio-contextual, metacognitive, and professional contexts comes with high demands on engineering design course students and instructors where innovation and socio-contextual integration of fundamental technical knowledge into a plausible design and engineering project occurs. For instructors this challenge is further delineated in the continuous course improvement process where instructors reflect on their student's performance relative to the CEAB graduate attributes and the course learning outcomes and attempt to determine what should be improved and how to go about it within the courses they currently teach (Appendix C). The question about where and when in the program items should be placed is often outside the instructors' sphere of influence and rests with the department and the faculty, typically on a committee that may or may not be effective at driving change and an instructor may or may not have input to the committee. A course instructor has to work with the preparation and knowledge framework of the students registered in the course – and that preparation may vary from cohort to cohort depending on teaching assignments and the cohort make up. The systematic application of a generalized theoretical framework (Chapter 6; Appendices D and E) to engineering program analysis and redevelopment could speed course and curriculum redevelopment and address variation in student preparation. Program level change and evaluation is required alongside deliberate instructor development. A competency-based system that addresses academic integrity is a necessity to change student learning behavior and move from the currently dominant surface and strategic learning strategies toward deep learning. Competency based assessment has recently been implemented in first year program redevelopment at the University of Saskatchewan (Maw et al., 2021) and for first year design course development at U of A (Jamieson, 2021).

8.3 Significance: Bridging the Gaps and Continual Improvement

The practice of engineering is design and operation within constraints (Chapters 1 and 6). The question of when does learning engineering practice begin for students and how much knowledge is needed for meaningful practice arises as does the question of how effective is fundamental knowledge retention without reflective practice? This tension could be lessened if the practice of life-long learning and the application of reflective learning, as early engineering practice, was an integral part of the engineering program from start to finish. According to Dr. Ruth Graham of MIT, this would appear to be the direction engineering schools identified as emerging leaders are taking:

> "Distinctive educational features of the 'emerging leaders' include work-based learning, multidisciplinary programs and ***a dual emphasis on engineering design and student self-reflection***. Case study evaluations suggest that the 'emerging leader' programs have benefitted from strong and visionary academic leadership, a faculty culture of educational innovation and new tools that support educational exploration and student assessment." (Graham, 2017; 2018)

A faculty culture of innovation can be grounded in a continual improvement process using the CEAB-GA performance measures (Appendix C) and include instructors' reflection on the courses taught and how they can improve graduate attribute performance and their own teaching practice. This is a metacognitive process – reflection with intent to take action (Appendices C and D). In order for instructors to model reflective processes for students and to participate in continual improvement, they must be aware of the role of metacognition in the practice of engineering. They must be conscious practitioners rather than unconsciously competent with tacit knowledge (Polanyi, 1967). They must be able to articulate the process in order to teach it to students (Chapter 3). The development of this reflective practice for engineering educators must be a necessary part of the transformation of traditional discipline based engineering programs to collaborative and sustainable engineering programs supportive of future practice requirements and the development of the whole engineer. In addition, emerging leaders in engineering education were either new programs or programs where systemic reform was undertaken (Graham, 2017). Continual improvement and incrementally improved programs were not among the emerging leaders. Major changes in both engineering education paradigms and systems are required. Systemic change is necessary to move forward with developing a graduate attribute based and future oriented engineering program. Chapters 3-6 outline a foundation for systemic change and Appendices D and E provide a rationale as to why change in engineering education has been difficult.

Constructivist learning theory suggests that explicitly linking the assessment outcomes to the learning objectives allows students to participate in learning activities that create meaningful learning and competency outcomes (Appendix A1.4). This requires instructors to be aware of constructive alignment and open to applying it to their teaching practice. The ability to identify individual student's development needs and to have students target areas for practice to achieve competency (and become a lifelong learner) suggests an effective and efficient learning model. It also presupposes the instructor is willing and able to develop learning activities situated in realistic practice and the instructor understands metacognitive development, student autonomy and the requirements of engineering practice (Appendices D and E). Formal training and development for faculty and instructors would be useful in supporting engineering education transformation. Teaching institutes often focus on constructive alignment and active learning. This is an excellent beginning. However, we need to go further.

The graduate attribute outcome assessment criteria are largely based on the practice of engineering requiring engineers to learn fundamentals and *apply* them to practice in a lifelong iterative process. This process often requires the practitioner to investigate the means at hand and to apply them to create a pathway to imagined ends or goals (Appendix E). Structured case study based learning (Chapter 6), problem based learning, and project based learning (Chapter 4) are effective for contextualizing engineering problems beyond the technical aspects and encouraging deep learning because there is an anticipated requirement to apply the knowledge in real life (Chapters 1 and 3). Engineering is a very creative profession and one that encourages the effective and efficient use of resources. As described in Chapter 1, a key differentiator between surface and strategic learning compared with deep learning is that the latter is typically paired with an *anticipated required action*. Requiring reflective practice of students *and* instructors transforms the learning activity from review and recitation to one of engagement, relevance, and practice. Situating learning in a societal context requires reflection on the consequences of engineering and business goals on people and the quality of life delineating the necessity of engineering leadership and management to the transformation to a sustainable society (Chapter 5). Graduate attribute analysis through a learning theory lens (Appendix D) shows that graduate attributes embody elements of cognitive, behavioral, and situational learning. Engineering education must move beyond an isolated constructivist approach to achieve learning outcomes, as the graduate attributes require students to demonstrate more than just thinking. Being a whole engineer requires: cognition, cognitive regulation, affective regulation, behaviours, and learned engineering practices. Learning diversity in our teaching practices and course and curriculum design is dictated by the reflection of engineering practice in the graduate attributes. In order to move forward with engineering education reform we must move beyond the cognitive constructivist mindset in developing our learning interactions to include behaviourist, situative, and social constructivist perspectives in our learning culture (Appendix D).

8.4 Engineering at the University of Alberta – CEAB and Institutional Graduate Attributes

The University of Alberta vision statement could guide the transformation of engineering education and potentially the education offered by the university as a whole:

> “To inspire the human spirit through outstanding achievements in *learning, discovery, and citizenship in a creative community*, building one of the world’s great universities for the public good.” (University of Alberta Vision, 2016)

U of A undergraduate students were instrumental in the development of the university wide graduate attributes (UGA) at the U of A. Significant effort was expended on developing the UGA and implementing them, yet adoption is limited. The CEAB graduate attributes necessarily describe the expected competencies of a graduate engineer. The UGA are more generic and target employability. Considerable international debate was required to establish the initial engineering graduate attributes and significant time was spent on their consideration. The Washington Accord delineates the fundamental purpose of engineering education is to lay the foundation for engineering practice. A link between fundamental knowledge and engineering practice to inform a formative engineering identity as described by the graduate attributes is clearly established (Appendix E). Engineering education is much more than a grounding in fundamental knowledge (Chapter 1) and engineering education programs should embrace this integration as they transform to support sustainable system design and operation (Chapters 5 and 6) by educating the whole engineer. As such the CEAB-GA and the UGA find considerable agreement and both find resistance to adoption. Clues to this resistance may be found in the structure of higher education institutions and what constitutes valued work, the structure, philosophical paradigm, and educational goals of engineering (or other university) programs, the assignment of accountability and responsibility for course and program content, epistemic cognition as a result of how individuals believe we come to know what we know, what counts as evidence, what can and cannot be measured, whether the measurement is valid and thus counts as knowledge (Appendix E). The development, measurement, and management of graduate attributes must consider these aspects of (justifiable) resistance and examine the epistemic cognition (including belief, disposition, and skill) of the instructors and administrators being asked to develop, measure, and manage educational programs and graduate attributes (Chapter 7). Course and program development should be intentional and periodically reviewed with the stakeholders including instructors and students considering both time and cognitive demands on both instructors and students (Chapter 7 and Appendix C). A program review committee that does not include input from instructors who teach courses in a program is missing input and stakeholders. Unfortunately, this means that time needs to be allocated for this activity in (often) overcommitted schedules.

8.5 Engineering Graduate Attribute Assessment Management

Institutional level GA management requires a collaborative administrative team to allocate resources, develop an implementation vision, and execute a strategy supporting a learning culture to develop a management structure (Gopakumar, 2013; Dew, 2014) and monitor the implementation process shown in Figure 8.1. The program level approach focuses on mapping the graduate attributes to the curriculum, the developmental trajectory of the graduate attributes or the learning pathway (Meikleham, 2018) over the program years, and integrating the goals of the professional program into the course objectives. The third level targets specific course design coordinated with the developmental trajectory of the graduate attributes on the learning path for the program (Jamieson, 2015; 2016; 2018). It is at this critical third level that an innovative faculty culture is developed, the graduate attributes are operationalized and support a transformative learning experience for students or they become meaningless because the measurement is not aligned with the objective or poorly reported. This makes meaningful and ongoing faculty level engagement with the process an essential element for success.

The theoretical framework developed for engineering education and practice (Chapter 6; Appendices D and E) and the Leadership and Management Development Matrix (LMDM) (Chapter 5) is proposed for course and program content analysis. This may allow for easier assessment and integration of multiple types of activities as credible methods for effective graduate attribute development at the program level. The LMDM was recently applied to effectively analyze the leadership, management and sustainability content of the first year design courses at the University of Guelph and the University of Alberta in a comparative analysis (Jamieson and Donald, 2021).

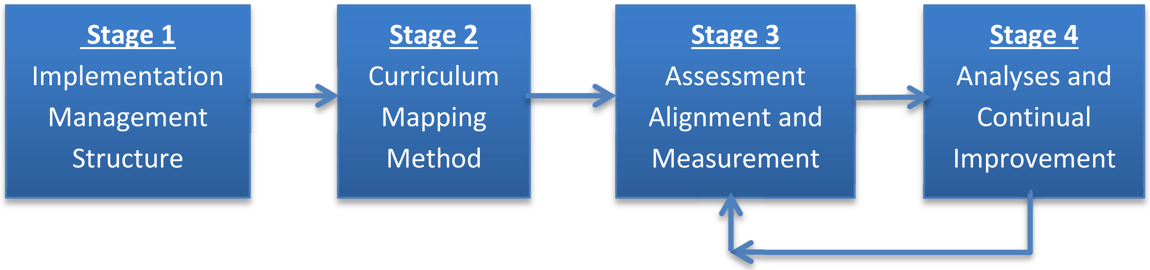


Figure 8.1. GACIP implementation: From initial structure to closing the continual improvement loop.

The complexity of GA management is underscored in Chapter 7 as we examine the interactions between the prescribed graduate attributes at the institutional level and the program level. A feedback loop in the form of a consultative process may be necessary for meaningful implementation so that the development of the graduate attributes becomes a part of teaching practice as described in Chapters 4, 5 and 6. In order for outcomes based learning to become a meaningful part of engineering education and teaching practice, stakeholders must have input into the graduate attribute process including updates to the graduate attributes and there must be accreditation gatekeepers who ensure that programs meet the requirements from a technical, metacognitive, socio-contextual, and professional knowledge and skill perspective. We must have a level for what a minimum standard is and ensure this is equitably and not arbitrarily applied. Change requires work and risk management and this requires time and effort to be allocated to it and funded. Addressing the chemical process safety issues of the 20th century required systemic change and a change in the practices and beliefs of individuals operating within corporate cultures from a culture where safety risks were sometimes unknown and acceptable to one where identifying and mitigating risk was a priority. Although the high workload concern was not directly examined in this work it was consistently observed as a systemic issue impacting students, instructors, and administrators.

Efforts to implement and manage the CEAB graduate attribute continual improvement process (Appendices A1.3, A1.4) as part of accreditation come at a cost. In a comprehensive literature summary Parker et al. (2019) estimated the cost of a recent accreditation visit to the University of Alberta Faculty of Engineering at over a million dollars and "requiring over 16,000 hours of personnel time (p. 8)" underscoring the urgency of developing effective and *efficient* processes to demonstrate accountability to accrediting and regulatory bodies. This suggests the administrative workload and financial cost for accreditation must be balanced against the investment in faculty development to support program and course redevelopment that encompasses the four key elements of engineering education and practice (Chapters 1 and 6; Appendices D and E) and achieves the goals of accreditation. The requirement to provide evidence supporting competency-based outcome achievement can erode resources that might otherwise be directed to teaching and learning and/or result in higher education costs while overall institutional funding remains static or is decreasing underscoring the necessity for innovative faculty engagement with the graduate attribute management process. An examination of the development of a learning culture and how the general theoretical framework could support the development of an engineering learning culture and a collaborative faculty learning culture with an embedded continual improvement process is proposed as part of this work. In other words, is the priority to measure progress or make progress? What counts as evidence of progress and how much evidence is needed to demonstrate the graduate attributes?

8.6 Accreditation and Lifelong Learning Graduate Attribute Assessment

In 2016, the CEAB decided to keep the current accreditation unit levels and not reduce them (GACIP Summit, 2016). The requirement to demonstrate measurement of the graduate attributes and a continual improvement process is now part of the accreditation review (GACIP Summit, 2017). This process can be time consuming for an engineering faculty and some attributes can be difficult to meaningfully assess quantitatively (GACIP Summit, 2018). The challenge of a positivist paradigm where objective quantitative measurement is a core value can lead to frustration for those attempting to identify meaningful objective measurements for reflective or professional practice graduate attributes that describe the engineering identity and emerge when students engage in experiential and reflective learning (Appendix E).

> **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 (CEAB, 2004; 2019).

The twelfth graduate attribute, lifelong learning, is particularly challenging to teach and evaluate from a knowledge based objective assessment perspective as it requires explicitly introducing metacognitive skills and the practice of reflection into the undergraduate program. These are not objective practices. Although one can assess if students can recall the process after they have learned it, like design, it is challenging to determine if skills are applied and practiced, to what degree and if the learning gaps have been correctly identified and successfully addressed to the extent required for competency without the creation of an artifact such as design report or perhaps a learning report. It is in the assessment of that artifact, typically using a rubric for grading, that one determines if the result is achieved. In other words, the assessor must do qualitative data analysis (Chapter 6 and Appendix C). This type of assessment requires an epistemic shift from an objectivist epistemology for both the student and the instructor (Appendix E).

References

Accreditation Board, Canadian Engineering Accreditation Board: Accreditation Criteria and Procedures. Ottawa: Canadian Council of Professional Engineers, (2004). Accessed June 1, 2015. http://www.engineerscanada.ca/e/pu_ab.cfm

Briber, R., Kovacevic, J., Yortsos, Y., After COVID-19: The Role of Engineering Schools in the Post-Pandemic Era - Featuring Engineering Deans - in (moderators) Kahl, N., and Adams, S. ASEE, 2020

Canadian Engineering Accreditation Board. (2019). *Accreditation criteria and procedure*. Canadian Council of Professional Engineers. https://engineerscanada.ca/sites/default/files/accreditation/Accreditation-Criteria-Procedures-2019.pdf

Dew, S., Driver, R., Thomas, G., Mandal, M., and Choi, P. (2014). Scalability of a graduate attributes assessment and continuous improvement process. in *Proc. 2014 Canadian Engineering Education Conf. (CEEA14)*, Canmore, AB, June 8-11, 2014, Paper 60.

Donald, J., Lachapelle, S., McIsaac, J., Abraham, T., Clemmer, R., Gordon, K., McCook, S., and Zytner, R.G. (2015). Training versatile engineers: a historical and present perspective on the place of the humanities and social sciences in the Canadian engineering context. *Proc. 2015 Canadian Engineering Education Association* (CEEA15) Conf. Paper 049; McMaster University; May 31 – June 3, 2015.

Donnell, J. A., Aller, B. M., Alley, M., & Kedrowicz, A. A. (2011). Why industry says that engineering graduates have poor communication skills: What the literature says. *ASEE Annual Conference And Exposition, Conference Proceedings*, (118th ASEE Annual Conference and Exposition), 13 p.

Engineers Canada, (2020). Updating the IEA's Graduate Attributes and Professional Competencies Framework. Web Page Published November 19, 2020: https://engineerscanada.ca/news-and-events/news/updating-the-ieas-graduate-attributes-and-professional-competencies-framework

Felder, R.M., Rugarcia, A. Stice, J.E. (2000a). The Future of Engineering Education V. Assessing Teaching Effectiveness and Educational Scholarship. Chem. Engr. Education, 34(3), 198–207.

Felder, R.M., Woods, D.R., Rugarcia, A. Stice, J.E. (2000b). The Future of Engineering Education II, teaching Methods that Work. Chem. Engr. Education, 34(1), 26-39.

GACIP (2016). GACIP summit meeting 2016, December 8, 2016, University of Toronto.

GACIP (2017). GACIP summit meeting 2017, December 7, 2017, University of Toronto.

GACIP (2018). GACIP summit meeting 2018: Aggregating data. December 6, 2018, https://egad.engineering.queensu.ca/?page_id=4291

Gopakumar, G., Dysart-Gale, D., and Ali Akgunduz, A. (2013). Creating faculty buy in: Leadership challenges in implementing CEAB graduate attributes. in *Proc. 2013 Canadian Engineering Education Conf. (CEEA13)*, University de Montreal, June 17-20, 2013, Paper 55.

Graham R. (2017). The global state-of-the-art in engineering education: Outcomes of Phase 1 benchmarking study. https://rhgraham.org/resources/Phase-1-engineering-education-benchmarking-study-2017.pdf

Graham R. (2018). The global state of the art in engineering education. New Engineering Education Transformation, MIT. https://res2.weblium.site/res/5e5837aee8e6180021564660/5edeabcd44e8300022bf5a9f

Jamieson, M.V., Donald, J.R., (2021). "Building the Engineering Mindset: Developing Sustainable Leadership and Management Competencies in First Year Engineering," Canadian Engineering Education Conference (CEEA-ACEG 2021) UPEI

Jamieson, M.V. (2015). Application of Blended and Active Learning to Chemical Engineering Design Instruction, 2015 MSc Thesis

Jamieson, M.V., Ead, A. S., Rowe, A., Miller-Young, J. and Carey, J.P. (In Press 2021). Design at Scale in a First-Year Transdisciplinary Engineering Design Course, IJEE.

Jamieson, M.V., and Shaw, J.M. (2018). Graduate attribute based continuous improvement in a blended learning engineering design course – a writing seminar case study. *Proc. 2018 Canadian*

Engineering Education Conference (CEEA18), P. Ostafichuk (ed) (Vancouver, British Columbia; 3-6 June 2018), Paper 77.

Jamieson, M.V., (2020). Keeping a Learning Community and Academic Integrity Intact after a Mid-Term Shift to Online Learning in Chemical Engineering Design During the COVID-19 Pandemic. *Journal of Chemical Education* ***2020*** *97 (9), 2768-2772 DOI: 10.1021/acs.jchemed.0c00785*

Jamieson, M.V., Shaw, J.M. (2016). Pre and post course student self assessment of CEAB graduate attributes - A tool for outcomes assessment, student skill and course improvement. *Proc. 2016 Canadian Engineering Education Association* (CEEA16) Conf. Paper 037; Dalhousie University; June 19 – 22, 2016

Kai, L. & Mun, A. (2016). Do Communities of Practice Make A Difference? Health Professions Education 2(2) 61–74

Maw S., Huang, S., Cree, D., Kennell, G., James, W. (2021). “"Lessons Learned from Using Competency Based Assessment (CBA) in a First Year Engineering Statics Course,” Canadian Engineering Education Conference (CEEA-ACEG 2021) UPEI

Meikleham, A., Brennan, R., and Hugo, R. (2018). Utilizing the CDIO syllabus to reveal CEAB graduate attribute pathways in a mechanical engineering curriculum. in *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) Vancouver, British Columbia; 3-6 June 2018.

National Academy of Engineering (NAE) (2004). The Engineer of 2020: Visions of Engineering in the New Century, Washington, DC: The National Academies Press. https://doi.org/10.17226/10999

Parsons, B. (2016). Engineering Graduates. *Canadian Consulting Engineer*, *57*(7), 22-23.

Parker A.M., Watson E, Ivey M, Carey JP (2019). Approaches to graduate attribute and continual improvement processes in faculties of engineering across Canada: a narrative review of the literature, *Proceedings 2019 Canadian Engineering Education Association (CEEA-ACEG19) Conference*. Ottawa, Ontario. https://doi.org/10.24908/pceea.vi0.13736

Petkau, D. (2015). Industry perceptions of graduate attribute competencies for the workplace. *Proc. 2015 Canadian Engineering Education Association* (CEEA15) Conf. Paper 078; McMaster University; May 31 – June 3, 2015.

Petkau, D. (2015). Industry perceptions of graduate attribute requirements for the workplace. *Proc. 2015 Canadian Engineering Education Association* (CEEA15) Conf. Paper 079; McMaster University; May 31 – June 3, 2015.

Polanyi, M. (1967). The tacit dimension. Garden City, NY: Anchor Books/Doubleday.

University of Alberta, (2016). Vision, Mission and Values. https://www.ualberta.ca/strategic-plan/overview/our-vision-mission-and-values

Yew, E., Goh, K. (2016). Problem-Based Learning: An Overview of its Process and Impact on Learning, Health Professions Education 2(2) p 75–79

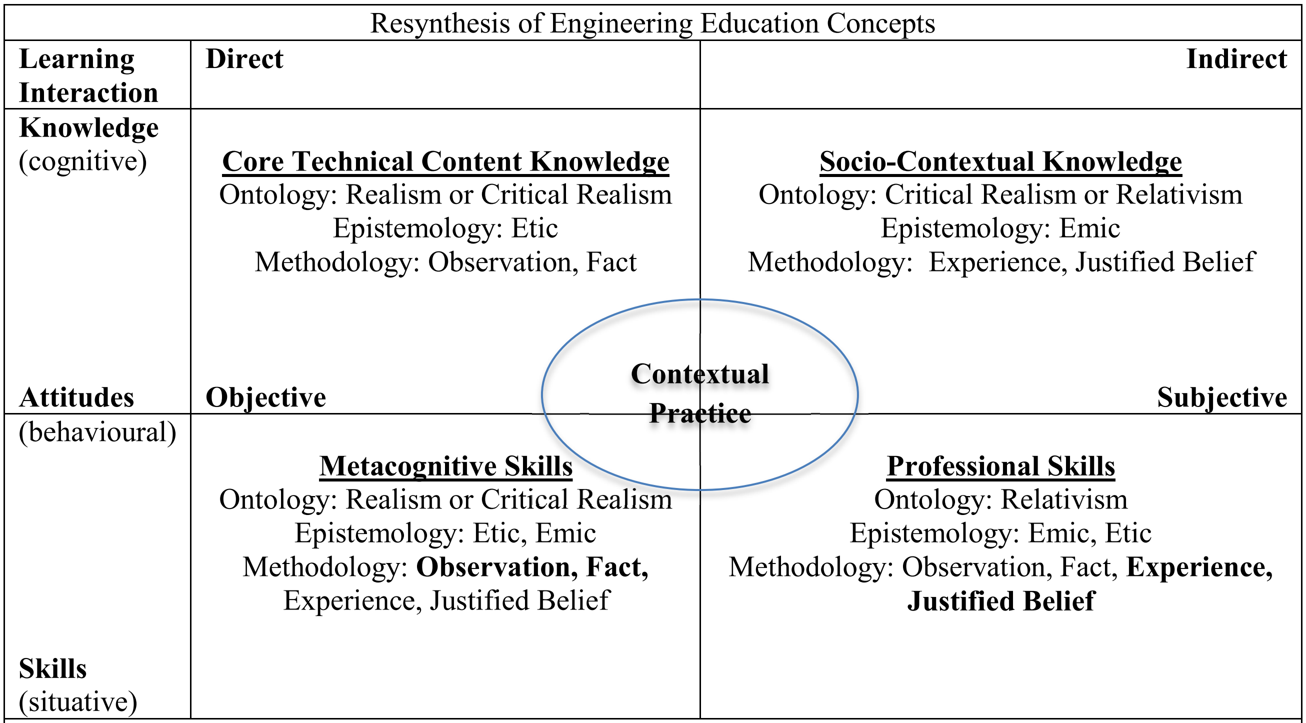
9. Conclusions and Recommendations

Engineering education lays the foundation for engineering practice and the graduate attributes are a blueprint for the evolving design and development of the whole engineer. The necessity for sustainable engineering to become our dominant practice is clear (Chapters 5 and 6). As described in Chapter 1, the question is no longer if we will move to include the sustainable development goals in our undergraduate engineering programs but how and how quickly. It is clear from the rapid pivot to online learning that we can pivot and we can move quickly. The International Engineering Alliance, Engineers Canada, and the Canadian Deans have all made their intention clear to support the inclusion of the UN sustainable development goals in our engineering programs. Do we have a critical mass of engaged instructors at institutions across Canada and globally? The problems we need to solve as engineers are complex and the solutions have impacts beyond the system boundaries that we may define to solve the problem. The need for sustainable engineering leadership and management is clear. The need for addressing diversity, equity and inclusion beyond the status quo to enable a transformation to a more equitable society is now beyond urgent and simply can no longer be ignored. It is also clear that systemic change could enable meaningful faculty development and effective system processes for monitoring, evolving, implementing, and managing graduate attributes on an ongoing basis.

From the exploratory phase of this work outlined in Chapter 2, the ontological and epistemic perspective of the research and the researcher were initially rooted in the realist paradigm traditionally associated with engineering, where the researcher is an objective observer who develops models and descriptions based on the observations made then interprets the findings relative to existing theories and draws conclusions. The results yielded incremental improvements and demonstrated interventions could be made to incrementally improve specific courses in a specific program with a specific group of students. Whether the interventions could be generalizable was unclear.

These results led to deeper questions about learning and the development of a learning culture to support graduate attribute development, the development of the whole engineer, and the continual improvement process itself. These questions led to a deeper exploration of the ontological, epistemological, and methodological roots of the graduate attributes, engineering practice, and educational theory outlined in Appendix C. As described in Chapter 7 and Appendix C, a continual improvement process should include and engage stakeholders and their experiences with the learning activities, courses, and programs in addition to assessments and measurements of learning outcomes. Grades do not tell the whole story with respect to student engagement and the graduate attribute outcomes nor do they tell the whole story about whether students are learning and building a foundation for engineering practice and graduate school. The ongoing assessment of students, courses, and programs requires more than a quantitative approach.

The conceptual and theoretical frameworks developed and applied in this work result from the exploration of engineering work, engineering practice, engineering design education, and the examination of the engineering graduate attribute outcomes from ontological, epistemological, and methodological perspectives and the alignment of those perspectives with four aspects of engineering practice, core technical knowledge, socio-contextual knowledge, metacognitive skills and professional skills as summarized in Figure 9.1 and Appendices D and E.



Resynthesis of Engineering Education Concepts

Learning Interaction	**Direct**	**Indirect**
Knowledge (cognitive) **Attitudes**	**Core Technical Content Knowledge** Ontology: Realism or Critical Realism Epistemology: Etic Methodology: Observation, Fact **Objective**	**Socio-Contextual Knowledge** Ontology: Critical Realism or Relativism Epistemology: Emic Methodology: Experience, Justified Belief **Subjective**
(behavioural) **Skills** (situative)	**Metacognitive Skills** Ontology: Realism or Critical Realism Epistemology: Etic, Emic Methodology: **Observation, Fact,** Experience, Justified Belief	**Professional Skills** Ontology: Relativism Epistemology: Emic, Etic Methodology: Observation, Fact, **Experience, Justified Belief**

Figure 9.1. Concept Integration and Re-synthesis based on Ontological, Epistemological and Methodological Classifications – Emergent Theoretical Framework

The work was also informed by the repeated and reflective application of a continual improvement process (practice) with the intent to improve the process design courses (Appendix C); and extensive interdisciplinary reading, inclusive of graduate attribute literature, to support the structure for the course content and culture (Appendix D). The method of development includes qualitative analysis and categorization of extensive interdisciplinary reading, integrating, and validating the resultant framework within interdisciplinary communities of practice (Appendix E). This framework and a case based mixed methods continual improvement process is proposed for ongoing engineering education program reform and continual improvement (Appendix C) in order to better assess student development as whole engineers foundational to engineering practice. The theoretical framework can be utilized as a content analysis tool and to facilitate the instructor and program level practice of reflective continual improvement (Chapter 6). It is less cumbersome to use for high-level program and course content analysis than the graduate attributes and it reflects the graduate attributes at a foundational level. Core technical and socio-contextual knowledge are currently described in the accreditation requirements, while metacognitive and professional skills are described in the CEAB graduate attributes. This framework enables faculty and instructors to allocate time to all four elements in the program and quickly incorporate changes to the graduate attributes within the content areas at the course level while keeping the program balanced. This framework is not a replacement for learning outcomes mapped to the graduate attributes rather it can be employed to balance course and program content.

The results of the second phase indicate the graduate attributes are complex and exhibit characteristics aligned with behaviorist, cognitivist, and situative learning environments indicating a learning culture for the development of the graduate attributes would likely require elements that embody multiple approaches, philosophical and epistemological positions beyond the traditional realist and objective knowledge approach typical of engineering science (Chapter 2; Appendices C, D, and E). The epistemology of engineering is a mix of objective and subjective knowledge types and the ontological position is more pragmatic than positivist. This position needs to be considered carefully when developing learning experiences and what is presented as knowledge and how we come to know things. Metacognitive skill development in engineering education emerged as a key area (Chapter 3) as a result of the examination of engineering work during theoretical framework development. The integration of technical knowledge with socio-contextual knowledge, professional, and metacognitive skills throughout engineering programs as described in Chapters 4, 5 and 6 is supportive of sustainability, innovation, and diversity, equity, and inclusion goals. An engagement with epistemic cognition and a resulting epistemic shift in engineering and engineering education is necessary to enable the transformation of engineering education to support sustainable engineering leadership and management of the complex structures and systems we now operate and those we will design and operate in the future.

The third phase of this research program was continual improvement including the prescriptive design and content development of learning activities and assessments within engineering design courses and the application of the framework to develop programs in the context of innovation and sustainability inclusive of core technical and socio-contextual knowledge development alongside metacognitive and professional skill development. A key objective in the design of the learning activities is to achieve broader coverage of the socio-contextual knowledge in the context of engineering design and the application of fundamental knowledge while concurrently developing metacognitive and professional skills. Elements and models used in professional practice (i.e. RBPSM) that contain core technical and socio-contextual content alongside metacognitive and professional skill practice can be mapped to design learning experiences (projects, problems, and cases) and bring situational learning to the classroom where students can gain practical experience in areas such as innovation, sustainability, engineering leadership, and management.

It is clear that sustainable engineering practices are not just within the purview of programs that have adopted the sustainable label. DEI, innovation, and digital literacy are all recognized as integral to future engineering practice along with the high probability of the emergence of new disciplines and practice areas underscoring the necessity for viewing engineering education through a new lens and adaptive learning culture that incorporates socio-contextual with core technical knowledge and includes metacognitive and professional skill development as a matter of course as described in the application of the engineering education and practice theoretical framework and the artefacts developed in Chapters 4, 5 and 6. The Risk Based Process Safety Management (RBPSM) framework and techniques, as outlined in Chapter 6 and Appendix A, could be used to operationalize sustainability and to develop management systems where control and responsibility are not separated. To avoid loss management incidents and to manage the risk more effectively, the people who are responsible and accountable should also have control and the management authority for the activity. The course continual improvement process described in Appendix C exemplifies this change management process as targets evolve and objectives are assessed courses and as a result programs evolve. The agility of a response must be balanced within the overall goals of the program to produce competent graduates who can execute engineering work as defined in Chapter 1 and with the technical, metacognitive, socio-contextual, and professional knowledge and skill balance required to negotiate the future where sustainable engineering is required. The complexity of GA management is underscored in Chapter 7 as the interactions and tensions between prescribed graduate attributes at the institutional level and the program level are examined.

The transformation of engineering education is upon us, and it has been accelerating over the past decade to the point where the graduate attributes have become a part of the accreditation process, of which continual improvement is a requirement (Chapter 7). The graduate attributes themselves can (and do) change as a result of the continual improvement process (Chapter 8). As engineering work and practice evolve, engineering education outcomes and hence graduate attributes must also evolve. The theoretical framework presented could empower students to plan their development as an engineer starting in first year and help to eliminate redundant GA indicators and inform data analysis and aggregation strategies. The conceptual and theoretical frameworks and development process presented in Appendices D and E suggest that the ontology and epistemology of engineering work and engineering practice are inconsistent with positivist ontology and an objectivist epistemology. An epistemic shift is necessary for engineering education transformation to support sustainable and inclusive engineering. This shift would also support diversity, equity and inclusion in a manner that truly welcomes diverse genders and social groups instead of just claiming it to be true. An engineering education paradigm shift supports our ability to meet the grand challenges resulting from the interactions of complex social, artificial and natural ecosystems. As with the graduate attributes, shifts in the conceptual framework are to be expected as engineering work and practice evolve. However, the four components of the theoretical framework are not expected to change significantly as they are drawn from the intersection of the ontological and epistemic spectrums.

As a result of the work completed several recommendations are made:

- **Systemic reform is needed.** An ontological and epistemic paradigm shift is necessary to transform engineering education. Incremental change is unlikely to propel a program towards the future rapidly. An examination of systems and cultures that results in systemic change is needed to transform engineering education.
- Systemic reform must include the graduate attribute process and university processes. Accreditation is expensive and creates a large burden for institutions impacting resources available for instruction and program development. **Change management is needed.**
- An explicit formal and informal feedback process from stakeholders including institutions offering accredited engineering programs to Engineers Canada and the International Engineering Alliance with input to graduate attributes changes is necessary. The Graduate Attribute and Continual Improvement Process (GACIP) meetings are a good start but are not a formal collection of stakeholder input. A method to include stakeholders and address concerns is needed. Engineering education and graduate attribute research should be a part of this input.
- National and provincial funding for engineering education research and development should be increased to support systemic change. Compared to the US it is difficult to fund engineering education research and initiatives in Canada. Currently limited funding is institutionally based.
- The application of the engineering education and practice general theoretical framework to program and course content analysis may be a simple and more rapid high level check with

respect to graduate attribute development in students. This framework is unlikely to change with graduate attribute specific changes and may give administrators and accreditation bodies an overall overview supported by specific graduate attribute implementation at the course level thus providing a more agile, stable, and cost effective system. Future work may be undertaken to quantify the impact.

- Learning activities and teaching practice inclusive of the complex ontology and epistemology of the graduate attributes and engineering practice should be considered when applying learning theory to selecting and developing learning activities. Constructive alignment is a useful course and program design tool, however it is not the only tool that can be employed to develop a learning culture supportive of graduate attributes and the development of the whole engineer. Situative, behavioural and social constructivist learning experiences may also be needed to develop the complex graduate attributes.
- Consistent contextualization using case studies, problem based learning, and project based learning are the most effective way to include all four areas of engineering practice in learning activities. Students connect and relate core content within a professional practice framework.
- Instructors must develop an appreciation for ontological and epistemic perspectives, learning theories and educational tools. The support of a teaching community of practice is essential (Chapter 4). Resources need to be allocated (money and time) for new and existing faculty to develop capacity while respecting workload and/or reallocating responsibilities. Student and instructor mental health are both of a concern. Just as there is only so much time available in a four-year program – there is only so much time available in a term and preparation work is a necessity for instructors. If we are to achieve the goals before us we need a paradigm shift where effective methods are employed to teach technical, socio-contextual, metacognitive, and professional skills concurrently.
- What is valued for academic performance and the measures of performance dictate what instructors and administrators focus on and where time and effort will be spent. Academic workload may need to be assessed and refocused without increasing demands and respecting time constraints.
- Sustainability, engineering leadership and management need to become a part of undergraduate engineering curricula. These aspects are a critical part of engineering work and are aspects that engineering graduates will use in the workforce alongside their technical skills. They are necessary to develop the whole engineer.

13. Bibliography

Aarup Jensen, A., Du, X. Kirkebæk, M. (2013). Teaching and Learning Culture : Negotiating the Context. Rotterdam : Sense Publishers.

ABET. (2019). *Criteria for Accrediting Engineering Programs, 2019 – 2020 | ABET*. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/

Accreditation Board, Canadian Engineering Accreditation Board: Accreditation Criteria and Procedures. Ottawa: Canadian Council of Professional Engineers, (2004). Accessed June 1, 2015. http://www.engineerscanada.ca/e/pu_ab.cfm

Accreditation Board, Canadian Engineering Accreditation Board: Engineering Instruction and Accreditation; Consultation on Advances in Accreditation. Ottawa: Canadian Council of Professional Engineers, (2016). Accessed January 5, 2019. https://engineerscanada.ca/sites/default/files/ec-consultation-document.pdf

AIChE CCPS. (2007). *Guidelines for risk based process safety*. AIChE. https://www.aiche.org/ccps/resources/certified-process-safety-professional/resources

Airasian, P.W. (1994). The Impact of the Taxonomy on Testing and Evaluation. In Anderson, L.W., Sosniak, L.A, (Eds.), Bloom's Taxonomy: A Forty Year Retrospective. The National Society For the Study of Education : Chicago, 200 pp.

Airasian, P. (1999). Assessment in the classroom, McGraw Hill.

Aleong, R.J. & Strong, D.S. "The Development of Life-Long Learning Competencies: Positioning Students for Self-regulation," Proc. CEEA15, 158, McMaster; May 31 – June 5, 2015.

Allen, D. E., Donham, R. S., & Bernhardt, S. A. (2011). Problem-based learning. *New Directions for Teaching and Learning*, *2011*(128), 21–29. https://doi.org/10.1002/tl.465

Amaya-Gómez, R. (2019). Process safety part of the engineering education DNA. *Education for Chemical Engineers*, 11.

Ambrose, S. A., Bridges, M.W., DiPietro, M., Lovett, M.C., Norman, M.K. (2009). How learning works: Seven Research-Based Principles for Smart Teaching, John Wiley & Sons.

American Society for Engineering Education (ASEE). 1994. Engineering Education for a Changing World. ASEE

Amyotte, P. R., & McCutcheon, D. J. (2006). *Risk Management—An Area of Knowledge for all Engineers. Technical Report. Discussion paper prepared for Canadian Council ofProfessional Engineers.* https://engineerscanada.ca/sites/default/files/risk_management_paper_eng.pdf

Anderson, N., Watson, E., Cocchio, J., Li, L., & Lefsrud, L. (2018). Fostering "Soft-Skill" Graduate Attribute Development using Multifaceted Instructional Strategies in an Undergraduate Engineering Course. *Journal of Online Engineering Education*, *9*(1), 1–11.

Anderson, T. and Shattuck, J., (2012). Design-Based Research: A Decade of Progress in Education Research? Educational Researcher, Vol. 41, No. 1, pp. 16–25, DOI: 10.3102/0013189X11428813

Andreasen, M. M., Hansen, C.T., and Cash, P., (2015). *Conceptual Design Interpretations, Mindset and Models*. Cham: Springer.

Andrews, G. C. (2009). Canadian professional engineering and geoscience. Practice and ethics, 4ed; Nelson Edu.: Toronto, p. 359.

Association of Professional Engineers and Geoscientists of Alberta (APEGA). 2013. Guidelines for ethical practice. Section 2.1 Professions (pg. 2).

Archer, M., Decoteau, C,. Gorski, P. Little, D., Porpora, D., Rutzou, T., Smith, C., Steinmetz, G., and Vandenberghe, F., (2016). What is Critical Realism? *Perspectives*, 38(2), pp. 4-9.

Arum, R. & Roska J (2010). *Academically Adrift: Limited learning on College Campuses*. Chicago, IL. Univesity of Chicago Press.

ASEE Workshop report, M. (2014). *Transforming Undergraduate Education in Engineering Phase I: Synthesizing and Integrating Industry Perspectives*. ASEE. https://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf

Ashwin, P. (2020). Transforming university education: A manifesto. Bloomsbury Academic.

Atwater, L. E., & Yammarino, F. J. (1992). Does self-other agreement on leadership perceptions moderate the validity of leadership and performance predictions? Personnel Psychology, 45, 141-164.

Avis, J., Fisher, R., Thompson, R. (2010). Teaching in lifelong learning: a guide to theory and practice. Milton Keynes : Open University Press, 303pp.

AU Task Force Report to Engineers Canada (2018). Retrieved from: https://engineerscanada.ca/sites/default/files/accreditation/Report-of-the-AU-Task-Force-FINAL-EN.pdf

Bain, K. (2004). What the Best College Teachers Do. Cambridge, MA: Harvard University Press ISBN: 0-674-01325-5

Barnett, R., (2013). Imagining the University. Abingdon: Routledge.

Barrie, S. C. (2006). Understanding what we mean by generic attributes of graduates. *Higher Education, 51,* 215-241. https://doi.org/10.1007/s10734-004-6384-7

Bass, B.M., (1985). Leadership and performance beyond expectations. New York: Free Press.

Bean, J.C., (2011). Engaging Ideas: The Professor's Guide to Integrating Writing, Critical Thinking, and Active Learning in the Classroom. 2nd ed. Jossey Bass : San Francisco, 360 p. 2011.

Belanger, R., & Pupulin, R. (2004). *APEGA Concepts of Professionalism 2004*. APEGA. https://www.apega.ca/docs/default-source/pdfs/professionalism.pdf?sfvrsn=ca3d5769_2

Bendixen, C., & Jacobsen, J. C. (2017). Nullifying quality: The marketisation of higher education. *Quality in Higher Education*, *23*(1), 20–34. https://doi.org/10.1080/13538322.2017.1294406

Bennett, N., Dunne, E., & Carre, C. (1999). Patterns of core generic skill provision in higher education. *Higher Education, 37*, 71–93. https://doi.org/10.1023/A:1003451727126

Berniker, E., & McNabb, D. E. (2006). Dialectical inquiry: A structured qualitative research method . *The Qualitative Report*, *11*(4), 643–664. https://nsuworks.nova.edu/tqr/vol11/iss4/2

Bhusari, A., Goh, A., Ai, H., Sathanapally, S., Jalal, M., & Mentzer, R. A. (2020). Process safety incidents across 14 industries. *Process Safety Progress*, *n/a*(n/a), e12158. https://doi.org/10.1002/prs.12158

Bhaskar, R. (1975). A realist theory of science. London: Verso.

Bhaskar, R., (2016). Enlightened Common Sense, the Philosophy of Critical Realism, edited by Mervyn Hartwig. London: Routledge.

Biggs, J. (1999). What the student does: teaching for enhanced learning. Higher Education and Development 18(1):57-75.

Biggs, J.B. (2003). Teaching for quality learning at university. Buckingham: Open University Press/Society for Research into Higher Education. (Second edition)

Biggs, J. B. (1996) Western Misperceptions of the Confucian-Heritage learning Culture. In: D.A. Watkins and J.B. Biggs, (Eds.) (1996) The Chinese Learner: Cultural, Contextual and Psychological Influences. Hong Kong, CERC and Melbourne: ACER. 45-68

Birkinshaw, J. M., (2010). *What is your Management Model?* 02-Sep-2010.: https://www.managementexchange.com/blog/what-your-management-model.

Birkinshaw, J. M., (2013). *Becoming a better boss: why good management is so difficult*. San Francisco, CA: Jossey-Bass, A Wiley Brand.

Blau, P. M. (1964). *Exchange and power in social life.* Wiley.

Blessing and Chakrabarti (2009). DRM, A Design Methodology. Springer : London

Blum, C., Bunke, D., Hungsberg, M., Roelofs, E., Joas, A., Joas, R., ..., & Stolzenburg, H. C. (2017). The concept of sustainable chemistry: Key drivers for the transition towards sustainable development. *Sustainable Chemistry and Pharmacy*, *5*, 94–104.

Briber, R., Kovacevic, J., Yortsos, Y., After COVID-19: The Role of Engineering Schools in the Post-Pandemic Era - Featuring Engineering Deans - in (moderators) Kahl, N., and Adams, S. ASEE, 2020

Bloom, B., Englehart, M. Furst, E., Hill, W., & Krathwohl, D. (1956). Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain. New York, Toronto: Longmans, Green.

Boekaerts, M. (1996). Self-regulated learning at the junction of cognition and motivation. European Psychologist, 1, 100–112.

Boekaerts, M., & Corno, L. (2005). Self-regulation in the classroom: A perspective on assessment and intervention. Applied Psychology: An International Review, 54, 199–231.

Bormotova, L. S. (2011). "A Qualitative Study of Metacognitive Reflection: The Beliefs, Attitudes and Reflective Practices of Developing Professional Educators". Theses and Dissertations (All). 434. http://knowledge.library.iup.edu/etd/434

Bosman L. and Fernhaber, S. (2018). *Teaching the Entrepreneurial Mindset to Engineers*. Cham: Springer.

Boud, D., Keogh, R. & Walker, D. (Eds.) (1993). Using experience for learning. Society for Research into Higher Education and Open University Press: University of Michigan.

Boud, D., Keogh, R. & Walker, D. (Eds.) (1985). Reflection: Turning experience into learning. Psychology Press.

Brennan, R.W., Hugo, R., Li, S., & Taboun, M. (2017). Evaluating an integrated course design tool for engineering graduate attributes. *Proc. 2017 Canadian Engineering Education Association Conf.,* Paper 59; University of Toronto; June 4 – 7, 2017

Briber, R., Kovacevic, J., Yortsos, Y., After COVID-19: The Role of Engineering Schools in the Post-Pandemic Era - Featuring Engineering Deans - in (moderators) Kahl, N., and Adams, S. ASEE, 2020

Brown, A. (1987). Metacognition, executive control, self control, and other mysterious mechanisms. In F. Weinert & R. Kluwe (Eds.), Metacognition, motivation and understanding, pp. 65-116. Hillsdale, NJ: Erlbaum.

Brown, H., and Keidan, B. (2015). Ontario Engineers find their place in the House of Commons. *Engineering Dimensions*, no. 5, p. 33.

Brownlee, Jo Lunn, Ferguson, Leila E., and Ryan, Mary (2017). Changing Teachers' Epistemic Cognition: A New Conceptual Framework for Epistemic Reflexivity, *Educational Psychologist*, 52(4), 242–252, DOI: 10.1080/00461520.2017.1333430

Bruner, J. (1985). Models of the learner. Educational Researcher, 14(6), 5–8.

Burns, J.M., (1978). Leadership. New York: Harper & Row.

Butun, E., Erkin, H.C., & Altintas, L. (2009). A new teamwork-based PBL problem design for electrical and electronic engineering education: A systems approach. *International Journal of Electrical Engineering Education, 45* (2), 110 – 120.

Callaghan, C.W. (2019). Transcending the threshold limitation: a fifth industrial revolution? *Management Research Review*, *43*(4), 447–461. https://doi-org.login.ezproxy.library.ualberta.ca/10.1108/MRR-03-2019-0102

Canadian Engineering Accreditation Board (2004). *Accreditation Criteria and Procedure*. Ottawa: Canada. Canadian Council of Professional Engineers

Canadian Engineering Accreditation Board, (2014). "Canadian Engineering Accreditation Board: Accreditation Criteria and Procedures", Ottawa: Canadian Council of Professional Engineers.

Canadian Engineering Accreditation Board (2017). *Canadian Engineering Accreditation Board: Accreditation Criteria and Procedures*. Ottawa: Canada. Canadian Council of Professional Engineers. Retrieved: https://engineerscanada.ca/sites/default/files/accreditation-criteria-procedures-2017.pdf [Accessed Nov. 25, 2018]

Canadian Engineering Accreditation Board (2019). *Accreditation Criteria and Procedure*. Ottawa: Canada. Canadian Council of Professional Engineers. Retrieved from https://engineerscanada.ca/sites/default/files/accreditation/Accreditation-Criteria-Procedures-2019.pdf

Canadian Engineering Accreditation Board (2018). Continual Improvement Rubric v3.2 https://engineerscanada.ca/accreditation/accreditation-resources [Accessed January 25, 2019]

Chinn, C., Buckland, L., & Samarapungavan, A. (2011). Expanding dimensions of epistemic cognition: Arguments from philosophy and psychology. Educational Psychologist, 46, 141–167. https://doi.org/10.1080/00461520.2011.587722

Clark, A.M., Lissel, S.L., & Davis, C. (2008). Complex Critical Realism: Tenets and Application in Nursing Research *Advances in Nursing Science*, 31(4), pp. E67-E79.

Clark, A.M., Briffa, T.G., Thirsk, L., Neubeck, L., Redfern, J., (2012). What football teaches us about complex health interventions *BMJ: British Medical Journal*, 345 (7888), pp. 25-27, Published by: BMJ Stable URL: http://www.jstor.org/stable/23493387 [Accessed: 22-06-2018 19:48 UTC]

Catmull, E., Wallace, A. (2014). Creativity, Inc.: Overcoming the Unseen Forces That Stand in the Way of True Inspiration. Random House: s.l.

Centre for Critical Realism (CCR) (2016). Roy Bhaskar – Transcendental Realism *About Critical Realism* CCR Blog at WordPress.com https://centreforcriticalrealism.com/about-critical-realism/basic-critical-realism/ Website established 1997 [Accessed: 22-06-2018]

Cloutier, G., Hugo, R., and Sellens, R. (2012). Mapping the relationship between the CDIO syllabus and the CEAB graduate attributes: An update. Int. J. Qual. Assur. Eng. Technol. Educ. vol. 2 no. 2, p. 34, 2012.

Colcleugh, D., (2013). Everyone A Leader: A Guide to High Performance Organizations for Engineers and Scientists. University of Toronto Press: Toronto

Cole, J. (1996). The two cultures revisited. The Bridge 26(3&4):15-21.

Committee on Accreditation of Canadian Medical Schools. (2019). *Standards for accreditation of medical education programs leading to the M.D. degree*. https://cacms-cafmc.ca/sites/default/files/documents/CACMS_Standards_and_Elements_-_AY_2019-2020.pdf

Condon, R.J., (2011). The Relationship between Self-Awareness and Leadership: Extending Measurement and Conceptualisation, University of Canterbury.

Condoor, S. (2004). *Importance of teaching the history of technology*. 34th ASEE/IEEE Frontiers in Education Conference.

Conner, M.L. and Clawson, J.G. (1993). Creating a Learning Culture : Strategy, Technology, and Practice. Cambridge : Cambridge University Press, 2004. Cornesky, R. A., Lind, J. (1993).The Quality Professor: Implementing TQM in the Classroom, Magna Publications Inc., Madison.

Cooke, D. L., & Rohleder, T. R. (2006). Learning from incidents: From normal accidents to high reliability. *System Dynamics Review*, *22*(3), 213–239.

Crawley, E. F., Malmqvist, J., Östlund, S., Brodeur, D. R. and Edström, K., (2014). *Rethinking Engineering Education - The CDIO Approach*. Cham: Springer International Publishing.

Crowl, D. A., & Louvar, J. F. (2019). *Chemical process safety: Fundamentals with applications /* (Fourth edition.). Pearson.

Crumpton-Young, L. et al. (2010). Engineering leadership development programs: A look at what is needed and what is being done. *Journal of STEM Education, 11*(3&4), 10 – 21.

Creswell, J.W. (2015). A concise introduction to mixed methods research. Sage Publications.

Creswell, J. W. (2005). Educational research: Planning, conducting, and evaluating quantitative and qualitative research (2nd ed.). Upper Saddle River, NJ: Pearson.

Creswell, J. W., Poth, C.N. (2018). Qualitative Inquiry and Research Design: Choosing among five approaches. (4th ed.). Thousands Oaks: Sage Publications

Crotty, M., (1998). Foundations of Social Research: Meaning and Perspective in the Research Process. London; Thousand Oaks, Calif.: Sage Publications.

Danielson, Vi. (2014, June 9). Raising the safety bar An interview with Syncrude veteran and safety guru Gord Winkel. *CIM Magazine*.

Dew, S., Csorba, E, Chelen, D, Yousefi, N., Andrews, N., & More, C. (2013). Graduate Attributes at the University of Alberta: A report of the Committee on the Learning Environment (CLE) Subcommittee on Attributes and Competencies. Retrieved from http://www.provost.ualberta.ca/en/~/media/provost/Documents/Information/GraduateAttributes.pdf

Dew, S., Driver, R., Thomas, G., Mandal, M., and Choi, P. (2014). Scalability of a graduate attributes assessment and continuous improvement process. in *Proc. 2014 Canadian Engineering Education Conf. (CEEA14)*, Canmore, AB, June 8-11, 2014, Paper 60.

Dewey, J. (1933). How we think: A restatement of the relation of reflective thinking to the education process. Boston: Houghton Mifflin. (Revised edn.1998)

Dixon, D. J., & Kohlbrand, H. T. (2015). Lending industrial experience through reactive hazard examples in university safety instruction. *Process Safety Progress*, *34*(4), 360–367. https://doi.org/10.1002/prs.11785

Donald, J., Lachapelle, S., McIsaac, J., Abraham, T., Clemmer, R., Gordon, K., McCook, S., and Zytner, R.G. (2015). Training versatile engineers: a historical and present perspective on the place of the humanities and social sciences in the Canadian engineering context. *Proc. 2015 Canadian Engineering Education Association* (CEEA15) Conf. Paper 049; McMaster University; May 31 – June 3, 2015.

Donath, L., Spray, R., Thompson, N.S., Alford, E.M., Craig, N., & Matthews, M.A., (2005). "Characterizing Discourse Among Undergraduate Researchers in an Inquiry-Based Community of Practice." *Journal of Engineering Education,* p 403–417.

Donnell, J. A., Aller, B. M., Alley, M., & Kedrowicz, A. A. (2011). Why industry says that engineering graduates have poor communication skills: What the literature says. *ASEE Annual Conference And Exposition, Conference Proceedings*, (118th ASEE Annual Conference and Exposition), 13 p.

Donia, M., O'Neill, T. A., & Brutus, S. (2015). The power of awareness: Increasing student performance in teams through repeated exposure to peer feedback. Poster presented at the annual meeting of the Canadian Psychological Association, Ottawa, ON.

Doré, S., Terriault, P., & Belleau, C. (2019). Gathering the voice of the students for accreditation through their definition of "engineer". in Proc. 2019 Canadian Engineering Education Association, Paper 27; University of Ottawa; June 9 – 12, 2019

Drucker, P. (1985). The Discipline of Innovation, *Harvard Business Review.*

Drummond, I., Nixon, I., & Wiltshire, J. (1998). Personal transferrable skills in higher education: The problems of implementing good practice. *Quality Assurance in Education, 6*(1), 44–58. https://doi.org/10.1108/09684889810200359

Duch, B. J., Groh, S. E., & Allen, D. E. (2001). *The power of problem-based learning: A practical "how to" for teaching undergraduate courses in any discipline* (1st ed.). Stylus Pub. http://site.ebrary.com/id/11170657

Duever, T., (2015). Ryerson University holds inaugural engineering conference. *Construction Canada*, p. NEWS, 31-Mar-2015.

Durkheim, E. (1964). The Division of Labor in Society, New York: Free Press.

Durning, S. J., & Artino, A. R. (2011). Situativity theory: A perspective on how participants and the environment can interact: AMEE Guide no. 52. *Medical Teacher*, *33*(3), pp. 188-199. doi:10.3109/0142159X.2011.550965

Dutson, A.J., Todd, R.H., Magleby, S.P., and Sorensen, C.D., (1997). A review of literature on teaching engineering design through project-oriented capstone courses. Journal of Engineering Education, 86(1), pp. 17-28.

Dweck, C.S., (1999). Self-theories: Their role in motivation, personality and development. Taylor Francis Psych. Press, Philadelphia.

Dweck, C.S. (2006). Mindset: The New Psychology of Success, Random House, New York, NY.

Dweck, C.S. (2012). “Mindsets and human nature: promoting change in the Middle East, the schoolyard, the racial divide, and willpower”, American Psychologist, Vol. 67 No. 8, pp. 614-622.

Egbo, Benedicta. (2005). “Critical Realism and Transformative Research in Educational Administration.” McGill Journal of Education 40 (2): 267–284.

Easa, S. M. (2013). Framework and guidelines for graduate attribute assessment in engineering education. *Canadian Journal of Civil Engineering*, 40(6), 547-556. https://doi.org/10.1139/cjce-2012-0485

Easton, G. (2010). Critical Realism in Case Study Research. Ind. Mark. Manag., vol. 39, no. 1, pp. 118–128, 2010

Efklides, A. (2006). Metacognition and affect: What can metacognitive experiences tell us about the learning process? Educational Research Review, 1, 3–14.

Efklides, A., (2008). Metacognition: Defining its facets and levels of functioning in relation to self- and co-regulation. European Psychologist, 13, 277–287.

Efklides, A., (2011). Interactions of Metacognition With Motivation and Affect in Self-Regulated Learning: The MASRL Model. Educational Psychologist, (46)1, 6-25.

Egbo, Benedicta. (2005). “Critical Realism and Transformative Research in Educational Administration.” McGill Journal of Education 40 (2): 267–284.

Ehrlinger, J., Ainsley L. Mitchum, Carol S. Dweck, C.S., (2016). Understanding overconfidence: Theories of intelligence, preferential attention, and distorted self-assessment, *Journal of Experimental Psychology*, 63(*2016*), 94-100, Elsevier.

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *Academy of Management Review*, *14*(4), 535–550.

ElAtia, S., & Ipperciel, D. (2015a). At the intersection of computer sciences and online education: Fundamental consideration in MOOCs education. *Queen’s University Educational Letter*, *11*(2). https://educ.queensu.ca/sites/webpublish.queensu.ca.educwww/files/files/Community/ed_letter_spring_2015.pdf

ElAtia, S., & Ippeciel, D. (2015b). Towards a 21st century competency-based model of higher education: The pragmatics of accountability. *International Journal of Advances in Education*, *1*(1), 5–13. https://www.semanticscholar.org/paper/Towards-a-21st-Century-Competency-Based-Model-of-of-ElAtia-Ipperciel/242c0c748d4f9164b0992391f863a9d950bb205a

ElAtia, S., & Ippeciel, D. (2017). Graduate Attributes Assessment Program: At the Intersection of Teaching and Learning. *Word Conference on Online learning*, Toronto, October 2017

ElAtia, S., Ipperciel, D., Bakhshinategh, B., Zaiane, O. R., & Thibaudeau, P. (2020). Graduate attribute assessment program. *The International Journal of Information and Learning Technology, 38*(1), 117–134. https://doi.org/10.1108/IJILT-03-2020-0025

ElAtia, S., Ipperciel, D., & Zaiane, O. R. (2016). *Data mining and learning analytics: Applications in educational research*. Wiley & Sons.

Engineering at Alberta (2020). Student View book, [Accessed May 15, 2020]

Engineers Canada (2012). Public guideline on the practice of engineering in Canada, Ottawa: Canadian Engineering Qualification Board. https://engineerscanada.ca/public-guideline-on-the-practice-of-engineering-in-canada#-the-engineers-canada-definition-of-the-practice-of-engineering

Engineering Deans Council and Corporate Roundtable. Washington, D.C.: ASEE

Engineering and Geoscience Professions Act. (2015). Section 1, p. 8 Queen's Printer, Alberta

Engineers Canada, (2020). Updating the IEA's Graduate Attributes and Professional Competencies Framework. Web Page Published November 19, 2020: https://engineerscanada.ca/news-and-events/news/updating-the-ieas-graduate-attributes-and-professional-competencies-framework

Entwistle, N. J. (1992). The Impact of Teaching on Learning Outcomes. Sheffield: CVCP, USDU.

Eshtiaghi, N., Shanthi Robertson, S., Warren-Myers, G., (2012). Good practice groundwork: Managing initial meetings with higher degree research students. *Education for Chemical Engineers* Volume 7 e196–e202

Evans, G.J., (2018). A windmills of your mind: metacognition and life long learning," *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, Paper 38, Vancouver, BC; 3-6 June 2018.

Everding-Wustl, G. (2004). Students learn more if they'll need to teach others. Futurity. Retrieved from: http://www.futurity.org/learning-students-teaching-741342/

Faculty of Engineering. (1955). *Calendar of the Faculty of Engineering 1955—56*. Univeristy of Alberta.

Farell, M., & Gallagher, R. (2015). *Journal of Risk and Insurance*, *82*(3), 625–657.

Faust, D. G. (2010, June 30). *The role of the university in a changing world.* Royal Irish academy, Dublin, Ireland.

Federation of Law Societies of Canada. (2018). *National requirement.* https://flsc.ca/wp-content/uploads/2018/01/National-Requirement-Jan-2018-FIN.pdf

Fleming, M., Harvey, K., & Cregan, B. (2018). Safety culture research and practice: A review of 30 years of research collaboration. *Journal of Applied Biobehavioral Research*, *23*(4), e12155.

Felder, R.M., & Brent, R. (2016). Teaching and learning STEM a practical guide. Jossey-Bass, San Francisco.

Felder, R.M., Rugarcia, A. Stice, J.E. (2000a). The Future of Engineering Education V. Assessing Teaching Effectiveness and Educational Scholarship. Chem. Engr. Education, 34(3), 198–207.

Felder, R.M., Woods, D.R., Rugarcia, A. Stice, J.E. (2000b). The Future of Engineering Education II, teaching Methods that Work. Chem. Engr. Education, 34(1), 26-39.

Flavell, J.H. (1992). Perspectives on perspective taking, In H. Beilin & P.B. Pufall (Eds.), *The Jean Piaget symposium series. Piaget's theory: Prospects and possibilities* (pp. 107-139). Hillsdale, NJ, US: Lawrence Erlbaum Associates, Inc.

Frank, B., McCahan, S., Watts, K.C., Fostaty-Young, S., Ostafichuk, P., Wolf, P., and Saleh, N. (2011). Engineering graduate attribute development (EGAD) project. in *Proc. CEEA Canadian Engineering Education Conf., CEEC11*, Andy Fisher (ed.) St. John's, NL; 6-8 June 6-8, 2011.

Frank, B., McCahan, S., Watts, K.C., Fostaty-Young, S., Ostafichuk, P., Wolf, P., & Saleh, N., (2011). Engineering graduate attribute development (EGAD) project. In *CEEA Canadian Engineering Education Conf.* St. John's, Canada. https://doi.org/10.24908/pceea.v0i0.3566

Fredricks, J.A., Blumenfeld, P., Friedel, J., & Paris, A. (2005). "School Engagement," in K. Moore & L. Lippman (Eds.), What Do Children Need to Flourish? (Vol. 3, pp. 305-321): Springer US.

French, E., Summers, J., Kinash, S., Lawson, R., Taylor, T., Herbert, J., Fallshaw, E., & Hall, C. (2014). The practice of quality in assuring learning in higher education. *Quality in Higher Education*, *20*(1), 24–43. https://doi.org/10.1080/13538322.2014.889432

French, R.P. (2016). The fuzziness of mindsets: Divergent conceptualizations and characterizations of mindset theory and praxis. *International Journal of Organizational Analysis*, 3(4), 673-691.

GACIP (2016). Summit Meeting, December 8, 2016, University of Toronto.

GACIP (2017). Summit Meeting, December 7, 2017, University of Toronto.

GACIP (2018). GACIP summit meeting 2018: Aggregating data, December 6, 2018. https://egad.engineering.queensu.ca/?page_id=4291

Gabriel, A. (2008). The meaning of theory. Sociological Theory, 26, 173 – 199.

Gabriel, D., 2013, Inductive and Deductive Approaches to Research (accessed on May 18, 2020) https://deborahgabriel.com/2013/03/17/inductive-and-deductive-approaches-to-research/

Garrison, D.R., & Vaughan, N.D. (2008). Blended Learning in Higher Education: Framework in Principles, and Guidelines. San Francisco, CA: Jossey-Bass, pp. 272.

Garrison*,* D.R., Anderson, T., & Walter Archer, W., (2000). Critical inquiry in a text-based environment: Computer conferencing in higher education," *The Internet and Higher Education*, *2*(2-3), 87-105.

Garrison*,* D.R., & Arbaugh, J.B. (2007). Researching the community of inquiry framework: Review, issues, and future directions," *The Internet and Higher Education*, *10*(*2007*), 157-172.

Garrison*,* D.R., & Cleveland-Innes, M., (2005). Facilitating cognitive presence in online learning: Interaction is not enough. *American Journal of Distance Education*, 19(3), 133−148.

Gehman, J., Lefsrud, L. M., & Fast, S. (2017). Social license to operate: Legitimacy by another name?(New Frontiers). *Canadian Public Administration*, *2*, 293.

George, A., & Peyton L. (2017). Faculty level support of graduate attribute assessment and continuous improvement processes. in *Proc. 2017 Canadian Engineering Education Association Conf.,* Paper 137; University of Toronto; June 4 – 7, 2017

Glass, D.J. & Hall, N. (2008). A brief history of the hypothesis. *Cell* 134(3) p.378-81.

Glanz, K. (2008). Health behavior and health education: theory, research, and practice. San Francisco: Jossey-Bass Inc.

Goldman, S. L. (1990). Philosophy, Engineering and Western Culture. In P. T. Durbin (Ed.), *Broad and Narrow Interpretations of Philosophy of Technology*. Kluwer.

Gollwitzer, P.M. & Bayer, U.C. (1999). Deliberative versus implemental mindsets in the control of action In Chaiken, S. and Trope, Y. (Eds.), Daul-Process theories in social psychology. Guilford Press, New York, NY.

Gopakumar, G., Dysart-Gale, D., and Ali Akgunduz, A. (2013). Creating faculty buy in: Leadership challenges in implementing CEAB graduate attributes. in *Proc. 2013 Canadian Engineering Education Conf. (CEEA13)*, University de Montreal, June 17-20, 2013, Paper 55.

Gomes, V.G., Barton, G.W., Petrie, J.G., Romagnoli, J., Holt, P., Abbas, A., Cohen, B., Harris, A.T., Haynes, B.S., Langrish, T.A.G., Orellana, J., See, H.T., Valix, M., & White, D. (2006). Chemical

Engineering Curriculum Renewal, Education for Chemical Engineers, 1(1), 2006, Pages 116-125, ISSN 1749-7728, https://doi.org/10.1205/ece.06020.

Gould, M. (2013). Capstone Courses and Experiences. *Research Starters: Education (Online Edition)*

Graham, M., Slocum, A., & Moreno Sanchez, R., (1996). Teaching High School Students and College Freshmen Product Development by Deterministic Design With PREP. *Journal of Mechanical Design* 2007, Volume 129 p. 677-681 DOI: 10.1115/1.2722334

Graham R. (2017). The global state-of-the-art in engineering education: Outcomes of Phase 1 benchmarking study. https://rhgraham.org/resources/Phase-1-engineering-education-benchmarking-study-2017.pdf

Graham R. (2018). The global state of the art in engineering education. New Engineering Education Transformation, MIT. https://res2.weblium.site/res/5e5837aee8e6180021564660/5edeabcd44e8300022bf5a9f

Grant, A. (2016). Originals: How Non-Conformists Move the World. Viking: New York.

Green, W., Hammer, S., & Star, C. (2009). Facing up to the challenge: Why is it so hard to develop graduate attributes? *Higher Education Research & Development, 28*(1), 17–20. https://doi.org/10.1080/07294360802444339

Greene, J. A., Sandoval,W. A., & Braten, I. (2016). Handbook of epistemic cognition. New York, NY: Routledge.

Greene, J. A., & Yu, S. B. (2016). Educating critical thinkers: The role of epistemic cognition. Policy Insights from the Behavioral and Brain Sciences, 3(1), 45–53. https://doi.org/10.1177/2372732215622223

Greeno, J., Collins, A., & Resnick, L., (1996). Cognition and Learning. In R. Calfee & D. Berliner (Eds.), *Handbook of educational psychology (*pp. 15–46). New York, NY: MacMillan.

Gribbin, A., (2003). Design and Critical Thinking: Applying Perry's Theory of Intellectual Development to Foundational Design Instruction". *Proceedings of the 19th National Conference on Beginning Student Design* (Southern Illinois University Carbondale).

Guerra, A. (2017). Integration of sustainability in engineering education: Why is PBL an answer? International Journal of Sustainability in Higher Education, (18) 3, pp. 436-454, 1467-6370

Guerra, A., & Smink, C. K. (2019). Students' Perspectives on Sustainability. In W. Leal Filho (Ed.), *Encyclopedia of Sustainability in Higher Education* (pp. 1–9). Springer International Publishing. https://doi.org/10.1007/978-3-319-63951-2_32-1

Guglielmino, L.M., (1977). Development of the self-directed learning readiness scale. Doctoral dissertation, University of Georgia, 1977.

Guldenmund, F. W. (2000). The nature of safety culture: A review of theory and research. *Safety Science*, *34*(1), 215–257. https://doi.org/10.1016/S0925-7535(00)00014-X

Gupta, A.K., & Govindarajan, V. (2002). Cultivating a global mindset. *Academy of Management Executive*, 16(1), 116-126.

Gwyn, M.L., and Gupta, R. (2015). Co-op employer evaluations of the graduate attributes: A comparison of two approaches. in *Proc. 2015 Canadian Engineering Education Conf. (CEEA15)*, McMaster University, May 31- June 5, 2015, Paper 34.

Gwyn, M. (2017). Finding the gaps: The development of a network for graduate attribute professionals. in *Proc. 2017 Canadian Engineering Education Association Conf.,* Paper 117; University of Toronto; June 4 – 7, 2017

Gwyn, M. (2016). Incorporating employer and student assessments into a graduate attribute assessment plan. in *Proc. 2016 Canadian Engineering Education Association Conf.*, Paper 76; Dalhousie University; June 19 – 22, 2016.

Hacker, D.J., Dunlosky, J., & Graesser, A.C. (1998). Metacognition in educational theory and practice. Mahwah, NJ: Erlbaum.

Hacker, D.J., Dunlosky, J., and Graesser, A. (Eds.). (2009). Handbook of Metacognition in Education. Routledge.

Hacker S., and Roberts, T. (2003). *Transformational Leadership : Creating Organizations of Meaning*. Milwaukee, Wisconsin: ASQ Quality Press.

Haena, K.M., Ramanb, D.R., Polushc, E., & Kemisd, M., (2012). Training the next generation of creative, innovative andadaptive scientists and engineers: The NSF Engineering Research Center for Biorenewable Chemicals (CBiRC) Research Experience for Undergraduates. *Education for Chemical Engineers* Volume 7 (2012) e230–e240

Haimovitz, K., and Dweck, C.S., (2017). "The Origins of Children's Growth and Fixed Mindsets: New Research and a New Proposal." *Child Development* 88 (6): 1849–59.

Hale, A., & deKroes, J. (1997). System in safety 10 years of the chair in safety science at the Delft University of Technology. *Safety Science*, *26*(1), 3–19.

Haluik, A. (2016). Risk perception and decision making in hazard analysis: Improving safety for the next generation of electrical workers. *2016 IEEE IAS Electrical Safety Workshop (ESW)*, 1–8. https://doi.org/10.1109/ESW.2016.7499712

Hamou-Lhadj, A.,Lynch, W., and Akgunduz, A. (2015). COGAF: A management framework fro graduate attribute assessment. *Proc. 2015 Canadian Engineering Education Conf. (CEEA15)*, McMaster University, May 31- June 5, 2015, Paper 107.

Harris, J. Steele, A., and Russell, D. (2011). Progress on defining the CEAB attributes at Carleton University. in *Proc. CEEA Canadian Engineering Education Conf., (CEEC11)*, St. John's, NL; June 6-8.

Hattie, J. "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, 2009

Hattie, J. (2009). Visible learning : A synthesis of over 800 meta-analyses relating to achievement. London; New York : Routledge.

Hewitt, B., Kidd, M., Smith, R., & Wearne, S., (2016). Developing a virtual engineering management community." *European Journal of Engineering Education*, 41:2, 220-230, DOI: 10.1080/03043797.2015.1056098

Henton, M. (1996). Adventure in the Classroom: Using Adventure to Strengthen Learning and Build a Community of Life-long Learners. Dubuque, Iowa: Kendall/Hunt.

Heron J. and Reason, P. (1997). A Participatory Inquiry Paradigm. Qual. Inq., vol. 3, no. 3, pp. 274–294.

Hofer, B. K. (2016). Epistemic cognition as a psychological construct: Advancements and challenges. In J. A. Greene, W. A. Sandoval, & I. Braten (Eds.), Handbook of epistemic cognition (pp. 19–38). New York, NY: Routledge.

Hofer, B. (2002). Personal epistemology as a psychological and educational construct: An introduction. In B. Hofer & P. Pintrich (Eds.), Personal epistemology: The psychological beliefs about knowledge and knowing (pp. 3–14). Mahwah, NJ: Erlbaum.

Hofer, B. K., & Bendixen, L. D. (2012). Personal epistemology: Theory, research, and future directions. In K. R. Harris, S. Graham, & T. Urdan (Eds.), Educational psychology handbook, Vol. 1: Theories, constructs, and critical issues (pp. 225-254). Washington, DC: American Psychological Association.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. Review of Educational Research, 67, 88–140.

IAEA. (1986). Summary report on the post accident review meeting on the Chernobyl accident. Safety SERIES No 75 INSAG 1, Rep. International Atomic Energy Agency (IAEA), Vienna.

IChemE. (2017). Accreditation of Chemical Engineering Progammes. A Guide forHigher Education Providers and Assessors. Technical Report. Institution ofChemical Engineers.

International Engineering Alliance (2015). A History of the International Engineering Alliance and its Constituent Agreements: Toward Global Engineering Education and Professional Competence Standards. Retrieved from http://www.ieagreements.org/assets/Uploads/Documents/History/IEA-History-1.1-Final.pdf

International Engineering Alliance (IEA). (2015). Best Practice in Accreditation of Engineering Programs: an Exemplar. IEA. http://www.ieagreements.org/

International Engineering Alliance (IEA). (2013.) Graduate Attributes and Professional Competencies. IEA. http://www.ieagreements.org/

International Engineering Alliance (IEA).(2021). Graduate Attributes and Professional Competencies v4, 2021. IEA. http://www.ieagreements.org/

Imenda, S., (2014). "Is There a Conceptual Difference between Theoretical and Conceptual Frameworks?" J Soc Sci, 38(2): 185-195 (2014)

Ipperciel, D., & ElAtia, S. (2014). Assessing graduate attributes: Building a criteria-based competency model. *The International Journal of Higher Education*, *3*(3), 27–39. https://doi.org/10.5430/ijhe.v3n3p27

IRGC. (n.d.). IRGC Risk Governance Framework. IRGC. Retrieved February 2, 2020, from https://irgc.org/risk-governance/irgc-risk-governance-framework/

IRGC. (2017). Introduction of the IRGC Risk Governance Framework, Revised version. International Risk Governance Council. https://irgc.org/risk-governance/irgc-risk-governance-framework/

Irving, T., (2017). Designing the engineer of 2050: Canadian engineering educators to meet in Toronto. University of Toronto Engineering News, https://news.engineering.utoronto.ca/designing-engineer-2050-canadian-engineering-educators-meet-toronto/

Isaacson, W. (2014). The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution. Simon & Schuster: New York, NY.

Ito, T., Ichikawa, T., Hanumara, N.C., & Slocum, A.H., (2014). "Teaching Creativity in Design Through Project-Based Learning in a Collaborative Distributed Educational Setting." In: Schaefer D. (eds) Cloud-Based Design and Manufacturing (CBDM). Springer, Cham, 2014.

Ivey, M., Dew S., Mandal M., Mohamed Y., Nychka J.A., Raboud D., Carey J.P. (2017). Using post course assessments to involve instructors in the continuous improvement process. in *Proc. 2017 Canadian Engineering Education Association Conf.,* Paper 41; University of Toronto; June 4 – 7, 2017

Ivey, M., Dew S., Mandal M., Mohamed Y., Nychka J., Raboud D., Rajendran A., Carey J.P. (20*17). It is possible to constructively involve instructors in the continuous improvement process?. Canadian Engineering Education Association Conference*. Toronto, Canada. https://doi.org/10.24908/pceea.v0i0.9519

Ivey, M., Mohamed Y., Musilek P., Raboud D., Rajendran A., and Carey J.P. (2018). Using a common course syllabus as part of the quality control loop and accreditation data collection process. *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) Vancouver, BC; 3-6 June 2018), Paper 41.

Jabareen, Y. (2009). Building a conceptual framework: Philosophy, definitions, and procedure. *Inter. Jour. of Qual. Meth.*, 2009, 49–62.

Jacobsen, D. M. (2002). *Building Different Bridges Two: A Case Study of Transformative Professional Development for Student Learning With Technology*. Paper presented at AERA 2002: Validity and Value in Educational Research, the 83rd Annual Meeting of the American Educational Research Association, New Orleans, LA: April 1 - 5.

Jamieson, M.V. (2015). Application of Blended and Active Learning to Chemical Engineering Design Instruction, 2015 MSc Thesis

Jamieson, M.V., (2020). Keeping a Learning Community and Academic Integrity Intact after a Mid-Term Shift to Online Learning in Chemical Engineering Design During the COVID-19 Pandemic. *Journal of Chemical Education* ***2020*** *97 (9), 2768-2772 DOI: 10.1021/acs.jchemed.0c00785*

Jamieson, M.V., Church, L., Vagi, F., Pick,W., Onuczko, T., Nychka, J., Nocente, N., Shaw, J.M. (2015). The University of Alberta chemical engineering capstone design course goes flipped! in *Proc. 2015 Canadian Engineering Education Conf. (CEEA15)*, McMaster University, May 31- June 5, 2015, Paper 93.

Jamieson M.V. and Donald, J. R. (2020). Building the Engineering Mindset: Developing Leadership and Management Competencies in the Engineering Curriculum, in *Proc. 2020 Canadian Engineering Education Conference (CEEA20).*

Jamieson, M.V., Donald, J.R., (2021). "Building the Engineering Mindset: Developing Sustainable Leadership and Management Competencies in First Year Engineering," Canadian Engineering Education Conference (CEEA-ACEG 2021) UPEI

Jamieson, M.V., Ead, A. S., Rowe, A., Miller-Young, J. and Carey, J.P. (In Press 2021). Design at Scale in a First-Year Transdisciplinary Engineering Design Course, IJEE.

Jamieson, M.V., Goettler, L., Liu, A., and Shaw, J.M., (2017). To Teach is to Learn: Student and Instructor Perspectives on Assignment Development as a Springboard to Deep Learning, in *Proc. of the 13th CDIO Conf.*, Calgary, Canada, 18-22, June, 2017

Jamieson, M.V., Lefsrud, L.M., Sattari, F., Donald, John R. (2021). Sustainable Leadership and Management of complex engineering systems: A team based structured case study approach," as published in Education for Chemical Engineers, *Education for Chemical Engineers*

Jamieson, M.V., Naef, M., Shaw, J.M., (In Press 2021). On Teaching Tacit Knowledge in Engineering Design and Professional Practice, IJEE.

Jamieson, M.V., and Shaw, J.M. (2017). Applications of peer teaching and deep learning in engineering education course design. *Proceedings of the 7th International Conference on Mechanics and Materials in Design* Albufeira/Portugal 11-15 June 2017. Editors J.F. Silva Gomes and S.A. Meguid. Publ. INEGI/FEUP.

Jamieson, M.V., and Shaw, J.M. (2017). Applying metacognitive strategies to teaching engineering innovation, design, and leadership. *Proc. 2017 Canadian Engineering Education Conference (CEEA17)*, G. Evans (ed)(Toronto, Ontario; 4-7 June 2017), Paper 045.

Jamieson, M.V., and Shaw, J.M. (2019, June). A continual improvement process for teaching leadership and innovation in a community of practice. *Proceedings of The American Society for Engineering Education Annual Conference & Exposition*, Tampa, Florida. 10.18260/1-2—31950

Jamieson, M.V., and Shaw, J.M. (2018). Graduate attribute based continuous improvement in a blended learning engineering design course – a writing seminar case study. *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) (Vancouver, British Columbia; 3-6 June 2018), Paper 77.

Jamieson, M.V., Shaw, J.M. (2019). Learning to learn: Defining an engineering learning culture. in *Proc. 2019 Canadian Engineering Education Association*, Paper 18; University of Ottawa; June 9 – 12, 2019

Jamieson, M.V., Shaw, J.M. (2016). Online learning element design – Development and application experiences. *Proc. 2016 Canadian Engineering Education Association* (CEEA16) Conf. Paper 038; Dalhousie University; June 19 – 22, 2016

Jamieson, M.V., Shaw, J.M. (2016). Pre and post course student self assessment of CEAB graduate attributes - A tool for outcomes assessment, student skill and course improvement. *Proc. 2016 Canadian Engineering Education Association* (CEEA16) Conf. Paper 037; Dalhousie University; June 19 – 22, 2016

Jamieson, M.V., Shaw, J.M. (2018). Teaching Engineering Innovation, Design, and Leadership within a Community of Practice. in *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed.) Vancouver, British Columbia; 3-6 June 2018, Paper 113.

Jamieson, M.V., Shaw, J.M. (2017). Student and instructor satisfaction and engagement with blended learning in chemical engineering design. Proc. 2017 Canadian Engineering Education Association Conf., Paper 40; University of Toronto; June 4 – 7, 2017

Johnston, C. R., Caswell, D.J., Douglas, D.M., Eggermont, M.J. (2011). A competency-based, student-centered assessment model for engineering design. in *Proc. CEEA Canadian Engineering Education Conf., CEEC11,* St. John's, NL; June 6-8.

Johnston, S., Lee, A., McGregor, H., & Society for Philosophy and Technology. (1996). Engineering as Captive Discourse. *Society for Philosophy and Technology Quarterly Electronic Journal*, *1*(3), 128–136. https://doi.org/10.5840/techne199613/413

Johanesson and Perjons, (2014). An Introduction to Design Science. Springer: London. Ch 1, p. 1-18.

Johnson, S. (2014). How We Got to Now. Penguin Group: London, UK.

Johnson, S. (2011). Where Good Ideas Come From: The Natural History of Innovation. Riverhead Trade.

Johri, A., & Olds, B. M., (2011). Situated Engineering Learning: Bridging Engineering Education Research and the Learning Sciences. Journal of Engineering Education, *100*(1), 151-185.

Joyner, F.F., Mann, D.T.Y., Harris, T. (2012). Engineering as a social activity: Preparing engineers to thrive in the changing world of work. *American Journal of Engineering Education*, 3(1), 67-81.

Kai, L. & Mun, A. (2016). Do Communities of Practice Make A Difference? Health Professions Education 2(2) 61–74

Kanuka, H., & Cowley, S. (2017). Graduand student attributes: A Canadian case. *The Canadian Journal of Higher Education, 47*(1), 61–79. https://doi.org/10.47678/cjhe.v47i1.186485

Katz, R.L., (1955). Skills of an effective administrator," *Harv. Bus. Rev.*, vol. 33, no. 1, pp. 33–42,.

Kaupp, J., Frank, B., Brenman, R., McCahan, S., Narayanan, L., Ostafichuk, P., Sepehri, N., and Watts, K.C. (2012). A comparison of institutional approaches to CEAB graduate attributes requirements," in *Proc. 2012 Canadian Engineering Education Association Conf.*, Witold Kinsner (ed). Winnipeg, MB; June 17-20, 2012.

Kaupp, J., and Frank, B. (2016). EGAD National snapshot survey: Change, progress and improvement. in *Proc. 2016 Canadian Engineering Education Association Conf.*, Paper 142; Dalhousie University; June 19 – 22, 2016.

Kavanagh, L., & Crosthwaite, C., (2007). Triple-objective team mentoring Achieving Learning Objectives with Chemical Engineering Students." *Education for Chemical Engineers*, Trans IChemE, Part D, Volume 2.

KEEN (2019). Engineering Unleashed, https://engineeringunleashed.com/resources.aspx accessed June 23, 2019

Kerin, T. (2018). Accounting for hindsight bias: Improving learning through interactive case studies. *Loss Prevention Bulletin*, *264*, 17–20.

Kitchner, Karen S., (1983). Cognition, Metacognition, and Epistemic Cognition A Three-Level Model of Cognitive Processing. Human Development 26:222-232

Kivunja, C. (2018). Distinguishing between Theory, Theoretical Framework, and Conceptual Framework: A Systematic Review of Lessons from the Field. International Journal of Higher Education 7(6)

Kivunja, C. (2015). Teaching students to learn and to work well with 21st century skills: Unpacking the career and life skills domain of the new learning paradigm. *Int. J. High. Educ.*, vol. 4, no. 1, pp. 4–11, 2015, doi: 10.5430/ijhe.v4n1p1.

Klassen, M., & Donald, J. (2018). Using an Academic Plan Model to Analyze Canadian Engineering Leadership Curriculum. *Proceedings of the Canadian Engineering Education Association (CEEA)*. https://doi.org/10.24908/pceea.v0i0.12981

Knefelkamp, L.L, Cornfield, J.L. (1979). Combining Student Stages and Style in the Design of Learning Environments. Paper presented at the Annual Meeting of the American College Personnel Association

Kolb, D. (1984). *Experiential learning: Experience as the source of learning and development.* Prentice Hall.

Kolb, A.Y. & Kolb, D.A., (2009). The Learning Way: Meta-cognitive Aspects of Experiential Learning," *Simulation & Gaming*, *40*(3), 297-327 2009.

Lappalainen, P. (2009). Communication as part of the engineering skill set. *European Journal of Engineering Education, 34* (2), 123 – 129.

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge, UK: Cambridge University Press.

Lavoie, P., Michaud, C., Bélisle, M., et al. (2018). Learning theories and tools for the assessment of core nursing competencies in simulation: A theoretical review, *J. Adv. Nurs*.; 74:239–250.

Lawson, R., Taylor, T., Herbert, J., Fallshaw, E., French, E., Hall, C., Kinash, S., & Summers, J. (2012). Strategies to engage academics in assuring graduate attributes. *Eighth International Conference on Education (ICE 2012): Educational Leadership & Management, 5-7 Jul 2012*, *Samos, Greece*.

Lhuillery Stéphane, Julio Raffo, and Intan Hamdan-Livramento, (2016). Economic Research Working Paper No. 31, Measuring Creativity: Learning from Innovation Measurement. World Intellectual Property Organization (WIPO), Geneva.

Maguire, K., & Gibbs, P. (2013). Exploring the notion of quality in quality higher education assessment in a collaborative future. *Quality in Higher Education*, *19*(1), 41–55. https://doi.org/10.1080/13538322.2013.774220

Mandeville, D., & Stoner, M. (2015). Assessing the Effect of Problem-Based Learning on Undergraduate Student Learning in Biomechanics. *Journal of College Science Teaching*, *45*(1), 66–75. JSTOR.

Mason, R. (1969). A Dialectical Approach to Strategic Planning. *Management Science*. Vol 15, No.8, pp. 403-414

Matthews, M., Longo, A., & Ryland, A. (2017). *Transforming Undergraduate Education in Engineering Phase II Insights from Tomorrow's Engineers Workshop Report*. ASEE. https://www.asee.org/documents/publications/reports/2017TUEEPhase2.pdf

Maw S., Huang, S., Cree, D., Kennell, G., James, W. (2021). Lessons Learned from Using Competency Based Assessment (CBA) in a First Year Engineering Statics Course, Canadian Engineering Education Conference (CEEA-ACEG 2021) UPEI

Mayer, R.E. (1987). Educational psychology: A cognitive approach. Scott Foresman & Co.

McCahan, S., & Anderson, P. Mark Kortschot, M., Weiss, P.E., Woodhouse, K.A. (2015). *Designing engineers: An introductory text*. Wiley.

McDermott, L. (1991). Millikan lecture 1990: What we teach and what is learned - closing the gap. *American Journal of Physics*, 59, 301-315.

McGuire, S.Y., & McGuire, S., (2015). *Teach Students How to Learn*, Stylus Publishing, 2015.

Meikleham, A., Brennan, R., and Hugo, R. (2018). Utilizing the CDIO syllabus to reveal CEAB graduate attribute pathways in a mechanical engineering curriculum. in *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) Vancouver, British Columbia; 3-6 June 2018.

Meiksins, P., (1988). The 'Revolt of the Engineers' Reconsidered. *Technol. Cult.*, vol. 29, no. 2, pp. 219–246, doi: 10.2307/3105524.

Mkpat, E., Reiners, G., & Cozzani, V. (2018). Process safety education: A literature review. *Journal of Loss Preverntion in the Process Industries*, *54*, 18–27.

Moldavska, A., & Welo, T. (2019). A Holistic approach to corporate sustainability assessment: Incorporating sustainable development goals into sustainable manufacturing performance evaluation. *Journal of Manufacturing Systems*, *50*, 53–68.

Moghaddam, Y. (2020). *The future of work : how artificial intelligence can augment human capabilities* (First edition.). Business Expert Press.

Mumford, M. D., Zaccaro, S. J., Harding, F. D., Jacobs, T. O., and Fleishman, E. A., (2000). Leadership skills for a changing world: Solving complex social problems.," *Leadersh. Q.*, (11), no. 1, pp. 12–23.

National Academy of Engineering 2004. *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10999.

National Research Council. (1997). Science Teaching Reconsidered: A Handbook. Washington, DC: The National Academies Press. doi: 10.17226/5287.

National Research Council. (1995). Engineering Education: Designing an Adaptive System. Board on Engineering Education. Washington, D.C.: National Academy Press.

National Science Foundation, (NSF). (1995). Restructuring Engineering Education: A Focus on Change. Report of an NSF Workshop on Engineering Education, June 6-9, 1994. NSF 95-65. Arlington, Va.: NSF.

Nestojko, J.F., Bui, D.C., Kornell, N., Bjork, E.L. (2014). Expecting to teach enhances learning and organization of knowledge in free recall of text passages. *Memory & Cognition 42*: 1038 -1048. doi:10.3758/s13421-014-0416-z

Newton, I. (1721). Opticks, or A Treatise of the Reflections, Refractions, Inflections, and Colours of Light, 1979 (New York: Dover Publications).

Nield, K., (2007). Understanding the Chinese Learner: a Case Study Exploration of the Notion of the Hong Kong Chinese Learner as a Rote or Strategic Learner. Journal of Hospitality, Leisure, Sport and Tourism Education, 6(1), DOI:10.3794/johlste.61.131

Northouse, P. G., (2018). *Leadership Theory and Practice Ch 3 Skills Approach*, 8th ed. Sage.

Norval, G. (2015a). Aspects Of Changing The Safety Culture In Today's Universities. *The Canadian Journal of Chemical Engineering*, *93*. https://doi.org/10.1002/cjce.22184

Norval, G. (2015b). Introduction to health and safety responsibilities. *Proceedings of the Canadian Engineering Education Association*. https://doi.org/10.24908/pceea.v0i0.5863

Novak, J. De, ed. (1987). Proceedings of the Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics. Ithaca, N. Y.:Cornell University.

O'Donnell, P., Rakhshani, B., Rae, A., & Smith, R. (2017). The adaptable graduate. In C. Normand & L. Anderson (Eds.), *Graduate attributes in higher education: Attitudes on attributes from across the disciplines* (pp. 19–38). Routledge.

Oliver, B. (2013). Graduate attributes as a focus for institution-wide curriculum renewal: Innovations and challenges. *Higher Education Research & Development*, *32*(3), 450–463.

Oliver, B., Jorre de St. Jorre, T. (2018). Graduate attributes for 2020 and beyond: recommendations for Australian higher education providers. *Higher Education Research & Development*, 37(4), 821-836.

Osserman, R. (2006). Mapping. *Encyclopædia Britannica.* https://www.britannica.com/science/mapping

O'Neill, T.A., Larson, N., Smith, J., Donia, M., Deng, C., Rosehart, W., & Brennan, R., (2019). Introducing a scalable peer feedback system for learning teams. *Assessment & Evaluation in Higher Education, 44,* 848-862.

O'Neill, T. A., Hoffart, G. C., McLarnon, M. W., Woodley, H. R., & Allen, N. J. (2018). The Structure and Function of Team Conflict State Profiles. *Journal Of Management*, *44*(2), 811-836.

O'Neill, T. A., Park, S., Larson, N., Deacon, A., Hoffart, G., Brennan, R., Eggermont, M., & Rosehart, W. (2015). Peer ratings and intentions to change: Adopting the CATME to explore outcomes of peer ratings. *ASEE Annual Conference And Exposition, Conference Proceedings*, *122nd ASEE Annual Conference and Exposition: Making Value for Society* (122nd ASEE Annual Conference and Exposition: Making Value for Society),

Oslo manual. [electronic resource] : guidelines for collecting and interpreting technological innovation data. n.p.: Paris : Organisation for Economic Co-operation and Development : Statistical Office of the European Communities, 2005., 2005. University of Alberta Library, EBSCOhost (accessed February 11, 2018).

Ostafichuk, P., Frank, B., Jaeger, C., and Hugo R., (2020) Remote Assessment E-CORE quick guide. https://ceea.ca/wp-content/uploads/2020/08/EQG_RemoteAssessmentV2.pdf

Parsons, B. (2016). Engineering Graduates. *Canadian Consulting Engineer*, *57*(7), 22-23.

Papaleontiou-Louca, E. (2008). *Metacognition and theory of mind.* Newcastle: Cambridge Scholars Pub.

Paris, S. G., & Winograd, P. (1990). How metacognition can promote academic learning and instruction. In B. F. Jones & L. Idol (Eds.), Dimensions of thinking and cognitive instruction (pp. 15-51). Hillsdale, NJ, US: Lawrence Erlbaum Associates, Inc.

Parker A.M., Watson E, Ivey M, Carey JP (2019). Approaches to graduate attribute and continual improvement processes in faculties of engineering across Canada: a narrative review of the literature, *Proceedings 2019 Canadian Engineering Education Association (CEEA-ACEG19) Conference*. Ottawa, Ontario. https://doi.org/10.24908/pceea.vi0.13736

Patel, S., (2015). *The research paradigm – methodology, epistemology and ontology – explained in simple language*. Retrieved from: http://salmapatel.co.uk/academia/the-research-paradigm-methodology-epistemology-and-ontology-explained-in-simple-language/

Pembridge J. J., Paretti, M. C., (2010). The Current State of Capstone Design Pedagogy. Proceedings of the American Society for Engineering Education Annual Conference & Exposition, (*ASEE10*), Louisville, KY.

Pembridge J. J., Paretti, M. C., (2011). An Examination of Mentoring Functions in the Capstone Course. Proceedings of The American Society for Engineering Education Annual Conference & Exposition, (*ASEE11*),Vancouver, British Columbia.

Perrier, M., Bertrand, F., Dubois, C., Klvana, D., Legros, R. & Farand, P. (2005). Integrating Process Control and Unit Operations in a Single Core Course of the Chemical Engineering Curriculum, 2nd Canadian Design Engineering Network Conference, Kananaskis, Alberta.

Perrier, M., Bertrand, F., Dubois, C., Klvana, D., Legros, R. & Farand, P. (2005). A Case Study in Curriculum Integration of Core Courses in Chemical Engineering, ASEE Annual Conference, Portland, Oregon, Session 3613.

Perry, W. G. (1970). Forms of Intellectual and Ethical Development in the College Years: a scheme. Holt, Reinhart and Winston, Inc. : New York.

Petkau, D. (2015). Industry perceptions of graduate attribute competencies for the workplace. *Proc. 2015 Canadian Engineering Education Association* (CEEA15) Conf. Paper 078; McMaster University; May 31 – June 3, 2015.

Petkau, D. (2015). Industry perceptions of graduate attribute requirements for the workplace. *Proc. 2015 Canadian Engineering Education Association* (CEEA15) Conf. Paper 079; McMaster University; May 31 – June 3, 2015.

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. P. Pintrich, & M. Zeidner (Eds.), Handbook of self-regulation (pp. 451–502). San Diego, CA: Academic.

Pittman, W., Mentzer, R., & Mannan, M. S. (2015). Communicating costs and benefits of the chemical industry and chemical technology to society. *Journal of Loss Prevention in the Process Industries*, *35*, 59–64. https://doi.org/10.1016/j.jlp.2015.03.020

Platanitis, G., & Pop-Iliev, R. (2011). Does program compliance with CDIO warrant automatic compliance with CEAB accreditation criteria for 2014? *Proceedings of the 2nd Annual CEEA Conference: Memorial University, St. John's, Newfoundland, June 6-8, 2011.* https://doi.org/10.24908/pceea.v0i0.3597

PMI. (2017). *Success Rates Rise Transforming the hihg cost of low performance*. https://www.pmi.org/-/media/pmi/documents/public/pdf/learning/thought-leadership/pulse/pulse-of-the-profession-2017.pdf

PMI. (2019). *The Future of Work: Leading the Way with PMTQ*. https://www.pmi.org/-/media/pmi/documents/public/pdf/learning/thought-leadership/pulse/pulse-of-the-profession-2019.pdf?sc_lang_temp=en

PMI. (2020a). *PMI 2020 Signposts report*. https://www.pmi.org/-/media/pmi/documents/public/pdf/learning/thought-leadership/pmi-signposts-2020.pdf?v=80eb681d-96b7-48ee-b0f9-a3753d8889b3

PMI. (2020b). *Pulse of the Profession (2020) | PMI*. https://www.pmi.org/learning/library/forging-future-focused-culture-11908

Polanyi, M. (1967). The tacit dimension. Garden City, NY: Anchor Books/Doubleday.

Pond, K., Ulhaq, R., & Wade, W. (1995). Peer Review: A Precursor to Peer Assessment. *Innovations In Education And Training International*, *32*(4), 314-23.

Prince, M.J., Vigeant, M.A.S., Nottis, K., (2010) A preliminary study on the effectiveness of inquiry-based activities for addressing misconceptions of undergraduate engineering students, *Education for Chemical Engineers* 4 (2), 29-41

Rattan, A., Good, E., and Dweck, C.S., (2012). It's Ok — Not Everyone Can Be Good at Math': Instructors with an Entity Theory Comfort (and Demotivate) Students." *Journal of Experimental Social Psychology* 48, no. 3 (May 2012): 731–37.

Renn, O. (2006). Risk governance—Towards an integrative approach (white paper). *IRGC Scientific and Technical Council*, 157.

Resnick, L. & Klopfer, L., (1989). (Eds.) *Toward the Thinking Curriculum: Current Cognitive Research*, 1989. Alexandria, VA: Association for Supervision and Curriculum Development.

Rhinesmith, S.H., (1992). Global mindset for global managers. *Training & Development*, 46 (10), 63-68.

Richlin, L., (2001). Scholarly Teaching and the Scholarship of Teaching, in Scholarship revisited: Perspectives on the scholarship of teaching and learning C. Kremer Ed., Jossey-Bass, San Francisco, pp. 57–68.

Rugarcia, A., Felder, R., Woods, D.R., & Stice, J.E. (2000). The future of engineering education: Part 1. A vision for a new century. Che*mical Engineering Education,* 34, 16-25.

Rulifson, Greg, B., Angela. (2019). Learning Social Responsibility: Evolutions of Undergraduate Students' Predicted Engineering Futures. *International Journal of Engineering Education*, *35*(2), 572–584.

Rupar and Strong (2021). Learning not Burning (Out): Sustainable Time Management in Engineering Education. *Proceedings of the Canadian Engineering Education Association Conference (CEEA-ACEG 2021)*, Charlottetown, PI

Saleh, J. H., & Pendley, C. C. (2012). From learning from accidents to teaching about accident causation and prevention: Multidisciplinary education and safety literacy for all engineering students. *Reliability Engineering and System Safety*, *99*, 105–113.

Salustri, F.A., and Neumann, W. P. (2016). Providing a uniform design experience in an undergraduate mechanical engineering program. in *Proc. 2016 Canadian Engineering Education Association Conf.*, Paper 40; Dalhousie University; June 19 – 22, 2016.

Santamarina, J. C., Torres-Cruz, L. A., & Bachus, R. C. (2019). Why coal ash and tailings dam disasters occur. *Science*, *364*(6440), 526–528.

Sarasvathy, S., and Venkataraman, S. (2001). What Makes entrepreneurs entrepreneurial? http://www.effectuation.org/paper/what-makes-entrepreneurs-entrepreneurial

Sarasvathy, S., and Venkataraman, S. (2011). "Entrepreneurship as Method: Open Questions for an Entrepreneurial Future, Entrepreneurship Theory and Practice. 35, No. 1: p. 113-135.

Sarfraz, Z., Sarfraz, A., Iftikar, H. M., & Akhund, R. (2021). Is COVID-19 pushing us to the Fifth Industrial Revolution (Society 5.0)?. *Pakistan journal of medical sciences*, *37*(2), 591–594. https://doi.org/10.12669/pjms.37.2.3387

Saylan, C., & Blumstein, D. (2011). *The Failure of Environmental Education (And How We Can Fix It).* University of California Press. https://login.ezproxy.library.ualberta.ca/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=e000xna&AN=367503&site=eds-live&scope=site

Schell, W.J., Hughes, B.E., & Tallman, B., (2018). Exploring the conflict between engineering identity and leadership, in *Proc. 2018 Canadian Engineering Education Conf.* (*CEEA18*), P. Ostafichuk (ed)(Vancouver, BC; 3-6 June 2018), Paper 157

Schon, D. (1987). Educating the reflective practitioner. Towards a new design for teaching and learning in the professions. San Francisco: Jossey-Bass.

Schon, D. (Ed). (1991). The reflective turn: Case studies in and on educational practice. NY: Teachers College, Columbia University.

Schon, D. (1995). The reflective practitioner: How professionals think in action. England: Arena.

Schoenfeld, A. (1987). What's all the fuss about metacognition? In Cognitive science and mathematics education (pp.189-215). Hillsdale, NJ: Erlbaum.

Schraw, G. (2009). A conceptual analysis of five measures of metacognitive monitoring. *Metacognition and Learning, 4*(1), 33-45.

Schumpeter, J., (1934). The Theory of Economic Development, Harvard University Press, Cambridge, Massachusetts.

Schunk, D.A., (2012). "Learning theories an educational Perspective," 6th ed, Pearson: Boston, MA.

Schweizer, P.-J., & Renn, O. (2019). Governance of systemic risks for disaster prevention and mitigation. *Disaster Prevention and Management: An International Journal*, *28*(6), 854–866. https://doi.org/10.1108/DPM-09-2019-0282

Seniuk Cicek, J., Ingram, S., Sepehri, N., Burak, J.P., Labossiere, P., Mann, D., Ruth, D., Parker, A., Ferens, K., Godavari, N., Oleszkiewicz J., and Topping, A. (2014). Rubrics as a vehicle to define the twelve CEAB graduate attributes, determine graduate competencies, and develop a common language for engineering stakeholders. in *Proc. 2014 Canadian Engineering Education Conf. (CEEA14)*, Canmore, AB, June 8-11, 2014, Paper 31.

Seniuk Cicek, J. (2017). Determining the relative importance of the graduate attributes for engineering: An exploratory case study at the University of Manitoba. PhD Thesis.

Sepehri, N., Kinsner, W., Burak, J.P., Shafai, C., Annakkage, U., Mann, D., Kuhn, D., Shalaby, A., Alfaro, M., Morrison, J., Ferens, K., Birouk, M., Labossiere, P., Torchia, M., and Beddoes, J. (2013). The process of continual improvement of engineering programs at the University of Manitoba: Now and next. in *Proc. 2013 Canadian Engineering Education Conf. (CEEA13)*, University de Montreal, June 17-20, 2013, Paper 134.

Shallcross, D. C. (2013a). Safety education through case study presentations. *Education for Chemical Engineers*, *8*(1), e12–e30. https://doi.org/10.1016/j.ece.2012.10.002

Shallcross, D. C. (2013b). Using concept maps to assess learning of safety case studies – The Piper Alpha disaster. *Education for Chemical Engineers*, *8*(1), e1–e11. https://doi.org/10.1016/j.ece.2013.02.001

Shavinina, L.V., Ferrari, M. (2004). Beyond knowledge: Extracognitive aspects of developing high ability. New York: Routledge.

Shehata, M.H., and Schwartz, M. (2015). Co-curricular activities and their role in supporting experiential learning. in *Proc. 2015 Canadian Engineering Education Conf. (CEEA15)*, McMaster University, May 31- June 5, 2015, Paper 146.

Shipway, B., (2011). A Critical Realist Perspective of Education. London: Routledge.

Simon, H.A. (1998). What we know about learning. *Journal of Engineering Education* 87(4) Wash. D.C.

Smith, K. (2016). A Classroom Experience That Builds the Top Skills Employers Want. *Manag. Teach. Rev.*, vol. 1, no. 2, pp. 73–78, 2016, doi: 10.1177/2379298116633870.

Sosik, J.J., & Megerian, L.E., (1999). Understanding leader emotional intelligence and performance. Group Organization Management, 24, 367-390.

Sosniak, L.A. (1999). An everyday curriculum for the development of talent. *Journal of Secondary Gifted Education*, 10(4), 166-172. [Electronic version]

Soysal ,Y., & Radmard, S., (2018) Social negotiations of meanings and changes in the beliefs of prospective teachers: A Vygotskian perspective, Educational Studies, 44:1, 57-80, DOI: 10.1080/03055698.2017.1345676

Spracklin-Reid, D., and Fisher, A. (2012). Course-based learning outcomes as the foundation for assessment of graduate attributes," in *Proc. 2012 Canadian Engineering Education Association (CEEA 12) Conf.*, Witold Kinsner (ed.) Winnipeg, MB; 17-20 June 17-20, 2012.

Spracklin-Reid, D., and Fisher, A. (2014). Curriculum mapping in engineering education: Linking attributes, outcomes, and assessments. in *Proc. 2014 Canadian Engineering Education Conf. (CEEA14)*, Canmore, AB, June 8-11, 2014, Paper 60.

Stackhouse, M. R. D., & Stewart, R. (2017). Failing to Fix What is Found: Risk Accommodation in the Oil and Gas Industry. *Risk Analysis: An International Journal*, *37*(1), 130–146.

Stake, R.E., (2006). Multiple Case Study Analysis, Guilford Publications, pp. 1-16.

Stahl, B. (2008). The Ethical Nature of Critical Research in Information Systems. Inf. Syst. J., vol. 18, no. 2, pp. 137– 163.

Stearns, P. N. (2020). *The industrial revolution in world history* (Fifth edition.). Routledge.

Sterling, L., & Landmann, P. (2011). The Duty to Consult Aboriginal Peoples-Government Approaches to Unresolved Issues. In D. A. Wright & A. M. Dodek (Eds.), *Public Law at the McLachlin Court: The First Decade* (pp. 235–244). http://www.cba.org/cba/cle/PDF/Constit09_Sterling_paper.pdf

Stiver, W. (2011). CEAB's Graduate attributes and Ontario's UUDLEs, in *Proc. Canadian Engineering Education Conf., CEEC11*, St. John's, NL; June 6-8 2011.

Stiver, W., Bradford, A., Chang, S., Farahbakhsh, K., Lubitz, D., Ryks, J., van Heyst, B., Zhou, H., and Zytner, R. (2010). Engineering graduate attributes – Investigation. in *Proc. CEEA Canadian Engineering Education Conf.*

Stoffle, C. J., & Pryor, J. M. (1980). Competency-based education and library instruction. *Library Trends, 29*(1), 55–67. https://www.researchgate.net/publication/306283368_Competency_Based_Education_and_Library_Instruction

Stubley, G., (2018). Thinking about learning – inferences from how we support curriculum design," in *Proc. (CEEA18)*, Paper 38.

Suddaby, R., & Lefsrud, L. (2010). Institutional Theory. Old and New. In E. Wiebe, G. Durepos, & A. J. Mills (Eds.), *Encyclopedia of Case Study Research* (pp. 464–473). Sage Publications.

Svinicki, M.D., & McKeachie, W.J. (2014). McKeachie's Teaching Tips: Strategies, Research, and Theory for College and University Teachers, Cengage Learning, Wadsworth.

Swuste, P., & Arnoldy, F. (2003). The safety adviser/manager as agent of organisational change: A new challenge to expert training. *Safety Science*, *41*(1), 15–27.

Thomas, G. P. (2012). The Metacognitive Science Teacher: A statement for enhanced teacher cognition and pedagogy, in Contemporary Science Teaching Approaches: Promoting Conceptual Understanding in Science F. Ornek, I. Saleh Eds., Information Age, Charlotte, pp. 29-53.

Thorpe, A., (2020) Why has critical realism not been used more in educational leadership and management research? A critical realist exploration, Journal of Critical Realism, 19:1, 29-44, DOI: 10.1080/14767430.2019.1682813

Treleaven, L., & Voola, R. (2008). Integrating the development of graduate attributes through constructive alignment. *Journal of Marketing Education, 30*(2), 160–173. https://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ801781&site=eds-live&scope=site

UN. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development | Department of Economic and Social Affairs*. https://sdgs.un.org/2030agenda

UN. (2020, nd accessed). *THE 17 GOALS | Department of Economic and Social Affairs*. https://sdgs.un.org/goals

UN Sustainable Development Summit. (2015). *UN Sustainable Development Goals*. UN. https://sustainabledevelopment.un.org/sdgs

Uppström, E., (2017). Re-Visiting IS Design Science Artifacts: Making a Case for Critical Realism, Proceedings of the 50th Hawaii International Conference on System Sciences

University of Alberta, (2016). Vision, Mission and Values. https://www.ualberta.ca/strategic-plan/overview/our-vision-mission-and-values

Valyashko, V.M. (2002). Derivation of complete phase diagrams for ternary systems with immiscibility phenomena and solid–fluid equilibria. *Pure Appl. Chem*., Vol. 74, No. 10, pp. 1871

van Konynenburgh, P.H.; Scott, R.L. (1980). Critical lines and phase equilibria in binary van der Waals mixtures. Philos. Trans. R. Soc. London, 298, 495–540

Vaughan, D. (1996). *The Challenger launch decision: Risky technology, culture, and deviance at NASA.* University of Chicago press.

Vaughan, N.D. (2010). A blended community of inquiry approach: Linking student engagement and course redesign, *The Internet and Higher Education,* vol. 13, no. 1, pp. 60-65.

Vesilind, P. A., (2010). *Engineering Peace and Justice The Responsibility of Engineers to Society*. Cham: Springer.

Verzat, C., Byrne, J., & Fayolle, A. (2009). Tangling with spaghetti: Pedagogical lessons from games. *Academy of Management Learning & Education, 8*(3), 356 – 369.

Vigeant, M., (2020). A portfolio replacement for a traditional final exam in thermodynamics, *Education for Chemical Engineers*, 35(2021) p. 1–6

Vygotsky, L. S. (1980). Mind in society: The development of higher psychological processes. Harvard university press.

Wang, B., Liu, Y., Qian, J., & Parker, S. K. (2020). Achieving Effective Remote Working During the COVID-19 Pandemic: A Work Design Perspective.

Watson E., Ivey, M., Mohamed Y., Musilek P., Raboud D., Rajendran A., Carey J.P. (2018). Building a culture that values learning outcomes as an integral part of effective program development - one faculty's example. *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) (Vancouver, British Columbia; 3-6 June 2018), Paper 030

Watson, J. (2008). Promising practices in online learning: Blended learning: The convergence of online and face-to-face education. *North American Council for Online Learning,* pp. 16.

Wenger, E., McDermott, R., and Snyder, W.M., (2002). Cultivating Communities of Practice" Boston: Harvard Bus. School Press.

Wellingtone. (2020). *The-State-of-Project-Management-Report-2020-Wellingtone.pdf*. https://wellingtone.co.uk/wp-content/uploads/2020/06/The-State-of-Project-Management-Report-2020-Wellingtone.pdf

Wells, M. (2019). Realizing the potential of Canadian engineers to change the world. The Star [Online]. Available: https://www.thestar.com/opinion/contributors/2019/12/31/realizing-the-potential-of-canadian-engineers-to-change-the-world.html?

Wiebe, E., Durepos, G., & Mills, A. J. (Eds.). (2010). *Encyclopedia of Case Study Research*. Sage Publications.

Wilkinson, A. (2015). The Creator's Code. Simon & Schuster: New York, NY.

Wilson, W. R. (2013). Using the Chernobyl Incident to Teach Engineering Ethics. *Science and Engineering Ethics*, *19*(2), 625–640.

Winne, P. H. (2004). Students' calibration of knowledge and learning processes: Implications for designing powerful software learning environments. Educational Research, 41, 466–488.

Wulf, W.A. (1998). The urgency of engineering education reform. The Bridge 28(1):15-21.

Wulf, W.A. (2002). The Urgency of Engineering Education Reform, ASEE Keynote Speech.

Zimmerman, B. J. (1986). Development of self-regulated learning: Which are the key sub processes? Contemporary Educational Psychology, 11, 307–313.

Yew, E., Goh, K. (2016). Problem-Based Learning: An Overview of its Process and Impact on Learning, Health Professions Education 2(2) p 75–79

Yun Dai, D., & Sternberg, R.J., (2004). Beyond Cognitivism: Toward an Integrated Understanding of Intellectual Functioning and Development, (Introduction) In David Yun Dai & Robert J. Sternberg (Eds.), Motivation, Emotion, and Cognition: Integrative Perspectives on Intellectual Functioning and Development (pp. 1–38). Routledge.

Zimmerman, B. J. (1998). Developing self-fulfilling cycles of academic regulation: An analysis of exemplary instructional models. In D. H. Schunk & B. J. Zimmerman (Eds.), Self-regulated learning: From teaching to self-reflective practice (pp. 1–19). New York, NY: Guilford.

Zimmerman, B. J. (2008). Investigating self-regulation and motivation: Historical background, methodological developments and future prospects. American Educational Research Journal, 45, 166–183.

Zimmerman, B.J., & Schunk, D.H. (1988). Albert Bandura: The scholar and his contributions to educational psychology, In B. J. Zimmerman & D. H. Schunk (Eds.), Educational psychology: A century of contributions (pp. 431–457). Mahwah, NJ: Erlbaum.

Zimmerman, B.J., & Schunk, D.H. (2004). "Self-Regulating Intellectual Processes and Outcomes: A Social Cognitive Perspective," In David Yun Dai & Robert J. Sternberg (Eds.), Motivation, Emotion, and Cognition: Integrative Perspectives on Intellectual Functioning and Development (pp. 323–349). Routledge.

Zou, X.Y., and Shaw, J.M. (2006). Phase behaviour of hydrocarbon mixtures. *Encyclopedia of Chemical Processing*, Taylor and Francis. DOI: 10.1081/E-ECHP-120040185

Appendix A. Glossary – Definition of Frameworks and Terms

This appendix includes the my definitions of terms and their source, the definitions of working frameworks such as the CEAB Graduate Attributes, a Graduate Attribute Continual Improvement process framework (proposed in prior work) and a conceptual framework development process adapted and used in this work.

A1. Terminology as used in this work

For the purpose of clarity, this section defines the frameworks and terms as they are used in this work. The definitions are generally drawn from key documents in the literature pertaining to the item. Where appropriate, the literature reference the definition is taken from or developed from is included. There may be other definitions or perspectives on these definitions in the literature or elsewhere. This is not an exhaustive list of definitions. Some of the definitions are purposely taken from IEA documents to be consistent with the Washington Accord definitions.

A1.1 Definitions

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).

Branch of engineering: a generally-recognised, major subdivision of engineering such as the traditional disciplines of Chemical, Civil, or Electrical Engineering, or a cross-disciplinary field of comparable breadth including combinations of engineering fields, for example Mechatronics, and the application of engineering in other fields, for example Bio-Medical Engineering. (IEA, 2013)

Broadly-defined engineering problems: a class of problem with characteristics defined in IEA, 2013 section 4.1. Cannot be resolved without engineering knowledge at the level of one or more of engineering specialist knowledge, engineering design knowledge, or engineering technologies knowledge and supported by a systematic theory based formulation of engineering fundamentals required in a recognized sub-discipline with a strong emphasis on the application of developed technology and some or all of the following characteristics: involve a variety of factors which may impose conflicting constraints, can be solved by well proven analysis techniques, belong to families of familiar problems which are solved in well accepted ways, may be partially outside those encompassed by standards or codes of practice, involve several groups of stakeholders with differing and occasionally conflicting needs, are parts of or systems within complex engineering problems. (IEA, 2013)

Broadly-defined engineering activities: a class of activities with characteristics defined in IEA, 2013 section 4.2. Engineering activities or projects that have some or all of the following characteristics: involve a variety of resources (for this purpose resources includes people, money, equipment, materials, information and technologies), require resolution of occasional interactions between technical, engineering or other issues of which few are conflicting, involves the use of new materials, techniques, or processes in non standard ways, have reasonably predictable consequences that are most important locally but may extend more widely, require a knowledge of normal operating procedures and processes. (IEA, 2013)

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: (1) a knowledge base for engineering, (2) problem analysis, (3) investigation, (4) design, (5) use of engineering tools, (6) individual and team work, (7) use of communication skills, (8) professionalism, (9) impact of engineering on society and the environment, (10) ethics and equity, (11) economics and project management, and (12) 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 the previous study (Jamieson, 2015), and is 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.

Complementary (contextual) knowledge: Disciplines other than engineering, basic and mathematical sciences, that support engineering practice, enable its impacts to be understood and broaden the outlook of the engineering graduate. (IEA, 2013)

Complex engineering problems: a class of problem with characteristics defined in IEA, 2013 section 4.1. Cannot be resolved without in-depth engineering knowledge at the level of one or more of the following a systematic theory based formulation of engineering fundamentals required in the engineering discipline, engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge from the accepted practice areas in the engineering discipline, knowledge which supports engineering design in a practice area, knowledge of engineering practice (technology) in the practice areas in the engineering discipline, engagement with selected knowledge in the research literature of the discipline which allows a fundamentals based, first principles analytical approach. (IEA, 2013)

Complex engineering activities: a class of activities with characteristics defined in IEA, 2013 section 4.2. Engineering projects or activities that have some of or all of the following: involves the use of diverse resources (for this purpose resources includes people, money, equipment, materials, information and technologies), require resolution of significant problems arising from the interactions between wide ranging and conflicting technical, engineering or other issues, involves the creative use of engineering principles and research based knowledge in novel ways, techniques, have significant consequences in a range of contexts characterized by difficulty of prediction and mitigation, can extend beyond previous experiences by applying principles based approaches. (IEA, 2013)

A **conceptual framework** is a more detailed version of the theoretical framework and proposes variables and factors impacting or influencing the theoretical relationships. The variables can often be measured and used to model the relationships. Theoretical and conceptual frameworks are related and the conceptual framework underlies the more generalized theoretical framework. A conceptual framework is the product of using a preliminary set of themes for a theoretical framework to define research questions and determine of the variables related to the question. A conceptual framework can often be presented visually and is supported by the interdisciplinary literature and validated by presentation and discussion to the disciplinary fields concerned. In this work the conceptual framework development procedure proposed by Jabereen (2009) was followed after developing initial key themes and reading areas.

A **Continual Improvement Process (CIP)** is defined, in this context, as a process demonstrating that design course outcomes are being assessed and results applied to further the development and improvement of the course and/or student outcome attainment. Assessment can includes student and instructor feedback on course effectiveness in achieving the requisite performance attributes – in this case, the CEAB graduate attributes (IEA, 2015; CEAB, 2014, 2017; Hattie, 2009; Jamieson, 2015).

Continuing Professional Development (CPD): the systematic, accountable maintenance, improvement and broadening of knowledge and skills, and the development of personal qualities necessary for the execution of professional and technical duties throughout an engineering practitioner's career. (IEA, 2013)

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 as defined above. 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). It is often presented in tabular or visual summary formats.

Critical realism is a research framework that asks "What must the world be like for knowledge of the world to be possible?" (Bhaskar, 1975) It holds that an objective reality exists regardless of an individual's subjective experience of the world. Epistemology (*knowledge, systems, thoughts, ideas, theories, language…*) is separated from ontology (*reality, being, things, objects of investigation, existents…*). (Center for Critical Realism, nd)

Complex critical realism is philosophical research framework that considers the differentiation between complex systems and complicated systems. In complicated systems a positivist realist approach may serve, however in a complex system when an action does not necessarily produce the same results twice this approach breaks down. Complex critical realism allows for a mind independent world with mind dependent perceivers allowing for scientific and perceptual investigation. (Clark, 2008)

Design I (CH E 464) or Introductory Process Design is the first chemical process design course taken in term 7 of the current undergraduate Chemical Engineering program. In the current format half of the course weight is lecture based with individual learning assessed by quizzes, a midterm, and final exam. The second half is problem and project based with team learning assessed by team lab assignments, a poster presentation, and a final report on the industry sponsored design project. This is a face-to-face course with lecture, laboratory, and project components. This course has been the target of ongoing small continuous improvement interventions but the overall structure of the course has remained intact.

Design II (CH E 435/465) or capstone process design is the capstone chemical engineering design course taken in term 8. In the current format (2015 to 2018) 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). This blended course has been the target of several structural continuous improvement interventions (Jamieson and Shaw, 2015).

Effectuation thinking: the identification and use of available means (Who I am, What I know, Whom I know) to produce imagined ends (Sarasvathy, 2001). This type of thinking can be classified as using metacognitive knowledge in a way where it is connected and recombined to achieve a possibly novel or innovative result.

"**Engineering** is *creating, designing* **what can be**, but it is **constrained by nature**, by cost, by concerns of safety, reliability, environmental impact, manufacturability, maintainability, and many other such "ilities"" Wulf (1998, 2002)

Engineering complimentary studies program component: Complementary studies complement the technical content of the curriculum. There should be some exposure to the humanities and/or social sciences, in order to impart some appreciation of the central issues and thought processes in these disciplines. Engineering economics, management and communications are also included in this area. (CEAB, 2016)

Engineering design knowledge: Knowledge that supports engineering design in a practice area, including codes, standards, processes, empirical information, and knowledge reused from past designs.

Engineering discipline: synonymous with branch of engineering. (IEA, 2013)

Engineering design program component: Engineering design integrates mathematics, natural sciences, engineering sciences, and complementary studies in order to develop elements, systems, and processes to meet specific needs. It is a creative, iterative, and open-ended process, subject to constraints, which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may also relate to economic, health, safety, environmental, societal or other interdisciplinary factors. The engineering curriculum must culminate in a significant design experience conducted under the professional responsibility of faculty licensed to practise engineering in Canada, preferably in the jurisdiction in which the institution is located. The significant design experience is based on the knowledge and skills acquired in earlier work and it preferably gives students an involvement in teamwork and project management. (CEAB, 2016)

Engineering fundamentals: a systematic formulation of engineering concepts and principles based on mathematical and natural sciences to support applications. (IEA, 2013)

Engineering laboratory program component: Appropriate laboratory experience must be an integral component of the engineering curriculum. Instruction in safety procedures must be included in preparation for students' laboratory and field experience. (CEAB, 2016)

Engineering leadership: the generic leadership functions of visioning, influencing, inspiring, and leading, applied together with engineering knowledge in contexts including the leadership of projects, construction, operations, maintenance, quality, risk, change and business.

Engineering management: the generic management functions of planning, organising, scheduling, and controlling, applied together with engineering knowledge in contexts including the management of projects, construction, operations, maintenance, quality, risk, change and business. (IEA, 2013)

Engineering mathematics program component: Mathematics is expected to include appropriate elements of linear algebra, differential and integral calculus, differential equations, probability, statistics, numerical analysis, and discrete mathematics. What is appropriate will depend on the program. (CEAB, 2016)

Engineering natural science program component: The natural sciences component of the curriculum is expected to include elements of physics and chemistry. Elements of life sciences and earth sciences would also be included in this category, as appropriate to the program. These subjects are intended to impart an understanding of natural phenomena and relationships through the use of analytical and/or experimental techniques. An Interpretive Statement on Natural Sciences is an appendix to this document. (CEAB, 2016)

Engineering practice: "The "practice of professional engineering" means any act of *planning, designing, composing, evaluating, advising, reporting,* ***directing or supervising*** that requires the *application* of **engineering principles** and that concerns the safeguarding of life, health, property, economic interests, the public welfare or the environment*, or* ***the managing of any such act***. In Canada, a licence is required to practise professional engineering. Engineering is constantly evolving and new areas of practice are always emerging." (Engineers Canada, 2012)

Engineering practice area: a generally accepted or legally defined area of engineering work or engineering technology. (IEA, 2013)

Engineering problem: is a problem that exists in any domain that can be solved by the application of engineering knowledge and skills and generic competencies. (IEA, 2013)

Engineering science knowledge: include engineering fundamentals that have roots in the mathematical and physical sciences, and where applicable, in other natural sciences, but extend knowledge and develop models and methods in order to lead to applications and solve problems, providing the knowledge base for engineering specializations. (IEA, 2013)

Engineering science program component: Engineering science subjects involve the application of mathematics and natural science to practical problems. They may involve the development of mathematical or numerical techniques, modeling, simulation, and experimental procedures. Such subjects include, among others, the applied aspects of strength of materials, fluid mechanics, thermodynamics, electrical and electronic circuits, soil mechanics, automatic control, aerodynamics, transport phenomena, and elements of materials science, geoscience, computer science, and environmental science. (CEAB, 2016)

Engineering speciality or specialization: a generally-recognised practice area or major subdivision within an engineering discipline, for example Structural and Geotechnical Engineering within Civil Engineering; the extension of engineering fundamentals to create theoretical frameworks and bodies of knowledge for engineering practice areas. (IEA, 2013)

Epistemic Cognition: is knowledge about knowledge. It is a process involving dispositions, beliefs, and skills regarding how individuals determine what they actually know, versus what they believe, doubt, or distrust (Chinn et al., 2011; Greene et al., 2016; Hofer & Bendixen, 2012). Epistemic cognition can be described as how an individual *evaluates* knowledge; uses that knowledge; and how we develop knowledge (Kitchner, 1983).

Etic concept or knowledge type: is defined independently of any particular context and which can therefore serve as a basis for comparisons across cultures. (Pike, 1954. 1967)

Emic concept or knowledge type: is grounded in the worldview of the participants and corresponds to the meanings participants themselves attach to their experience. (Pike, 1954, 1967)

Extracognitive factors: are factors associated with high achievement that have eluded traditional research treatments of creativity factors such as cognitive, cultural, psychological, sociological, and historical dimensions. Extracognitive factors include *beliefs*, aesthetics, intuitions, intellectual values, self imposed subjective norms and standards, and chance as contributing towards astonishing acts and products of creative endeavours. (Shavinina, 2004)

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 included. It is noted that a classroom may be flipped and not blended.

A **framework** is a system of rules, ideas, or beliefs used to plan, solve problems, or decide something (Cambridge Dictionary, 2020; Collins Dictionary, 2020). A framework can be developed using deductive or inductive processes. The inductive approach begins with observations and moves towards generalizations. The deductive approach begins with generalizations and tests to see if the special case fits with the theoretical construct. (Gabriel, 2013)

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)

Fundamental knowledge is also based on the idea of core math and natural science topics. It encompasses the first CEAB graduate attribute and is the traditional core knowledge of engineering.

International Engineering Alliance (IEA) is composed of signatory countries to the three constituency agreements regarding engineering education equivalence, namely the Washington accord (Engineers), Sydney Accord (Engineering technologists), and the Dublin Accord (Engineering technicians) and to the four professional competency agreements, namely IPEA (international competence framework for professional engineers, 2013, revised from 1997 - same standards as for APEC engineering but global economies), APEC (substantial equivalence of professional engineering competence standards in place for the Asia Pacific Economic Cooperation, 2000), IETA (substantial equivalence for fully qualified engineering technologists), and AIET (substantial equivalence for fully qualified engineering technologists).

Internship course model is the 2010 - 2018 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 Engineering Procurement and Construction (EPC) office and students are treated as accountable interns in a work experience environment. Students are expected to plan their work, monitor their own progress and project schedule weekly, and reflect regularly.

A knowledge framework is a human's organizational system for storing integrated knowledge, emotions, and experiences. A knowledge framework is the product of learning. This framework can hinder or accelerate the learning process depending on whether or not it is active, sufficient, appropriate, and accurate (Ambrose, 2010, p.13-14).

Knowledge framework organization describes how pieces of knowledge are arranged and connected in the human mind. Novices in an area may have sparse superficial structures lacking relationship connections and experts tend to have rich highly connected structures with relationships between the pieces (Ambrose, 2010, p.40-50)

Knowledge, skills, and attitudes (KSA) is term used as a general definition of graduate competence; understanding, which is an Anderson-Krathwohl level of engagement with knowledge and abilities which duplicates elements already there are avoided. See also: A Rugarcia et al (2000) "…profiles [of engineers] may be conveniently sketched in terms of three components: (1) their knowledge—the facts they know and concepts they understand; (2) the skills they use in managing and applying their knowledge, … ; (3) the attitudes that dictate the goals toward which their skills and knowledge will be directed" (IEA, 2015)

Learning is a human process that occurs in the mind when a change in knowledge, beliefs, behaviors, or attitudes results from what a student does, experiences or interprets experiences (Adapted from Mayer, 2002 as cited in Ambrose, 2010, p.3).

Learning objectives are defined as the requirement of the student to perform a specified task under certain conditions and can be assessed with the results 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).

Learning outcomes 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.

Life Long Learning is the twelfth CEAB graduate attribute. In this work it is defined as the application of metacognitive strategies such as self-awareness, self-monitoring, and self-regulation to identify personal learning needs while engaging in engineering problems and/or activities and while developing and maintaining professional competency as an engineer. A component of life long learning is self-regulated learning (SRL).

Metacognition is roughly defined by Flavell as "knowledge and cognition about cognitive phenomena" (Flavell, 1992 p.113) and more specifically as "any knowledge or cognitive activity that takes as its object, or regulates, any aspect of any cognitive enterprise" (Flavell, 1992, p. 114;) - essentially second order cognition. **Metacognition** is knowledge about all cognitive processes (memory, perception, reasoning, etc.) and involves the *monitoring* of and *reasoning* about these processes. (Brown, 1987). Metacognitive knowledge and metacognitive experience are key conceptualizations in the study of metacognition (Flavell, 1992, p.115). More recently, **Metacognition** definitions have gradually broadened to include the knowledge and regulation of one's knowledge, cognitive and affective processes and states (cognitive and affective - Hacker, 1998; Papaleontiou-Louca, 2003, 2008). Two essential features are self-appraisal and self-management (Paris &Winograd, 1990). **In this work, the latter definitions inclusive of self-appraisal and self-management of one's knowledge, cognitive, and affective processes and states are used.**

Metacognitive experience: cognitive or affective experiences that pertain to a cognitive enterprise. They may occur before, during, or after a cognitive endeavour. They may be simple or complex; fully conscious and describable or less fully conscious and more tacit. They may be brief or longer and may evolve over time. They are more likely to occur in situations where one is expected to engender careful conscious monitoring of one's own cognitions. An example is the realization that one does not understand what one is reading. (Flavell, 1992, p. 117). Metacognitive experience is a realization and serves to invoke an adaptive reaction. As metacognitive experiences can have an affective character, there is a theoretical basis for connecting metacognition with motivation and affect (Efklides, 2006, 2011).

Metacognitive judgement: judgement about one's learning and performance. Metacognitive judgements can be classified as prospective (before the task), concurrent (during the task), or retrospective (after the task). (Schraw, 2009. p. 416.)

Metacognitive knowledge: knowledge and beliefs accumulated through experience and stored in long term memory that concern the human mind and its (cognitive) doings. This knowledge can be subdivided into categories of knowledge about persons, tasks, and strategies. These categories may be classified as declarative or procedural knowledge or a bit of both. The bulk of metacognitive knowledge concerns the interaction among categories (Flavell, 1992, p. 115). Metacognitive knowledge is gained by thinking – examining, connecting, classifying, and/or judging knowledge about people, tasks, and strategies and the relevance for future use in determining an initial perspective taken on new situations.

Metacognitive knowledge types are defined as *declarative* (knowing what), *procedural* (knowing how), and *conditional* (knowing when and why). (Schraw, 2009. p. 416.)

Metacognitive learning strategies: specific kinds/uses of metacognition that aid learning including: planning, checking, monitoring, selecting, revising and evaluating. (Shoenfeld, 1987) Metacognitive learning strategies differ from scaffolding as the learner is in control of the regulation and *not relying on external support or scaffolding*. This could be classified as an andragogical learning strategy.

Metacognitive habit is a conscious and ongoing habit of using reflective activity to structure experience in a knowledge framework. "active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conditions to which that constitutes reflective thought" (Dewey, 1933)

Metacognitive regulation: is the regulation of the cognitive and affective processes and learning experiences through a set of activities that help people control their learning (Papaleontiou-Louca, 2008). The key to effective self-regulation is *accurate self-assessment* of what is known and what is not known (Shoenfeld, 1987).

Metacognitive skills: are the conscious control processes such as planning and monitoring of the progress of processing, effort allocation, strategy use and regulation of cognition (Papaleontiou-Louca, 2008). Reflection on the outcome(s) of the executed task, strategy, or personal interaction is a metacognitive skill. Conscious control and monitoring of affective processes is also a metacognitive skill.

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.

Mindset is a set of beliefs, attitudes, and dispositions that is applied to a person's everyday life and experience when performing cognitive (learning and engineering) tasks. It can impact how a skillset is applied and whether a task is framed as possible or not possible and the level of feasibility. There is substantial divergence on the conception of mindset in the literature as defined by implemental and deliberative, global, growth and fixed mindset constructs (French, 2016). The original *Würzburgian* theory of mindset ***connects a particular grouping of cognitive processes activated to complete a specific task***. This definition is rooted in cognitive psychology literature where mindset is "the sum total of the activated cognitive procedures" (Gollwitzer and Bayer, 1999, p. 405) for a given task. A ***deliberative*** mindset is the sum total of the cognitive processes employed to determine a specific goal and is particularly effective at impartially processing information and accurately assessing the feasibility of a goal. An ***implemental*** mindset can be described as the sum total of the cognitive processes employed to plan to achieve a goal and may overestimate the feasibility of the goal (French, 2016, p.677). Social psychology and organizational leadership conceptualization mindset as a specific focus (or ***cognitive filter***) used throughout the totality of an individual or organization's collective cognition processes (French, 2016, p.678; Gupta and Govindarajan, 2002, p.116; Rhinesmith, 1992, p. 63). Positive psychology (*growth* and *fixed* mindsets) and global conceptualizations of mindset are characterized by individual beliefs either about themselves or about their worldview with constructs defining openness to other beliefs and/or traditions. (French, 2016 p. 680-3; Dweck, 2006, p.15, 215; Dweck, 2012, p.615) Recently an *entrepreneurial* mindset has been introduced to characterize a set of beliefs that embody innovation and self-efficacy and has become popular in engineering program redevelopment (KEEN, 2019). Mindset constructs appear to be linked to *implicit* epistemological and ontological constructs and *assumptions*. Mindset constructs can be used to describe individual *and* organization cognitive processes and knowledge structures.

Objectivist epistemologies: "can be dominant in adolescents and adults of all ages. They reflect the natural assumptions that our *observations represent reality* and our inferences preserve truth. In addition, they are often reinforced by social, cultural, religious, political, and educational systems." (Moshman, 2016)

Professional skills are trans-disciplinary and required when people work collaboratively and/or with the public or external organizations. This category includes but is not limited to: team and leadership skills, communication skills, ethics, equity, professional behaviour, logistics, accountability, organization, planning, and time management.

Reflective activity is a process that involves the perception of relationships and connections between the parts of an experience (Dewey, 1933). A reflective activity enables effective problem solving in an iterative process of integrating experience with knowledge (Dewey, 1998 cited in Bormotova, 2011, p.19).

Reflective practice is the reflection on a learner's *own experiences* pursued with the *intent* of further action. The practice encompasses the emotional and cognitive aspects of the experience and examines and processes incomplete items, questions, and makes connections between pieces of knowledge and associated feelings in a knowledge framework. (Boud, 1985; Schon, 1987,1991,1995; Dewey, 1998 cited in Bormotova, 2011, p.32)

Review activity is the study of content with the purpose of (short term) later recall. This is often a surface and/or strategic practice developed by learners to pass exams or do well on exams. (Bain, 2004)

A **research framework** is the *perspective* the researcher will be taking on for the study and provides the starting assumptions on the nature of being (ontology) and the nature of knowledge (epistemology) which dictate *how* researchers discover knowledge and the type of knowledge that can be discovered. It guides the research process, hypothesis and question formation, and experimental design. It may be explicit or implicit depending on the discipline and the framework. It may be deductive as in a theoretical framework or inductive as in a conceptual framework.

Risk based process safety management (RBPSM): a framework for reducing process safety incidents (and loss incidents in general) built around four pillars 1) Understand the hazards and risks, 2) Manage the risks, 3) Commit to process safety, 4) Learn from experience. (AIChE)

Scientific experimentation frameworks are defined as *hypothesis* or *model* frameworks (Glass, 2008). Scientific research frameworks are often implicit and carry philosophical assumptions, in order to be explicit they are defined here. A **model framework** is derived from data based observations and is subject to verification. It need not be discarded if errors or inconsistencies are noted as a model can be *improved* since it is derived from data and the objective is to work towards a generalizable construct. A **hypothesis framework** requires an idea or postulate stated as a fact (Glass, 2008). Data is collected in order to subject the hypothesis to falsification not verification. A hypothesis framework starts with an unproven premise and uses deductive reasoning to arrive at a conclusion (to determine if the statement can be proven false) while a model framework starts with the data and uses inductive reasoning to derive a model that can be validated. This work uses a model framework and starts the exploratory phase with questions arising from previous work, observations, and curiosity. “Hypotheses are not to be regarded in experimental Philosophy” (Newton, 1721).

Scaffolding: interactional support for student learning that is gradually withdrawn (Bruner, 1985) as the learner transitions from external to internal support for and control (Vygotsky, 1978) of cognitive and affective task completion as they transition from novice to increasing mastery of a given cognitive or affective task.) Scaffolding describes learning supports used to effect the transference described by Brown (1987) from other regulation to self regulation as learners develop task related skill. The interrogative and regulatory role is initially fulfilled externally via social (interpsychological) interactions and shifts to individual (intrapsychological) interactions or metacognitive regulation. Scaffolding can be classed as a pedagogical tool.

Self-regulated learning (SRL) emphasizes the agentic role of the learner (Boekaerts, 1996, 1999; Boekaerts & Corno, 2005; Pintrich, 2000; Winne, 2004; Zimmerman, 1998, 2008) and refers to the setting of one's goals in relation to learning and ensuring that the goals set are attained. Key components of SRL are cognition, *metacognition*, motivation, affect, and volition (Boekaerts, 1996).

Socio-contextual knowledge describes the knowledge framework engineers need to practice in the work world. Engineering is completed in the context of projects, businesses, users, stakeholders, investors, sustainability, and risk management with cultural and political requirements in a global setting. From the CEAB perspective, complimentary studies support the development of socio-contextual knowledge.

Student cognitive task level is defined according to Bloom's taxonomy (Bloom, 1956) and discussed in Jamieson, 2015, Appendix D. 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) Cognitive, behavioral, and emotional aspects are the dimensions of engagement studied (Fredricks, 2005).

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 Appendix D. 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 CHE 435/465 final report, the performance assessment is a criterion referenced assessment (CRA).

The final report quality is a significant determinant of course performance. 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.

Sustainability is defined as the ability to maintain a specific practice over an extended period of time, with minimal long term adverse consequences to society & environment.

Sustainable development is defined as development that meets the societal needs of the present without compromising the ability of future generations to meet their own needs (Andrews, 2009; Brundlant Commission, 1987).

Sustainable Development Goals are those put forward by the United Nations and include 1) No poverty; 2) Zero hunger; 3) Good health and well being; 4) Quality education; 5) Gender Equality; 6) Clean water and sanitation; 7) Affordable and Clean Energy; 8) Decent Work and Economic Growth; 9) Industry, Innovation, and Infrastructure; 10) Reduced inequalities; 11) Sustainable cities and communities; 12) Responsible consumption and production; 13) Climate action; 14) Life below water; 15) Life on land; 16) Peace, justice and strong institutions; 17) Partners for sustainability.

Teaching is the design and implementation of learning experiences that prepare the student to learn and guide their learning. It enables active and experiential learning in the context of future work.

A **theoretical framework** is used to explain broad relationships between themes or concepts. It is grounded in theory – often social or behavioral science theories (Creswell, 2015). It is the product of understanding relationships developed from the findings of many studies. A theoretical framework provides the background or the frame for research questions. It generally is addressed in the literature review and may be represented visually.

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) and lower student to instructor ratio. An online component was present, but no in class restructuring had occurred.

The **whole engineer** is defined in this work, as an engineer who is able to practice in the context of sustainability and the resolution of complex problems that require specialized technical knowledge and skills applied in a contextual and regulatory framework, professional skills (including engineering leadership and management skills), metacognitive knowledge and skills. The whole engineer is capable of considering the environmental, systemic, and social impacts when evaluating a design and/or designing a complex system. The current engineering graduate attributes generally describe characteristics of the whole engineer with the exception of environmental and societal sustainability in design and the maintenance and operation of complex designs.

The **whole engineering instructor** is defined in this work as a practicing engineer who has become competent in the transdisciplinary field of engineering education. This includes an understanding of the contextual nature of practice and the requisite technical, metacognitive, and professional knowledge and skills and an ability to design learning objective based courses that employ effective methods to teach these aspects concurrently. Like the whole engineer, they are capable of considering the environmental, systemic, and social impacts when evaluating a design and/or designing a complex system. The current engineering graduate attributes generally describe characteristics of the whole engineer with the exception of environmental and societal sustainability in design and the maintenance and operation of complex designs.

A1.2 CEAB 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.*

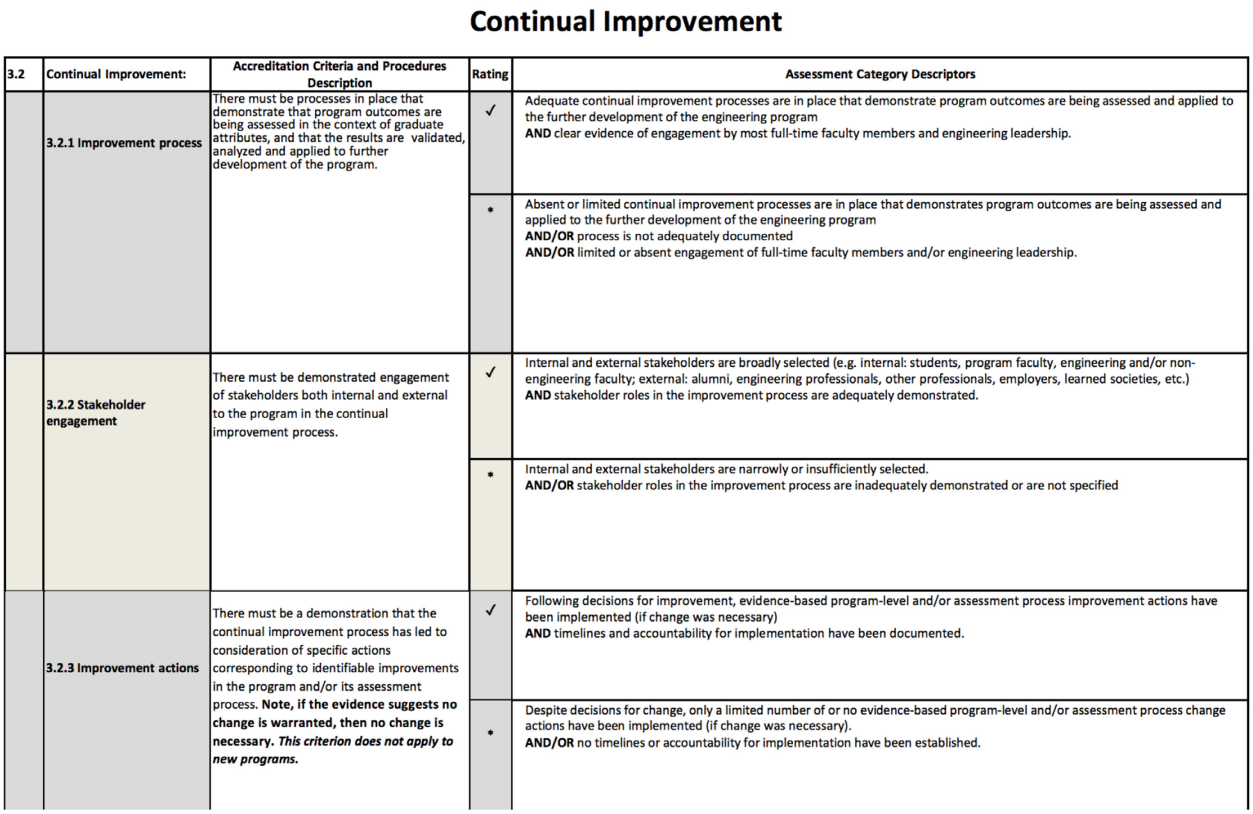
10. Ethics and equity: *An ability to apply professional ethics, accountability, and equity.*

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.*

A1.3 CEAB Graduate Attributes Continual Improvement Process

Figure A.1 Canadian Engineering Accreditation Board Continual Improvement Process Evaluation Rubric (Paper Appendix published in A Continual Improvement Process... Appendix C)



Continual Improvement

3.2	Continual Improvement:	Accreditation Criteria and Procedures Description	Rating	Assessment Category Descriptors
	3.2.1 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, analyzed and applied to further development of the program.	✓	Adequate continual improvement processes are in place that demonstrate program outcomes are being assessed and applied to the further development of the engineering program **AND** clear evidence of engagement by most full-time faculty members and engineering leadership.
			*	Absent or limited continual improvement processes are in place that demonstrates program outcomes are being assessed and applied to the further development of the engineering program **AND/OR** process is not adequately documented **AND/OR** limited or absent engagement of full-time faculty members and/or engineering leadership.
	3.2.2 Stakeholder engagement	There must be demonstrated engagement of stakeholders both internal and external to the program in the continual improvement process.	✓	Internal and external stakeholders are broadly selected (e.g. internal: students, program faculty, engineering and/or non-engineering faculty; external: alumni, engineering professionals, other professionals, employers, learned societies, etc.) **AND** stakeholder roles in the improvement process are adequately demonstrated.
			*	Internal and external stakeholders are narrowly or insufficiently selected. **AND/OR** stakeholder roles in the improvement process are inadequately demonstrated or are not specified
	3.2.3 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.***	✓	Following decisions for improvement, evidence-based program-level and/or assessment process improvement actions have been implemented (if change was necessary) **AND** timelines and accountability for implementation have been documented.
			*	Despite decisions for change, only a limited number of or no evidence-based program-level and/or assessment process change actions have been implemented (if change was necessary). **AND/OR** no timelines or accountability for implementation have been established.

A1.4 Continual Improvement Framework (Prior work)

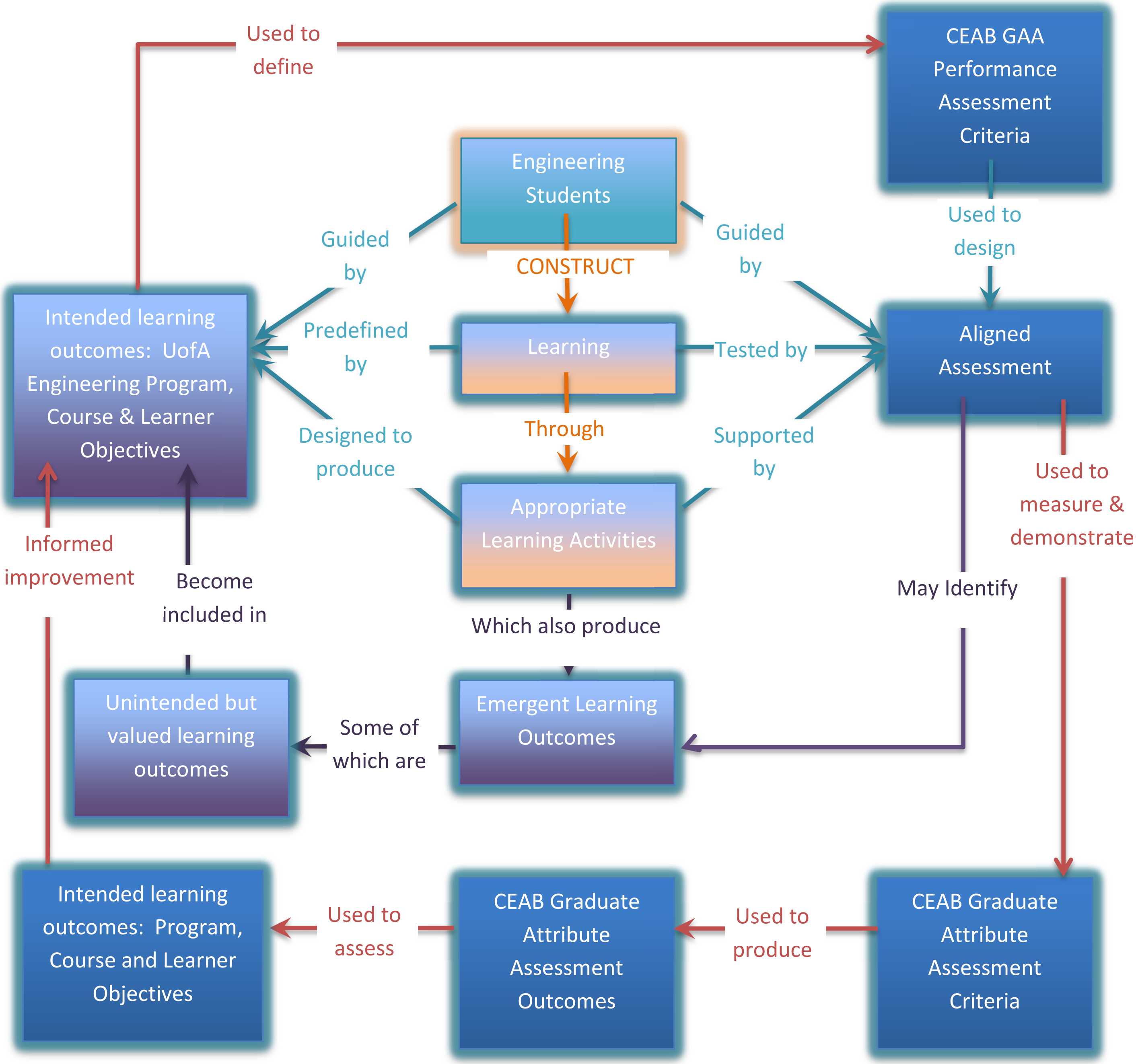


Figure A.2. Continual improvement process algorithm for the University of Alberta Engineering Program Curriculum and Course Design Using CEAB GAA performance criteria based on a curriculum design process concept map (Hattie, 2009) illustrating constructive alignment (Biggs, 1996) as a core element and the feedback process of graduate performance measurement to inform program and course design (Jamieson 2015) -Adapted by MV Jamieson, 2015

A1.5 U of A CEAB Graduate Attributes and Indicators

Additional Information Published with Intersecting Roadmaps Paper

Table A1.5.1 List of CEAB GA Attributes and Indicators (Mechanical Engineering)

1. Knowledgebase for Engineering

Aspect	Indicator
Mathematics	Completes a sequence of math courses involving calculus, differential equations and linear algebra
Mathematics	Self-assessment of knowledge base for mathematics
Chemistry	Completes a sequence of physical chemistry courses
Physics	Completes a sequence of foundational physics courses
Natural Sciences	Self-assessment of knowledge base for natural sciences
Engineering Fundamentals	Completes a sequence of foundational engineering courses
Engineering Fundamentals	Self-assessment of knowledge base for engineering fundamentals
Specialized Engineering Knowledge	Self-assessment of specialized engineering knowledge
Thermal Sciences	Applies the principles of thermodynamics to solve multicomponent power or refrig
Solid Mechanics	Applies the concepts of strength materials to analyze failure by: applied load; or by deflection; or due to instability
Fluid Mechanics	Apply the extended Bernoulli equation to a flow system that includes local and distributed losses or pumps/turbines
Mechanics	Apply the concepts of kinematics and dynamics to system of rigid bodies that form a mechanism
Dynamics and Control	Apply either root locus or Bode plots to design a lead/lag compensator.
Bio Med	Apply the basic concepts of solid mechanics to soft or hard tissue.

2. Problem Analysis

Aspect	Indicator
Understand the Problem	Able to state the essential problem to address
Understand the Problem	Self-assessment of ability to understand the problem
Assemble Knowledge	Assembles the relevant models and formulae
Assemble Knowledge	Self-assessment of ability to assemble requisite knowledge to solve the problem
Apply Models	Applies the appropriate formulae or technique to generate a result
Apply Models	Self-assessment of ability to assemble requisite knowledge to solve the problem
Evaluate	Assesses the result for reasonableness and applicability to models used
Evaluate	Self-assessment of ability to solve the problem

3. Investigation

Aspect	Indicator
Recognizes Unknowns	Identifies the unknown information or behavior to solve a problem
Measures Data	Employs appropriate techniques to collect data
Analyzes Data	Analyzes and interprets data
Analyzes Data	Assess data uncertainty and error
Reaches Conclusions	Reaches supported conclusions from the investigation and compares to model or theory

Self-Assessment	Self-assessment of ability to apply investigation
4. Design	
Aspect	**Indicator**
Requirements	Elicits and articulates project requirements from the client
Requirements	Determines appropriate regulatory, legal, environmental, social, ethical constraints and sensitivities
Creativity	Synthesizes plausible solutions
Analysis	Analyzes performance of proposed solution
Iteration	Recognizes iterative process refining solution until requirements met
Assessment	Assesses impact of solution against social and environmental factors as appropriate
Assessment	Assesses effectiveness of solution against customer's requirements, as well as impact on social and environmental factors
Self-Assessment	Self-assessment of ability to design
5. Use of Engineering Tools	
Aspect	**Indicator**
Computation	Uses computer programming to solve engineering problems
System Description	Uses Computer Aided Design (CAD) software to define complex structural systems
System Modeling	Uses finite numerical methods to numerically solve engineering problems
Analysis	Applies software to analyze thermo fluids or lumped parameter dynamic models
Measurement	Understanding of base measurement tools including one of: pressure, temperature, length, strain, current and voltage
Self-Assessment	Self-assessment of ability to use engineering tools
6. Individual and Teamwork	
Aspect	**Indicator**
Time Management	Completes essential tasks on time with an appropriate amount of effort
Team work - roles	Understands and performs assigned role
Team work - responsible	Meets expected responsibilities and tasks
Team work - participates	Actively contributes to team discussion and planning
Team work - Respect	Respects contributions of other team members
Team work - member	Self assessment as team member
Team work - leader	Self-assessment as leader
7. Communication	
Aspect	**Indicator**
Organized Message	Presents information in an organized fashion
Writing	Uses proper grammar and punctuation
Writing	Uses language effectively
Reading	Comprehends written document
Speaking	Prepares and delivers an effective oral presentation
Use of Graphics	Makes effective use of graphical elements to support message
Self-Assessment	Self-assessment of ability to communicate complex engineering concepts

8. Professionalism	
Aspect	**Indicator**
Legal Responsibilities	Understands responsibilities and consequences set out under EGGP Act and OHS legislation
Licensure Requirements	Understands requirements for licensure in province, across Canada and in USA
Safety	Understands concepts of safety and risk management
Self-Assessment	Self-assessment of professionalism
9. Impact on Society and the Environment	
Aspect	**Indicator**
Awareness of the Impacts of Technology on Society	Completes ITS Elective
Impact Assessment	Understands concepts of environmental impact in an engineering context
Impact Assessment	Analyzes environmental impact of proposed engineering project
Sustainable Design	Understands concept of sustainability in engineering context
Sustainable Design	Designs to meet sustainability criteria
Self-Assessment	Self-assessment of awareness of impact of engineering on society and the environment
10. Ethics and Equity	
Aspect	**Indicator**
Awareness of Ethical Issues	Feels confident in ability to address ethical dilemmas
Code of Ethics	Identifies provisions of the APEGA Code of Ethics
Makes Ethical Choices	Makes ethical choices in complex situations
Awareness of Equity Issues	Identifies situations containing equity issues
Awareness of Equity Issues	Is aware of provisions within the Alberta Human Rights, Citizenship and Multiculturalism Act
Awareness of Equity Issues	Feels confident in ability to address equity
11. Economics and Project Management	
Aspect	**Indicator**
Engineering Economics	Completes Engineering Economics required course
Engineering Economics	Self-assessment of ability to incorporate engineering economics into engineering practice
Economic Assessment	Includes economic analysis within design project
Project Management	Prepares and follows a project management process
Project Management	Feels competent to manage a project
12. Lifelong learning	
Aspect	**Indicator**
Curious	Demonstrates an interest in sustaining learning
Able to Assess Needs	Develops a research plan identifying information needed
Resourceful	Identifies and accesses appropriate sources of knowledge/ training
Discriminating	Evaluates information sources critically for accuracy and relevancy
Self-Assessment	Self-assessment of ability to address learning needs

A1.6 University Graduate Attributes (UGA)

1. Ethical Responsibility: Can adopt the perspective of moral principles rather than self-interest

Ethical Responsibility: Global citizenship [attitude]

		Can consider issues from a global perspective
1	Emergent	Displays an awareness of global issues
2	Basic	Shows a willingness to participate in discussions on global issues
3	Adequate	Adopts behaviour that demonstrates strong beliefs in and sensitivity toward global solidarity/interdependence
4	Superior	Can explain and/or defend one's own beliefs in global solidarity/interdependence
5	Exceptional	Displays an ingrained commitment for global values

Ethical Responsibility: Community engagement [attitude]

		Can consider issues from the perspective of their impact on the community
1	Emergent	Displays and awareness of community issues
2	Basic	Shows a willingness to participate in discussions on community issues
3	Adequate	Adopts behaviour that demonstrates strong beliefs in and sensitivity toward community solidarity
4	Superior	Can explain and/or defend one's own beliefs in community solidarity
5	Exceptional	Displays an ingrained commitment for communities

Ethical Responsibility: Social and environmental awareness [attitude]

		Can adopt the perspective of the public good and take into consideration our embeddedness within society and nature
1	Emergent	Displays and awareness of social and environmental issues
2	Basic	Shows a willingness to participate in discussions on environmental issues
3	Adequate	Adopts behaviour that demonstrates strong beliefs in and sensitivity toward environmental issues
4	Superior	Can explain and/or defend one's own beliefs and involvement in environmental issues
5	Exceptional	Displays an ingrained commitment for environmental issues

Ethical Responsibility: Professionalism [attitude]

		Is willing to meet the level of expertise and deontological expectations of her intended profession
1	Emergent	Displays and awareness of deontological and professionalism issues
2	Basic	Shows a willingness to participate in discussions on deontology and professionalism
3	Adequate	Adopts behaviour that demonstrates strong beliefs in and sensitivity toward professionalism and deontology
4	Superior	Can explain and/or defend one's own beliefs in professionalism and deontology
5	Exceptional	Displays an ingrained commitment for professional and deontological behaviour

2. Scholarship: Can rely on a body of established knowledge to guide her action

Scholarship: Knowledge breadth and depth [knowledge]

		Can make use of a broad range of knowledge while displaying mastery in specific areas
1	Emergent	Can describe a wide array of ideas and facts, some of them in great detail
2	Basic	Can explain a wide array of ideas and events, some of them in great detail
3	Adequate	Can use a wide array of ideas and events, some of them in great detail for specific purposes
4	Superior	Can break a wide array of ideas and events into parts and patterns, some of them highly specialized, and combine them in a novel way
5	Exceptional	Can assess the value of a wide array of ideas and events, some of them being highly specialized

Scholarship: Interdisciplinarity [skill]

		Can integrate into a single activity / project knowledge drawn from more than one academic discipline
1	Emergent	Can identify and recognize the potential contributions of other disciplines to an activity/project
2	Basic	Can contrast the potential contributions of other disciplines to an activity/project
3	Adequate	Can organize knowledge drawn from more than one academic discipline so as to form a coherent result benefitting an activity/project
4	Superior	Can realize an original and insightful project that seamlessly integrates multidisciplinary knowledge
5	Exceptional	Can consistently realize an original and insightful project that seamlessly integrates multidisciplinary knowledge

Scholarship: Lifelong learning [attitude]

		Is willing to engage in autonomous self-teaching in our outside the classroom
1	Emergent	Displays an awareness of the importance of autonomous learning
2	Basic	Shows a willingness to engage in autonomous learning
3	Adequate	Adopts behaviour that demonstrates an engagement in autonomous self-teaching
4	Superior	Can explain and/or defend one's own engagement in autonomous learning
5	Exceptional	Displays an ingrained commitment for autonomous self-teaching

Scholarship: Investigation [skill]

		Can effectively conduct research with the help of established methods and tools
1	Emergent	Has knowledge of the established research methods and tools with which s/he can find information
2	Basic	Can evaluate the relative value of the different established research methods and tools, as well as the information they yield
3	Adequate	Can set a research plan and use relevant information that supports the research topic
4	Superior	Can set an original and insightful research plan
5	Exceptional	Can consistently set an original and insightful research plan

3. Critical Thinking: Can contextually assess given information (incl. self-related) through reflection and debate, taking nothing for granted [questioning assumptions, consider context]

Critical Thinking: Analytic and Synthetic Reasoning [skill]

		Can gather various detailed information, organize it for specific purposes and assess its validity
1	Emergent	Can identify relevant information and arguments (e.g. the central problem, implicit and explicit assumptions)
2	Basic	Can identify alternative perspectives and justify the choice of relevant perspectives
3	Adequate	Can (re-)organize relevant information for specific purposes (e.g. reconstruct arguments) and evaluate assumptions (incl. methodology, evidence and inference)
4	Superior	Can assess the implications and potential conclusions of an argument
5	Exceptional	Cans consistently assess the validity of information and arguments

Critical Thinking: Interpretive proficiency [skill]

		Can convert individual facts into meaningful information and knowledge
1	Emergent	Can identify relevant information and arguments
2	Basic	Can identify alternative perspectives and weigh their respective value
3	Adequate	Can frame personal inferences from given facts
4	Superior	Can make fruitful interpretations that gives holistic meaning to facts
5	Exceptional	Can consistently make fruitful interpretations that gives holistic meaning to facts

Critical Thinking: Intellectual curiosity [attitude]

		Is eager to learn beyond what is readily available (in classrooms or in common knowledge)
1	Emergent	Displays and awareness of the importance of intellectual curiosity
2	Basic	Shows a willingness to learn beyond what is readily available
3	Adequate	Adopts behaviour that demonstrates learning beyond what is readily available
4	Superior	Can explain and/or defend why s/he should learn beyond what is readily available
5	Exceptional	Displays an ingrained commitment for learning beyond what is readily available

Critical Thinking: Information literacy [skill]

		Can effectively identify, access and assess information within its broader societal contexts, incl. knowledge-dependent contexts requiring scientific, digital or technology literacy
1	Emergent	Can identify and access relevant information from reliable sources
2	Basic	Can identify alternative information and sources
3	Adequate	Can prioritize information sources in order to accomplish a planned purpose
4	Superior	Can assess knowledge-specific information in its broader societal context
5	Exceptional	Can consistently assess knowledge-specific information in its broader societal context

4. Communication: Can exchange thoughts, feelings and information effectively in various situations

Communication: Writing skills [skill]

		Can write effectively various types of writing pieces.
1	Emergent	Knows and adheres to writing conventions (spelling, grammar, punctuation)
2	Basic	Can identify the main thesis of a writing piece and use sources to support it
3	Adequate	Can organize a text so as to make a message clear and convincing (logically and rhetorically)
4	Superior	Can convey a clear and coherent message with insight, originality and style
5	Exceptional	Can consistently convey a clear and coherent message with insight, originality and style

Communication: Oral skills [skill]

		Can speak effectively in various formal and informal settings
1	Emergent	Knows and adheres to speaking conventions (grammar, elocution, poise)
2	Basic	Can identify the main thesis of a writing piece and use sources to support it
3	Adequate	Can organize a presentation so as to make a message clear and convincing (logically and rhetorically)
4	Superior	Can convey a clear and coherent message with insight, originality and style
5	Exceptional	Can consistently convey a clear and coherent message with insight, originality and style

Communication: Visual communication [skill]

		Can convey ideas effectively through visual aid
1	Emergent	Knows and adheres to visual communication conventions (design, charts and graphs, fonts, colour)
2	Basic	Uses visual means to support and reinforce the conveying of a message
3	Adequate	Can organize visual elements so as to make a message clear and convincing
4	Superior	Can convey a clear message through original and stylistically riche use of visual means
5	Exceptional	Can consistently convey a clear message through original and stylistically riche use of visual means

Communication: Multilingualism [skill]

		Can communicate effectively in more than one language
1	Emergent	Knows the basic everyday activities/tasks
2	Basic	Can communicate in common and predictable contexts about basic needs, familiar and common everyday activities that have immediate personal relevance.
3	Adequate	Can communicate in familiar and personal contexts and situations related to education, work, social and daily activities as well in some unpredictable contexts.
4	Superior	Can communicate effectively, appropriately, accurately and fluently about most topics in a wide range of contexts and situations: predictable, unfamiliar, general, professional, complex and specific.
5	Exceptional	Can communicate, a native-like, using language within high-stakes or high-risk social, academic and work-related context.

5. Collaboration: Can complete tasks effectively by working jointly with others who share a common goal

Collaboration: Openness to diversity [attitude]

		Can engage with a diversity of people (in terms of race, religion, cultures, classes, sex orientation and appearance)
1	Emergent	Displays and awareness in the value of engaging with a diversity of people
2	Basic	Shows a willingness to engage with diverse people
3	Adequate	Adopts behaviour that demonstrates sensitivity toward a diversity of people
4	Superior	Can explain and/or defend one’s own engagement with diverse people
5	Exceptional	Displays an ingrained commitment to engage with a diversity of people

Collaboration: Interpersonal skills [skill]

		Can demonstrate skills necessary for effective interaction and communication (incl. empathy, active listening, respect)
1	Emergent	Listens carefully to others and uses appropriate and polite language in interactions
2	Basic	Shows a willingness to share thoughts and ideas
3	Adequate	Actively participates in a cooperative manner
4	Superior	Displays empathy in her/his interaction with others
5	Exceptional	Displays a consistent and genuine consideration and openness to others

Collaboration: Adaptability and compromise [attitude]

		Can change or suspend a personal belief in order to further the realization of a common goal or to adjust to new circumstances
1	Emergent	Displays an awareness in the value of suspending belief in order to further the realization of a common goal or to adjust to new circumstances
2	Basic	Shows a willingness to suspend her/his belief in order to further the realization of a common goal or to adjust to new circumstances
3	Adequate	Adopts behaviour that demonstrates the suspension of personal belief in order to further the realization of a common goal or to adjust to new circumstances
4	Superior	Can explain and/or defend the suspension of a personal belief in order to further the realization of a common goal or to adjust to new circumstances
5	Exceptional	Displays an ingrained commitment to suspending personal belief in order to further the realization of a common goal or to adjust to new circumstances

Collaboration: Individual contribution [attitude]

		Can take an active role in collaborative work
1	Emergent	Displays and awareness in the value of taking an active role in collaborative work
2	Basic	Shows a willingness to take an active role in collaborative work
3	Adequate	Adopts behaviour that demonstrates taking an active role in collaborative work
4	Superior	Can explain and/or defend one's own active role in collaborative work
5	Exceptional	Displays an ingrained commitment to taking an active role in collaborative work

6. Creativity: Can produce something new and valuable (incl. ideas, works or products)

Creativity: Imagination [skill]

		Can conjure up new ideas and representations in a productive manner
1	Emergent	Can think of new ideas
2	Basic	Can decide which ideas are worth pursuing
3	Adequate	Can design an artefact (text, project, program, etc.) that coherently brings together new ideas
4	Superior	Can design an artefact that is new and original in a meaningful way
5	Exceptional	Can consistently design artefacts that are new and original in a meaningful way

Creativity: Innovation [skill]

		Can devise novel and better ways of doing things through knowledge (scientific, technological, methodological)
1	Emergent	Can think of new ideas in a scientific or technological context
2	Basic	Can decide which ideas are worth pursuing in a scientific or technological context
3	Adequate	Can design an artefact (text, project, program, etc.) that coherently brings together new ideas in a scientific or technological context
4	Superior	Can design an artefact that is new and original in a meaningful way in a scientific or technological context
5	Exceptional	Can consistently design artefacts that are new and original in a meaningful way in a scientific or technological context

Creativity: Divergent thinking [attitude]

		Can explore new avenues in a non-conformist and risk-taking fashion
1	Emergent	Displays and awareness in the value of exploring new avenues in a non-conformist and risk-taking fashion
2	Basic	Shows a willingness to explore new avenues in a non-conformist and risk-taking fashion
3	Adequate	Adopts behaviour that demonstrates exploring new avenues in a non-conformist and risk-taking fashion
4	Superior	Can explain and/or defend one's own exploring of new avenues in a non-conformist and risk-taking fashion
5	Exceptional	Displays an ingrained commitment to exploring of new avenues in a non-conformist and risk-taking fashion

Creativity: Artistic sensibility [attitude]

		Can be compelled by artistic work and, ideally, partake in expressive artistic production
1	Emergent	Displays and awareness in the value of being compelled by artistic work and, ideally, partaking in expressive artistic production
2	Basic	Shows a willingness to engage with artistic work and, ideally, to partake in expressive artistic production
3	Adequate	Adopts behaviour that demonstrates sensitivity to artistic work and/or, ideally, partakes in expressive artistic production
4	Superior	Can explain and/or defend one's own engagement with artistic work
5	Exceptional	Displays an ingrained commitment to engaging with artistic work

7. Confidence: Can act and think decisively

Confidence: Leadership and empowerment [attitude]

		Can influence others into adopting an appropriate course of action toward a common task
1	Emergent	Can recognize the importance of personal leadership
2	Basic	Shows a willingness to influence others into adopting an appropriate course of action toward a common task
3	Adequate	Adopts behaviour that demonstrates the capacity to influence others into adopting an appropriate course of action toward a common class-based task
4	Superior	Can explain and/or defend one's own influencing others into adopting an appropriate course of action toward a common class-based task
5	Exceptional	Displays an ingrained disposition to influence others into adopting an appropriate course of action toward a common task

Confidence: Independence [attitude]

		Can work and think productively with no or little supervision
1	Emergent	Displays and awareness in the value of working and thinking productively with no or little supervision
2	Basic	Shows a willingness to work and think productively with no or little supervision
3	Adequate	Adopts behaviour that demonstrates a capacity to work and think productively with no or little supervision
4	Superior	Can explain and/or defend one's working and thinking productively with no or little supervision
5	Exceptional	Displays an ingrained commitment to working and thinking productively with no or little supervision

Confidence: Initiative [attitude]

		Can initiate a course of action without prompting
1	Emergent	Displays and awareness in the value of initiating a course of action without prompting
2	Basic	Shows a willingness to initiate a course of action without prompting
3	Adequate	Adopts behaviour that demonstrates a capacity to initiate a course of action without prompting
4	Superior	Can explain and/or defend one's initiation of a course of action without prompting
5	Exceptional	Displays an ingrained commitment to initiating a course of action without prompting

Confidence: Resilience [attitude]

		Can follow through on a course of action over time
1	Emergent	Displays and awareness in the value of following through on a course of action over time
2	Basic	Shows a willingness to follow through on a course of action over time
3	Adequate	Adopts behaviour that demonstrates a capacity to follow through on a course of action over time
4	Superior	Can explain and/or defend one’s own decision to follow through on a course of action over time
5	Exceptional	Displays an ingrained commitment to follow through on a course of action over time

A1.7 Conceptual Framework Analysis Process (Condensed version)

The methodology is composed of the following key steps as outlined by Yosef Jabareen, 2009.

Step 1: Mapping the selected data sources

"This process includes identifying text types and other sources of data, such as existing empirical data and practices…it is also recommended to undertake initial interviews with practitioners, specialists, and scholars from various disciplines whose work focuses on the targeted phenomenon." (Jabareen, 2009, p.53)

Step 2: Extensive reading and categorizing of the selected data

"The aim in this phase is to read the selected data and categorize it...This process maximizes the effectiveness of our inquiry and ensures effective representation..." (Jabareen, 2009, p.54)

Step 3: Identifying and naming concepts

"The aim in this phase is to read and reread the selected data and "discover" concepts (Glaser & Strauss. 1967; Strauss & Corbin. 1990). Its result is a list of numerous competing and sometimes contradictory concepts. Generally, this method allows concepts to emerge from the literature." (Jabareen, 2009, p.54)

Step 4: Deconstructing and categorizing the concepts

"The aim of this phase is to deconstruct each concept; to identify its main attributes, characteristics, assumptions, and role; and, subsequently, to organize and categorize the concepts according to their features and ontological, epistemological, and methodological role. The result of this phase is a table that includes four columns. The first includes the names of the concepts; the second includes a description of each concept; the third categorizes each concept according to its ontological, epistemological, or methodological role; and the fourth presents the references for each concept." (Jabareen, 2009, p.54)

Step 5: Integrating concepts

"The aim in this phase is to integrate and group together concepts that have similarities to one new concept. This phase reduces the number of concepts drastically and allows us to manipulate to a reasonable number of concepts." (Jabareen, 2009, p.54)

Step 6: Synthesis, resynthesis, and making it all make sense

"The aim in this phase is to synthesize concepts into a theoretical framework. The researcher must be open, tolerant, and flexible with the theorization process and the emerging new theory. This process is iterative and includes repetitive synthesis…until the researcher recognizes a general theoretical framework that makes sense." (Jabareen, 2009, p.54)

Step 7: Validating the conceptual framework

"The aim in this phase is to validate the conceptual framework. The question is whether the proposed framework and its concepts make sense not only to the researcher but also to other scholars and practitioners. Does the framework present a reasonable theory for scholars studying the phenomenon from different disciplines? Validating a theoretical framework is a process that starts with the researcher, who then seeks validation among "outsiders." Presenting an evolving theory at a conference, a seminar, or some other type of academic framework provides an excellent opportunity for researchers to discuss and receive feedback." (Jabareen, 2009, p.54)

Phase 8: Rethinking the conceptual framework

"A theory or a theoretical framework representing a multidisciplinary phenomenon will always be dynamic and may be revised according to new insights, comments, literature, and so on. As the framework is multidisciplinary, the theory should make sense for those disciplines and enlarge their theoretical perspective on the specific phenomenon in question." (Jabareen, 2009, p.55)

A1.8 ABET Student Outcomes and the CEAB Graduate Attributes Mapping

This section presents the mapping between the CEAB GA and both the previous ABET Student Outcomes (a-k) and the current (2019 -2020) Student Outcomes 1-7. (Chapter 6 Supplementary Material)

Reference: **Criteria for Accrediting Engineering Programs, 2019 – 2020**
https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/#GC2 Accessed September 6, 2020

ABET Criterion 3. Student Outcomes (1-7)

The program must have documented student outcomes that support the program educational objectives. Attainment of these outcomes prepares graduates to enter the professional practice of engineering. Student outcomes are outcomes (1) through (7), plus any additional outcomes that may be articulated by the program.

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Reference: **Criteria for Accrediting Engineering Programs, 2018 – 2019**
https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2018-2019/
Accessed Sept 6, 2020
Reference: Comparison mapping
https://www.abet.org/wp-content/uploads/2018/03/C3_C5_mapping_SEC_1-13-2018.pdf Accessed Sept 6, 2020

ABET Criterion 3. Student Outcomes (a-k)

The program must have documented student outcomes that prepare graduates to attain the program educational objectives. Student outcomes are outcomes (a) through (k) plus any additional outcomes that may be articulated by the program.

a. an ability to apply knowledge of mathematics, science and engineering
b. an ability to design and conduct experiments, as well as to analyze and interpret data
c. an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d. an ability to function on multidisciplinary teams

e. an ability to identify, formulate, and solve engineering problems
f. an understanding of professional and ethical responsibility
g. an ability to communicate effectively (3g1 orally, 3g2 written)
h. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i. a recognition of the need for, and an ability to engage in life-long learning
j. a knowledge of contemporary issues
k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Definitions

Reference: ABET **Criteria for Accrediting Engineering Programs, 2019 – 2020**

Program Educational Objectives *--Program educational objectives are broad statements that describe what graduates are expected to attain within a few years after graduation. Program educational objectives are based on the needs of the program's constituencies.*

Student Outcomes *-- Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the skills, knowledge and behaviors that students acquire as they progress through the program.*

Assessment *-- Assessment is one or more processes that identify, collect, and prepare data to evaluate the attainment of student outcomes and program educational objectives. Effective assessment uses relevant direct, indirect, quantitative and qualitative measures as appropriate to the objective or outcome being measured. Appropriate sampling methods may be used as part of an assessment process.*

Evaluation *-- Evaluation is one or more processes for interpreting the data and evidence accumulated through assessment processes. Evaluation determines the extent to which student outcomes and program educational objectives are being attained. Evaluation results in decisions and actions regarding program improvement.*

Table A1.8.1 Mapping CEAB Graduate Attributes with ABET Student Outcomes (A-K) and (1-7)

CEAB Graduate Attribute (GA 1-12)	**ABET Student Outcomes (SO A-K)**	**ABET Student Outcomes (SO 1-7)**
1. KB for Engineering - Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	A. an ability to apply knowledge of mathematics, science and engineering	1. an ability to identify, formulate, and solve complex engineering problems by ***applying principles of engineering, science, and mathematics*** (assumes a knowledge of such principles)
2. Problem Analysis - An ability to use appropriate knowledge and skills to identify, formulate,	E. an ability to identify, formulate, and solve engineering problems	1. ***an ability to identify, formulate, and solve complex engineering***

analyze, and solve complex engineering problems in order to reach substantiated conclusions.		***problems*** by applying principles of engineering, science, and mathematics
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.	B. an ability to design and conduct experiments, as well as to analyze and interpret data	6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw 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.	C. an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
5. Use of Eng. 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.	K. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	*No equivalent to map to* (Implies this ability is necessary for outcomes 1, 2 and 6 solve problems, design solutions, investigate and experiment)
6. Teamwork - An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	D. an ability to function on multidisciplinary teams	5. ***an ability to function effectively on a team whose members together provide leadership***, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
7. Communication - 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.	G. an ability to communicate effectively (3g1 orally, 3g2 written)	3. an ability to communicate effectively with a range of audiences
8. Professionalism - An understanding of the roles and responsibilities of the professional engineer in society, especially the	F. an understanding of **professional** and ethical **responsibility**	4. an ability to recognize... professional responsibilities...

primary role of protection of the public and the public interest.		
9.Impact of Engineering - 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.	H. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context J. a knowledge of contemporary issues	4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, ***which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts***
10. Ethics & Equity - An ability to apply professional ethics, accountability, and equity.	F. an understanding of professional and **ethical responsibility**	4. an ability to recognize ethical... responsibilities... 5. ...create a collaborative and ***inclusive environment***, establish goals, plan tasks, and meet objectives
11.Economics & PM - 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.	*No equivalent to map to in ABET SO (a-k)*	5. ...create a collaborative and inclusive environment, ***establish goals, plan tasks, and meet objectives***
12. Lifelong 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.	I. a recognition of the need for, and an ability to engage in life-long learning	7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

A1.9 UN Sustainable Development Goals

Chapter 6 Paper Published in ECE Appendix B: UN Sustainable Development Goals[12]

Goal 1. End poverty in all its forms everywhere

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Goal 3. Ensure healthy lives and promote well-being for all at all ages

Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Goal 5. Achieve gender equality and empower all women and girls

Goal 6. Ensure availability and sustainable management of water and sanitation for all

Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all

Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Goal 10. Reduce inequality within and among countries

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable

Goal 12. Ensure sustainable consumption and production patterns

Goal 13. Take urgent action to combat climate change and its impacts*

Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

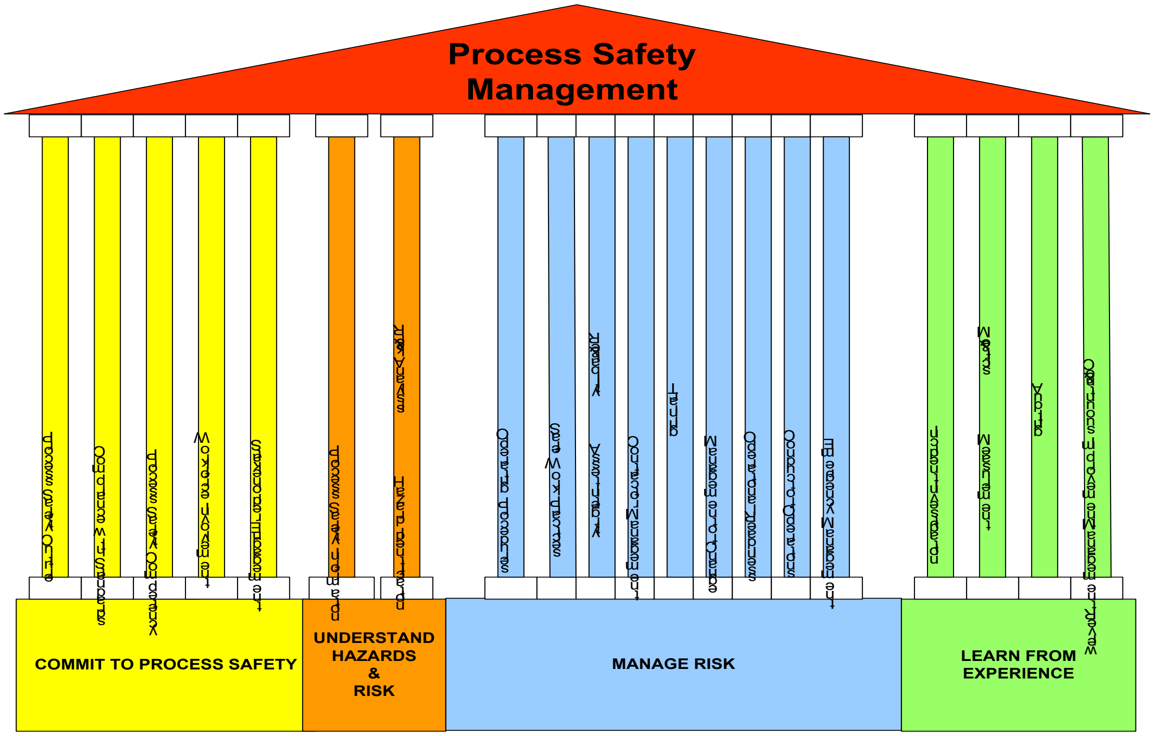
Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development

---

[12] Downloaded and used according to the guidelines. https://www.un.org/sustainabledevelopment/news/communications-material/

A1.10 Risk Based Process Safety Management

Chapter 6 Published Paper Appendix C: Risk Based Process Safety Management Elements[13]



Short summary of Risk Based Process Safety

<u>Foundational Block: Commit to Process Safety</u>

Element 1 - Process Safety Culture: A positive environment where employees at all levels are committed to process safety. This starts at the highest levels of the organization and is shared by all. Process safety leaders nurture this process.

Element 2 - Compliance with Standards: Applicable regulations, standards, codes, and other requirements issued by national, state/provincial, and local governments, consensus standards organizations, and the corporation. Interpretation and implementation of these requirements. Includes development activities for corporate, consensus, and governmental standards.

---

[13] Downloadable AIChE CCPS reference material from: https://www.aiche.org/sites/default/files/docs/summaries/overview-of-risk-based-06-25-14.pdf and https://www.aiche.org/sites/default/files/docs/summaries/short-summary-of-risk-based-process-safety_updated.pdf

Element 3 - Process Safety Competency: Skills and resources that the company needs to have in the right places to manage its process hazards. Verification that the company collectively has these skills and resources. Application of this information in succession planning and management of organizational change.

Element 4 - Workforce Involvement: Broad involvement of operating and maintenance personnel in process safety activities, to make sure that lessons learned by the people closest to the process are considered and addressed.

Element 5 - Stakeholder Outreach: Activities with the community to help outside responders and the public to understand the plant's hazards and potential emergency scenarios and how to address these scenarios.

Foundational Block: Understand Hazards and Risk

Element 6 - Process Knowledge Management: The assembly and management of all information needed to perform process safety activities. Verification of the accuracy of this information. Confirmation that this information is correct and up-to-date. This information must be readily available to those who need it to safely perform their jobs.

Element 7 - Hazard Identification and Risk Analysis: Identification of Process Safety hazards and their potential consequences. Definition of the risk posed by these hazard scenarios. Recommendations to reduce or eliminate hazards, reduce potential consequences, reduce frequency of occurrence. Analysis may be qualitative or quantitative depending on the level of risk.

Foundational Block: Manage Risk

Element 8 - Operating Procedures: Written instructions for a manufacturing operation that describes how the operation is to be carried out safely, explaining the consequences of deviation from procedures, describing key safeguards, and addressing special situations and emergencies.

Element 9 - Safe Work Practices: Procedures to safely maintain and repair equipment such as permits-to-work, line breaking, and hot work permits.

Element 10 - Asset Integrity and Reliability: Activities to ensure that important equipment remains suitable for its intended purpose throughout its service. Includes proper selection of materials of construction; inspection, testing, and preventative maintenance; and design for maintainability

Element 11 - Contractor Management: Practices to ensure that contract workers can perform their jobs safely, and that contracted services do not add to or increase facility operational risks

Element 12 - Training and Performance Assurance: Practical instruction in job and task requirements and methods for operation and maintenance workers, supervisors, engineers, leaders, and process safety professionals. Verification that the trained skills are being practiced proficiently.

Element 13 - Management of Change: Process of reviewing and authorizing proposed changes to facility design, operations, organization, or activities prior to implementing them, and that the process safety information is updated accordingly.

Element 14 - Operational Readiness: Evaluation of the process before start-up or restart to ensure the process can be safely started. Applies to restart of facilities after being shut down or idled as well as after process changes and maintenance. Also applies to start-up of new facilities.

Element 15 - Conduct of Operations: Means by which management and operational tasks required for process safety are carried out in a deliberate, faithful, and structured manner. Managers ensure workers carry out the required tasks and prevent deviations from expected performance.

Element 16 - Emergency Management: Plans for possible emergencies that define actions in an emergency, resources to execute those actions, practice drills, continuous improvement, training or informing employees, contractors, neighbors, and local authorities, and communications with stakeholders in the event an incident does occur.

Foundational Block: Learn from Experience

Element 17 - Incident Investigation: Process of reporting, tracking, and investigating incidents and near-misses to identify root causes, taking corrective actions, evaluating incident trends, and communicating lessons learned.

Element 18 - Measurement and Metrics: Leading and lagging indicators of process safety performance, including incident and near-miss rates as well as metrics that show how well key process safety elements are being performed. This information is used to drive improvement in Process Safety.

Element 19 - Auditing: Periodic critical review of process safety management system performance by auditors not assigned to the site to identify gaps in performance and identify improvement opportunities, and track closure of these gaps to completion.

Element 20 - Management Review and Continuous Improvement: The practice of managers at all levels of setting process safety expectations and goals with their staff and reviewing performance and progress towards those goals. May take place in a staff or “leadership team” meeting or one-on-one. May be facilitated by process safety lead but is owned by the line manager.

A1.11 IRGC Risk Governance Framework

Chapter 6 Published Paper Appendix D: IRGC Risk Governance Framework[14]

1. Pre-assessment – Identification and framing. [Mapped to Commit to Process Safety]

- Leads to framing the risk, early warning, and preparations for handling it,
- Involves relevant actors and stakeholder groups, so as to capture the various perspectives on the risk, its associated opportunities, and potential strategies for addressing it.

2. Appraisal – Assessing the technical and perceived causes and consequences of the risk. [Mapped to Learn from Experience]

- Develops and synthesises the knowledge base for the decision on whether or not a risk should be taken and/or managed and, if so,
- Identifies and selects what options may be available for preventing, mitigating, adapting to or sharing the risk.

3. Characterisation and evaluation – Making a judgment about the risk and the need to manage it. [Mapped to Understand Hazards and Risks]

- Process of comparing the outcome of risk appraisal (risk and concern assessment) with specific criteria,
- Determines the significance and acceptability of the risk, and
- Prepares decisions.

4. Management – Deciding on and implementing risk management options. [Mapped to Manage Risk]

- Designs and implements the actions and remedies required to avoid, reduce (prevent, adapt, mitigate), transfer or retain the risks.

5. Cross-cutting aspects – Communicating, engaging with stakeholders, considering the context. [Mapped to situation appraisal and stakeholder understanding]

- Crucial role of open, transparent and inclusive communication,
- Importance of engaging stakeholders to both assess and manage risks, and

Need to deal with risk in a way that fully accounts for the societal context of both the decision that will be made and the risk that will be taken.

---

[14] https://irgc.org/risk-governance/irgc-risk-governance-framework/

A1.12 Case Studies - Resources

Chapter 6 Published Paper Appendix E: Getting Started with Case Studies

Case studies are an excellent way for students to learn about chemical process safety and many instructors have used this approach, some for many years. There are a number of excellent resources available if you are just beginning to develop and use case studies or if you are interested in connecting your core course to engineering practice, engineering leadership, engineering management and or engineering sustainability. Below we list a few places to look for incident summaries and ready-made case studies to get you started.

The Canadian Transport Safety Board (TSB) investigates transportation related incidents for air, marine, pipeline and rail in Canada and posts the reports. Often these reports are an excellent starting point for instructor case development or as a resource if you choose to have students research and present their own cases. The Lac Mégantic derailment investigation report is an example and can be found here: https://www.tsb.gc.ca/eng/rapports-reports/rail/2013/r13d0054/r13d0054-r-es.html

The US Chemical Safety Board (CSB) videos: The CSB provides incident investigation summaries with significant resources that both instructors and students can use to study incidents or develop case studies from a variety of perspectives. The re-enactment videos are excellent. (https://www.csb.gov/videos/) The MGPI incident investigation can be found here: https://www.csb.gov/mgpi-processing-inc-toxic-chemical-release-/

Minerva Safety Management: Here you will find cases that can be used for engineering and business schools. The cases are free to use and reproduce according to the terms noted on the website: https://safetymanagementeducation.com/teaching-resources/case-studies-instructor-notes/

The Flixborough Court of Inquiry Report (https://www.icheme.org/media/13689/the-flixborough-disaster-report-of-the-court-of-inquiry_repaired.pdf) is an excellent resource and the incident remains a rich source of teachable moments.

The IChemE Safety Center (ISC) also has individual case studies available for purchase: https://www.icheme.org/knowledge/safety-centre/case-studies/

The Center for Chemical Process Safety (AIChE CCPS) https://www.aiche.org/ccps is an excellent resource for understanding process safety, investigation, risk management and the associated tools and resources. Many of their books are available electronically. One particularly relevant resource summarizes defining process safety incidents: "Incidents that Define Process Safety" by J. Atherton and G. Frederic

(CCPS, Wiley Interscience, 2008). CCPS also has a multitude of tools and database resources in addition to useful publications.

The Canadian center for occupational health and safety outlines investigation procedures for incidents that may be of assistance to students learning about incident investigation. https://www.ccohs.ca/oshanswers/hsprograms/investig.html

Incidents relating to process, transport, and chemical safety can be found globally. Researching local safety boards and their incident reports may provide a resource for public domain incident information. This may also be a source for local legislation and regulation resources. Connecting to local incident investigation and resources may make the case study more relevant to students. The Fire and Blast Information Group https://www.fabig.com/industrial-accidents/ provides summaries of major incidents, which can be filtered by continent, type of incident, and date.

Incidents that make excellent case studies include stories about people who lived ordinary lives with everyday routines prior to the incident and chronicle the information leading up to the incident. The cases typically have ordinary beginnings that end with tragic consequences. Students are invited in to the story and then can explore and investigate the incident while learning about engineering methods and tools used in practice.

The following list provides examples of incidents that work well for a case study and illustrate a variety of incident types, hazards, and risk management tools. Well-known and classic incident cases include: Bhopal, Flixborough, Piper Alpha, BP Macondo Deepwater, and BP Texas City. Less well known but equally haunting cases that can be linked to a variety of core subject areas including chemistry, physics, corrosion, fluid mechanics, thermodynamics, release and dispersion modeling, toxicology, and/or energy conversion are listed below with links to resources to get started.

The ice arena ammonia release at Fernie, B.C., Canada (https://www.youtube.com/watch?v=BBxzXKRSjsc and https://www.worksafebc.com/en/about-us/news-events/news-releases/2018/August/investigation-into-tragic-event-fernie-memorial-arena);

The rupture, hydrocarbon release, explosion, and fire at the Esso gas plant, Longford, Victoria, Australia (https://www.parliament.vic.gov.au/papers/govpub/VPARL1998-99No61.pdf and https://www.icheme.org/knowledge/safety-centre/news/the-long-view-on-longford/);

The West Fertilizer ammonium nitrate explosion and fire, West, Texas, United States (https://www.csb.gov/west-fertilizer-explosion-and-fire-/);

The off site chlorine gas release at MGPI Processing Inc, Atchison, Kansas, United States (https://www.csb.gov/mgpi-processing-inc-toxic-chemical-release-/).

Appendix B. List of Publications

The following tables list publications associated with my discipline based education research (DBER) in engineering education. Table B.1 contains publications arising from "Application of Blended and Active Learning to Chemical Engineering Design," (Jamieson, 2015) and describes work done to redesign the blended capstone design course and the neutral impact on academic outcomes for cohorts.

Table B.1. Publications arising from "**Application of Blended and Active Learning to Chemical Engineering Design Instruction**" (Jamieson, MSc Thesis, 2015).

Year	Publications Title and Publication Details	Author(s)
2015	"The University of Alberta Capstone Design Course Goes Flipped!" Proc. 2015 Canadian Engineering Education Association (CEEA15) Conf., Paper 093; McMaster University; May 31 – June 3, 2015 http://ojs.library.queensu.ca/index.php/PCEEA/article/viewFile/5752/pdf	Jamieson, M.V., Church, L., Vagi, F., Pick,W., Onuczko, T., Nychka, J., Nocente, N., Shaw, J.M.
2015	A Case Study in Chemical Engineering "The Flipped College Classroom: Conceptualized and Re-Conceptualized". Edited by Ross Perkins, Lucy Santos Green, Jen Banas (Springer: New York)	Jamieson, M., Shaw J.M., Nocente N.,
2016	"Pre and Post Course Student Self Assessment of CEAB Graduate Attributes - A Tool for Outcomes Assessment, Student Skill and Course Improvement", Proc. 2016 Canadian Engineering Education Association (CEEA16) Conf. Paper 037; Dalhousie University; June 19 – 22, 2016 https://ojs.library.queensu.ca/index.php/PCEEA/article/view/6497	Jamieson, M.V., Shaw, J.M.
2016	"Online Learning Element Design – Development and Application Experiences", Proc. 2016 Canadian Engineering Education Association (CEEA16) Conf. Paper 038; Dalhousie University; June 19 – 22, 2016 https://ojs.library.queensu.ca/index.php/PCEEA/article/view/6498	Jamieson, M.V., Shaw, J.M.

Table B.2 begins with lists publications from the exploratory first phase of this doctoral study including follow up analyses of the blended learning project. The first phase utilizes mixed methods studies to retrospectively evaluate design course improvements; the second phase describes the theoretical framework development for an engineering learning culture and the evolution of the community of practice; the third phase describes the continual improvement process development and course design evaluation; while the fourth phase develops tools for incorporating sustainable leadership and management into the undergraduate curriculum and consideration of the implications of professional program GA integration with University wide GAs and the COVID-19 move to remote learning for engineering programs and the University community. The foundational work for the inclusion of engineering leadership, management, practice, and innovation aspects in the undergraduate and graduate curriculum is captured in "Building the Engineering Mindset: Developing Leadership and Management Competencies in the Engineering Curriculum" and "Sustainable leadership and management of complex engineering systems: A team based structured case study approach" while the last two papers interrogate our future direction for engineering education and the impact of remote learning and the move towards institutional level graduate attributes. Not all publications are included in the text of this doctoral thesis, however, all played a role in the development of the dissertation and my intellectual development and thinking with respect to engineering education, the application of the graduate attributes and the necessity of broadening the undergraduate program with a foundation beyond the technical.

Table B.2. Publications underlying this doctoral thesis: "**Designing and Developing the Whole Engineer,**" (Jamieson, PhD Thesis, 2021).

Year	**Study Phase**	**Publications Title and Publication Details**	**Author(s)**
2016	Exploratory Abstract Peer Review	"Team Midterm in an Introductory Process Design Course", Proc. 2016 Canadian Engineering Education Association (CEEA16) Conf. Paper 036; Dalhousie University; June 19 – 22, 2016 https://ojs.library.queensu.ca/index.php/PCEEA/article/view/6496	Jamieson, M.V., Shaw, J.M.
2017	Exploratory Extended Abstract Peer Review Conference	"**Student and Instructor Satisfaction and Engagement with Blended Learning in Chemical Engineering Design**", Proc. 2017 Canadian Engineering Education Association (CEEA17) Conf. Paper 040; University of Toronto; June 4 – 7, 2017	Jamieson, M.V., Shaw, J.M.
2017	Exploratory Extended Abstract Peer Review Conference	"**Applying Metacognitive Strategies to Teaching Engineering Innovation, Design, and Leadership**", Proc. 2017 Canadian Engineering Education Association (CEEA17) Conf. Paper 045; University of Toronto; June 4 – 7, 2017 https://ojs.library.queensu.ca/index.php/PCEEA/article/view/9531	Jamieson, M.V., Shaw, J.M.
2017	Exploratory Engineering Education Forum Conference	"Application of Peer Teaching and Deep Learning in Engineering Education Course Design", in Proc. of the 7th International Conference on Mechanics and Materials in Design (M2D2017) Plenary Session Extended Abstract; Algarve, Portugal; June 10 – 15, 2017 https://paginas.fe.up.pt/~m2d/Proceedings_M2D2017/data/papers/6958.pdf	Jamieson, M.V., Shaw, J.M.
2017	Exploratory Full Peer Review Conference	"To Teach is to Learn: Student and Instructor Perspectives on Assignment Development as a Springboard to Deep Learning", in Proc. of the 13th International CDIO Conf. Paper 106; Calgary, Canada; June 18-22, 2017. http://www.cdio.org/files/document/cdio2017/106/106_Final_PDF.pdf	Jamieson, M.V., Goettler, L., Liu, A., Shaw, J.M.,
2018	Exploratory Full Peer Review Conference	"**Graduate Attribute Based Continuous Course Improvement in a Blended Learning Design Course** – A Writing Seminar Case Study", Proc. 2018 Canadian Engineering Education Association (CEEA18) Conf. Paper 077; University of British Columbia; June 3 – 6, 2018 https://ojs.library.queensu.ca/index.php/PCEEA/article/view/13022	Jamieson, M.V., Shaw, J.M.
2018	Exploratory Full Peer Review Conference	"**Teaching Engineering Innovation, Design, and Leadership within a Community of Practice**", Proc. 2018 Canadian Engineering Education Association (CEEA18) Conf. Paper 113; University of British Columbia; June 3 – 6, 2018	Jamieson, M.V., Shaw, J.M.

		https://ojs.library.queensu.ca/index.php/PCEEA/article/view/13058	
2018	Continual Improvement Full Peer Review Conf	“**CATME or ITP Metrics? Which one should I choose?**” Proc. 2018 American Society for Engineering Education (ASEE18) Conf. Paper 113; Salt Lake City, Utah; June 23 – 27, 2018 https://www.asee.org/public/conferences/106/papers/23029/view	Jamieson, M.V., Shaw, J.M.
2019	**Theoretical Framework** Full Peer Review	“**Learning to Learn: Defining an Engineering Learning Culture**”, Canadian Engineering Education Association (CEEA 2019) Conf., Paper 18, Ottawa, ON; June 9-12, 2019	Jamieson, M.V., Shaw, J.M.
2019	Continual Improvement Full Peer Review	“**A Continual Improvement Process for Teaching Leadership and Innovation Within a Community of Practice**”, Proc. 2019 American Society for Engineering Education (ASEE19) Conf. Paper ID 27452; Tampa, Florida; June 16 – 19, 2019 https://www.asee.org/public/conferences/140/papers/27452/view	Jamieson, M.V., Shaw, J.M.
2019	Continual Improvement Invited Paper Ext. Abstract	“A Model for Engineering Design Education and a Continual Course Improvement Method”, in Proc. of the 8th International Conference on Mechanics and Materials in Design (M2D2019); Bologna, Italy; Sept. 3 – 6, 2019 Engineering Education Forum	Jamieson, M.V., Shaw, J.M.
2019	Full Peer Review Journal	“**Teaching Engineering for a Changing Landscape**” *The Canadian Journal of Chemical Engineering*, 2019	Jamieson, M.V., Shaw, J.M.
2020	Full Peer Review Journal	**“Teaching Engineering Innovation, Design, and Leadership Through a Community of Practice”** *Education for Chemical Engineers, 2020*	Jamieson, M.V., Shaw, J.M.
2020	Full Peer Review Conference	“Building the Engineering Mindset: Developing Leadership and Management Competencies in the Engineering Curriculum” Canadian Engineering Education Association (CEEA 2019) Conf., Paper 30, Montreal, QB; June 17-22, 2020	Jamieson, M.V., Donald, J.R.
2020	Full Peer Review Conference	**“Sustainable Leadership and Management of Complex Engineering Systems: A Team Based Structured Case Study Approach.”** Proc. 2020 American Society for Engineering Education (ASEE20) Conf. Paper ID; Virtual Conference Montreal, QB; June 22 – 25, 2020	Jamieson, M.V., Lefsrud, L.M., Sattari, F., Donald, J.R.
2020	Full Peer Review Journal	**“Sustainable leadership and management of complex engineering systems: A team based structured case study approach.”** *Education for Chemical Engineers*, 2020, *35, pp.* 37–46, https://doi.org/10.1016/j.ece.2020.11.008	Jamieson, M.V., Lefsrud, L.M., Sattari, F., Donald, J.R.
2020	Full Peer Review Journal	**“Keeping a Learning Community and Academic Integrity Intact after a Mid Term Shift to Online Learning in Chemical Engineering Design During the COVID-19 Pandemic**,” *Journal of Chemical Education*, (97)*9*, 2768–2772, 2020. https://pubs.acs.org/doi/10.1021/acs.jchemed.0c00785	Jamieson, M.V.
2021	Full Peer Review Journal	**“Intersecting Roadmaps: Resolving Tension Between Profession-Specific and University-Wide Graduate Attributes,”** *Canadian Journal of Higher Education - Revue canadienne d’enseignement supérieur*, (51) 1, pp. 71-98, 2021.	El Atia, S., Carey, J.P., Jamieson, M.V., Alibrahim, B., Ivey, M.

Appendix C. Course Continual Improvement Process Development (ASEE 2019 Paper)

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

(American Society for Engineering Education **Full Peer Reviewed Paper**, 2019, https://peer.asee.org/a-continual-improvement-process-for-teaching-leadership-and-innovation-within-a-community-of-practice)

Marnie V. Jamieson and John M. Shaw
Department of Chemical and Materials Engineering, University of Alberta

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 A1.2) 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 A1.3. 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. Course 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[15] adopted. To set the stage, we describe the frameworks underpinning capstone design course instruction. Engineering work is ***complex***[16] 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

---

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

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

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 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.[17] Complex systems may have a range of short term and

---

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

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 C.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 C.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 C.2).

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, 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 (figure C.3) 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.

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

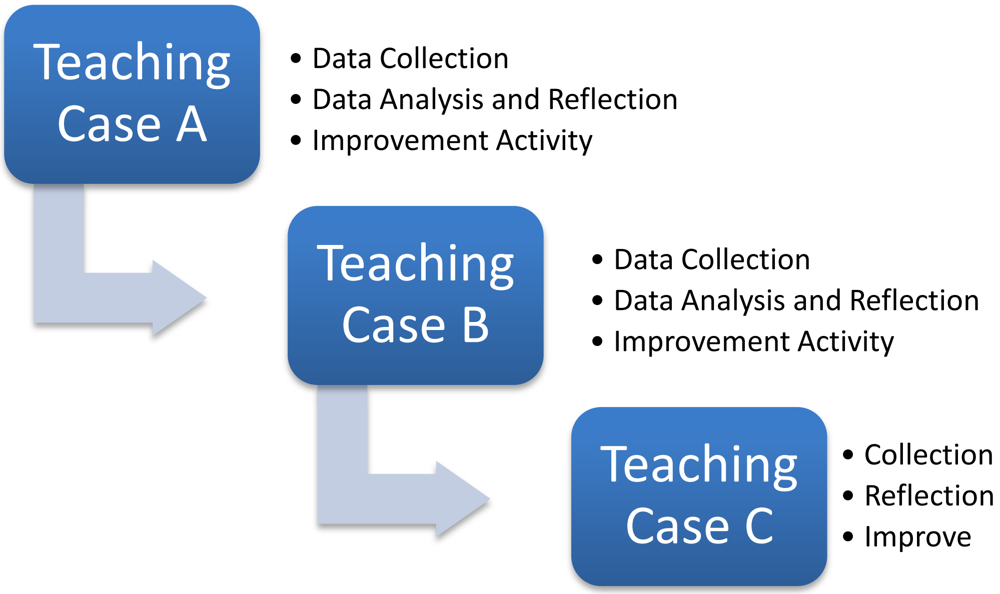


Figure C.1. Continual Improvement Process Overview

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

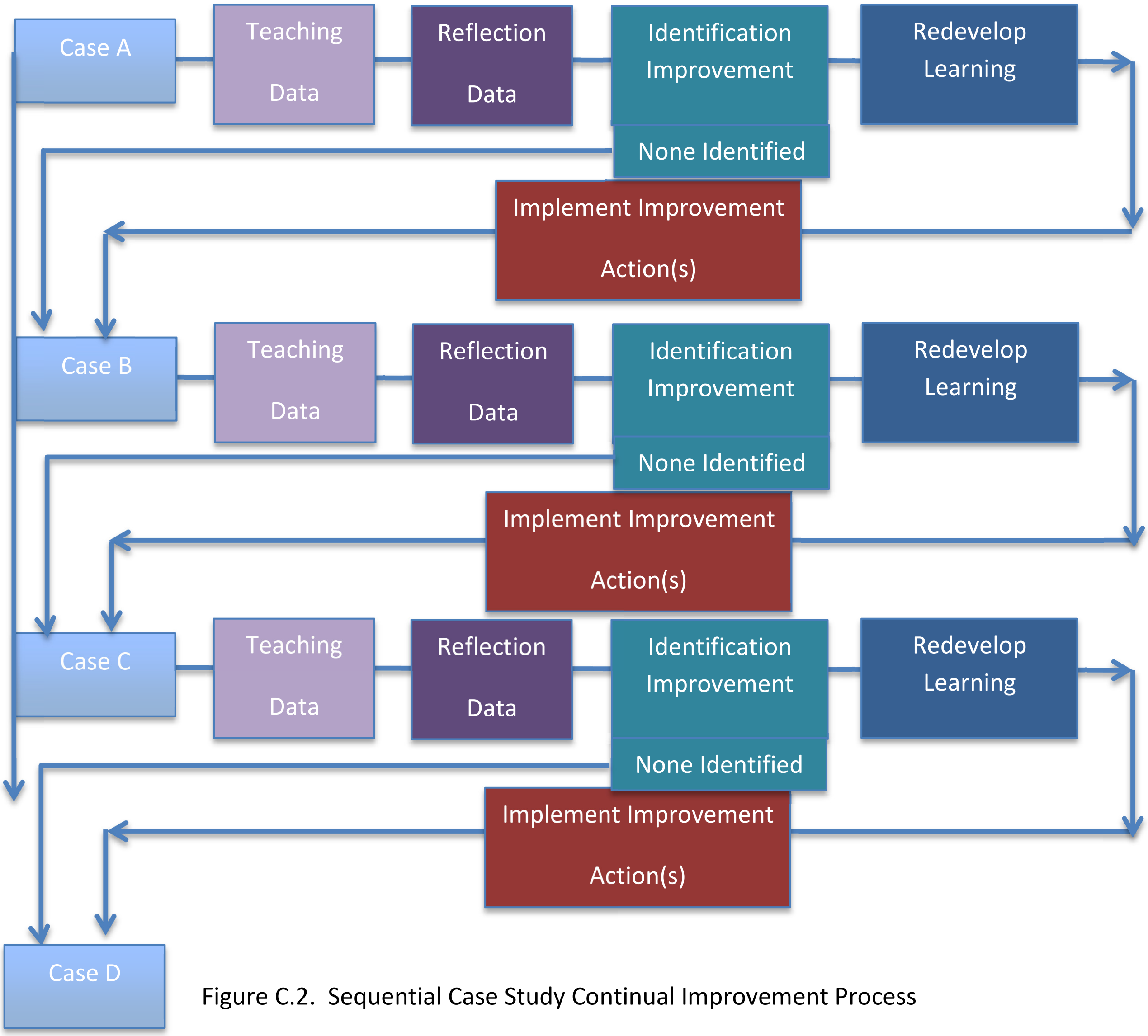


Figure C.2. Sequential Case Study Continual Improvement Process

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

Table C.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

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

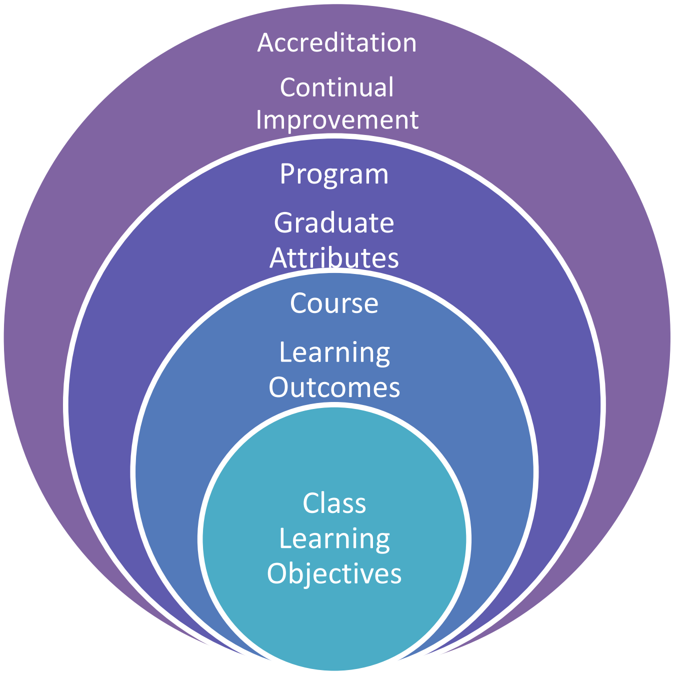


Figure C.3. Outcomes Based Engineering Education Model Supporting Ongoing Quality and Relevance Improvement

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 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 C.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

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 C.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 C.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 C.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

Table 3.3 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. 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).

Table C.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
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	
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

Table C.3. Learning activities developing team and leadership skills.			
Activity Type	**Description (and Assessment)**	**Frequency**	**Assessor(s)**
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

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 C.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.

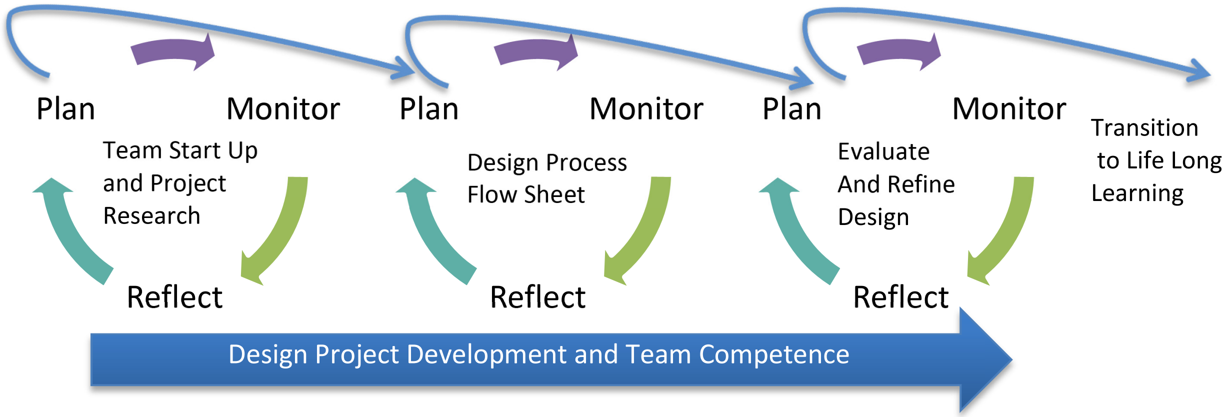


Figure C.4. Design Course Metacognitive Cycles Progressing Team and Project Development

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.

Update (2021)

A key outcome of this work is learning interventions make a difference for some students but not all students all of the time. Student engagement and satisfaction improved with the second iteration of the course. Amended ethics approval was granted for an additional online version of the survey for the fifth iteration of the blended course. Although a very small number of respondents participated (n=3), the results indicated the students were engaged with learning and generally positive about the experience. Some still prefer only face-to-face material delivery to blended learning, while most appreciated the ability to go back and review the online materials. The amount of material available would be well served with a search or index function, however that is still not an option for the learning management system beyond what is provided as a course overview. During the early blended course iterations, instructors were learning how to manage the new course format, make the CEAB-GAs explicit to students, encourage students to adopt the CEAB-GAs as their goal, and nurture the development of the graduate attributes as an *engineering identity*.

References

Atwater, L. E., & Yammarino, F. J. (1992). Does self-other agreement on leadership perceptions moderate the validity of leadership and performance predictions? Personnel Psychology, 45, 141-164.

Archer, M., Decoteau, C,. Gorski, P. Little, D., Porpora, D., Rutzou, T., Smith, C., Steinmetz, G., and Vandenberghe, F., (2016). What is Critical Realism? *Perspectives*, 38(2), pp. 4-9.

Bass, B.M., (1985). Leadership and performance beyond expectations. New York: Free Press.

Biggs, J., (1999). What the student does: teaching for enhanced learning, *Higher Education and Development* 18(1): 57-75.

Bhaskar, R. (1975). A realist theory of science. London: Verso.

Bhaskar, R., (2016). Enlightened Common Sense, the Philosophy of Critical Realism, edited by Mervyn Hartwig. London: Routledge.

Burns, J.M., (1978). Leadership. New York: Harper & Row.

Canadian Engineering Accreditation Board, “Canadian Engineering Accreditation Board: Accreditation Criteria and Procedures”, Ottawa: Canadian Council of Professional Engineers, 2014.

Canadian Engineering Accreditation Board (2018). Continual Improvement Rubric v3.2 https://engineerscanada.ca/accreditation/accreditation-resources [Accessed January 25, 2019]

Clark, A.M., Lissel, S.L., Davis, C. (2008). Complex Critical Realism: Tenets and Application in Nursing Research *Advances in Nursing Science*, 31(4), pp. E67-E79.

Clark, A.M., Briffa, T.G., Thirsk, L., Neubeck, L., Redfern, J., (2012). What football teaches us about complex health interventions *BMJ: British Medical Journal*, 345 (7888), pp. 25-27, Published by: BMJ Stable URL: http://www.jstor.org/stable/23493387 [Accessed: 22-06-2018 19:48 UTC]

Centre for Critical Realism (CCR) (2016). Roy Bhaskar – Transcendental Realism *About Critical Realism* CCR Blog at WordPress.com https://centreforcriticalrealism.com/about-critical-realism/basic-critical-realism/ Website established 1997 [Accessed: 22-06-2018]

Catmull, E., Wallace, A. (2014). Creativity, Inc.: Overcoming the Unseen Forces That Stand in the Way of True Inspiration. Random House: s.l.

Colcleugh, D., (2013). Everyone A Leader: A Guide to High Performance Organizations for Engineers and Scientists. University of Toronto Press: Toronto

Condon, R.J., (2011). The Relationship between Self-Awareness and Leadership: Extending Measurement and Conceptualisation, University of Canterbury.

Creswell, J. W. (2005). Educational research: Planning, conducting, and evaluating quantitative and qualitative research (2nd ed.). Upper Saddle River, NJ: Pearson.

Creswell, J. W., Poth, C.N. (2018). Qualitative Inquiry and Research Design: Choosing among five approaches. (4th ed.). Thousands Oaks: Sage Publications

Donnell, J. A., Aller, B. M., Alley, M., & Kedrowicz, A. A. (2011). Why industry says that engineering graduates have poor communication skills: What the literature says. ASEE Annual Conference And Exposition, Conference Proceedings, (118th ASEE Annual Conference and Exposition), 13p.

Donia, M., O'Neill, T. A., & Brutus, S. (2015). The power of awareness: Increasing student performance in teams through repeated exposure to peer feedback. Poster presented at the annual meeting of the Canadian Psychological Association, Ottawa, ON.

Durning, S. J., & Artino, A. R. (2011). Situativity theory: A perspective on how participants and the environment can interact: AMEE Guide no. 52. *Medical Teacher*, *33*(3), pp. 188-199. doi:10.3109/0142159X.2011.550965

Dutson, A.J., Todd, R.H., Magleby, S.P., and Sorensen, C.D., (1997). A review of literature on teaching engineering design through project-oriented capstone courses. Journal of Engineering Education, 86(1), pp. 17-28.

Entwistle, N. J. (1992). The Impact of Teaching on Learning Outcomes. Sheffield: CVCP, USDU.

Grant, A. (2016). Originals: How Non-Conformists Move the World. Viking: New York.

Henton, M. (1996). Adventure in the Classroom: Using Adventure to Strengthen Learning and Build a Community of Life-long Learners. Dubuque, Iowa: Kendall/Hunt.

Isaacson, W. (2014). The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution. Simon & Schuster: New York, NY.

Ivey, M., Dew S., Mandal M., Mohamed Y., Nychka J.A., Raboud D., Carey J.P., (2017). Using post course assessments to involve instructors in the continuous improvement process. *Proc. 2017 Canadian*

Engineering Education Conference (CEEA17), G. Evans (ed) (Toronto, Ontario; 4-7 June 2017), Paper 041.

Ivey, M., Mohamed Y., Musilek P., Raboud D., Rajendran A., and Carey J.P., (2018). Using a common course syllabus as part of the quality control loop and accreditation data collection process. *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) (Vancouver, British Columbia; 3-6 June 2018), Paper 034.

Jamieson, M.V., (2016). "Application of Blended and Active Learning to Chemical Engineering Design Instruction", University of Alberta

Jamieson, M.V., and Shaw, J.M. (2017). Applications of peer teaching and deep learning in engineering education course design. *Proceedings of the 7th International Conference on Mechanics and Materials in Design* Albufeira/Portugal 11-15 June 2017. Editors J.F. Silva Gomes and S.A. Meguid. Publ. INEGI/FEUP.

Jamieson, M.V., and Shaw, J.M. (2017). Applying metacognitive strategies to teaching engineering innovation, design, and leadership. *Proc. 2017 Canadian Engineering Education Conference (CEEA17)*, G. Evans (ed)(Toronto, Ontario; 4-7 June 2017), Paper 045.

Jamieson, M.V., and Shaw, J.M. (2018). CATME vs. ITP Metrics – Which one should I choose? *Proceedings of The American Society for Engineering Education Annual Conference & Exposition*, *(ASEE18)*, Salt Lake City, Utah; 24-27 June 2018.

Jamieson, M.V., Shaw, J.M., (2018). Graduate attribute based continuous improvement in a blended learning engineering design course – a writing seminar case study. *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) (Vancouver, British Columbia; 3-6 June 2018), Paper 77.

Jamieson, M.V., Shaw, J.M., (2016). Pre and Post Course Student Self Assessment of CEAB Graduate Attributes - A Tool for Outcomes Assessment, Student Skill and Course Improvement. Proc. 2016 Canadian Engineering Education Association (CEEA16) Conf. Paper 037; Dalhousie University; June 19 – 22, 2016

Jamieson, M.V., Shaw, J.M., "Student and Instructor Satisfaction and Engagement with Blended Learning in Chemical Engineering Design", Proc. 2017 Canadian Engineering Education Association (CEEA17) Conf. Paper 040; University of Toronto; June 4 – 7, 2017

Jamieson, M.V., Shaw, J.M., (2018). Teaching Engineering Innovation, Design, and Leadership within a Community of Practice. *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) (Vancouver, British Columbia; 3-6 June 2018), Paper 113.

Jamieson, M.V., Church, L., Vagi, F., Pick,W., Onuczko, T., Nychka, J., Nocente, N., Shaw, J.M. (2015). The University of Alberta chemical engineering capstone design course goes flipped! Proc. 2015 Canadian Engineering Education Conf. (CEEA15),

Johnson, S. (2014). How We Got to Now. Penguin Group: London, UK.

Johnson, S. (2011). Where Good Ideas Come From: The Natural History of Innovation. Riverhead Trade.

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge, UK: Cambridge University Press.

Lhuillery Stéphane, Julio Raffo, and Intan Hamdan-Livramento, (2016). Economic Research Working Paper No. 31, Measuring Creativity: Learning from Innovation Measurement. World Intellectual Property Organization (WIPO), Geneva.

National Research Council. (1995). Engineering Education: Designing an Adaptive System. Board on Engineering Education. Washington, D.C.: National Academy Press.

National Research Council. (1997). Science Teaching Reconsidered: A Handbook. Washington, DC: The National Academies Press. doi: 10.17226/5287.

National Science Foundation (NSF). (1995). Restructuring Engineering Education: A Focus on Change. Report of an NSF Workshop on Engineering Education, June 6-9, 1994. NSF 95-65. Arlington, Va.: NSF.

O'Neill, T. A., Hoffart, G. C., McLarnon, M. W., Woodley, H. R., & Allen, N. J. (2018). The Structure and Function of Team Conflict State Profiles. *Journal Of Management*, *44*(2), 811-836.

O’Neill, T. A., Park, S., Larson, N., Deacon, A., Hoffart, G., Brennan, R., Eggermont, M., & Rosehart, W. (2015). Peer ratings and intentions to change: Adopting the CATME to explore outcomes of peer ratings. *ASEE Annual Conference And Exposition, Conference Proceedings*, *122nd ASEE Annual Conference and Exposition: Making Value for Society* (122nd ASEE Annual Conference and Exposition: Making Value for Society),

Oslo manual. [electronic resource] : guidelines for collecting and interpreting technological innovation data. n.p.: Paris : Organisation for Economic Co-operation and Development : Statistical Office of the European Communities, 2005., 2005. University of Alberta Library, EBSCOhost (accessed February 11, 2018).

Pembridge J. J., Paretti, M. C., (2010). The Current State of Capstone Design Pedagogy. Proceedings of the American Society for Engineering Education Annual Conference & Exposition, (*ASEE10*), Louisville, KY.

Pembridge J. J., Paretti, M. C., (2011). An Examination of Mentoring Functions in the Capstone Course. Proceedings of The American Society for Engineering Education Annual Conference & Exposition, (*ASEE11*),Vancouver, British Columbia.

Pond, K., Ulhaq, R., & Wade, W. (1995). Peer Review: A Precursor to Peer Assessment. *Innovations In Education And Training International*, *32*(4), 314-23.

Stake, R.E., (2006). Multiple Case Study Analysis, Guilford Publications, pp. 1-16.

Sosik, J.J., & Megerian, L.E., (1999). Understanding leader emotional intelligence and performance. Group Organization Management, 24, 367-390.

Watson E., Ivey, M., Mohamed Y., Musilek P., Raboud D., Rajendran A., Carey J.P., (2018). Building a culture that values learning outcomes as an integral part of effective program development - one faculty’s example, *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) (Vancouver, British Columbia; 3-6 June 2018), Paper 030.

Wilkinson, A. (2015). The Creator's Code. Simon & Schuster: New York, NY.

Wulf, W.A. (1998). The urgency of engineering education reform. The Bridge 28(1):15-21.

Appendix D. Learning to Learn: Defining an Engineering Learning Culture

Proceedings of the 2019 Canadian Engineering Education Association (CEEA19) Conference
Full Peer Reviewed Paper[18]

Marnie Vegessi Jamieson and John M. Shaw
Department of Chemical and Materials Engineering, Faculty of Engineering, University of Alberta

Abstract *– Learning is a cultural construct. Beliefs, perceptions and values regarding learning shape the culture of a classroom and a program of study. A framework for engineering education and engineering education research grounded in the Canadian Engineering Accreditation Board (CEAB) Washington Accord derived Graduate Attributes and engineering practice is proposed. Methods and activities to shape a learning culture in engineering design education consistent with a community of practice and lifelong learning are also proposed. This transformational approach offers an opportunity to teach lifelong learning and integrate engineering practice and engineering education, while entrenching graduate attributes more deeply in the engineering curriculum. Accountability, engagement, recognition, motivation, appreciation, credibility, and continual improvement are key elements of a functional learning culture. Learning moments are a concise way to make learning to learn a relevant part of each session and encourage student reflection and metacognition.*

Keywords: Community of Practice, Graduate Attributes, Design, Capstone, Student, Self, Outcomes, Course, Life Long, Learning, Culture, Competency-based, Metacognition, Engagement, Motivation, Reflection, Learning Moments, Engineering Education Framework

D.1. INTRODUCTION

This contribution describes the definition and development of a learning culture framework, its foundation in the literature, and its application to engineering design education. To define a learning culture we examine conceptions and beliefs regarding learning, teaching, community, intelligence, motivation, accountability, innovation, and learning culture design.

A learning culture is developed in an engineering program of studies as a result of interactions between learners, teachers, system designers, and administrators. In this work we investigate the underlying philosophical orientations and themes of a learning culture relevant to graduate attribute

---

[18] The original paper has been modified slightly for inclusion as an Appendix in this doctoral dissertation. It includes additional explanations and the paper appendices are incorporated as figures or in the text.

development. This work attempts to answer several questions related to the interaction of engineering education with the graduate attributes. The initial presumptions are outlined below.

What defines a learning culture? Beliefs, perceptions, and values regarding learning and intelligence underlie the preparation of course materials, delivery, assessment, and the ensuing student approaches to learning [1,10,11,12,24,29,55,58]. The learning framework and philosophical orientation we choose to inform learning activity design whether behaviorist (empiricist), cognitive (constructivist/ rationalist), or situative (pragmatist/functionalist) [31,57], has defining elements rooted in differing philosophical perspectives (Figure D.1) The methodology and methods we choose to deliver learning activities, courses and indeed programs are grounded in our values (axiology), our belief regarding the nature of knowledge and how we come to know (epistemology), and our beliefs regarding the nature of reality (ontology). Figure D.2 aligns direct interactions with an instructor with the realist ontology where knowledge is acquired by observation and transmitted by sharing and demonstrating these observations. An example of this would be students carrying out experiments that are designed for them by an instructor who wishes to transmit certain observations and related conceptions to the student. These direct interactions can also be the experience and construction of ideas by the instructor for the students. Face to face teacher-centered institutional instruction with grades as a reward for learning the specified items is characteristic of this type of learning culture. Indirect interactions are aligned with the relativist perspective and the idea that learning is constructed by the student and is dependent on the integration of the material into the student's prior experiences. Face to face student centered instruction with limited formative or no assessment would characterize this learning culture. The unschooling movement would be an example of the relativist and constructivist perspectives embracing learning as a natural and subjective relational activity. Formal assessment is sometimes imposed by government regulatory bodies but is inconsistent with an unschooling approach. A community of inquiry would be characteristic of this approach; questions are answered, discussed, and learning is modeled for the learners. Online, face-to-face, or blended learning courses may emulate either direct or indirect teacher student interactions depending on whether the delivery is synchronous or asynchronous. Asynchronous delivery is more likely to have indirect interactions. Depending on the method of learning assessments chosen, any form of instruction may include realist or relativist perspectives of the nature of learning. A blend of direct and indirect interactions is characteristic of a learning community of practice where the teacher assessor is an instructional guide who leads the student centered learning process. The assessment is a blend of formative and summative with assessment and feedback from multiple sources. These perspectives can be utilized in a complementary fashion to achieve a variety of learning outcomes [31,68] using critical realism [7] and metacognitive teaching strategies [26] to support outcomes-based engineering education [36,45,46,49,50,58] and continual improvement [44,46].

What characteristics are required to be an engineer? The twelve CEAB outcome-based performance criteria, referred to as graduate attributes [14], include fundamental knowledge, comprehension, analysis, socio-contextual, metacognitive, and professional practice outcomes [13,55,56,65,66]. The CEAB graduate attributes are based on international agreements distinguishing characteristics of engineering work from technologist and technician work [36,37]. Outcomes-based assessment criteria can be conceptualized as holistic and context-dependent combinations of knowledge, skills, and attitudes [35,56]. An engineering identity is grounded in an engineering program including design and project-based learning experiences [14,36,37] aimed at integrating fundamental and complementary knowledge with metacognition in a professional community of practice.

What defines an engineering learning culture? A theoretical framework identifies the major themes of a phenomenon of interest. The supporting conceptual framework is a network of linked concepts [35]. The CEAB graduate attribute performance outcome measurement and the phenomena of their application to a continual improvement process [14] for engineering education presuppose ontological (related to the nature of reality and existence) and epistemological (related to the nature of knowledge and systems) assumptions or beliefs. A thematic analysis of graduate attribute pre-post process design course student self-assessment constructs [46] accompanied by extensive reading, and categorization of graduate attribute related literature and discourse produced four core engineering education themes: core content knowledge, socio-contextual knowledge, professional skills, and metacognitive skills. These core graduate attribute themes inform a proposed theoretical framework (Figure D.3) that may be employed for engineering education learning culture development and continual improvement processes [41,44]. The CEAB graduate attributes along with their history, mapping, implementation, implications for engineering practice and identity inform the conceptual framework (Figure D.4) elaborated in this contribution. The proposed conceptual framework was developed using a multistep conceptual framework analysis process [39] presented in the methodology section. The penultimate step of the process is the presentation of the proposed framework to scholars and practitioners for validation, a key objective of this work.

We propose using the theoretical framework presented in Figure D.3, for positive learning culture development in engineering education and for fostering an emerging professional engineering identity, in students, as anticipated by CEAB graduate attribute attainment levels at the end of an engineering program.

Key Framework Relationships

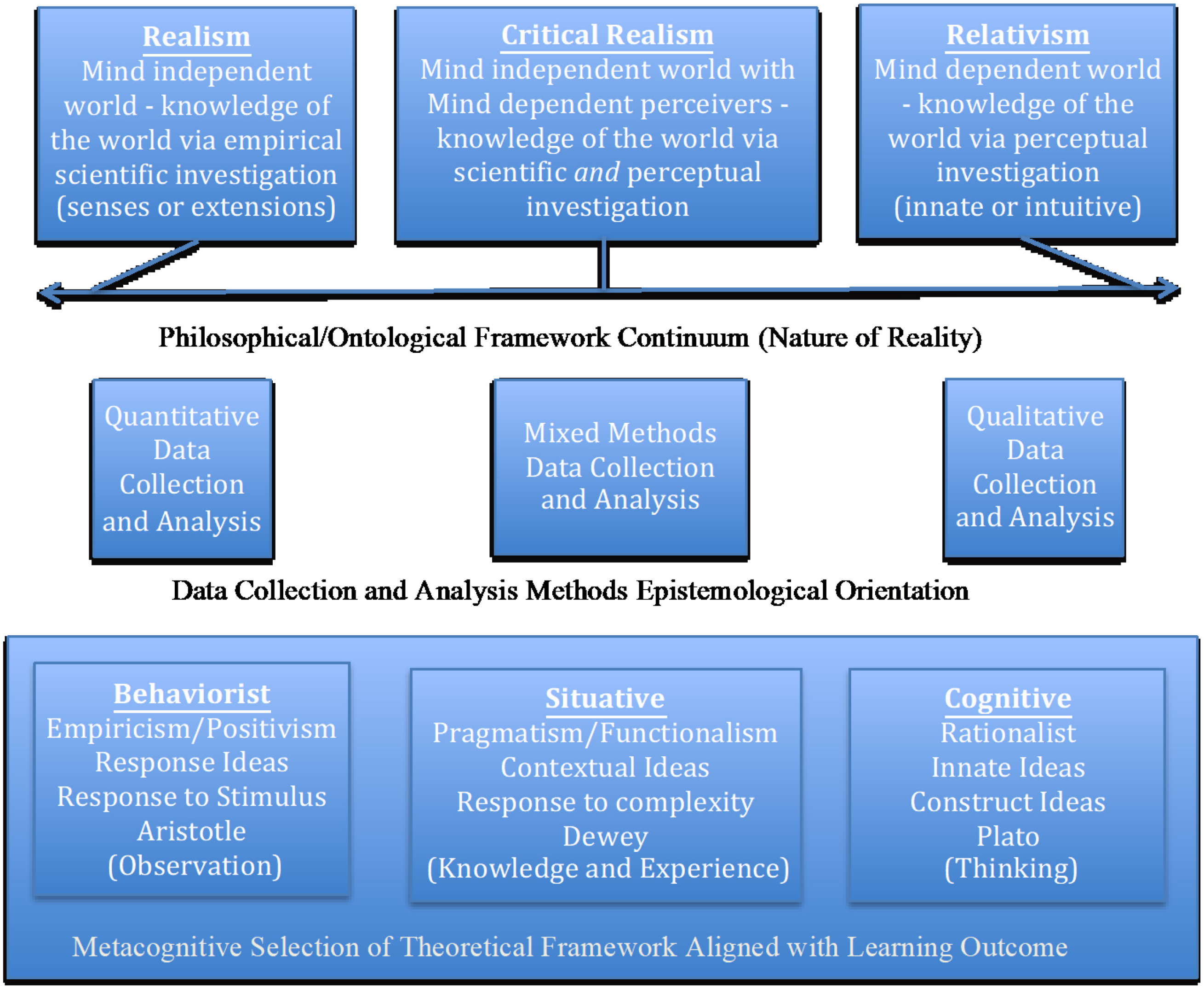


Figure 1. Key Learning Theoretical Frameworks with Underlying Philosophical Frameworks

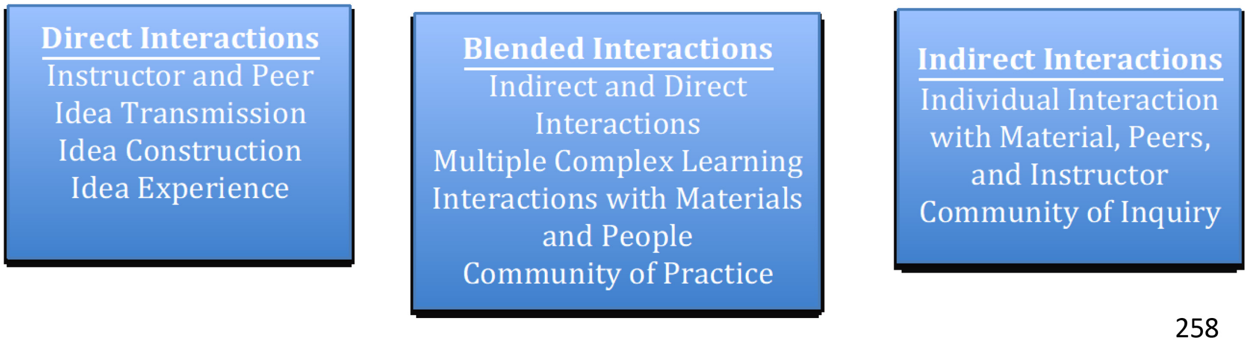


Figure 2. Combined Metacognitive Course and Program Delivery Frameworks

D.1.1 Literature Review

Engineering work is *complex* [16] and is typically a response to a societal need. Engineering education can also be described as *complex* and a response to societal needs. This complexity includes the development of a transferable learning culture [34]. A learning culture is developed regardless of whether we pay attention to its development. Elements of a positive learning culture include accountability behaviours, self-regulation, engagement with cognitive tasks, appropriate level of task difficulty, community, motivation for learning, recognition of achievement, appreciation of effort, and credibility. We explore this complexity in the literature.

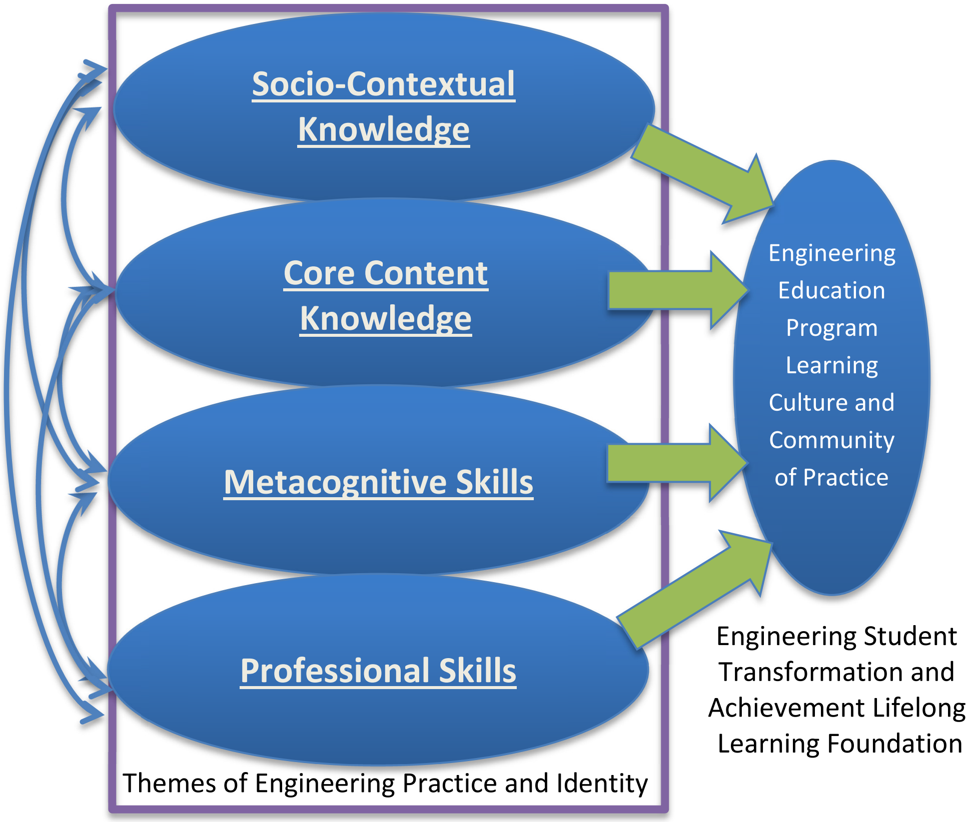


Figure D.3. Proposed Engineering Education and Practice Theoretical Framework

D.1.1.1 Learning and Teaching. Student development and learning can be enhanced with metacognitive strategies, feedback, engagement, spaced practice [35], contextual content, and realistic practice [34]. Including these strategies in a program of study and deliberately teaching learning behaviors, concepts, and strategies assists students to develop the technical, contextual, metacognitive [26,68], and professional skills required to achieve the CEAB graduate attribute performance outcomes, and supports the emergence of a positive learning culture foundational to life-long learning [2,12,18,29,34,36,55,58,71]. "Teachers who consider their students' self-efficacy beliefs, goal setting, strategy use, and other forms of self-regulation in their instructional plans not only enhance students' academic knowledge, but they also increase their students' capability for self-directed learning throughout their life span." [71, p.35] Human learning and self-regulation are a complex interplay between behavioral, cognitive/ affective, and environmental/social factors [71].

Behaviorist learning theories have evolved toward neural network knowledge models [31], and support retrieval and organization of knowledge in response to stimuli. Content tends to be hierarchical and progressive from simple to complex. Cognitive learning theories [31,36,48] support student knowledge acquisition as concepts and knowledge development processes in active learning environments [26,30,36,48,57]. Students who develop self-conscious management of the learning process (metacognition) often perform better than those who do not [8,9,13,31,36,50]. Situative or functional (contextual) learning theories including student discourse related activities such as collaborative learning, leadership, task planning, and work strategies combined with iterative design processes can lead to metacognitive regulation and a recursive learning cycle [20,23,35,54,52,58]. Reflection during learning cycles leads to targeted practice that further develops technical, design, team, and leadership skills that transfer to new circumstances [2,11,12,36,46]. A community of practice is inherently a situative learning environment since it requires participation in relevant discourse on discipline knowledge, concepts, and applications [29,30,31,46]. These learning orientations reflect differing perspectives on the nature of knowledge, learning, and motivation, but all address knowledge aggregation - from individual to societal and from simple to complex.

D.1.1.2 Failure and Intelligence. Instructor responses to student successes, struggles, and failures impact student outcomes [24,58,61]. Valuing effort and failure associated with the learning process can result in the development of a growth mindset associated with student achievement and success [24,33,58,61]. Strategy-based instructor feedback on student performance can positively impact student motivation and investment in learning while feedback intended to comfort following a struggle or failure does not [61]. In addition, student beliefs about intelligence as an entity theory construct (fixed mindset) is related to their overconfidence level and a preference for ease in learning activities while an incremental theory construct (growth mindset) is related to a more accurate estimation of abilities (greater self-insight), and a tendency to attempt more challenging problems [25]. Student and instructor beliefs about intelligence, effort and strategy can change when presented with new conceptions and evidence to consider [24,25,33,58,61].

D.1.1.3 Motivation and Accountability. Life-long learning is characterized by initiative, independence, self-discipline, curiosity, confidence and persistence in learning; accepting responsibility for learning; viewing problems as challenges not obstacles; use of basic study skills, time management, pacing, task planning, goal setting, and learning enjoyment [32,58,59]. Guglielmino [32] characterizes life-long learning as a collection of values, beliefs, behaviors, and perceptions about learning and personal efficacy when learning. "*Life-long learning may operate as a critical resilience factor that combats fatigue and exhaustion associated with the ongoing demands and challenges…*" [59, p.128].

D.1.1.4 Innovation. Innovation processes [46,63] and effectuation thinking [63,64] can be employed in design courses. Contextual learning of this nature is described as *strengthening the practices of the community* [31, 55]. To be effective learners must be offered *legitimate peripheral participation* [34,55]. Innovation requires thinking processes, goal setting [60], and strategies [21,36,51,63,64] including effectuation thinking [63,64]. Effectuation describes a thinking process used when there is uncertainty and imagined solutions must be developed from available means within constraints. The practice of innovation requires an environment where development of imagined ends is necessary [21,51]. Learning innovation requires legitimate participation in a community of practice where innovation is valued. Student participation in a community of practice affords opportunities for development of innovation, leadership, and professional capabilities [41,48].

D.1.1.5 Learning Culture Design. Online and blended learning environments have highlighted the importance of the social and community aspects of learning. An online learning community of inquiry requires social, cognitive, and teaching presences to be effective [30]. This necessitates student *cognitive* engagement with content, engaged social *behaviors*, and learning goals [60] in the *context* of the discipline standards and the communication media. These elements describing an online learning *culture* are found in face to face, blended [27,28,47,69], and corporate based learning cultures [1,22,70]. They are essential elements of mentorship [67], lifelong learning practices [2,58,67] and pre-industrialization and Indigenous communities of practice [22]. *"Social cognitive theory assumptions address the reciprocal interactions among persons, behaviors, and environments; enactive and vicarious learning (i.e., how learning occurs); the distinction between learning and performance; and the role of self-regulation"* [67, p.119]. An evidence based learning culture supporting graduate attribute outcomes recognizes learning for individual students is unique *and* common. Learning precedes performance. Strategies for learning (and teaching) can be examined and chosen depending on the nature of the graduate attribute performance outcome. A learning culture leverages a contextual community of practice, innovation opportunities, growth mindsets and life long learning characteristics. It encompasses multiple learning perspectives, engagement dimensions, and the values rooted in the graduate attribute outcomes and emerging professional engineering identities.

D.1.2 Philosophical Framework

Critical Realism [7] allows for individual subjective human interpretation of an objective independent reality or existence [15]. Critical realism separates ontology (views of the nature of reality and existence) from epistemology (views of the nature of knowledge and systems) [17]. The cultural, moral, technological, economic, environmental, and safety realities of individuals 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"* [41, p.5].

The phenomena studied may influence our ontological perspective. Phenomena can be complicated or *complex* [16]. A complicated phenomenon is one where an outcome can be reliably predicted using the past behaviour of the system, mathematical modeling, and prediction [16]. A *complex* phenomenon is one where the outcome is not easily predicted. There are many interacting variables and outcomes are not easily or reliably measured and modeled mathematically [16]. Our ontological framework is Complex Critical Realism (CCR) [15]. Our epistemological framework is situative (knowledge is contextual) and depending on the research question, qualitative, quantitative, or mixed methods may be required [19] as illustrated in Figure D.1.

A practice based learning culture is rooted in CCR. More than just a pragmatic view of using "whatever works" for an individual to achieve the learning outcomes; complex critical realism ***expects*** different perspectives (behaviourist, cognitive, and situative) in a complex system. The learning tools associated with theories that describe part of the whole can be combined in an emergent learning environment that is the sum of the parts. Learning tools are selected by learners and teachers depending on the task at hand to achieve the common goal of graduate attribute outcome achievement during a course or a program of study [41].

D.1.3 Problem Definition and Motivation

The rapidly changing work of engineers [53] creates additional tension between historical engineering education paradigms and the requirements for practicing engineering now and in the near future. The continual improvement process and focus on graduate attribute development will have an ongoing impact on our learning culture. Developing the capacity for life-long learning and the ability to integrate it into a sustainable learning culture is the key motivation for this work. Our ongoing continual improvement process [38,40,41,44] initially focused on the capstone process design course was then extended to the process design course sequence and now to collaboration with administrators and other instructors to achieve program and cultural improvements.

D.1.4 Solutions Explored

The capstone process design course instructors participated in an ongoing university wide digital learning initiative. The objectives of the instructors were to enhance the interactions between instructors and student design teams [49] and to align the course strategically with the graduate attributes [14]. A blended-learning project-based course structure was designed and implemented using aligned course objectives, learning activities, and performance based assessment. The course was evaluated and compared to the traditional delivery iterations [40,45]. A continual improvement process [40,41] grounded in the performance attribute work of Hattie [35] and the constructive alignment work of Biggs [6] was recommended, as were specific continual improvement interventions [40,42-50]. Further work led to the identification and enhancement of the metacognitive structure of the capstone chemical process design course as three successive cycles built around design project phases and milestones (Figure D.5) [42,43], and a course based continual improvement process linked to the program level continual improvement process [38,41].

In this work, we explore the application of the proposed engineering education theoretical and conceptual frameworks (Figures 4.3 and 4.4) to learning culture development, graduate attribute achievement support, and a transferable learning orientation [1,18,34,62]. The adoption of complex critical realism as a philosophical framework allows for combined learning perspectives and tools to further support an effective graduate attribute informed learning culture (Figure D.1). A CCR perspective encourages instructors to examine the impact of their own experiences, beliefs, perceptions, and values on their teaching and is consistent with the scholarship of teaching and learning (SoTL). Industrial and practicing engineers allied with a design teaching team form a community of practice where committed practicing engineers contribute projects and *participate* in innovation and learning processes with students. This engagement provides an explicit learning space for discipline specific discourse and supports an incremental theory of intelligence by providing models of life long learners. *Learning Moments*, patterned like safety moments used to develop safety culture in industry, are proposed to enhance ongoing student engagement with metacognition, learning behaviors, cognitive strategies, and contextual professional practice.

D.1.5 Significance

Student and instructor feedback combined with writing assignments has provided qualitative data and is used along with quantitative assessment data for course evaluation and identifying improvement actions then used as input for the program level continual improvement process [41]. This process integrated with the application of the proposed theoretical and conceptual frameworks has led to the development of a learning culture supported by a discipline relevant community of practice. Students are engaged, motivated, and appear to enjoy design [47]. The learning culture established persists from year to year due to support from a stable design teaching team, community of practice, and inter-cohort peer to peer interactions.

D.2.0 DEFINING A LEARNING CULTURE

Undergraduate engineering curricula should provide opportunities for students to learn, practice, and demonstrate development of CEAB graduate attributes, to reflect on progress *and* then target next steps to continue learning. A learning culture supports this goal. Identifying the key elements of an *undergraduate engineering* learning culture and encouraging its growth improves the quality of undergraduate engineering education. Evidence based elements of our learning culture include: recognizing achievement and rewarding learning behaviors; engagement with cognitive and metacognitive development; growth mindset oriented feedback to encourage effort and to initiate strategies for improvement; contextual innovation and design processes with relevant contextual problems embedded in a community of practice. These elements embrace the behavioral, cognitive, contextual, and practice dimensions of learning and the learning required to be an engineer.

Learning moments and learning objectives presented at the start of each lecture or tutorial keep learning a priority. Frequent formative assessments with generous feedback leading up to summative assessments encourage learning *behaviors*. The construction of learning activities by students in an environment where the learning objectives of a program of study are consistent with the required assessments and outcomes are central to the theory of constructive alignment [6,27,31,35,67] and to *cognitive* course design. Learning about learning and reflective strategies [20,21,65,66,71] introduces students to and teaches them about metacognition, teamwork, design, and innovation processes

[34,35,40,48,52,57,58]. A blended and active learning environment engages students in engineering work processes and encourages reflection and sense making [27,35,40]. Ongoing formative feedback and self-assessment are inputs to a growth mindset [58] and life long learning [2,34]. A formal community of practice provides mentors and models of the engineering design and innovation process for students in a learning environment intended to give *contextual* practice of innovation, leadership, professional, and project management skills [42,48].

D.3.0 METHODOLOGY

Three related qualitative data analysis studies were undertaken to identify essential learning theory elements for a future relevant, graduate attribute achievement driven, and continually improving chemical engineering design course based learning culture. The overall intent of Study 1 is to develop the theoretical and conceptual frameworks (Figures 4.3 and 4.4) relating graduate attribute outcome achievement to the learning and development processes. The overall intent of Studies 2 and 3 is to identify key features in a learning culture informed by the CEAB graduate attributes, by examining the learning frameworks and conditions required to achieve the outcomes suggested by the graduate attributes. Study 2 uses learning theory coding tags to analyze the CEAB graduate attributes do determine if the use of multiple learning theories may be required for engineering learning culture development. Study 3 maps our design course learning activities to metacognitive cycles to understand how metacognition may be a part of design courses in general. The intent is to go from specific to look identify generalizable patterns and application to a broader conception of a practice based learning culture. The condensed version of the method used for Study 1, a *Conceptual Framework Analysis Process,* is composed of the following eight steps as outlined by Yosef Jabareen, 2009.

Step 1: Mapping the selected data sources: “This process includes identifying text types and other sources of data, such as existing empirical data and practices…it is also recommended to undertake initial interviews with practitioners, specialists, and scholars from various disciplines whose work focuses on the targeted phenomenon.” (Jabareen, 2009, p.53)

Step 2: Extensive reading and categorizing of the selected data: “The aim in this phase is to read the selected data and categorize it...This process maximizes the effectiveness of our inquiry and ensures effective representation...” (Jabareen, 2009, p.54)

Step 3: Identifying and naming concepts: “The aim in this phase is to read and reread the selected data and “discover” concepts (Glaser & Strauss. 1967; Strauss & Corbin. 1990). Its result is a list of numerous competing and sometimes contradictory concepts. Generally, this method allows concepts to emerge from the literature.” (Jabareen, 2009, p.54)

Step 4: Deconstructing and categorizing the concepts: "The aim of this phase is to deconstruct each concept; to identify its main attributes, characteristics, assumptions, and role; and, subsequently, to organize and categorize the concepts according to their features and ontological, epistemological, and methodological role. The result of this phase is a table that includes four columns. The first includes the names of the concepts; the second includes a description of each concept; the third categorizes each concept according to its ontological, epistemological, or methodological role; and the fourth presents the references for each concept." (Jabareen, 2009, p.54)

Step 5: Integrating concepts: "The aim in this phase is to integrate and group together concepts that have similarities to one new concept. This phase reduces the number of concepts drastically and allows us to manipulate to a reasonable number of concepts." (Jabareen, 2009, p.54)

Step 6: Synthesis, resynthesis, and making it all make sense "The aim in this phase is to synthesize concepts into a theoretical framework. The researcher must be open, tolerant, and flexible with the theorization process and the emerging new theory. This process is iterative and includes repetitive synthesis…until the researcher recognizes a general theoretical framework that makes sense." (Jabareen, 2009, p.54)

Step 7: Validating the conceptual framework "The aim in this phase is to validate the conceptual framework. The question is whether the proposed framework and its concepts make sense not only to the researcher but also to other scholars and practitioners. Does the framework present a reasonable theory for scholars studying the phenomenon from different disciplines? Validating a theoretical framework is a process that starts with the researcher, who then seeks validation among "outsiders." Presenting an evolving theory at a conference, a seminar, or some other type of academic framework provides an excellent opportunity for researchers to discuss and receive feedback." (Jabareen, 2009, p.54)

Phase 8: Rethinking the conceptual framework: "A theory or a theoretical framework representing a multidisciplinary phenomenon will always be dynamic and may be revised according to new insights, comments, literature, and so on. As the framework is multidisciplinary, the theory should make sense for those disciplines and enlarge their theoretical perspective on the specific phenomenon in question." (Jabareen, 2009, p.55)

D.3.1 Study 1: Conceptual Framework Analysis Method

Here we investigated emerging common themes for the application of the graduate attributes to an engineering education continual improvement process. The scope of work included an analysis of the skills required for successful student teams in chemical process design using a multi-step conceptual framework analysis process described above with the goal of generalizing a theoretical framework.

In the first step, documents related to the history and development of the CEAB graduate attributes, performance outcome-based education, online and blended learning delivery, learning theories, motivation, intelligence, design, innovation, metacognition and reflection, engineering practice and leadership, lifelong learning, qualitative and quantitative research methods, continual improvement, and learning culture were identified. As I am a practicing engineer, my over thirty years of work experiences and interactions with colleagues were an incidental input to this step. The second step comprised "reading for a multidisciplinary perspective" and included engineering accreditation and work descriptions [14,36,37,52,53], education, education psychology, learning, innovation, metacognitive and life-long learning literatures. The results of this step are outlined in our literature review and presented as a graphical summary of the philosophical, epistemic, learning theory, and delivery framework relationships in Figure D.1. The next two steps comprised contextual and conceptual analysis of pre-post course student skill self-assessment constructs. These constructs were developed from capstone design instructor observations from 2004 to 2014 of the knowledge, skills, and attitudes (KSA) a student team required to be successful and excel in the course. The same process was applied to selected documents including the CEAB graduate attribute descriptions, graduate attribute accreditation evaluation procedures [14], International Engineering Alliance documents related to the Washington Accord [36,37], and our existing practices. During the fifth step, key themes describing engineering education were identified. These resulted in the theoretical framework presented in Figure D.3. The conceptual network (Figure D.4) and the metacognitive course structure (Figure D.5) are outcomes of step six.

The seventh step is the validation of the proposed theoretical and conceptual frameworks shown in Figures D.3 and D.4. As presented in Table D.1, this step progressed over eighteen months and includes feedback from presentations at eight conferences, two posters, four papers, three workshops, and extensive personal communications with engineers, nurses, mixed methods researchers, engineering education researchers, instructors, designers, and colleagues.

D.3.2 Study 2: Graduate Attribute Outcome Learning Framework Categorization Coding

Here we categorized the CEAB graduate attributes using behaviorist (empiricist), cognitive (rationalist), or situative/contextual (pragmatic/functionalism) tags, and studied the philosophical underpinnings of the graduate attributes, the design course, and our developing learning culture. The purpose of study 2 was to examine the graduate attribute outcomes and determine the perspective that might be required to teach and learn how to demonstrate graduate attribute attainment achievement.

D.3.3 Study 3: Metacognitive Structure Mapping Method

Here we mapped the course cognitive and metacognitive structure. We considered impacts of time progression, social cognitive interactions including the community of practice and course milestones. The metacognitive cycle structure of plan/monitor/reflect was applied. The plan/do/check/act cycle could also be applied and mapped to the course structure. The former was chosen to make the act of reflection explicit for students when the model is presented as a learning moment.

Table D.1. Theoretical and Conceptual Framework Development and Validation Presentations

Step	Conceptual Framework Analysis Activity
1	✔Mapping the selected data sources
2	✔Extensive reading and categorizing the selected data sources
3	✔Identifying and naming concepts – Graduate Attributes
4	✔Deconstructing and Categorizing the Concepts
5	✔Integrating the Concepts
6	✔Synthesis and resynthesis and Making it all make sense
7	✔Validating the conceptual framework
May 31-June 2	✔CCWEST 2018 Edmonton (Equity, Diversity, Inclusivity Team Focus)
June 20	✔IIQM 2018 Thinking Participatively (Methods Interdisciplinary Focus -poster)
October 28-31	✔CSChE 2018 Toronto (Engineering Education Focus – journal paper)
March 26-28	✔MMIRA-CC 2019 (Mixed Methods Design and Interdisciplinary Focus)
May 12-16	✔PPEPPD 2019 (Thermodynamics and Design Focus - poster)
June 9-12	✔CEEA 2019 (Engineering Education Research Focus – paper and workshop)
June 15-20	✔ASEE 2019 - Continual Improvement (Leadership Focus - paper)
June 26	✔Metacognition and Lifelong Learning 2019 – Faculty Forum PD (workshop)
August 14-18	✔Diseño de Plantas Peru 2019 – Professional Development (workshop)
September 3-6	✔M2D2019 (Interdisciplinary Design Education Focus – paper and forum)

D.4.0 RESULTS AND DISCUSSION

In this work and for the purpose of validating the framework a brief summary of the results is included.

D.4.1 Study 1: Conceptual Framework Analysis

A team selection tool requires the capstone design teams to collectively identify their individual skills brought to the team and to develop a plan to address their collective weaknesses. Although the intent of the tool has been consistent historically, during the blended course redevelopment the activity was moved online (2015) and later integrated into the introductory design course. As a result of previous graduate attribute mapping, the identified skills are categorized using the CEAB graduate attributes. The pre and post course self-assessment activities measure student perceptions of their development with respect to the attributes. Irrespective of the ongoing activity development and continual improvements applied, the skills have remained consistent and describe skills teams need to complete their process design projects successfully [40,46]. The graduate attributes were analyzed for common themes using the categorized pre-post test KSA constructs and the graduate attribute descriptions. Four themes emerged from the analysis of the two key data sources. Documents listed in the references were used to provide further categorical evidence. The skills were sorted into four themes to produce the conceptual framework presented in Figure D.4. It is noted that some of the KSA constructs overlap thematic classifications. For example, validation requires core content knowledge and metacognitive skills; innovation, risk management, and environmental sustainability all require core content knowledge, socio-contextual knowledge, and metacognitive and professional skills. These constructs are placed at the boundaries to recognize the complexity of the constructs and their link to engineering practice opportunities and experience.

D.4.2 Study 2: Graduate Attribute Outcome Learning Framework Categorization Coding

A qualitative textual analysis of the twelve CEAB Graduate Attributes with respect to the categorization of the behavioral, cognitive, and contextual response expected by the graduate attribute outcome descriptions is summarized in Table D.2. The tagged classifications are presented in Figure D.6. An item was tagged as behavior if the primary response is a behaviorist expectation and/or a response to a stimulus (if *condition* then *expected action*); items were tagged as cognitive if the primary response was a cognitive expectation and or related to constructing meaning; items were tagged as situative if the response was classified as primarily contextual and/or was likely to require multiple integrated perspectives to develop a response. Cognitive task descriptions in the graduate attributes such as analyze, synthesize, evaluate, create were typically tagged as cognitive and descriptors such as understand, demonstrate, were tagged as behaviorist as a response to a stimulus appears to be expected. If an item could be categorized more than once, a forced choice was made with a bias to the category that was not already noted for a specific graduate attribute.

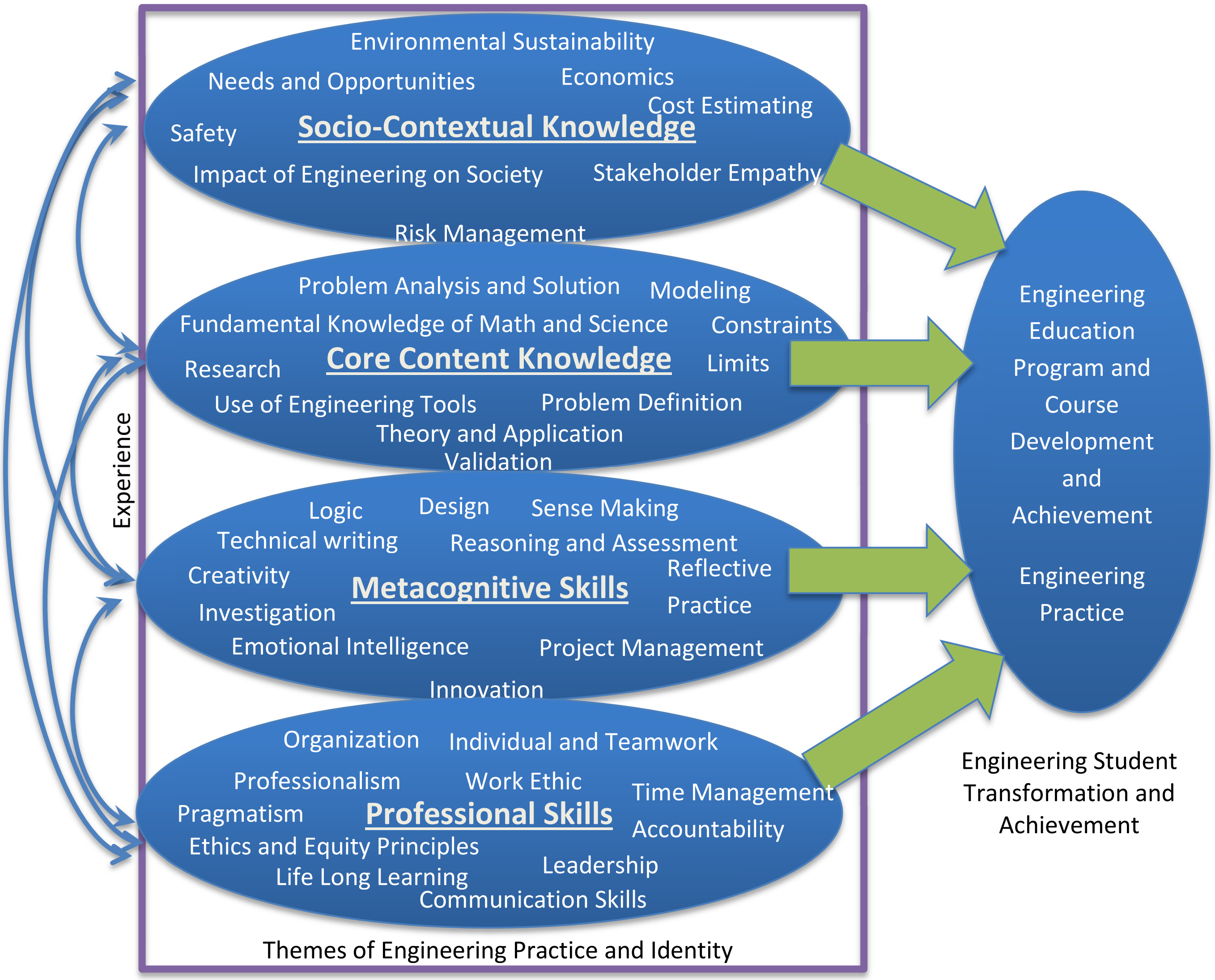


Figure D.4. Proposed Engineering Education and Practice Conceptual Framework

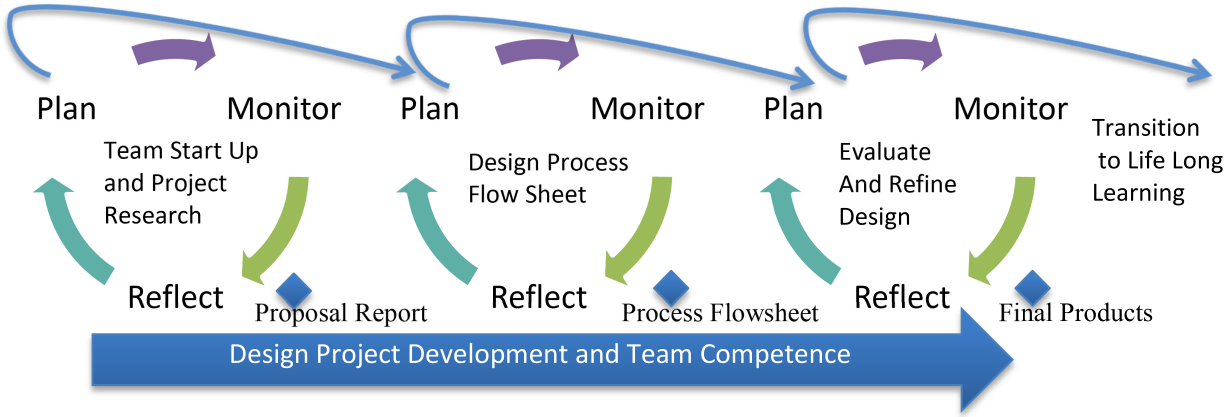


Figure D.5. Design Course Metacognitive Cycles Progressing Team and Project Development

The coding for: “***9. Impact of engineering on society and the environment”*** provides an illustrative example. *“An ability to analyze”* is tagged as a cognitive response as it suggests constructing meaning. An ability to *construct* an analysis of possible or actual impacts and rate or classify impacts whether quantitatively or semi-quantitatively and according to degree of impact relative to ranking criteria. The remainder of the phrase *“social and environmental aspects of engineering activities,”* is tagged as situative because it requires a contextual response or evaluation of the quantitative and qualitative data required for the analysis content *and* context. *“Such ability includes an understanding of interactions that engineering has”*. Understanding is a response to a stimulus (a requirement to understand) and is coded as behaviorist. *Engineering interactions with…* is coded as cognitive as it suggests cognitive analysis and sorting. *“[W]ith the economic, social, health, safety, legal, and cultural aspects of society,”* is contextual and is coded as situative. *“[T]he uncertainties in the prediction of…”* is coded as cognitive for the conceptual relationship uncertainty analysis underlying the extension to the use and integration of the contextual information which is coded as situative. *“[S]uch interactions and the concepts of sustainable design and development and environmental stewardship* were coded as a response to accountability requirements, and thus behaviorist. *Concepts* was coded cognitively and *interactions* was coded as situative. Aspects of all three elements could be seen in this text. Elements of all three learning theory perspectives were found in each graduate attribute.

Table D.2. Study 2 Summary: CEAB Graduate Attribute Learning Framework Response Coding

Attribute	Behaviorist	Cognitive	Situative
1	1	4	2
2	2	4	2
3	1	5	1
4	1	5	7
5	3	2	2
6	1	1	1
7	3	2	7
8	4	1	1
9	4	4	5
10	1	1	1
11	1	3	3
12	1	4	1
Total	23	36	33

D.3 Study 3: Metacognitive Structure Mapping

This study addressed the time structure and progression of student development and their design projects in the introductory and capstone process design courses. The structure of the milestone learning actives was found to comprise three metacognitive cycles per course that roughly span 4-week periods. The cycles, illustrated in Figure D.5, are characterized by formal interactions within the community of practice, the cognitive and behavioral requirements of the course to produce project milestone

CEAB Graduate Attribute Coding

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.*

Figure D.6. Canadian Engineering Accreditation Board Graduate Attributes (Response Coding)

Coding Legend: behaviour response *cognitive* response ***situative contextual*** response requirements, and the final products (reports, posters, presentations). Academic advisors and the student teams manage the behaviorist aspects of the cycles. Both design courses require initial reflection on individual and team personal development then further plan, monitor, and reflect cycles progress the design teamwork and the course toward completion.

D.5.0 CONCLUSIONS

The CEAB graduate attributes appear to describe an emerging professional identity and along with a continual improvement process determine the required characteristics of an undergraduate learning culture. The engineering education and practice framework was developed, in part, by the examination of the skills design instructors have historically observed to underlie student team success in the capstone process design course and more recently associated with successful graduate attribute achievement. The proposed theoretical framework was used to further develop the learning culture in the chemical process design sequence including metacognitive skill development activities. The theoretical framework consists of four themes: core content, socio-contextual content, metacognitive and professional skills. This theoretical framework is proposed along with the supporting conceptual framework as a basis for the creation of an engineering education learning culture informed by the CEAB graduate attribute outcomes.

Further examination of the graduate attributes in the context of learning frameworks indicates elements of behaviorist, cognitive, and situative learning constructs. It would appear the CEAB graduate attributes are conceptualized as holistic and context-dependent combinations of knowledge, skills and attitudes requiring a mixed learning theory framework to support development. An examination of the learning activities and learning culture created in the process design courses also demonstrates elements of a mixed learning theory framework. This is consistent with the adoption of complex critical realism as a philosophical perspective for engineering design education and the complimentary use of a variety of learning perspectives to achieve the *complex* CEAB graduate attribute performance outcomes.

Acknowledgements

The design course redevelopment was funded by the Provost's Office (University of Alberta). The CTL blended learning research project, of which this research is a part, received research ethics approval from the University of Alberta Research Ethics Board, No. *Pro00048272*. The authors acknowledge with thanks the support given by our community of practice – our students, our teaching team, our research community, and our industry participants. A special thank you to Drs. Michel Perrier, Sylvie Doré, Norma Nocente, and John Nychka for their helpful review and comments.

REFERENCES

[1] Annie Aarup, Jensen, Xiangyun Du, and Mikkel Kirkebæk. *Teaching and Learning Culture : Negotiating the Context*. Rotterdam : Sense Publishers, 2013.

[2] Richard J. Aleong, & David S. Strong, "The Development of Life-Long Learning Competencies: Positioning Students for Self-regulation," Proc. CEEA15, 158, McMaster; May 31 – June 5, 2015.

[3] M. Archer, C. Decoteau, P. Gorski, D. Little, D. Porpora, T. Rutzou, C. Smith, G. Steinmetz, & F. Vandenberghe, "What is Critical Realism?" *Perspectives*, 38(2), pp. 4-9, 2016.

[4] Ken Bain, *What the Best College Teachers Do.* Cambridge, Mass.: Harvard University Press, 2004.

[5] John C. Bean, *Engaging Ideas: The Professor's Guide to Integrating Writing, Critical Thinking, and Active Learning in the Classroom*. 2nd ed. Jossey Bass : San Francisco, 360 p. 2011.

[6] John Biggs, What the student does: teaching for enhanced learning, Higher Education and Development 18(1):57-75, 1999.

[7] Roy Bhaskar, A realist theory of science. London: Verso, 1975.

[8] Monique Boekaerts, "Self-regulated learning at the junction of cognition and motivation," *European Psychologist*, 1, 100–112, 1996.

[9] M. Boekaerts & L. Corno, "Self-regulation in the classroom: A perspective on assessment and intervention," *Applied Psychology*: An International Review, 54, 199–231, 2005.

[10] Liliya S. Bormotova, "A Qualitative Study of Metacognitive Reflection: The Beliefs, Attitudes and Reflective Practices of Developing Professional Educators," Theses and Dissertations, http://knowledge.library.iup.edu/etd/434, 2011.

[11] David Boud, Ruth Keogh, & David Walker (Eds), "Using experience for learning," *Society for Research into Higher Education* University Press: University of Michigan, 1993.

[12] David Boud, Ruth Keogh, & David Walker (Eds), Reflection: Turning experience into learning, Psychology Press, 1985.

[13] A. Brown, (1987.) Metacognition, executive control, self control, and other mysterious mechanisms, in F. Weinert & R. Kluwe (Eds.), Metacognition, motivation and understanding, pp. 65-116. Hillsdale, NJ: Erlbaum.

[14] Canadian Engineering Accreditation Board, "Canadian Engineering Accreditation Board: Accreditation Criteria and Procedures", Ottawa: Can. Council of Prof. Engineers, 2014. Accessed June 20, 2015.

[15] Alex M. Clark, S.L. Lissel, C. Davis, (2008). Complex Critical Realism: Tenets and Application in Nursing Research *Advances in Nursing Science*, 31(4), pp. E67-E79.

[16] Alex M. Clark, T.G. Briffa, L. Thirsk, L. Neubeck, J. Redfern, What football teaches us about complex health interventions *BMJ: British Medical Journal*, 345 (7888), pp. 25-27, (2012). [Accessed: 22-06-2018] Published by: BMJ URL: http://www.jstor.org/stable/23493387

[17] Centre for Critical Realism (CCR) (2016). "Roy Bhaskar – Transcendental Realism" *About Critical Realism* CCR Blog at WordPress.com Website established 1997 [Accessed: 22-06-2018]

[18] Marcia L. Conner, and James G. Clawson. *Creating a Learning Culture : Strategy, Technology, and Practice*. Cambridge : Cambridge University Press, 2004.

[19] John W. Creswell, A concise introduction to mixed methods research. Sage Publications, 2015.

[20] John Dewey, How we think: A restatement of the relation of reflective thinking to the education process. Boston: Houghton Mifflin, 1998.

[21] Peter Drucker, The Discipline of Innovation, *Harvard Business Review*, 1985.

[22] Emile Durkheim, The Division of Labor in Society. New York: Free Press, 1964.

[23] S.J. Durning, & A.R. Artino, "Situativity theory: A perspective on how participants and the environment can interact": AMEE Guide no. 52. *Medical Teacher*, *33*(3), pp. 188-199, 2011.

[24] Carol S. Dweck, "Self-theories: Their role in motivation, personality and development," Taylor Francis Psych. Press, Philadelphia, 1999.

[25] Joyce Ehrlinger, Ainsley L. Mitchum, Carol S. Dweck, "Understanding overconfidence: Theories of intelligence, preferential attention, and distorted self-assessment," *Journal of Experimental Psychology*, 63(*2016*), 94-100, Elsevier, 2016.

[26] Greg J. Evans "A windmills of your mind: metacognition and life long learning," *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, Paper 38, Vancouver, BC; 3-6 June 2018.

[27] D. Randy Garrison and Norman D. Vaughan, *Blended Learning in Higher Education: Framework in Principles, and Guidelines.* San Francisco, CA: Jossey-Bass, 2008, 272 pp.

[28] D. Randy Garrison*,* Terry Anderson, & Walter Archer, "Critical inquiry in a text-based environment: Computer conferencing in higher education," *The Internet and Higher Education*, *2*(2-3), 87-105, 2000.

[29] D. Randy Garrison*,* & J.B. Arbaugh, "Researching the community of inquiry framework: Review, issues, and future directions," *The Internet and Higher Education*, *10*(*2007*), 157-172 2007.

[30] D. Randy Garrison*,* & Marti Cleveland-Innes, Facilitating cognitive presence in online learning: Interaction is not enough. *American Journal of Distance Education*, 19(3), 133−148, 2005.

[31] J. Greeno, A. Collins, & L. Resnick, Cognition and Learning. In R. Calfee & D. Berliner (Eds.), *Handbook of educational psychology (*pp. 15–46). New York, NY: MacMillan, 1996.

[32] L.M. Guglielmino, Development of the self-directed learning readiness scale. Doctoral dissertation, University of Georgia, 1977.

[33] Kyla Haimovitz, and Carol S. Dweck. 2017. "The Origins of Children's Growth and Fixed Mindsets: New Research and a New Proposal." *Child Development* 88 (6): 1849–59.

[34] M. Henton, Adventure in the Classroom: Using Adventure to Strengthen Learning and Build a Community of Life-long Learners, Dubuque Iowa: Kendall/Hunt, 1996.

[35] John Hattie, "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, 2009.

[36] International Engineering Alliance (IEA), Graduate Attributes and Professional Competencies, 2013. IEA. http://www.ieagreements.org/

[37] International Engineering Alliance (IEA), Best Practice in Accreditation of Engineering Programs: an Exemplar, 2015. IEA.

[38] Marcus Ivey, S. Dew, M. Mandal, Y. Mohamed, J. A. Nychka, D. Raboud, J.P. Carey, "Using post course assessments to involve instructors in the continuous improvement process," *Proc. CEEA2017*, G. Evans (ed) (Toronto, Ontario; 4-7 June 2017), Paper 041.

[39] Yosef Jabareen, "Building a Conceptual Framework: Philosophy, Definitions, and Procedure." *Inter. Jour. of Qual. Meth.*, 2009, 49–62.

[40] Marnie V. Jamieson, "Application of blended and active learning to chemical engineering design instruction", University of Alberta, 2016.

[41] Marnie V. Jamieson and John M. Shaw, "A continual improvement process for teaching leadership and innovation within a community of practice," *Proceedings of The American Society for Engineering Education Conference*, *(ASEE19)*, Tampa, Florida; 16-19 June 2019.

[42] Marnie V. Jamieson and John M. Shaw, "Applying metacognitive strategies to teaching engineering innovation, design, and leadership," in *Proc. 2017 Canadian Engineering Education Conf.* (*CEEA17*), G. Evans (ed), Toronto, ON; 4-7 June 2017), Paper 045

[43] Marnie V. Jamieson and John M. Shaw, "CATME vs. ITP Metrics – Which one should I choose?" *Proceedings of (ASEE18)*, Salt Lake City, Utah; 24-27 June 2018.

[44] Marnie V. Jamieson and John M. Shaw, "Graduate attribute based continuous improvement …– a writing seminar case study," in *Proc. (CEEA18)*, Paper 77 P. Ostafichuk (ed) Van., BC; 3-6 June 2018.

[45] Marnie V. Jamieson and John M. Shaw, "Online learning element design – development and application experiences", *Proc. (CEEA16),* Paper 038, Dalhousie University; June 19 – 22, 2016.

[46] Marnie V. Jamieson and John M. Shaw, "Pre and Post Course students self assessment of CEAB Graduate Attributes – A Tool for …Course Improvement," *Proc. (CEEA16)* Paper 037 Dal., 2016.

[47] Marnie V. Jamieson and John M. Shaw, "Student and Instructor Satisfaction and Engagement with Blended Learning in Chemical Engineering Design", in *Proc. (CEEA17)* Paper 040; U of T, 2017

[48] Marnie V. Jamieson and John M. Shaw, "Teaching Engineering Innovation, Design, and Leadership within a Community of Practice," *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, Paper 113, P. Ostafichuk (ed) Vancouver, BC; 3-6 June 2018.

[49] Marnie V. Jamieson, Len Church, Frank Vagi, William Pick, Tracy Onuczko, John Nychka, Norma Nocente and John M. Shaw, "The University of Alberta Chemical Engineering Capstone design Course Goes Flipped!" in *Proc.* (CEEA15) Paper 93, McMaster University; May 31 – June 3, 2015.

[50] Marnie V. Jamieson, Leah Goettler, Albert Liu, and John M. Shaw, "To Teach is to Learn: Student and Instructor Perspectives on Assignment Development as a Springboard to Deep Learning," in *Proc. of the 13th CDIO Conf.*, Calgary, Canada, 18-22, June, 2017

[51] Steve Johnson, *Where Good Ideas Come From: The Natural History of Innovation*, Riverhead Trade, 2011.

[52] Aditya Johri & Barbara M. Olds, Situated Engineering Learning: Bridging Engineering Education Research and the Learning Sciences. Journal of Engineering Education, *100*(1), 151-185 2011.

[53] Joyner, F.F., Mann, D.T.Y., Harris, T. (2012). Engineering as a social activity: Preparing engineers to thrive in the changing world of work. *American Journal of Engineering Education*, 3(1), 67-81.

[54] Alice Y. Kolb & David A. Kolb, “The Learning Way: Meta-cognitive Aspects of Experiential Learning,” *Simulation & Gaming*, *40*(3), 297-327 2009.

[55] J. Lave & E. Wenger, Situated learning: Legitimate peripheral participation. Cambridge, UK: Cambridge University Press. 1991.

[56] Patrick Lavoie, Cécile Michaud, Marilou Bélisle, et al. “Learning theories and tools for the assessment of core nursing competencies in simulation: A theoretical review,” *J. Adv. Nurs*.; 74:239–250, 2018.

[57] Stéphane Lhuillery Julio Raffo, and Intan Hamdan-Livramento, Economic Research Working Paper No. 31, Measuring Creativity: Learning from Innovation Measurement, World Intellectual Property Organization, Geneva, 2016.

[58] Saundra Y. McGuire & Stephanie McGuire, *Teach Students How to Learn*, Stylus Publishing, 2015.

[59] Thomas A. O'Neill, Amanda Deacon, Nicole L. Larson, Genevieve C. Hoffart, Robert W. Brennan, Marjan Eggermont, William Rosehart, “Life-long learning, conscientious disposition, and longitudinal measures of academic engagement in engineering design teamwork,” *Learning and Indiv. Diff.,* 39(2015), 124-131, Elsevier, 2015.

[60] P.R. Pintrich, “The role of goal orientation in self-regulated learning” in M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), Handbook of self-regulation p. 451–502. San Diego, CA: Academic, 2000.

[61] Aneeta Rattan, Catherine Good, and Carol S. Dweck. “‘It’s Ok — Not Everyone Can Be Good at Math’: Instructors with an Entity Theory Comfort (and Demotivate) Students.” *Journal of Experimental Social Psychology* 48, no. 3 (May 2012): 731–37.

[62] L. Resnick, & L. Klopfer, (Eds.) *Toward the Thinking Curriculum: Current Cognitive Research*, 1989. Alexandria, VA: Association for Supervision and Curriculum Development.

[63] S. Sarasvathy & S. Venkataraman, “What Makes Entrepreneurs Entrepreneurial?” www.effectuation.org 2001.

[64] S. Sarasvathy, & S. Venkataraman, "Entrepreneurship as Method: Open Questions for an Entrepreneurial Future," Entrepreneurship Theory and Practice. 35, No. 1: p. 113-135.

[65] Donald Schon, Educating the reflective practitioner Towards a new design for teaching and learning in the professions. San Francisco: Jossey-Bass, 1987.

[66] Donald Schon, The reflective practitioner: How professionals think in action. England: Arena, 1995.

[67] Dale A. Schunk “Learning theories an educational Perspective,” 6th ed, Pearson: Boston, MA, 2012.

[68] Gordon Stubley, “Thinking about learning – inferences from how we support curriculum design,” in *Proc. (CEEA18)*, Paper 38, 2018.

[69] Norman D. Vaughan, “A blended community of inquiry approach: Linking student engagement and course redesign,” *The Internet and Higher Education,* vol. 13, no. 1, pp. 60-65, 2010.

[70] E. Wenger, R. McDermott, and W.M. Snyder, “Cultivating Communities of Practice” Boston: Harvard Bus. School Press, 2002.

[71] Barry J. Zimmerman & Dale H. Schunk, “Albert Bandura: The scholar and his contributions to educational psychology,” In B. J. Zimmerman & D. H. Schunk (Eds.), Educational psychology: A century of contributions (pp. 431–457). Mahwah, NJ: Erlbaum.

Appendix E. Drivers for Engineering Education Transformation

This appendix presents the development process for the conceptual framework (presented in Chapter 3 and Appendix D) and the emergence of a theoretical framework using a method similar to one outlined in Jabareen (2009). The motivation for developing a conceptual and then a theoretical framework grounded in the graduate attributes and engineering practice is to reframe engineering education in the context of achieving the prescribed graduate attribute outcomes and addressing the contemporary issues of sustainability; equity, diversity, and inclusion (EDI); mental health; ethics and professional engineering practice. Current engineering education ontological and epistemological norms are typically grounded in isolated and traditional disciplinary knowledge systems that are resistant to change. This resistance is embodied in the initial reluctance to implement the CEAB GA in Canada and partially explained by the success of historic and globally accredited engineering programs, which have produced graduates who have changed the world through four industrial revolutions of mechanization, electrification, automation, and digitalization. The fifth industrial revolution, personalization or where mind meets machine, appears to be dawning (Sarfraz, 2021; Callaghan, 2020; Stearn, 2019) possibly accelerated by the global COVID-19 pandemic migration to remote work (Wang, 2020) and more specifically in remote engineering education (Jamieson, 2020).

The advancements of the past century are significant, and arose from the assumptions and worldview of the past engineering education paradigm. As engineering education and mobile engineering practice in an equity and environmentally concerned global geo-political-social and wealth distribution structure would seem to constitute a complex system, the past success of the engineering education paradigm does not predict its future success. Engineering projects and the development and approval process in the past was more local (regional/national) and less complex. The use of social media and the rapid dissemination of information on the Internet have changed this – it is no longer a regional conversation. The stakeholders have changed, the call for innovation is loud, the grand challenges are urgent, and what society might accept as plausible solutions is also changed. The paradigm of the past may not be adequate for the future and the challenges of the future (Stearn, 2019) and an examination of the underlying concepts relevant to engineering education and practice could provide guidance for the future. A goal of the conceptual framework development process is to provide an interpretive perspective of linked concepts. All concepts are constructs, which have a history, ontological, epistemological, and methodical attributes. To examine the underlying ontology and epistemology of the graduate attributes, their context within current engineering practice and in the future of engineering work given the societal demand for a global transition to sustainability, diversity, equity, and inclusion must be examined.

In this chapter, the context of graduate attributes is examined, a brief background for the engineering outcomes-based assessment is presented, and steps for developing conceptual and theoretical frameworks are elucidated. The ontological and epistemic paradigm shifts required to transform the engineering education learning culture to one where sustainable and inclusive engineering are integral components is then presented. The application of the conceptual and theoretical frameworks to this transformation using effectuation and design thinking is discussed at the end of the chapter. Examples of the application of the emerging theoretical framework to design engineering education related artefacts and to a subsequent paradigm shift are presented as Chapters 3-7. The topics range from development of metacognitive skills in engineering education (CH 3), an innovation model for design courses (CH 4), inclusion of engineering leadership and management learning activities within the context of a course or program (CH 5), rapid operationalization of sustainability, ethics and equity via structured incident case studies (CH 6), and the reconciliation of university wide and CEAB graduate attributes (CH 7).

E.1 Cultural Change and Program Improvement

The tension between the development of technical competence and required professional practice skills in the context of a heavily committed accredited four-year undergraduate program has been an ongoing source of discussion and debate in Canada for at least the past two decades. Change to include content and experiences to develop the graduate attributes and sustainability outside of design courses is seen as desirable and necessary. Even so, arguments are still made that we do not have time in our undergraduate programs and we worry about diluting technical content. In addition, we now worry about student and instructor mental health, academic integrity, and instructor and student workload as programs are delivered and new demands are made on both students and instructors. These significant concerns were exacerbated by the COVID-19 pandemic shift to remote learning (Jamieson, 2020; Wang, 2020).

Canadian accredited engineering programs average 2119 AU[19] exceeding the minimum by ~170 accreditation unit (AU) on average. This suggests a high value is placed upon ensuring program AUs are well above the 1950 AU threshold for full accreditation, as the penalty for not achieving this threshold is another accreditation visit in three years instead of six years. While this strategy manages the risk of dipping below the minimum it also contributes to skewing the program toward the engineering science core content knowledge and ensuring the program is very full with little room for socio-contextual or other

---

[19] AU Task Force Report to Engineers Canada (2018).

intellectual development. A slightly lower minimum value between 1800 and 1875 AU was proposed (AU Taskforce, 2018) and a value of 1850 AU was approved. Many Canadian programs still rely on late program design courses for the development and assessment of graduate attributes six to twelve rather than integrated development across programs. Given the current student mental health crisis and academic dishonesty issues we face, balance is a necessary point to address (Rupar & Strong, 2021) along with the current and future societal demands of sustainability on engineering practice making graduate attributes six to twelve more necessary for engineering graduates beginning their careers. This overly full and somewhat unbalanced program with heavy time demands creates time and performance pressure for students. Pressure, opportunity, and rationalization are proposed as the underlying factors for academic dishonesty and increases in pressure increase the likelihood students will engage in misconduct (Ostafichuk et al., 2020). An overly full program with minimal coordination between instructors encourages a situation where pressure to perform, rationalization (everyone is doing it to get through), and opportunity coexist. Thus, ethics are addressed in the context of imposed sanctions for academic dishonesty rather than in a learning environment where tools such as case studies could be employed. Policing academic dishonesty rather than teaching engineering ethics and professionalism early in a program creates a significant burden for instructors and administrators. For students, it is either a difficult process with negative outcomes if they are caught or they ‘get away with it’ and are then better able to rationalize it the next time they experience pressure and have the opportunity to cheat, which is inconsistent with Professionalism (GA 8) and Ethics and Equity (GA 10). This situation does not contribute to a collegial and professional learning culture as the role of the instructors and administrators shifts from that of a guide/sage to that of reporter/enforcer or the instructors become complicit and ignore the issue or are overwhelmed by it and simply do not have adequate time to address it. This seems to have been more of an issue during the COVID remote delivery.

Engineering work is more than solving problem sets and a wholistic context is fundamental to engineering work, practice, and education. A fundamental shift in how and why we teach is required and not just what we teach and when in order to design a program within the time constraints. This work is positioned to address the how and why we teach *throughout* the program in order to enable a needed paradigm shift in what we teach while respecting the design constraints of a four-year accredited program along with student and instructor mental health. The motivation for developing this framework is to enable our collective imagination and the transition of engineering education from a bloated historical program to a future oriented sustainable engineering education program that will enable the engineering work of the future. To affect this vision, we must consider the ontological, epistemic, and axiological roots of the graduate attributes and whether the graduate attributes are a proxy for engineering practice. This examination of the philosophical roots of the graduate attributes and engineering practice may illuminate inconsistent beliefs and practices that undermine wholistic engineering education. An enriched perspective may enable a paradigm shift and the transformation to inclusive and sustainable engineering with a grounded framework that can be used for content analysis of engineering programs and courses grounded in the future of engineering and not the past. An integrated approach may enable us to address the current time and workload pressures we collectively face as the demands for transformation to sustainable and inclusive engineering mount.

E.2 Engineering Graduate Attribute Background

In 1989, Canada became one of the six original signatories of the Washington Accord. The main purpose of this accord is recognition by signatory countries of the academic equivalence of BSc level engineering programs. This international discussion has precipitated significant changes in the criteria for accreditation of engineering schools that now incorporate outcomes-based performance criteria. Outcomes based criteria known as engineering graduate attributes were first proposed in 2001 by the signatories to the Washington Accord in Thornybush, South Africa (IEA, 2013). The first version of the Canadian Engineering Accreditation Board (CEAB) graduate attributes was open for comment in 2004 (CEAB, 2004). In 2013, signatories to the Washington Accord (professional engineers), the Sydney Accord (engineering technologists), and the Dublin Accord (engineering technicians) approved version 3 of the IEA graduate attributes and supporting definitions. An ongoing dialogue among accreditation bodies, universities, professional associations, engineering education researchers, and instructors on what the outcomes of undergraduate engineering programs are, how outcomes are achieved, and when they should be measured is shaping changes in Canadian engineering curricula and course delivery methods. The first stage of ongoing engineering professional development is the attainment of an *accredited educational qualification*, the graduate stage. “The fundamental purpose of *engineering education* is to build a knowledge base and attributes *to enable the graduate to continue learning* and to proceed to formative development that will develop the competencies required for independent practice,” (IEA, 2013, *emphasis mine*). The tensions between what *practicing* engineers do and defining the fundamental knowledge *required* to begin practice creates a heavy workload for undergraduate engineering students in programs where the professional abilities of the graduates are questioned and the career paths are diverse.

Wulf (1998) described most undergraduate engineering programs as “bloated” and still not covering requisite material. Arguments put forward that *all* material is required and that nothing can be removed are frequently countered with arguments regarding the limited effectiveness of outdated content and teaching practices. Canadian universities are currently confronting the challenges of CEAB GA measurement and accompanying continual improvement requirements. Canadian universities are also confronting a shift to online learning delivery, the rapid expansion of knowledge-based materials on the internet, societal demands for sustainability, funding pressure on institutions, and the question of who can teach sustainable practice content – some of which may not yet have been developed in industry or academia. It seems likely the problem of reimagining engineering education and supporting a transformation to sustainable engineering may require ontological and epistemic paradigm shifts in order to address these conflicts. The traditional positivist perspective may no longer suffice. Engineers are no longer objective observers of a problem who may draw an arbitrary and convenient boundary in order to provide a profitable solution. The presenting complex engineering grand challenges rooted in the old paradigm require a broader understanding of system integration, what counts as knowledge, and an expansion of the nature of reality to include multiple layers. There is no single human experience and human experience is contained within intransitive and transitive structures, where actual events occur outside individual consciousness. Objective and subjective observations, perspectives, interactions, and justified belief must be considered.

E.3 Method: Conceptual and Theoretical Framework Development

The conceptual and theoretical frameworks presented in Appendix D are developed using the method described by Jabareen (2009) and summarized in point form below. This section describes the development of the framework using these steps and the evolution of the framework as the development process was employed.

- *Step 1: Mapping the selected data sources – Graduate Attributes and the capstone design skillset*
- *Step 2: Extensive reading and categorizing of the selected data – GA implementation*
- *Step 3: Identifying and naming concepts*
- *Step 4: Deconstructing and categorizing the concepts*
- *Step 5: Integrating concepts*
- *Step 6: Synthesis, resynthesis, and making it all make sense*
- *Step 7: Validating the conceptual framework*
- *Step 8: Rethinking the conceptual framework*

E.3.1 Step 1: CEAB and ABET Graduate Attribute Mapping and Comparison

The first step in the conceptual framework development process employed is to identify text types and other sources of data, practices and map them. Understanding the practice of targeted phenomena by interviewing or interacting with practitioners is also part of this step. In order to effect this step, the CEAB graduate attributes, the ABET student outcomes, definitions of engineering, and the International Engineering Alliance (IEA) descriptions of engineering work and the graduate attributes were studied and mapped. The mapping of the CEAB and ABET outcomes are presented in this section. In addition, the CEAB GA, the UN Sustainable Development Goals and the Risk Based Process Safety Management frameworks were identified as important data sources for engineering work now and in the future. The integration of these frameworks is presented in step 5 (Section 5.3.7). As an engineering design educator since 2010 and a practicing engineer I am immersed in the practice of engineering, engineering design, the practice of engineering education, and the implementation and assessment of the graduate attributes, as such I bring the practitioner perspective to this step of the research process. In addition, I teach engineering design as part of a team. I observe and am engaged in the process of teaching and learning, graduate attribute implementation, the practice of engineering and then in the practice of reflection and redesign for continual improvement.

After the 1989 Washington Accord, engineering education programs accredited by signatories, such as the Canadian Engineering Accreditation Board (CEAB) and the American Accreditation Board for Engineering and Technology (ABET) are recognized as equivalent by professional registration jurisdictions supporting international mobility for professional engineers. In 2009, Washington Accord accrediting bodies introduced the engineering graduate competency-based outcomes as part of the accreditation process (Frank, 2011; Easa, 2013; Gopakumar, 2013; Dew, 2014; Stiver, 2010). The current (2020) ABET student outcomes (1- 7) and the CEAB Graduate Attributes (1-12) are similar. The mapping equivalence is demonstrated in Table E.1. The mapping of the CEAB-GA 1-12 with the previous ABET student outcomes (a-k) is shown in Figure E.1. Project management is explicitly identified in CEAB GA 11 and does not appear explicitly in the ABET student outcomes (a-k). There is an explicit mention of project management activities in Outcome 5 "*establish goals, plan tasks, and meet objectives"* in the current (1-7) student outcomes (Table 5.1). In addition, economics is not a standalone item in the ABET student outcomes. It only appears in the context of design and the impact of engineering solutions. The capstone design skillset was mapped to the graduate attributes in previous work (Jamieson, 2016).

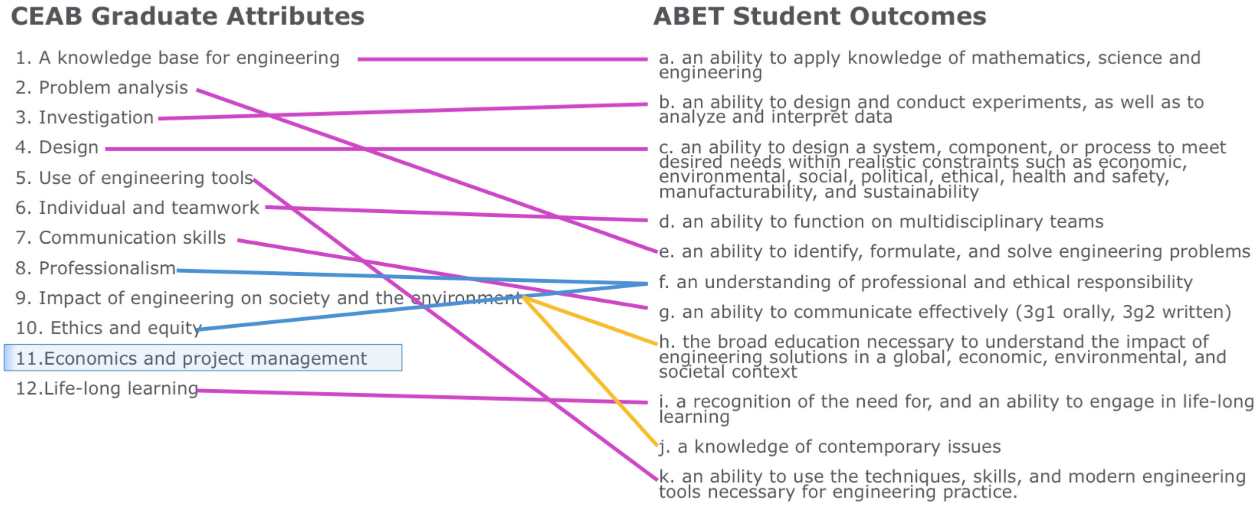


Figure E.1 CEAB Graduate Attributes (1-12) mapped to ABET Student outcomes (a-k)

E.3.2 Step 2: Reading the Literature - Graduate Attribute Implementation

The next step in the process is to engage with the literature and categorize the selected data. Appendix D details some of this engagement with respect to educational psychology, learning theory and culture literature. This section focuses on the graduate attribute literature review. This step in the process is intended to ensure effective representation of concepts. In addition to engaging with the literature, I also attended the annual GACIP meetings, CEEA-ACEG EGAD workshops and conferences, and engaged with the University of Alberta Graduate Attribute process prior to, during, and after the conceptual framework development. This section is focused on a presentation of the context of the graduate attribute implementation in Canada and the University of Alberta and establishing the equivalency of the CEAB GA with the ABET student outcomes, both being rooted in the IEA literature and agreements. This equivalency as demonstrated in Table 5.1 establishes the likelihood the conceptual and theoretical frameworks are generalizable beyond the Canadian engineering education context.

Canadian engineering programs began grappling with how these graduate attributes (GAs) would become a part of the accreditation process with limited direction from the CEAB or Washington Accord signatories (IEA). Engineering schools began implementing processes to review curriculum and map graduate attributes to curriculum content, develop assessment criteria, and then measure the graduate achievement of these attributes. The twelve CEAB Graduate Attributes (CEAB-GAs) and the associated continual improvement process (IEA 2015) have become a significant part of the accreditation process in Canada (CEAB, 2017, 2018; Kaupp, 2016). The CEAB-GAs have driven changes to the accreditation process, program and course level assessment; instigated curriculum mapping and pathway assessments; provoked debates on their efficacy and utility; raised objections based on workload impacts; launched research projects relating the attributes to engineering identity; and highlighted the need for a university culture shift that supports the scholarship of teaching and *learning* at the institutional, program and course levels as part of the continual improvement process (Meikleham, 2018; Dew, 2014; Jamieson, 2019; Doré, 2019; Parker, 2019).

Table E.1 Mapping CEAB Graduate Attributes with ABET Student Outcomes (A-K) and (1-7)

CEAB Graduate Attribute (GA 1-12)	**ABET Student Outcomes (SO A-K)**	**ABET Student Outcomes (SO 1-7)**
1. KB for Engineering - Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	A. an ability to apply knowledge of mathematics, science and engineering	1. an ability to identify, formulate, and solve complex engineering problems by ***applying principles of engineering, science, and mathematics*** (assumes a knowledge of such principles)

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.	E. an ability to identify, formulate, and solve engineering problems	1. ***an ability to identify, formulate, and solve complex engineering problems*** by applying principles of engineering, science, and mathematics
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.	B. an ability to design and conduct experiments, as well as to analyze and interpret data	6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw 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.	C. an ability to design a system, component, or process to meet desired needs within realistic constraints - economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
5. Use of Eng. 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.	K. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	*No equivalent to map to* (Implies this ability is necessary for outcomes 1, 2 and 6 solve problems, design solutions, investigate and experiment)
6. Teamwork - An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	D. an ability to function on multidisciplinary teams	5. ***an ability to function effectively on a team whose members together provide leadership***, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
7. Communication - 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.	G. an ability to communicate effectively (3g1 orally, 3g2 written)	3. an ability to communicate effectively with a range of audiences
8. Professionalism - An understanding of the roles and responsibilities of the professional engineer in society, especially the	F. an understanding of **professional** and ethical **responsibility**	4. an ability to recognize... professional responsibilities...

primary role of protection of the public and the public interest.		
9.Impact of Engineering - 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.	H. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context J. a knowledge of contemporary issues	4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, ***which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts***
10. Ethics & Equity - An ability to apply professional ethics, accountability, and equity.	F. an understanding of professional and **ethical responsibility**	4. an ability to recognize ethical... responsibilities... 5. ...create a collaborative and ***inclusive environment***, establish goals, plan tasks, and meet objectives
11.Economics & PM - 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.	*No equivalent to map to in ABET SO (a-k)*	5. ...create a collaborative and inclusive environment, ***establish goals, plan tasks, and meet objectives***
12. Lifelong 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.	I. a recognition of the need for, and an ability to engage in life-long learning	7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Since 2014, engineering programs in Canada are required to report graduate attribute achievement and demonstrate the use of a continual improvement process to identify program improvement opportunities or justify the status quo (CEAB, 2018) as part of the accreditation process (CEAB, 2017). At Canadian universities, the implementation of the CEAB-GAs for assessing the quality of engineering education and graduates is mandated by the national accreditation board and supported by provincial regulators. Consequently, academic program administrators and instructors in engineering faculties are working toward meaningful implementation of these attributes within their curricula, developing management strategies, and writing about their ongoing progress and struggles. Key contributors include the Engineering Graduate Attribute Development (EGAD) program inaugurated by Queen's University, the University of

Calgary, UBC, the University of Toronto, Dalhousie, and the University of Guelph (Johnston, 2011; Stiver, 2010, 2011, Frank, 2011; Kaupp, 2012, 2016; Brennan, 2017), Ryerson University (Easa, 2013; Shehata, 2015, Salustri, 2016), Concordia University, (Gopakumar, 2013; Hamou-Lhadj, 2015), the University of Manitoba (Sepheri, 2013; Seniuk-Cicek, 2014; 2017), the University of Alberta (Dew, 2013; 2014; Jamieson, 2015; 2016 - 2019; Ivey, 2017; 2018; Watson, 2018; Parker, 2019), the University of Victoria, (Gwyn, 2015; 2016; 2017), the University of Ottawa (George, 2017), and Memorial University (Spracklin-Reid, 2012, 2014). In addition, some engineering schools associated with the CDIO program have investigated how the CEAB accreditation requirements map to CDIO program standards and syllabus (Platanitis, 2011; Cloutier, 2012; Meikleham, 2018). Parker et al. (2019) provides a comprehensive summary of the Canadian engineering graduate attribute literature from 2010 to 2017. Kaupp (2012; 2016) provides the results of two national surveys on the implementation status of the graduate attribute continual improvement process (GACIP) at Canadian engineering schools.

During an exploratory phase, graduate attribute scholars and professionals investigated and designed graduate attribute measurement and management systems, began to implement them at their institutions, and shared their learning. Each management system has unique aspects because each university has a unique history, character, set of programs, and compliment of people who deliver and administer engineering programs. From this exploratory and development phase, three common levels of graduate attribute implementation and management can be observed: the institutional level, the program level, and the course level. For a continual improvement process to emerge, information must be effectively shared and integrated across these three implementation and management levels.

The meaningful implementation of the CEAB graduate attributes as a competency performance measure tied to an ongoing continual improvement process is complex and challenging (Stiver, 2011; Harrison, 2011; Johnston, 2011; Kaupp, 2012; Sepheri, 2013; Hamou-Lhadj, 2015; Dew, 2014; Jamieson, 2016; 2019; Kaupp, 2016; Oliver, 2018; Parker, 2019) and requires time, effort, engagement, and buy in from multiple stakeholders at institutional, program, and course levels (including students!) to be successful (Gopakumar, 2013; Hamou-Lhadj, 2015, Jamieson, 2017). The development of the Washington Accord graduate attributes took nearly a decade (Stiver, 2011; Parker, 2019), another decade passed before they were introduced into the Canadian accreditation process in 2009 (Parker, 2019), and it is expected to take another two accreditation cycles for full integration of the graduate attribute continual improvement process (GACIP) in to accreditation reviews (Jamieson, 2019). The inclusion of multiple stakeholders invested in qualified university graduates including potential employers, communities of practice, accreditation, and regulatory bodies into the academic assessment process requires the management and control of a complex process at the institutional, program, and classroom level.

E.3.3 Step 3: Identify and name the Concepts

The third step in the framework development process is to read the selected data and identify the concepts contained in the sources. The capstone design team formation and development knowledge, skills, and attitudes (KSA) list used for individual student self-assessment pre and post course was a rich source of concepts related to developing the graduate attributes in the context of engineering practice. This form was developed over a number of course iterations with input from multiple instructors to help students select teams and then identify KSA areas of strength and weakness illuminating where they may need to develop to be successful in the course (Jamieson, 2016). This tool is currently used as an online pre-post course reflective student skill self-assessment activity in chemical process design and a modified version is used in first year design. The KSA constructs are mapped to the CEAB GA. This list contains numerous concepts students engage with during design problem definition, research investigation, design work, design evaluation, and design communication. In addition, several conceptual items were added to this list as a result of reading the literature cited in Appendix D, the graduate attribute literature and the definitions of engineering work. The KSA list and added items are presented and analyzed in Table E.2 as part of Step 4 outlined in Section E.4.4. The concept summary is presented in Figure E.2 and analyzed in Table E.4.

E.3.4 Step 4: Deconstruct and Categorize the Concepts

The purpose of the fourth step of the conceptual framework development is to “deconstruct each concept; to identify its main attributes, characteristics, assumptions, and role; and, subsequently, to organize and categorize the concepts according to their features and ontological, epistemological, and methodological role” (Jabareen, 2009). This categorization is critical to understanding potential discrepancies between the traditional engineering paradigm of the past and the graduate attribute outcome based paradigm of the present and future. Personal philosophical paradigms inform the way we think, the way we evaluate what we think, and how we develop knowledge. Our personal paradigm informs what we accept as true, what is believable, what we doubt, and what we think is knowable and provable. The lens we view reality through influences what we will accept as evidence; how we classify information as true, false, justified belief, or as opinion, relevant or irrelevant. In addition, personal philosophical frameworks include values (ethics and aesthetics) and influence what we think is possible. Our personal paradigm, as teachers and as learners, influences the layers of cognition shown in Figure E.2. Epistemic cognition can be described as how an individual *evaluates* knowledge; uses that knowledge; and how we develop knowledge (Kitchner, 1983). Critical thinking requires epistemic cognition (Greene, 2016). Epistemic cognition, dispositions and beliefs are significantly influenced by the implicit or the explicit philosophical paradigm adopted by an individual (Greene, 2016; Brownlee, 2016). In addition, how we teach and learn is predicted by and significantly influenced by our epistemic beliefs and cognition (Brownlee, 2017). According to Kitchner (1983), epistemic cognition, knowledge about knowledge and cognition about knowledge, is a third order cognitive process. Essential features are critical thinking and evaluation of knowledge, including conceptual change *and the resolution of conceptual conflicts* (Brownlee, 2017). Metacognition is roughly defined by Flavell as "knowledge and cognition about cognitive phenomena" (Flavell, 1992 p.113) and more specifically as "any knowledge or cognitive activity that takes as its object, or regulates, any aspect of any cognitive enterprise" (Flavell, 1992, p. 114;) - essentially second order cognition. Metacognition definitions have gradually broadened to include the knowledge and regulation of one's knowledge, cognitive and affective processes and states (cognitive and affective - Hacker, 1998; Papaleontiou-Louca, 2003, 2008). Two essential features are self-appraisal and self-management (Paris &Winograd, 1990). Bloom's taxonomy (1956) of the cognitive domain skills presents a useful hierarchical classification: remember, understand, apply, analyze, synthesize, evaluate, and finally create – the alternating application of synthesis and evaluation.

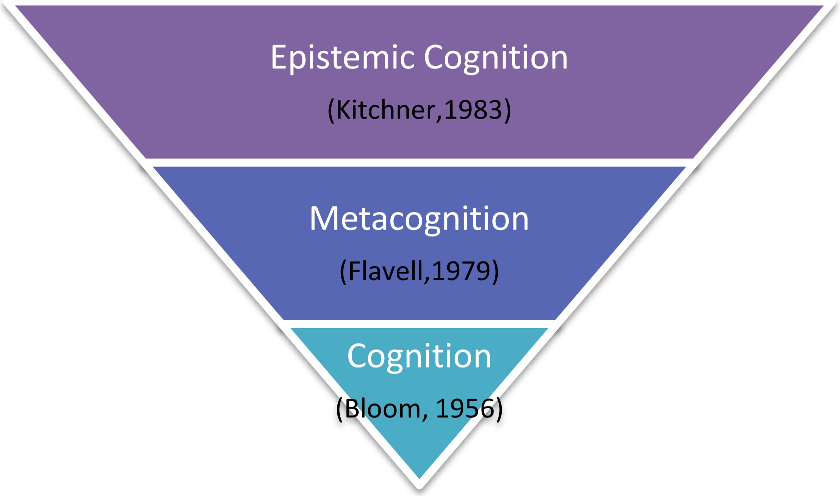


Figure E.2. Layers of Cognition (Kitchner, 1983)

The objective of the deconstruction is to uncover the hidden implicit assumptions and contradictions within the source, in this case engineering education outcomes as elucidated by the CEAB GA and corroborated by the ABET student outcomes. This deconstruction allows for a critical examination of the implicit assumptions to interpret the student outcomes in the context of what is necessary for engineering education in order to demonstrate the outcomes. This new lens may allow an epistemic transition to a new perspective or paradigm that enables engineering education change supporting the future of engineering work in the context of sustainable systems, the ultimate objective of this work. As demonstrated by the mapping in Step 1, the CEAB GA are closely related to the ABET student outcomes and both are results of the International Engineering Alliance (IEA) documents and Washington Accord objectives. The implicit assumption is that these outcomes reflect what is currently and globally agreed to be necessary to begin practice as an engineer in training irrespective of one's geographic location in an accredited program. *The student outcomes are assumed to be reflective of engineering practice.* The implementation of the graduate attributes as the outcomes for engineering programs is grounded in the belief these outcomes are necessary for the requirements of engineering education of today and of the future. Resistance to the graduate attribute implementation may be rooted in the epistemic beliefs and disposition of the teacher or the learner.

The capstone process design student KSA constructs, reflective of the CEAB GA and intended to enable success in the course and a transition to practice, were grouped using the CEAB GA (Table E.2). This list was subsequently deconstructed to characterize the ontological, epistemological, and methodological orientations for each item. The knowledge, skills, and attitudes are characterised on the basis of ontological (realism, critical realism, relativism) and epistemological (objective, subjective) positions, the epistemic type of knowledge represented (etic, emic), the implicit learning theory (behavioural, situative, cognitive), and plausible learning interaction type (direct, blended, indirect). The skills were also deconstructed with respect to metacognitive knowledge type declarative (what), procedural (how), or contextual (why). Building on the qualitative analysis of the implicit learning theory underlying the engineering graduate attributes presented in Figure D.6, the skills were classified with respect to the perceived underlying learning theory (behavioural, situative, cognitive) associated with acquiring the knowledge, skill or attitude. The results of this deconstruction are presented in Table E.2. The coding legend follows the table. The last two columns represent subsequent process steps, concept integration and synthesis with respect to the plausible thematic classification.

E.3.5 Step 5: Integrating the Concepts

The concept integration step is intended to group together concepts that have similarities to one new concept. As the objective is to reduce the number of concepts and develop a conceptual framework for engineering education that supports engineering practice today and in the future two relevant frameworks for engineering work, the UN Sustainable Development Goals (UN SDG) and Risk Based Process Safety Management (RBPSM) were examined with respect to their connection to the CEAB GA as presented in Table E.3. The UN SDGs and RBPSM are both current and aspirational frameworks for engineering work, design, projects, and systems. An examination of the current student outcomes in the context of the aspirations of engineering practice is of value as transformational engineering education change is contemplated and implemented. The motivation for change is to meet the needs of the present and the needs of the future. The three frameworks are examined for similarities. As shown in Table E.3, the CEAB GA can be mapped to both the UN SDG and the RBPSM frameworks giving assurance the student outcomes are reflective of current risk-based engineering practice and supportive of the aspirational UN SDG. The context and interpretation of the student outcomes could be adapted to support plausible future and societal expectations of engineers and engineering programs. Although the CEAB GA are not new concepts, the connection of current and future oriented frameworks to the student outcomes is reassuring and adds evidence to a justified belief that the undergraduate student outcomes can support an aspirational vision of engineering practice as well as the transition to engineering practice KSA of the capstone course. With this reassurance, the assumption that the student outcomes are connected to engineering practice appears to be valid. The capstone KSA connection to the CEAB GA and thus to current and plausible future engineering practice also appears to be valid. The deconstructed concepts (Table E.2) are then integrated to produce a conceptual summary and presented in Figure E.3 and Table E.4.

Table E.2. Classification of Pre-Post Course KSA - Individual Analysis for Team Development

Graduate Attribute/skill (KSA construct)	Ontology R,CR,RL Epistem-ology Et or Em	Method-ology OB, F, EXP, JB	Know-ledge Type D, P, C	Learning Theory B,S,C	Learning Interaction D, BL, I	EE Theme SC,C M,P	Conceptual Framework Item
1 Engineering Knowledge						**C**	✔
Industrial / coop experience	CR, RL	All	D, P, C	S	BL, I	SC,**C**,M,P	
Chemical engineering practice	R, CR	All	D, P, C	S	BL, I	SC,**C**,M,P	
chemicals	CR, Et	F, EXP	D, P, C	S	BL, I	SC,**C**,M,P	✔Implicit
gas processing	CR, Et	F, EXP	D, P, C	S	BL, I	SC,**C**,M,P	✔Implicit
oil/heavy oil	CR, Et	F, EXP	D, P, C	S	BL, I	SC,**C**,M,P	✔Implicit
biological processes	CR, Et	F, EXP	D, P, C	S	BL, I	SC,**C**,M,P	✔Implicit
research	CR, Et	F, EXP	D, P, C		BL, I	SC,**C**,M,P	✔Implicit
Chemical engineering process design theory	R, Et	OB, F	D, P,C	B, C	D, I	**C**	✔Implicit
chemical reaction (reactors)	R, Et	OB, F	D, P, C	B, C	D, I	**C**	✔Implicit
phase separation (separators)	R, Et	OB, F	D, P, C	B, C	D, I	**C**	✔Implicit
chemical separation (distillation)	R, Et	OB, F	D, P, C	B, C	D, I	**C**	✔Implicit
heat/mass transfer (equipment)	R, Et	OB, F	D, P, C	B, C	D, I	**C**	✔Implicit
pump/compressor design	R, Et	OB, F	D, P, C	B, C	D, I	**C**	✔Implicit
fluid mechanics (piping)	R, Et	OB, F	D, P, C	B, C	D, I	**C**	✔Implicit
material selection (corrosion)	R, Et	OB, F	D, P, C	B, C	D, I	**C**	✔Implicit
thermodynamics	R, Et	OB, F	D, P, C	B, C	D, I	**C**	✔Implicit
process control	R, Et	OB, F	D, P, C	B, C	D, I	**C**	✔Implicit
2 Problem Analysis	CR, Et	All	P, C	S, C	D, BL, I	**C**	✔
Identify and **define problems**	CR, Et	F, EXP,JB	P	S	D, BL, I	SC, **C**, M	✔
Analyze and solve	CR, Et	F, EXP,JB	P, C	S	D, BL, I	**C**, M	✔

problems							
Reach substantive conclusions	CR, Et	F, EXP,JB	C	S, C	BL, I	C, **M**	✔
3 Investigation						C	✔
Research Design problems	R, Et	OB, F	D, P, C	S, C	BL, I	**C**	✔
Create solution options	CR, Et	EXP, JB	P, C	S, C	BL, I	**M**	✔
Develop analysis criteria	CR, Et	EXP, JB	P	S, C	BL, I	**M**	✔(needs)
Synthesis of information	CR, Et	EXP, JB	P, C	S, C	BL, I	**M**	✔Implicit
Draw valid conclusion	R, Et	EXP, JB	C	S, C	BL, I	**M**	✔Implicit
(last two=sense making) Error analysis (validation)	R, Et	F	P	B	D, BL	**C**	✔
4 Design						**M**	
Dev. boundary constraints	R, Et	OB, F	D, P, C	S, C	D, BL, I	SC, **C**	✔
Design process system	R, Et	OB, F	D, P, C	S, C	D, BL, I	SC, C, **M**	✔Implicit
Design process components	R, Et	OB, F	D, P, C	S, C	D, BL, I	SC, C, **M**	✔Implicit
Assess technical, economic, safety, environmental criteria & risk	CR, Et	OB, F, EXP, JB	D, P, C	S, C	D, BL, I	**M**	✔
Consider regulatory and societal implications of design	CR, Et	OB, F, EXP, JB	D, P, C	S, C	D, BL, I	**M**	✔
5 Engineering Tools							✔
Process simulator experience	R, Et	F	D, P	S	D,BL	**C**	✔Implicit
ASPEN/HYSYS	R, Et	F	D, P	S	D,BL	**C**	✔Implicit
VMGSIM	R, Et	F	D, P	S	D,BL	**C**	✔Implicit
Computational/ modeling skills	R, Et	OB, F	D, P	S	D,BL	**C**	
economic analysis	R, Et	OB, F, JB	D, P,C	S	D,BL	**C,** SC, M	✔
sizing and costing analysis	R, Et	OB, F	D, P	S	D,BL	**C**	✔
analysis skills using spreadsheets	R, Et R, Et	OB, F OB, F	D, P D, P	S, C S, C	D,BL D,BL	**C,** M	✔Implicit
6 Individual and Team Work						**P**	✔
Team work/team building	RL, Em	EXP, JB	P, C	B, S	BL, I	M, **P**	✔
Integrity/accountability	RL, Em	EXP, JB	P, C	B, S	BL, I	**P**	✔
Relationships	RL, Em	EXP, JB	P, C	B, S	BL, I	**P**	✔Implicit
Persuasion	RL, Em	OB,F, JB	P, C	B, S	BL, I	**P**	✔Implicit
Coaching and development	RL, Em	EXP, JB	P, C	B, S	BL, I	**P**	✔Implicit
Active listening	RL, Em	EXP, JB	P, C	B, S	BL, I	**P**	✔Implicit
Learning styles/ Myers Briggs	RL, Em	EXP, JB	P, C	S, C	BL, I	M	✔Implicit
Working knowledge of team formation processes	RL, Em	EXP, JB	P, C	S, C	BL, I	M, **P**	✔Implicit
Emotional Intelligence	CR, Em	EXP, JB	P, C	B, S, C	BL, I	M	✔
Leadership skills	RL, Em	EXP, JB	P, C	B, S,C	BL, I	**P**	✔
Vision/strategic thinking	RL, Em	F,EXP, JB	P, C	S, C	BL, I	SC, M, **P**	✔Implicit
Decision making/consensus	RL, Em	F,EXP, JB	P, C	S, C	BL, I	M	✔Implicit
Conflict management /resolution	RL, Em	F,EXP, JB	P, C	B, S, C	BL, I	M**, P**	✔Implicit
7 Communication						**P**	✔

Technical writing skills	CR, Et	F,EXP, JB	P, C	S, C	D, BL, I	**P**	✔Implicit
Text preparation and organization	CR, Et	F,EXP, JB	P, C	S, C	D, BL, I	M, **P**	✔Implicit
Text editing	CR, Et	O, F, EXP	P, C	S, C	D, BL, I	**P**	✔Implicit
Figure generation	CR, Et	O, F, EXP	P, C	S, C	D, BL, I	**P**	✔Implicit
Report preparations software	CR, Et	O, F, EXP	P, C	S, C	D, BL, I	**P**	✔Implicit
Typing/keyboarding skills	CR, Et	F, EXP S, EXP	P, C	S, C	D, BL, I	**P**	✔Implicit
Technical reading skills	CR, Em	F, EXP	P, C	S, C	D, BL, I	SC, C, **P**	✔Implicit
Oral presentation skills	CR, Et	O, F, EXP	P, C	S, C	D, BL, I	**P**	✔Implicit
8 Professionalism						**P**	✔
Responsibility of Engineers	CR, Et	F,EXP, JB	D, P, C	B, S, C	BL, I	**P**	✔Implicit
Protection of public	CR, Em	F,EXP, JB	D, P, C	B, S, C	BL, I	SC, **P**	✔Implicit
Protection of public interest	CR, Em	F,EXP, JB	D, P, C	B, S, C	BL, I	**P**	✔Implicit
Timeliness of task completions	CR, Et	F,EXP, JB	D, P, C	B, S, C	BL, I	**P**	✔
9 Impact of engineering						**SC**	✔
Environmental impact analysis	CR, Em	F,EXP, JB	D, P, C	S, C	BL, I	**SC**, C	✔
Analysis of societal impacts	CR, Em	F,EXP, JB	D, P, C	S, C	BL, I	**SC**	✔
Sustainable design concepts	CR, Em	F,EXP, JB	D, P, C	S, C	BL, I	**SC**, C	✔
Environmental stewardship	CR, Em	F,EXP, JB	D, P, C	S, C	BL, I	**SC**	✔Implicit
Loss management skills	CR, Em	F,EXP, JB	D, P, C	S, C	BL, I	**SC**, C	✔
HAZOP experience	CR, Em	F,EXP, JB	D, P, C	S, C	BL, I	**SC**, C	✔Implicit
simple risk assessment	CR, Em	F,EXP, JB	D, P, C	S, C	BL, I	**SC**	✔
safe design practices	CR, Em	F,EXP, JB	D, P, C	S, C	BL, I	**SC**, C	✔
10 Ethics and equity						**P**	✔
Professional ethics	CR, Et	F,EXP, JB	D, P, C	B, S	BL, I	**P**	✔
Accountability	CR, Et	F,EXP, JB	P, C	B, S	BL, I	**P**	✔
Application of equity principles	CR, Et	F,EXP, JB	P, C	B, S	BL, I	**P**	✔
11 Economics & Project Management						**SC,** M	✔
Deviation management	CR, Et	F,EXP, JB	P, C	S, C	BL, I	**M**, P	✔Implicit
Risk management	CR, Et	F,EXP, JB	P, C	S, C	D, BL	**SC**, M, P	✔
Schedule management	CR, Et	F,EXP, JB	P, C	S, C	BL, I	**M**, P	✔
Economic and Business Analysis	CR, Et	F,EXP, JB	P, C	S, C	D, BL	C, SC**, M**	✔
Organizational skills	CR, Et	F,EXP, JB	P, C	S, C	BL, I	**P**	✔
planning / scheduling	CR, Et	F,EXP, JB	P, C	S, C	BL, I	M, **P**	✔
adaptability (pragmatism)	CR, Em	F,EXP, JB	P, C	S, C	BL, I	M, **P**	✔
communication	CR, Em	F,EXP, JB	P, C	S, C	BL, I	M, **P**	✔
12 Life-long learning						P	✔
Ability to identify educational needs for self (reflection)	RL, Em	F,EXP, JB	D, P, C	B, S, C	BL, I	**P**	✔
Ability to meet educational needs	RL, Em	F,EXP, JB	P, C	B, S, C	BL, I	**P**	✔Implicit
Ability to develop competence	RL, Em	F,EXP, JB	P, C	B, S, C	BL, I	**P**	✔Implicit
Ability to understand	RL, Em	F,EXP, JB	P, C	B, S, C	BL, I	**P**	✔Implicit

limitations							
Items added to the conceptual framework (KSA as stated in the above listing)	Ontology R,CR,RL Epistemology Et or Em	Methodology OB, F, EXP, JB	Knowledge Type D, P, C	Learning Theory B,S,C	Learning Interaction D, BL, I	EE Theme SC,C M,P	Conceptual Framework Item
Reflection/ reflective practice (identify educational needs)	CR, Em	EXP, JB	P, C	B, S, C	BL, I	M	✔
Needs and opportunities (identify and define problems, develop boundary conditions, develop criteria)	CR, Et	EXP, JB	P, C	S, C	BL, I	SC	✔
Sense making (Synthesis of information + substantive conclusions)	CR, Et, Em	EXP, JB	P, C	B, S, C	BL, I	M	✔
Logic (Draw valid conclusions	CR, Et	F,EXP, JB	P, C	S, C	BL, I	M	✔
Creativity and innovation (create solutions, synthesis and evaluation processes)	CR, Em	F,EXP, JB	D, P, C	B, S, C	BL, I	M	✔
Stakeholder empathy (identify and define problems and boundary conditions)	RL, Em	F,EXP, JB	P, C	B, S, C	BL, I	**SC**	✔
Validation (error analysis)	R, Et	O, F	P, C	S, C	D, BL, I	**C**, M	✔
Work Ethic	RL, Em	EXP, JB	P, C		D, BL, I	**P**	✔

Table E.2 Classification Legend

Ontology Classifications: R-Realism, CR-Critical Realism, RL-Relativism

Epistemological position: Et-Etic (objective), Em-Emic (subjective)

Methodology: (Knowledge categories)

Etic types: OB- Observation, F- Fact;

Emic types: EXP- Experience, JB- Justified Belief, S-Somatic knowledge

Knowledge Type: D-Declarative (what), P-Procedural (how), C-Contextual (why)

Learning Theory Classifications: B-Behaviorist/Empiricist, S-Situative/Pragmatist, C-Cognitive/Constructivist

Learning Interaction: D-Direct interaction (synchronous), BL- Blend of direct and indirect (synchronous and asynchronous) interaction, I-indirect interaction (asynchronous)

Engineering Education Thematic Category: SC-Socio-Contextual, C-Core Technical Content, M-Metacognitive Skills, P-Professional Skills

Table E.3 Integrative mapping of CEAB Graduate Attributes, the UN Sustainable Development Goals and the Risk Based Process Safety Management frameworks.

CEAB Graduate Attribute	UN Sustainable Development Goal (SDG)	Risk Based Process Safety Management (RBPSM)
1. KB for Engineering	Goal 4. ...quality education... Can support all goals	Element 6 - Process Knowledge Management Element 7 - Hazard Identification and Risk Analysis Element 12 - Training and Performance Assurance Element 17 - Incident Investigation
2. Problem Analysis	Can support all goals	Element 2 - Compliance with Standards Element 8 - Operating Procedures Element 9 – Safe Work Practices Element 10 - Asset Integrity and Reliability
3. Investigation	Can support all goals	Element 7 - Hazard Identification and Risk Analysis Element 17 - Incident Investigation
4. Design	Goal 1. End poverty in all its forms everywhere Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 6. Ensure availability and sustainable management of water and sanitation for all Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 12. Ensure sustainable consumption and production patterns Goal 13. Take urgent action to combat climate change and its impacts Engineering design may impact all SD goals. Goals requiring engineering for solutions are specifically mapped above.	Element 2 - Compliance with Standards Element 5 - Stakeholder Outreach Element 10 - Asset Integrity and Reliability

5. Use of Engineering Tools	Can supports all goals	Element 7 - Hazard Identification and Risk Analysis Element 13 - Management of Change Element 14 - Operational Readiness Element 15 - Conduct of Operations Element 16 - Emergency Management Element 17 - Incident Investigation Element 18 - Measurement and Metrics
6. Teamwork and Leadership	Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development	Element 4 - Workforce Involvement Element 5 - Stakeholder Outreach Element 8 - Operating Procedures Element 9 – Safe Work Practices Element 11 - Contractor Management
7. Communication	Can supports all goals	Element 1 - Process Safety Culture Element 4 - Workforce Involvement Element 5 - Stakeholder Outreach Element 11 - Contractor Management Element 16 - Emergency Management
8. Professionalism	Can supports all goals	Element 1 - Process Safety Culture Element 2 - Compliance with Standards Element 11 - Contractor Management Element 16 - Emergency Management Element 19 – Auditing Element 20 - Management Review and Continuous Improvement
9.Impact of Engineering on Society and Environment	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 12. Ensure sustainable consumption and production patterns Goal 13. Take urgent action to combat climate change and its impacts* Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat	Element 2 - Compliance with Standards Element 4 - Workforce Involvement Element 5 - Stakeholder Outreach Element 7 - Hazard Identification and Risk Analysis Element 8 - Operating Procedures Element 9 – Safe Work Practices Element 10 - Asset Integrity and Reliability Element 11 - Contractor Management Element 13 - Management of Change Element 14 - Operational Readiness Element 15 - Conduct of Operations

	desertification, and halt and reverse land degradation and halt biodiversity loss Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development	Element 16 - Emergency Management Element 19 – Auditing Element 20 - Management Review and Continuous Improvement
10. Ethics & Equity	Goal 4. Ensure inclusive and equitable quality education Goal 5. Achieve gender equality and empower all women and girls Goal 10. Reduce inequality within and among countries	Element 1 - Process Safety Culture Element 3 - Process Safety Competency Element 4 - Workforce Involvement Element 13 - Management of Change Element 14 - Operational Readiness Element 15 - Conduct of Operations
11.Economics & Project Management	Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Element 3 - Process Safety Competency Element 6 - Process Knowledge Management Element 8 - Operating Procedures Element 9 – Safe Work Practices Element 10 - Asset Integrity and Reliability Element 11 - Contractor Management Element 12 - Training and Performance Assurance Element 13 - Management of Change Element 14 - Operational Readiness Element 15 - Conduct of Operations Element 16 - Emergency Management
12. Lifelong learning	Goal 4. promote lifelong learning opportunities for all	Element 3 - Process Safety Competency Element 12 - Training and Performance Assurance

E.3.6 Step 6: Synthesis and sense making

The sixth step is synthesis and sense making. A theoretical framework that makes sense should emerge from the conceptual framework based on the work completed in the proceeding steps. A high level view of the key concepts of engineering education grounded in the CEAB graduate attributes could reduce the complexity of program and course content analysis and support positive change towards a learning culture and future engineering practice. It could also inform instructional practice and instructor development.

Table E.4. Summary Table of Concept Integration (Step 5)			
Concept	Concept Description	Ontological, Epistemological Methodological Role Potential Methods	Key References and/or CEAB GA
Stakeholder empathy	An ability to identify stakeholders (clients and others) and understand their perspectives to elucidate needs and design criteria.	Critical Realism, **Relativism** Situative Emic, Etic Qualitative, Mixed Methods	GA 2, 3, 4, 7 8, 9, 10 Design Initiation
Needs and opportunities	Problem identification, definition, including constraints, requirements, and solution ideation and generation	Critical Realism, **Relativism** Cognitive, Situative Etic, Emic Qualitative, Mixed Methods, Semi Quantitative	GA 2, 3, 4, 7 Design exploration RBPSM UNSDG
Economics	Business aspects of an engineering project or design. Comparative cashflow analysis, an ability to translate regulatory requirements into cost	Realism, **Critical Realism** Behaviourist, Situative, Etic Quantitative, semi quantitative	GA 11, 9, 8, 10 Design evaluation RBPSM UNSDG
Cost Estimating	Sizing and selecting equipment for processes, parts for machines, raw materials, utilities, energy use, emissions, recycling, waste disposal, remediation, etc., as inputs for economic analysis	Realism, **Critical Realism** Behaviourist, Situative Etic Quantitative, Mixed Methods	GA 11, 9, 8, 10 Design and design evaluation
Safety	Consideration for the safety of the user(s), operator(s), and maintainer(s) of the design and those who may be impacted by the operation and/or lifecycle of the design including recycle and reclamation.	**Critical Realism** Situative, Cognitive, Behaviourist Etic, Emic Mixed Methods, Qualitative, Quantitative, Semi quantitative	GA 9, 4, 2, 8, 10 Design and design evaluation RBPSM UNSDG
Environmental sustainability	Consideration for the impact of the design and its operation or lifecycle on the environment. Includes waste produced during production and during use and disposal.	**Critical Realism** Situative, Cognitive Etic, Emic Mixed Methods, Qualitative, Quantitative	GA 9, 4, 2, 8, 10 Design and design evaluation RBPSM UNSDG
Impact of Engineering on society	An ability to analyze social and environmental aspects of engineering activities. Includes an understanding of	**Critical Realism** Situative or may also be Cognitive, Behaviourist	GA 9, 4, 11 Design and design

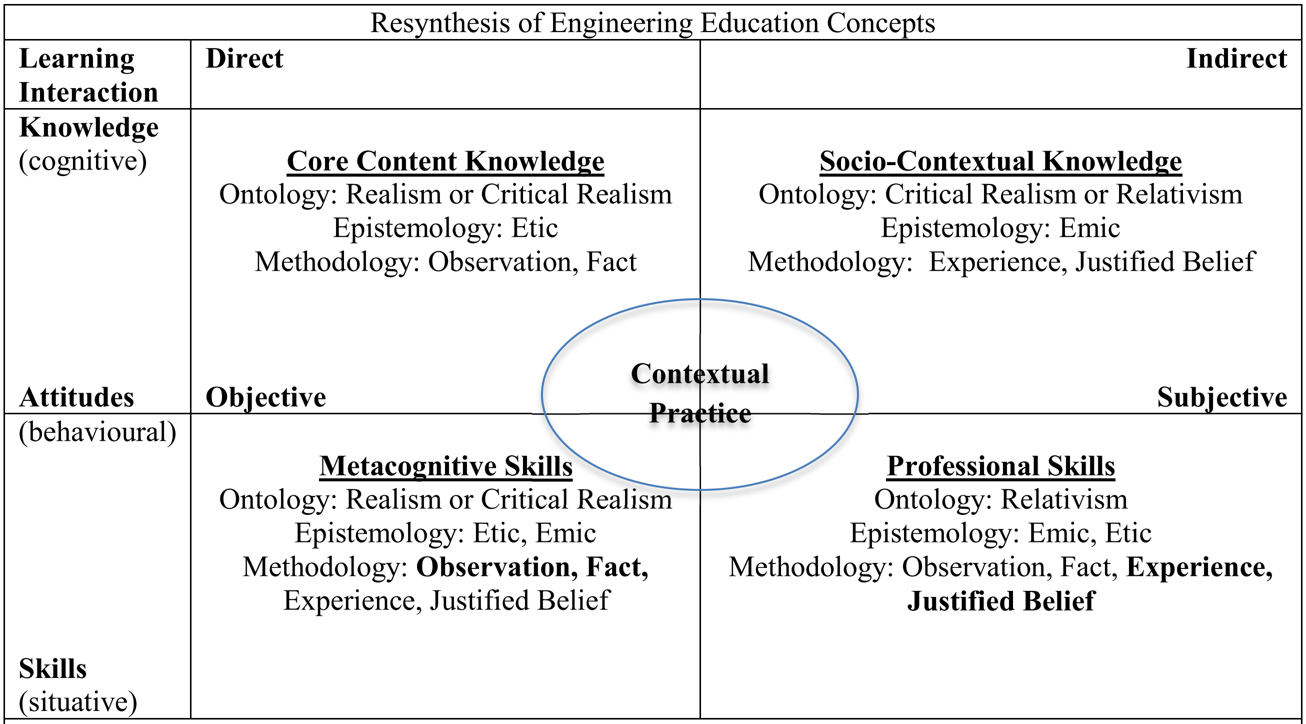
	the interactions with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.	Etic, Emic Mixed methods, Qualitative, Quantitative approaches may be required to gather and analyze data	evaluation RBPSM UNSDG
Risk Management	As above with respect to determining hazards and consequences with respect to the economic, social, health, safety, legal, and cultural impacts of the hazard leading to an incident and endangering people and or the environment.	**Critical Realism,** Realism Situative or may also be Cognitive, Behaviourist Etic, Emic Mixed methods, Qualitative, Semi quatitative Quantitative approaches may be required	GA 11, 4 Design and design evaluation RBPSM
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.	**Realism,** Etic Behaviourist, Cognitive Quantitative (Scientific Method)	GA 2
Fundamental knowledge	Knowledge of math, natural and engineering sciences	**Realism,** Etic Behaviourist, Cognitive Scientific Method	GA 1
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. This includes the ability to select and use models to predict outcomes, use programing languages to solve problems, use engineering design and drawing software, etc.	**Realism,** Etic Behaviourist, Cognitive Quantitative	GA 5
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. Use of engineering and other tools and resources to understand the plausibility of a potential solution and determine if it meets the constraints	**Realism**, Critical Realism, Relativism depending on the problem or context. Etic Behaviourist, Cognitive, or Situative (context dependant) Quantitative Scientific Method	GA 3

	and/or to determine an appropriate model.		
Research (problem definition/ investigation)	Use resources /relevant literature to understand the problem background to develop possible solutions or new knowledge.	**Realism,** Critical Realism, or Relativism (context dependant) Etic/Emic Behaviourist, Cognitive, or Situative (context dependant)	GA 3
Validation	Use the literature to validate model results and / or test or scale the design.	**Realism** Behaviourist Etic, Empirical	GA 3, 4
Sense Making	Comparing predictions and models to the real world context, incorporating the context of the problem in the	Critical Realism Situative Etic, Emic	GA 1, 2, 3, 4, 5, 9
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.	**Critical realism,** Realism, Relativism - context dependant Situative Etic, Emic Mixed methods, Quantitative, Semi Quantitative Qualitative	GA 4, 9
Lifelong 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.	Realism, Critical Realism, Relativism depending on the problem or context. Etic, Emic Behaviourist, Cognitive, or Situative - context dependant	[2] Aleong and Strong, 2015 GA 12
Innovation	An ability to design and object, product, or a process using engineering knowledge and tools in novel and different ways. Lateral thinking (DeBono, 1967)	Realism, Critical Realism, Relativism depending on the problem or context. Etic, Emic Behaviourist, Cognitive, or Situative depending on context	GA 4, 9
Creativity	The use of imagination and creative ideas in problem solving, research, investigation, design, the creation of tools, processes, systems, etc.	Realism, Critical Realism, Relativism depending on the problem or context. Etic, Emic Behaviourist, Cognitive, or Situative depending on context	GA 2, 3, 4, 9
Project Management/ Deviation Management	An ability to break work down into tasks, order them, progress them, determine and track critical path, resources the schedule and manage contributions / Recognizes deviations in work quality, quantity, timeliness, and other goals that may have been set individually or by the team and	Realism, Critical Realism, Relativism depending on the problem or context. Etic Behaviourist, Cognitive, or Situative depending on context	GA 11, 6, 4

	acts to manage the gap between actual and expectation		
Reflective Practice	A practice of considering how planned work, goals, actions, etc., were executed; considering how well a model represented reality; considering how well project criteria represent client and stakeholder interests, etc.	Realism, Critical Realism, Relativism depending on the problem or context. Etic, Emic Behaviourist, Cognitive, or Situative depending on context	GA 12, 4, 6, 9, 8, 10, 11
Emotional Intelligence	Manage one's own affective state and respond appropriately to others. Receiving and Responding in Bloom's Taxonomy Affective Domain classification	Realism, Critical Realism, Relativism depending on the problem or context. Emic, Etic Behaviourist, Cognitive, or Situative depending on context	GA 12, 6
Organization	An ability to plan including: categorize and keep track of and document information, prepare for meetings, coordinate relationships and projects	Critical Realism, **Relativism** Emic, Stituative Observation, Experience, Justified Belief	GA 8, 7, 11
Pragmatism	An ability to assess theory in terms of practical applications such as engineering design	Critical Realism, **Relativism** Emic, Stituative Experience, Justified Belief	GA 2, 3, 4
Individual and teamwork	Valuing and organizing in Bloom's Taxonomy Affective Domain classification	Critical Realism, **Relativism** Emic, Stituative Experience, Justified Belief	GA 6, 7
Time Management	Ability to prioritize work, critical path, to meet and manage deadlines.	Critical Realism, **Relativism** Emic, Stituative Experience, Justified Belief	GA 8, 11, 6
Engineering Management	Enable the effective management of complex engineering systems in a sustainable manner including recycling and remediation.	Critical Realism, **Relativism** Emic, Stituative Observation, Fact, Experience, Justified Belief	GA 11, 9 RBPSM
Professionalism	Internalizes professional characteristics and ethical values consistent with the engineering code of ethics and the duty to protect the public.	Critical Realism, **Relativism** Emic, Stituative Observation, Fact, Experience, Justified Belief	GA 8
Work ethic	Based on discipline and motivation to stay on task and complete work/projects that have been started	Critical Realism, **Relativism** Emic, Stituative Observation, Fact, Experience, Justified Belief	GA 8
Ethics and Equity	Duty to the public, protection of the public and to be fair and impartial	Critical Realism, **Relativism** Emic, Stituative Experience, Justified Belief	GA 10 UNSDG
Engineering Leadership	Enable effective collaboration of cross disciplinary teams to investigate and solve	Critical Realism, **Relativism** Emic, Stituative	GA 6, 9 RBPSM

	complex engineering problems in a manner that considers and balances the competing aspects of sustainability and societal impact while protecting the public and the public interest	Experience, Justified Belief	UNSDG
Communication Skills	Effective oral and written communication of engineering proposals, drawings, reports, etc.	Critical Realism, **Relativism** Emic, Stituative, Cognitive, Behaviorist (context dependent) Observation, Fact, Experience, Justified Belief	GA 7, 6
Critical Thinking Skills	An ability to carefully examine ideas (concepts, problems, solutions, criteria, information, etc.) assess the validity of information and the trustworthiness of an information source, analyze and synthesize the information	Critical Realism, **Relativism** Emic, Stituative, Cognitive, Behaviorist (context dependent) Observation, Fact, Experience, Justified Belief	Epistemic Cognition CEAB-GA RBPSM UNSDG

The deconstruction precedes a reclassification or sorting of the concepts into like categories as found in Table E.2 in the column labelled *EE Theme*. Some items may fit into more than one classification and may contain contradictory or competing concepts. The origin of the thematic categories is based on an analysis of multiple definitions of engineering as presented in Chapter 1. All items could be classified into at least one of the thematic categories: socio-contextual knowledge, core technical knowledge, metacognitive skills and professional skills. As such, no additional categories were added at the concept integration or theoretical framework stage. The theoretical framework that emerged by classifying the concepts into broader thematic categories is shown in Figure E.3. The ontological and epistemic classifications of the concepts and the integrated concepts suggest a different paradigm from the implicit positivist ontology and corresponding objectivist epistemology of engineering education in the past. As a result of this work, an *explicit* conceptual and generalized theoretical framework are developed and validated for outcomes-based engineering education as overlaid in Figure E.4. These frameworks are grounded in the development of engineering practice, engineering work, the graduate attribute outcomes, learning theory, motivational theory, and cognitive theory relationships and connections to engineering practice and education. The concepts are grounded in the specific knowledge, skills, and ability constructs necessary for student teams to navigate a capstone design course and connected to sustainable development and risk-based process safety management. The conceptual and theoretical frameworks are forward looking with respect to future requirements of engineering practice. The epistemic position of these frameworks embraces both etic and emic perspectives and the ability to distinguish and move between these perspectives when required. What counts as knowledge has been expanded to reflect the current and future practice of engineering in our complex world. Knowledge about knowledge (epistemic cognition) and the influence of one's personal paradigm on cognitive and affective regulation (metacognition) and tasks (Bloom's Taxonomies) is relevant to the application, analysis, synthesis and evaluation of core content knowledge, especially in engineering design. The ability to empathize with the reality of diverse lived experience of the same intransitive entities and actual events is recognized as part of engineering design. These socio-contextual, metacognitive, and professional aspects are integral to engineering practice alongside core content knowledge and hence to engineering education.



Resynthesis of Engineering Education Concepts		
Learning Interaction	**Direct**	**Indirect**
Knowledge (cognitive) **Attitudes**	**Core Content Knowledge** Ontology: Realism or Critical Realism Epistemology: Etic Methodology: Observation, Fact **Objective**	**Socio-Contextual Knowledge** Ontology: Critical Realism or Relativism Epistemology: Emic Methodology: Experience, Justified Belief **Subjective**
(behavioural) **Skills** (situative)	**Metacognitive Skills** Ontology: Realism or Critical Realism Epistemology: Etic, Emic Methodology: **Observation, Fact,** Experience, Justified Belief	**Professional Skills** Ontology: Relativism Epistemology: Emic, Etic Methodology: Observation, Fact, **Experience, Justified Belief**

Figure E.3. Concept Integration and Re-synthesis based on Ontological, Epistemological and Methodological Classifications – Emergent Theoretical Framework

E.3.7 Step 7: Validating the Conceptual Framework

"The aim in this phase is to validate the conceptual framework. The question is whether the proposed framework and its concepts make sense not only to the researcher but also to other scholars and practitioners. Does the framework present a reasonable theory for scholars studying the phenomenon from different disciplines? Validating a theoretical framework is a process that starts with the researcher, who then seeks validation among "outsiders." Presenting an evolving theory at a conference, a seminar, or some other type of academic framework provides an excellent opportunity for researchers to discuss and receive feedback." (Jabareen, 2009, p.54)

As presented in Table E.5 validation and feedback progressed over eighteen months and included feedback from presentations at eight conferences, two posters, four papers, three workshops, and extensive personal communications with engineers, nurses, mixed methods researchers, engineering education researchers, instructors, designers, and colleagues. The reaction to the framework was generally positive. Resistance to the use of graduate attributes as outcomes in engineering education was noted in one case.

Table E.5. Validating the Theoretical and Conceptual Frameworks

Date	**Validation Presentations**
May 31-June 2	✔CCWEST 2018 Edmonton (Equity, Diversity, Inclusivity Team Focus)
June 20	✔IIQM 2018 Thinking Participatively (Methods Interdisciplinary Focus -poster)
October 28-31	✔CSChE 2018 Toronto (Engineering Education Focus – journal paper resulted)
March 26-28	✔MMIRA-CC 2019 (Mixed Methods Design and Interdisciplinary Focus)
May 12-16	✔PPEPPD 2019 (Thermodynamics and Design Focus - poster)
June 9-12	✔CEEA 2019 (Engineering Education Research Focus – paper and workshop)
June 15-20	✔ASEE 2019 - Continual Improvement (Leadership Focus - paper)
June 26	✔Metacognition and Lifelong Learning 2019 – Faculty Forum PD (workshop)
August 14-18	✔Diseño de Plantas Peru 2019 – Professional Development (workshop)
September 3-6	✔M2D2019 (Interdisciplinary Design Education Focus – paper and forum)
October	✔Teaching Excellence Egypt 2020 – Professional Development (workshop)

When encountered, resistance tended to be rooted in a more general resistance to the Washington Accord graduate attributes and the perspective the graduate attributes have been unnecessarily imposed on engineering educators. Feedback from the methods conferences was positive and supportive that the theoretical framework could be broadly applicable to professional programs. Feedback from design and engineering education conferences was positive and encouraging. Presentation in engineering leadership and professional development workshops was met with acceptance. The frameworks made sense to most people as presented with comments that some of the concepts may understandably overlap categories.

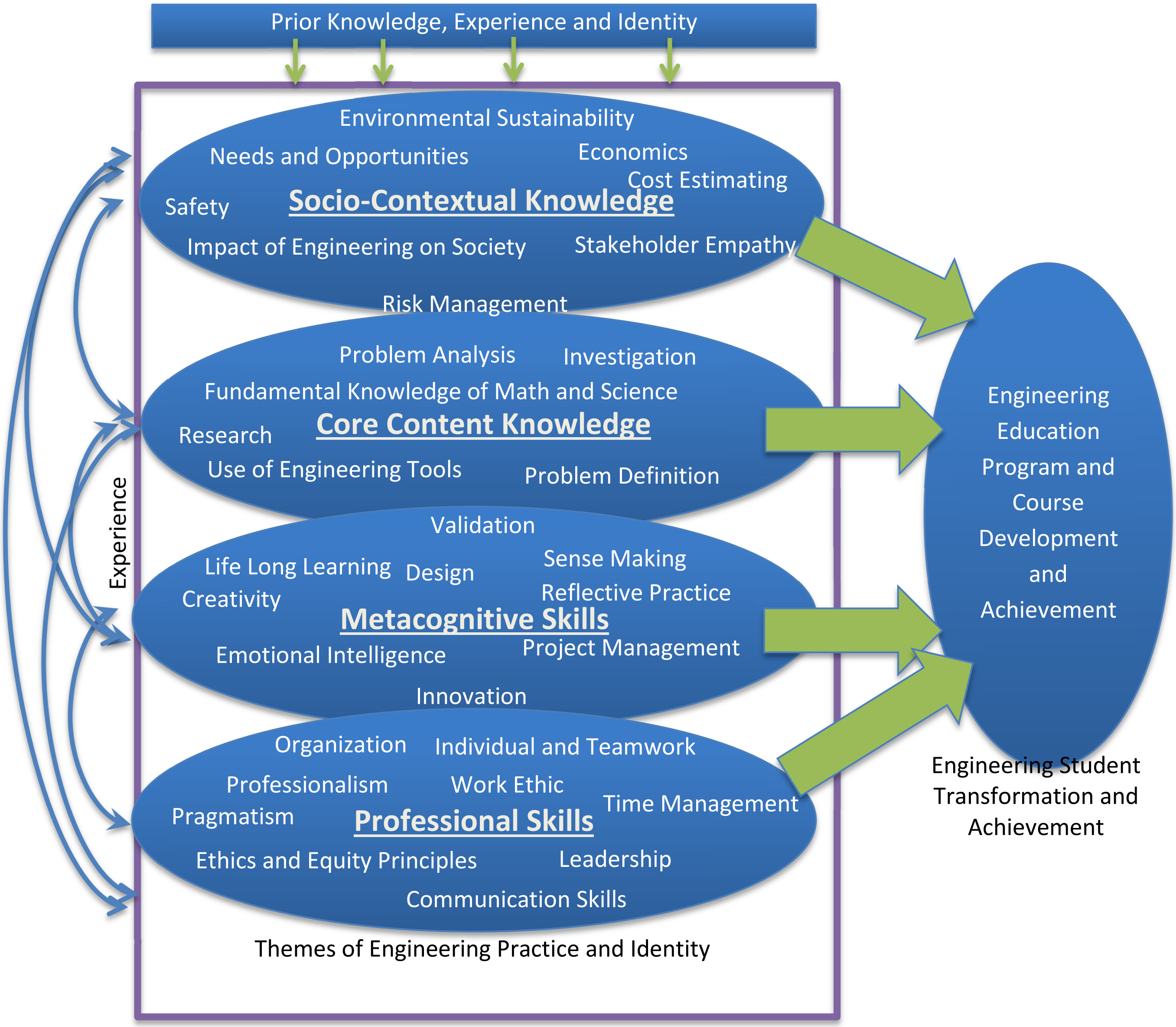


Figure E.4 Engineering Education and Practice Theoretical and Conceptual Frameworks Overlaid

E.3.8 Step 8: Rethinking the conceptual framework

The final phase of this work is communicating the validated frameworks and using them for designing engineering programs, courses, and learning activities that enable engineering education transformation to meet the needs of a sustainable and diverse society. The theoretical framework presented in Figure D.3 and overlaid with the conceptual framework in Figure E.4 represents a synthesis of the engineering education student outcomes (CEAB GA, ABET SO, IEA outcomes) engineering work and practice, the UN SDG, RBPSM, education and educational psychology literature and practice, and a transdisciplinary perspective (Jamieson et al., 2021) with respect to disciplines within engineering and external to engineering. According to the development method employed, the resultant framework represents "a multidisciplinary phenomenon (that) will always be dynamic and may be revised according to new insights, comments, literature, and so on," (Jabareen, 2009, p.55). The graduate attributes can evolve as evidenced by the ABET update from a-k to SO 1-7 and the recent IEA Graduate Attributes and Professional Competences update (June 21, 2021). As researchers and engineering educators work with the student outcomes conceptual overlap, missing elements, and ambiguity are noted and updates to the outcomes are necessary. As engineering work and education evolve similar updates may be required. Like the graduate attributes, as engineering work changes and evolves, the concepts that make up the framework may change and thus may result in changes to the conceptual framework. The more general theoretical framework may be more robust and resilient to changes. It is perhaps generalizable to professional work based on feedback obtained at the methods conferences. The general framework should enlarge the theoretical perspective on the phenomena of engineering education. In this context, the conceptual and theoretical frameworks developed would appear to highlight the need for a shift in the epistemic beliefs and disposition of engineering educators and administrators to include knowledge and ways of knowing beyond a traditional positivist orientation without throwing out the technical knowledge and skills that underpin the ability of engineers to design and build complex items and systems. Engineering Innovation is needed.

E.4 Engineering Educators: Innovation and Effectuation

The effectuation process as described by Sarasvathy (2001) (Figure E.5) is the identification and use of available means (*Who I am*, What I know, Whom I know) to produce imagined ends (Goals, artefacts, events, designs, etc.). The available means can be the same for several different imagined (and then created) end results depending on how available resources are assembled and the goals are set. The given means available to engineering educators (who we are, what we know, whom we know, and the resources available to us) can be used to rebalance the content, time allocations, and focus for undergraduate engineering programs using the elucidated theoretical framework as one of the means.

The available means are often constrained so that all imagined ends cannot be explored fully or brought to fruition – choices must be made. For engineering education, the choices as to whether to include the reflective, professional, and socio-contextual aspects of the practice of engineering as required program elements along with fundamental and complementary knowledge must be made within the constraints of the program resources and timeline. Engaging the theoretical framework suggests the available means must be directed towards better integration of the missing elements with the core content and a critical examination of the fundamental sciences and math required to *begin* engineering practice. Rebalancing the program content within the time allocations for undergraduate engineering programs is an imagined end that must be designed within the constraints and it must meet the accreditation requirements. Although an undergraduate degree is a pathway to graduate school, the undergraduate degree primarily serves as the foundation upon which engineering practice is built. As such, this primary objective should be the priority as engineering education is reinvented and redesigned. This may necessitate changes in graduate programs.

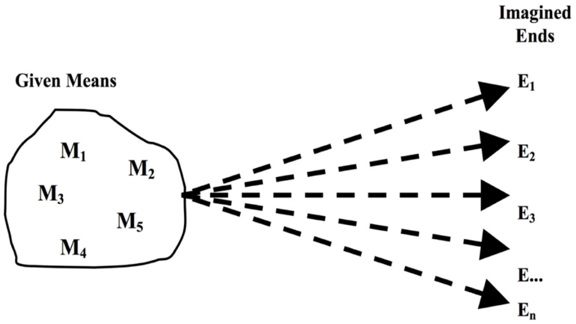


Figure E.5. Effectuation Model (Sarasvathy, 2001)

Who we are, *our lived experience* and what we *believe* have an impact on how we educate engineering students, what we chose to include in programs, and what we leave out. The engagement of engineers with industry experience as teaching stream faculty and their pathway in the academic system is becoming more common increasing our ability to bring engineering practice into undergraduate education experience. At many institutions this practice remains a tentative structure or it may not exist at all.

> "At most schools, for example, it's hard to bring someone onto the faculty who has spent their career in industry, even though such people would be extremely valuable to the students; their resumes simply don't fit what the reward system values. Sometimes, it's even hard to get recognition for a sabbatical in industry." (Wulf, 1998)

Wulf made a case for complementary faculty in 1998 and recognized the challenges. As this practice has emerged (circa 1990 at the University of Alberta), the role of teaching stream professors has slowly evolved and they have taken on larger roles including course design and input to program design. Faculty with academic and research credentials are complimented by individuals with industrial and practice credentials creating a partnership to construct an engineering education model focused on the practice of applying the fundamentals as they are being learned. Regardless of their roots, the development of engineering instructors with respect to education and engineering practice is a critical means for transforming engineering education. Given the epistemic diversity of the knowledge required for effective engineering practice, an examination of instructors' personal epistemic disposition and beliefs can enable a deeper understanding of the engineering practice in the context of driving and creating our collective global future. The ontological and epistemic diversity of the graduate attribute outcomes and the underlying learning theory suggests multiple methods may be required to achieve the learning outcomes beyond the currently popular constructivist approach (Plato) and the more traditional behaviorist approach (Aristotle). Enabling instructors to expand their understanding of knowledge and the different types of knowledge beyond what they may have been focused on during their own education increases the available means and resources to achieve the imagined end of an innovative education process relevant to the future of engineering practice. There is a significant body of literature on the impact of epistemic cognition on discipline teaching and learning including the influence of instructors epistemic belief on the modification of the epistemological belief and disposition of their students (Brownlee, 2017; Greene, 2016). This influence extends beyond engineering education and impacts academic outcomes including critical thinking development and epistemic dispositions. "Objectivist epistemologies can be dominant in adolescents and adults of all ages. They reflect the natural assumptions that our observations represent reality and our inferences preserve truth. In addition, they are often reinforced by social, cultural, religious, political, and educational systems," (Moshman, 2016). In the context of engineering practice and education, addressing instructor epistemic belief and disposition (and as a consequence student epistemologies) may be an effective way to change engineering education to better support sustainable development and engineering practices and potentially better support diversity, equity, and inclusion in engineering education.

E.5 Educational Innovation and Continual Improvement Processes

The third phase of this study examines the continual improvement processes of the process design courses over the past five years and the design of interventions or course improvements (artefacts). The emergent theoretical framework has impacted the continual improvement applied to the process design courses, my teaching, and has influenced the development and evolution of our new first year design program. It has been my observation that student feedback has become more positive between the first iteration and the fifth iteration and that student engagement in the courses is high. It is not because of blended learning in and of itself but because blended learning gave the instructional team the time needed for continual improvement processes and more time to spend directly interacting with student teams as mentors on a regular basis. There was a fundamental shift in focus from delivering content to interaction and sense making. Class time was spent on discussion allowing for the content delivered online to become relevant to the students' projects and their developing practice as engineering students. Chapter 3 explores the conceptual and theoretical framework in the context of engaging faculty in examining their learning environment and the inclusion of explicit metacognitive learning activities. The next chapters explore various facets of the graduate attribute based continual improvement process and resulting interventions (CH 4, 5 & 6 - sustainability and innovation, CH 5 - engineering leadership and management, and CH 6 - incident case studies) developed at the course level. Chapter 7 further interrogates the integration of the UGA and the CEAB GA in the Faculty of Engineering.

References

AU Task Force Report to Engineers Canada (2018). Retrieved from: https://engineerscanada.ca/sites/default/files/accreditation/Report-of-the-AU-Task-Force-FINAL-EN.pdf

Biggs, J.B. (2003). *Teaching for Quality Learning at University: What the Student Does*. Buckingham; Philadelphia. Society for Research into Higher Education: Open University Press.

Brownlee, Jo Lunn, Ferguson, Leila E., and Ryan, Mary (2017). Changing Teachers' Epistemic Cognition: A New Conceptual Framework for Epistemic Reflexivity, *Educational Psychologist*, 52(4), 242–252, DOI: 10.1080/00461520.2017.1333430

Callaghan, C.W. (2019). Transcending the threshold limitation: a fifth industrial revolution? *Management Research Review*, *43*(4), 447–461. DOI: 10.1108/MRR-03-2019-0102

Canadian Engineering Accreditation Board (2004). *Accreditation Criteria and Procedure*. Ottawa: Canada. Canadian Council of Professional Engineers

Canadian Engineering Accreditation Board (2018). *Continual Improvement Rubric v3.2*. Retrieved from https://engineerscanada.ca/accreditation/accreditation-resources

Canadian Engineering Accreditation Board (2017). *Canadian Engineering Accreditation Board: Accreditation Criteria and Procedures*. Ottawa: Canada. Canadian Council of Professional Engineers. Retrieved from https://engineerscanada.ca/sites/default/files/accreditation-criteria-procedures-2017.pdf

Canadian Engineering Accreditation Board (2019). *Accreditation Criteria and Procedure*. Ottawa: Canada. Canadian Council of Professional Engineers. Retrieved from https://engineerscanada.ca/sites/default/files/accreditation/Accreditation-Criteria-Procedures-2019.pdf

Cloutier, G., Hugo, R., & Sellens, R., (2012). Mapping the relationship between the CDIO syllabus and the CEAB graduate attributes: An update. *Int. J. Qual. Assur. Eng. Technol. Educ.* , 2 (2), 34-44. Retrieved from http://www.cdio.org/files/document/file/b4-cloutier2011ceabcanada.pdf

Dew, S., Csorba, E, Chelen, D, Yousefi, N., Andrews, N., & More, C. (2013). Graduate Attributes at the University of Alberta: A report of the Committee on the Learning Environment (CLE) Subcommittee on Attributes and Competencies. Retrieved from http://www.provost.ualberta.ca/en/~/media/provost/Documents/Information/GraduateAttributes.pdf

Easa, S. M. (2013). Framework and guidelines for graduate attribute assessment in engineering education. *Canadian Journal of Civil Engineering*, 40(6), 547-556. https://doi.org/10.1139/cjce-2012-0485

Frank, B., McCahan, S., Watts, K.C., Fostaty-Young, S., Ostafichuk, P., Wolf, P., & Saleh, N., (2011). Engineering graduate attribute development (EGAD) project. In *CEEA Canadian Engineering Education Conf.* St. John's, Canada. https://doi.org/10.24908/pceea.v0i0.3566

GACIP (2018). Summit 2018: Aggregating data. https://egad.engineering.queensu.ca/?page_id=4291

Greene, Jeffrey A. and Yu, Seung B. (2016). Educating critical thinkers: The role of epistemic cognition. *Policy Insights from the Behavioral and Brain Sciences* Vol. 3(1) 45–53 DOI: 10.1177/2372732215622223

Gopakumar, G., Dysart-Gale, D., & Ali Akgunduz, A.. (2013). Creating faculty buy in: Leadership challenges in implementing CEAB graduate attributes. In *Canadian Engineering Education Conf. (CEEA13)*. (pp.1-5). Montréal, Québec: Université de Montréal. https://doi.org/10.24908/pceea.v0i0.4850

Gwyn, M., (2016). Incorporating employer and student assessments into a graduate attribute assessment plan. In *Canadian Engineering Education Association.* Halifax, Canada. Dalhousie University. Retrieved from http://web.uvic.ca/~mgwyn/CEEA2016/Gwyn.pdf

Gwyn, M.L., & Gupta, R., (2015). Co-op employer evaluations of the graduate attributes: A comparison of two approaches. in *2015 Canadian Engineering Education Conf. (CEEA15)*. (pp.1-5). Hamilton, Canada. McMaster University. https://doi.org/10.24908/pceea.v0i0.5788

Gwyn, M., (2017). Finding the gaps: The development of a network for graduate attribute professionals. in *Canadian Engineering Education Association Conf.* (pp.1-4). Toronto, Canada. https://doi.org/10.24908/pceea.v0i0.3143

Hamou-Lhadj, A.,Lynch, W., & Akgunduz, A., (2015). COGAF: A management framework fro graduate attribute assessment. In *Canadian Engineering Education Conf. (CEEA15)*. (pp. 1-6). Hamilton, Canada. McMaster University. https://doi.org/10.24908/pceea.v0i0.5762

Harris, J. Steele, A., and Russell, D., (2011). Progress on defining the CEAB attributes at Carleton University. In *CEEA Canadian Engineering Education Conf., (CEEC11)*, St. John's, Canada. https://doi.org/10.24908/pceea.v0i0.3628

Hattie, J. The Black Box of Tertiary Assessment: An Impending Revolution (2009). 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.

International Engineering Alliance (IEA), Graduate Attributes and Professional Competencies v4, 2021. IEA. http://www.ieagreements.org/

International Engineering Alliance (IEA), Best Practice in Accreditation of Engineering Programs: an Exemplar, 2015. IEA.

International Engineering Alliance (2015). A History of the International Engineering Alliance and its Constituent Agreements: Toward Global Engineering Education and Professional Competence Standards. Retrieved from http://www.ieagreements.org/assets/Uploads/Documents/History/IEA-History-1.1-Final.pdf

International Engineering Alliance (IEA), Graduate Attributes and Professional Competencies, 2013. IEA. http://www.ieagreements.org/

Ivey, M., Dew S., Mandal M., Mohamed Y., Nychka J.A., Raboud D. & Carey J.P., (2017). Using post course assessments to involve instructors in the continuous improvement process. in *2017 Canadian Engineering Education Association Conf.,* Toronto, Canada. https://doi.org/10.24908/pceea.v0i0.9519

Ivey, M., Dew S., Mandal M., Mohamed Y., Nychka J., Raboud D., Rajendran A., Carey J.P. (20*17). It is possible to constructively involve instructors in the continuous improvement process?. Canadian Engineering Education Association Conference*. Toronto, Canada. https://doi.org/10.24908/pceea.v0i0.9519

Ivey, M., Mohamed Y., Musilek P., Raboud D., Rajendran A., & Carey J.P., (2018). Using a common course syllabus as part of the quality control loop and accreditation data collection process. In *2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed). Vancouver, Canada. https://doi.org/10.24908/pceea.v0i0.12983

Jabareen, Y., (2009). "Building a Conceptual Framework: Philosophy, Definitions, and Procedure." Inter. Jour. of Qual. Meth., 49–62.

Jamieson, M.V., (2016a). Application of blended and active learning to chemical engineering design instruction, University of Alberta

Jamieson, M.V., and Shaw, J.M. (2019a). A continual improvement process for teaching leadership and innovation in a community of practice. *Proceedings of The American Society for Engineering Education Annual Conference & Exposition*, Tampa, Florida; 15-19 June 2019.

Jamieson M.V. and Donald, J. R. (2020). Building the Engineering Mindset: Developing Leadership and Management Competencies in the Engineering Curriculum, in *Proc. 2020 Canadian Engineering Education Conference (CEEA20).*

Jamieson, M.V., Ead, A. S., Rowe, A., Miller-Young, J. and Carey, J.P. (In Press 2021). Design at Scale in a First-Year Transdisciplinary Engineering Design Course, IJEE.

Jamieson, M.V., and Shaw, J.M. (2018a). Graduate attribute based continuous improvement in a blended learning engineering design course – a writing seminar case study. *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) (Vancouver, British Columbia; 3-6 June 2018).

Jamieson, M.V. (2020). Keeping a Learning Community and Academic Integrity Intact after a Mid-Term Shift to Online Learning in Chemical Engineering Design During the COVID-19 Pandemic. *Journal of Chemical Education **2020** 97 (9), 2768-2772 DOI: 10.1021/acs.jchemed.0c00785*

Jamieson, M.V., Shaw, J.M. (2019b). Learning to learn: Defining an engineering learning culture. in *Proc. 2019 Canadian Engineering Education Association*; University of Ottawa; June 9 – 12, 2019

Jamieson, M.V., Shaw, J.M. (2016b). Pre and post course student self-assessment of CEAB graduate attributes - A tool for outcomes assessment, student skill and course improvement. in *Proc. 2016 Canadian Engineering Education Association*; Dalhousie University; June 19 – 22, 2016

Jamieson, M.V., Shaw, J.M. (2018b). Teaching Engineering Innovation, Design, and Leadership within a Community of Practice. in *Proc. 2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) Vancouver, British Columbia; 3-6 June 2018, Paper 113.

Kaupp, J., Frank, B., Brenman, R., McCahan, S., Narayanan, L., Ostafichuk, P., Sepehri, N., & Watts, K.C. (2012). A comparison of institutional approaches to CEAB graduate attributes requirements. In *2012 Canadian Engineering Education Association Conf.*, Witold Kinsner (ed.). Winnipeg, Manitoba https://doi.org/10.24908/pceea.v0i0.4642

Kaupp, J., & Frank, B., (2016). EGAD National snapshot survey: Change, progress and improvement. In *2016 Canadian Engineering Education Association Conf.* Halifax, Nova Scotia. Dalhousie University.https://doi.org/10.24908/pceea.v0i0.6503

Kitchner, Karen S., (1983). Cognition, Metacognition, and Epistemic Cognition A Three-Level Model of Cognitive Processing. Human Development 26:222-232

Meikleham, A., Brennan, R., & Hugo, R., (2018). Utilizing the CDIO syllabus to reveal CEAB graduate attribute pathways in a mechanical engineering curriculum. In *2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed) Vancouver, British Columbia. https://doi.org/10.24908/pceea.v0i0.12988

Ostafichuk, P., Frank, B., Jaeger, C., and Hugo R., (2020) Remote Assessment E-CORE quick guide. https://ceea.ca/wp-content/uploads/2020/08/EQG_RemoteAssessmentV2.pdf

Parker A.M., Watson E, Ivey M, Carey JP (2019). Approaches to graduate attribute and continual improvement processes in faculties of engineering across Canada: a narrative review of the literature, *Proceedings 2019 Canadian Engineering Education Association (CEEA-ACEG19) Conference*. Ottawa, Ontario. https://doi.org/10.24908/pceea.vi0.13736

Platanitis, G., & Pop-Iliev, R., (2011). Does program compliance with CDIO warrant automatic compliance with CEAB accreditation criteria for 2014?. In *CEEA Canadian Engineering Education Conf., CEEC11.* St. John's, NL. https://doi.org/10.24908/pceea.v0i0.3597

Rupar and Strong (2021). Learning not Burning (Out): Sustainable Time Management in Engineering Education. *Proceedings of the Canadian Engineering Education Association Conference (CEEA-ACEG 2021)*, Charlottetown, PI

Salustri, F.A., & Neumann, W. P., (2016). Providing a uniform design experience in an undergraduate mechanical engineering program. In *2016 Canadian Engineering Education Association Conf.* Halifax, Nova Scotia. Dalhousie University.

Sarfraz, Z., Sarfraz, A., Iftikar, H. M., & Akhund, R. (2021). Is COVID-19 pushing us to the Fifth Industrial Revolution (Society 5.0)?. *Pakistan journal of medical sciences*, *37*(2), 591–594. https://doi.org/10.12669/pjms.37.2.3387

Seniuk Cicek, J., Ingram, S., Sepehri, N., Burak, J.P., Labossiere, P., Mann, D., Ruth, D., Parker, A., Ferens, K., Godavari, N., Oleszkiewicz J., & Topping, A., (2014). Rubrics as a vehicle to define the twelve CEAB graduate attributes, determine graduate competencies, and develop a common language for engineering stakeholders. in *2014 Canadian Engineering Education Conf. (CEEA14)*. Canmore, AB. https://doi.org/10.24908/pceea.v0i0.5876

Sepehri, N., Kinsner, W., Burak, J.P., Shafai, C., Annakkage, U., Mann, D., Kuhn, D., Shalaby, A., Alfaro, M., Morrison, J., Ferens, K., Birouk, M., Labossiere, P., Torchia, M., & Beddoes, J., (2013). The process of continual improvement of engineering programs at the University of Manitoba: Now and next. In *2013 Canadian Engineering Education Conf. (CEEA13)*. Montréal: Canada. Université de Montreal.

Shehata, M.H., and Schwartz, M., (2015). Co-curricular activities and their role in supporting experiential learning. In *2015 Canadian Engineering Education Conf. (CEEA15)*. Hamilton, ON. McMaster University.https://doi.org/10.24908/pceea.v0i0.5791

Spracklin-Reid, D., & Fisher, A., (2012). Course-based learning outcomes as the foundation for assessment of graduate attributes. In *2012 Canadian Engineering Education Association (CEEA 12) Conf.* Witold Kinsner (ed.). Winnipeg, MB. https://doi.org/10.24908/pceea.v0i0.4928

Spracklin-Reid, D., & Fisher, A., (2014). Curriculum mapping in engineering education: Linking attributes, outcomes, and assessments. *2014 Canadian Engineering Education Conf. (CEEA14)*. Canmore, AB. https://doi.org/10.24908/pceea.v0i0.5897

Stearns, P. N. (2020). *The industrial revolution in world history* (Fifth edition.). Routledge.

Stiver, W., (2011). CEAB's Graduate attributes and Ontario's UUDLEs. In *Canadian Engineering Education Conf., CEEC11*. St. John's, NL. https://doi.org/10.24908/pceea.v0i0.3605

Stiver, W., Bradford, A., Chang, S., Farahbakhsh, K., Lubitz, D., Ryks, J., van Heyst, B., Zhou, H., and Zytner, R., (2010). Engineering graduate attributes – Investigation. in *Proc. CEEA Canadian Engineering Education Conf.* https://doi.org/10.24908/pceea.v0i0.3143

Thorpe, A., (2020) Why has critical realism not been used more in educational leadership and management research? A critical realist exploration, Journal of Critical Realism, 19:1, 29-44, DOI: 10.1080/14767430.2019.1682813

Uppström, E., (2017). Re-Visiting IS Design Science Artifacts: Making a Case for Critical Realism, Proceedings of the 50th Hawaii International Conference on System Sciences

Wang, B., Liu, Y., Qian, J., & Parker, S. K. (2020). Achieving Effective Remote Working During the COVID-19 Pandemic: A Work Design Perspective. *Applied psychology = Psychologie appliquee*, 10.1111/apps.12290. Advance online publication. https://doi.org/10.1111/apps.12290

Watson E., Ivey, M., Mohamed Y., Musilek P., Raboud D., Rajendran A., & Carey J.P., (2018). Building a culture that values learning outcomes as an integral part of effective program development - one faculty's example. In *2018 Canadian Engineering Education Conference (CEEA18)*, P. Ostafichuk (ed). Vancouver, British Columbia. https://doi.org/10.24908/pceea.v0i0.12979

Wulf, W.A. (1998). The urgency of engineering education reform. The Bridge 28(1):15-21.