Determining the Relative Importance of the CEAB Graduate Attributes for Engineering: An Exploratory Case Study at the University of Manitoba

by

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Abstract

Changes to engineering accreditation requirements in Canada in 2009 initiated a shift to outcomes-based education and continual program improvement. The 12 CEAB graduate attributes were introduced – competencies all graduating engineers are required to demonstrate. They presented a conundrum: how best to teach and assess them? This, coupled with resolve to educate engineers to tackle 21st century problems, characterized one driver in the emerging global discipline of Engineering Education.

Generally, the CEAB graduate attributes are accepted as presented: individual competencies with emphasis on the first listed, the more 'traditional' skills. However, research in the field indicates that teamwork and communication skills are top competencies for engineering practice, and suggest attribute clusters. These findings diverge from the implied ranking and individual treatment of the CEAB graduate attributes.

Considering the research, and motivated to inform engineering curricular improvement at the University of Manitoba, this doctoral study was designed to investigate the relative importance of the CEAB graduate attributes, and how they cluster in engineering practice as perceived by engineering stakeholders. The content validity of the Biosystems Engineering program was then evaluated.

Findings showed that stakeholders ranked Individual and Teamwork and Communications Skills as the top engineering competencies, and all graduate attributes were between 6.1% - 10.9% relatively important, in sharp contrast to the Biosystems program, which is comprised of almost 50% Knowledge Base for Engineering. Findings demonstrated students placed more emphasis on value attributes than faculty or industry stakeholders, a perception worth exploring to diversify engineering populations.

Furthermore, the graduate attributes can be conceptualized as four new clusters, renamed *Problem Solving Skills, Interpersonal Skills, Ethical Reasoning*, and *Creativity and Innovation*, and can be theorized using Bloom's three Domains of Cognitive, Psychomotor, and Affective Learning.

The Biosystems Engineering Program is already designed to accommodate curricular changes to improve content validity. This research also informs curricular improvements for the greater faculty, and accredited engineering programs across Canada. Overall, the findings are supported by the literature, and stress the negligence of artificially separating engineering competencies, particularly into dichotomous 'traditional' and 'professional' skills, and encourage a paradigmatic shift towards thinking about, and educating, the whole engineer.

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Dedication

This thesis, and all that it represents, is dedicated to my husband, Nazim, and my kids, Nicholas, Michael, and Isabel. Without your love, support, and sacrifice, this work would not have been possible.

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Glossary of Terms

ABET –
Accreditation Board for Engineering and Technology, Inc., non-governmental organization responsible for accrediting 'college and university programs in the disciplines of applied science, computing, engineering and engineering technology at the associate, bachelor and master degree levels' (ABET 2017).

ABET General Criterion 3: Student Outcomes –
The now seven competencies (formerly 11 competencies pre 2015) that engineering programs seeking ABET accreditation are responsible for demonstrating in their programs and in their engineering students.

APEGM –
Former name of the Manitoba provincial professional engineer licensure body (now called Engineers Geoscientists Manitoba).

BIOE –
Biosystems Engineering

CEAB –
Canadian Engineering Education Accreditation Board, formed in 1965 by Engineers Canada with a mandate to: (i) Identify programs whose graduates are prepared to enter the profession of engineering; (ii) Develop accreditation criteria, processes, procedures; (iii) monitor Quality assurance; and (iv) support Continuous improvement (Peters 2007).

CEAB Graduate Attributes –
The list of 12 competencies that Canadian programs seeking/holding CEAB accreditation are responsible for demonstrating in their programs and in their graduating engineering students.

CE2P2E –
Centre for Engineering Professional Practice and Engineering Education. Located in the Faculty of Engineering at the University of Manitoba.

CIVL –
Civil Engineering

COMP –
Computer Engineering

Competencies (Learning Outcomes or Graduate Attributes) –
The skills and abilities that graduates should demonstrate at the end of their undergraduate program' (Passow and Passow 2017). Also, 'the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations such as professional work, civic engagement, and personal life' (Passow 2012 as quoted

in Passow and Passow 2017).

Content Validity –
Content evidence shows whether or not the content within the instrument is demonstrative of the intended concept to be measured (Gliner, Morgan, and Leech 2009). In this thesis, the content validity of an engineering program is being measured by comparing the percentage that each CEAB graduate attribute is taught and assessed to the relative importance of the graduate attributes as determined by engineering stakeholders of the program.

Dependency –
The reliance of one CEAB graduate attribute on another in order for the knowledge, skills, attitudes, values, and behaviours required to execute the attribute effectively is reliant on the knowledge, skills, attitudes, values, and behaviours of another graduate attribute. In other words, the degree to which an Engineer-in-Training (EIT) at the beginning of his/her career who is doing something that involves one graduate attribute (e.g., A Knowledge Base for Engineering) depends on, or requires, another graduate attribute (e.g., Problem Analysis).

ECE –
Electrical and Computer Engineering

EER –
Engineering Education Research

EIR –
Engineer-in-Residence – Industry members who, in partnership with industry and the Faculty of Engineering at the University of Manitoba, are hired to teach courses in the faculty designed to meet specific industry needs.

EIT –
Engineers-in-Training

ELE –
Electrical Engineering

Engineers Canada –
The national organization of the provincial and territorial associations that regulate the practice of engineering in Canada and license the country's 290,000 members of the engineering profession’ (Engineers Canada 2017).

Engineers Geoscientists Manitoba –
The Manitoba provincial professional engineer licensure body (formerly called APEGM).

ENREB –
The Research Ethics Board (REB) that governs research in Education and Nursing (EN) at the University of Manitoba.

Face Validity –
'…what a test appears to measure [i.e., 'looks' like is measures] to the untrained eye' (Messick 1987, p. 13).

Friends of Engineering –
Established in May 2008; comprised of a group of Manitoba industry members who are committed to a partnership with the U of M Faculty of Engineering to support excellence in engineering education (Friends of Engineering 2010).

Graduate Attributes Competencies (Competencies or Learning Outcomes) –
The skills and abilities that graduates should demonstrate at the end of their undergraduate program' (Passow and Passow 2017). Also, 'the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations such as professional work, civic engagement, and personal life' (Passow 2012 as quoted in Passow and Passow 2017).

IEA (International Engineering Alliance) –
The International Engineering Alliance (IEA) is a global not-for-profit organisation, which comprises members from 35 jurisdictions within 26 countries, across seven international agreements. These international agreements govern the recognition of engineering educational qualifications and professional competence. 'Through the Educational Accords and Competence Agreements members of the International Engineering Alliance establish and enforce internationally bench-marked standards for engineering education and expected competence for engineering practice' (International Engineering Alliance 2017b).

JEE (*Journal of Engineering Education*) –
Premier journal in engineering education.

Learning Outcomes (Competencies or Graduate Attributes) –
The skills and abilities that graduates should demonstrate at the end of their undergraduate program' (Passow and Passow 2017). Also, 'the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations such as professional work, civic engagement, and personal life' (Passow 2012 as quoted in Passow and Passow 2017).

MDS (Multidimensional Scaling) –
'A technique that creates a map displaying the relative positions of a number of objects, given only a table of the distances between them. The map may consist of one, two, three, or even more dimensions. The program calculates either the metric or the non-metric solution. The table of distances is known as the proximity matrix. It arises either directly from experiments or indirectly as a correlation matrix' (NCSS 2017).

MECH –
Mechanical Engineering

NEERC (National Engineering Education Research Colloquies) –
'Designed to collaboratively develop a national [U.S.] research framework and agenda to conduct rigorous engineering education research… the collective effort of more than seventy engineering, science, and mathematics education researchers, learning scientists, and practitioners who worked together during three face-to-face meetings' (Steering Committee of NEERC 2006).

NSF (National Science Foundation) –
'The National Science Foundation (NSF) is an independent federal agency created by [the U.S.] Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense..." NSF is vital because we support basic research and people to create knowledge that transforms the future… With an annual budget of $7.5 billion (FY 2017), we are the funding source for approximately 24 percent of all federally supported basic research conducted by America's colleges and universities. In many fields such as mathematics, computer science and the social sciences, NSF is the major source of [U.S.] federal backing' (National Science Foundation 2017).

OECD –
Organisation for Economic Co-operation and Development

Relative Importance –
The importance of one CEAB graduate attribute relative to the other 11 graduate attributes. Determined in this study by the perceived frequency (i.e., how often an Engineer-in-Training (EIT) at the beginning of his/her career will perform a task that clearly requires a graduate attribute) multiplied by the perceived criticality (i.e., the *potential effect* on workplace performance for an EIT at the beginning of his/her career if he/she does not have a sufficient level of competency for this graduate attribute).

RQ –
Research question

Stakeholder –
People who comprise a community and thereby have an invested interest or stake in how that community evolves. Engineering stakeholders include engineering students, faculty, administrators, industry members, parents, and the public.

Student Outcomes/Student Learning Outcomes –
Engineering competencies. Could be generic or referring to ABET General Criterion 3: Student Outcomes.

Washington Accord (WA) –
An international agreement between 19 signatories comprised of accreditation bodies responsible for accrediting engineering degree programmes (International Engineering Alliance 2017a).

Washington Accord Graduate Attributes –
A list of 12 competencies ‘adopted by the signatories as the exemplar (or reference point) against which substantial equivalence of their own accreditation requirements are to be assessed’ (International Engineering Alliance 2014).

Chapter One: Introduction

Prologue: Canadian Engineering Education in the Context of Engineering Education in America

Due to the influential and rapid growth of engineering education and engineering education research (EER) in the United States of America, (herein referred to as America), and their sizeable and dominant voices in the field, the context of engineering education in Canada is presented through the lens of the American engineering education evolution, and this research study is positioned within that. This is not the only way to understand engineering education in Canada, but it is one way (Froyd and Lohmann 2014).

i. The Current State of Engineering Education Research in America

Research in engineering education has become more rigorous and scientific in the 21st century, buoyed by theories, frameworks, research methodologies, and practices familiar to the learning and social sciences (Olds, Moskal, and Miller 2005; Jesiek, Newswander, and Borrego 2009; Case and Light 2011; Frank et al. 2011). Some maintain that 'The contemporary theory-driven approach that underpins engineering education can be traced to the 1950s when many argued that traditional practice-based instruction was unable to sufficiently empower students to make use of rapid technical and scientific advances' (Jørgensen, 2007 as cited in Trevelyan 2014). Perhaps this emphasis on rigor is deeply rooted; regardless, in the past decade, there have been several appeals to the EER community through the *Journal of Engineering Education (JEE),* the premier journal in the discipline, to continue to shape the field through theory (Wankat 2004; Olds, Moskal, and Miller 2005; Borrego 2007; Koro-Ljungberg and Douglas 2008). Specifically, it was discerned that up until 2002, there was a scarcity in the use of educational theories in *JEE* (Wankat 2004). Wankat (2004) concluded that the field was becoming more oriented towards research, but that there was only a minimal increase in articles reporting data, doing assessment, and employing educational or learning theories. He called for engineering education researchers to conduct more thorough literature reviews, and to broaden their choices of research approaches. A 2005 issue of *JEE* was dedicated to making the case for an increasingly rigorous, scientific approach in EER (Johri and Olds 2014). This call was renewed in articles published in the *JEE* January 2011 issue (Borrego and Bernhard 2011; Case and Light 2011; Johri and Olds 2011).

Another influential movement can be traced to the 2006 Special Report published by The Steering Committee of the National Engineering Education Research Colloquies: *The [U.S.] Research Agenda for the New Discipline of Engineering Education*. The report listed five areas of research that were envisioned to serve as a foundation for the emerging discipline of EER. The research areas were: 1. Engineering Epistemologies: what comprises engineering thinking and knowledge; 2. Engineering Learning Mechanisms: how engineering students' knowledge and competencies develop; 3. Engineering Learning Systems: research on the culture, infrastructure and epistemology of the institution and its educators; 4. Engineering Diversity and Inclusiveness: how diversity influences solutions to social and global challenges and the consequence of the engineering profession; and 5. Engineering Assessment: research on, and development of, assessment approaches, tools, and metrics to inform engineering education instruction and learning (Steering Committee of NEERC 2006; Borrego and Bernhard 2011).

Engineering education researchers in America (and Australia, as evidenced in the literature) are approximately 10 to 15 years ahead of Canada in regards to producing research in response to this demand for increased rigor in the field. This includes their work in answer to a change in engineering accreditation requirements that surfaced in the 1990s (Oliver 2013, p. 451), which emphasized outcomes-based assessment and was the impetus behind assessment being named as one of the five research areas that required attention for engineering education. American engineering education researchers have devised, implemented, and published work detailing comprehensive assessment plans for individual students, courses, and engineering programs. Their assessment data are derived from a number of sources and a variety of engineering stakeholders, and they are implementing changes in their engineering programs based on their findings from these assessment cycles and feedback loops.

This work has evolved. American engineering education researchers today are moving beyond the singular focus of accreditation, and shifting the focus to the outcomes required for the engineer of the 21st century (Robinson et al. 2005; Male, Bush, and Chapman 2011b; Sunthonkanokpong 2011; Pons 2016; Ebrahiminejad 2017; Passow and Passow 2017; Pellegrino 2017). Current engineers are required to be diverse, flexible, innovative, and fleet as they negotiate the shifting and challenging environment around them. This demands a change in our approach to educating engineers, as the competencies required for the engineer of today have evolved as our world has expanded technologically and globally. A ‘diverse engineering workforce’ is required, skilled in critical thinking, problem solving, communication, and innovation, and it is up to engineering educators to meet these challenges through the transformation of engineering curricula (Sunthonkanokpong 2011, p. 161).

Part of the urgency for the need for change from the current approach to engineering education is due to the ‘wicked problems’ (Simon 1976, as quoted in Radcliffe 2006, p. 263) that are becoming increasing persistent in the world and looming in our future. ‘Engineers face an increasingly complex world, in which large intractable problems such as poverty, sustainability and economic crises merge with increased globalization. Engineering graduates will need to be able to work in multidisciplinary, multicultural teams to both assess needs and co-create solutions with local and global communities’ (Sunthonkanokpong 2011, p. 161). Passow and Passow (2017) argue for the competencies necessary to engage in this type of world, with an engineering profile that demonstrates the importance of a social conscious intelligence in the application of engineering ‘to ensure the “most possible good” is derived for both present and future communities’ (p. 496).

Indeed, the stereotyped engineer behind broken glasses and a pocket protector has dissipated: ‘there is now a small but growing body of evidence from diverse sources demonstrating that engineering practice is dominated by intellectually challenging socio-technical activity that cannot easily be reconciled with earlier descriptions of engineering based on solitary technical design and technical problem solving activity’ (Trevelyan 2014, p. 35). Engineering is changing, and as a result, its educational needs are changing as well. In fact, Trevelyan (2014) argues that engineers are ill prepared by their education for the human elements required of engineering practice today (p. 36). He criticizes the ill-developed professional competencies, such as communication skills, that have been historically identified, and continue, almost unchanged today (p. 37).

In summation, the work being published by engineering education researchers in America presently is meeting the call for scientific rigor and for the changing needs of engineering education driven by the rapidly changing, arguably perishing, world.

Sophisticated research informed by established disciplines (including education, learning sciences, cognitive and social sciences, and other education discipline-based research) is being conducted (Fortenberry 2014; Froyd and Lohmann 2014; Johri and Olds 2014; Johri, Olds, and O'Connor 2014; Newstetter and Svinicki 2014; Roth 2014; Streveler et al. 2014), including research in the five areas delineated by the 2006 NEERC Special Report. Large movements to incite lasting change in engineering education are sweeping the American nation, in the shape of projects like RED (**RE**volutionizing engineering and computer science **D**epartments), large-scale, *disruptive*, national projects funded by the National Science Foundation (NSF) to 'enable engineering and computer science departments to lead the nation by successfully achieving significant sustainable changes necessary to overcome longstanding issues in their undergraduate programs and educate inclusive communities of engineering and computer science students prepared to solve 21st-century challenges' (Lord et al. 2017, p. 3). As Sunthonkanokpong (2011) eloquently states: 'Engineering education is a *grand challenge* that will have an impact on all of the other engineering grand challenges (p. 161) (emphasis added).

ii. The Current State of Engineering Education Research in Canada

In Canada, a large portion of the work being done in engineering education is focused on accreditation, and the changes in its requirements brought about by the shift, in part, to an outcomes-based model. This is understandable, as the Canadian Engineering Accreditation Board (CEAB) requirements were implemented in Canada in 2009, 13 years after ABET – the Accreditation Board for Engineering and Technology, the established accreditor of U.S. (and other) college and university programs in applied science, computing, engineering, and technology (ABET 2017) – made their accreditation changes. The processes and findings of Canadian engineering education researchers are typically being published in the Canadian Engineering Education Association's (CEEA-ACEG) annual conference proceedings, with a small showing in the American Society for Engineering Education (ASEE) conference proceedings. Very few Canadian researchers' works are published or cited in *JEE* (Williams et al. 2014; Wankat 2004) or other well known engineering education journals (Williams et al. 2014). For example, for articles in *JEE* from 1993 to 2002, out of the 33 most cited source authors, 32 were researchers from America, and only one was from Canada. From 2010-13, 90% of the authors published in *JEE* were from or based in America, 3% were from Europe, and 7% were determined as 'other,' with no specific mention of Canada. In the *European Journal of Engineering Education* (*EJEE*) during that same time period, of the 33% of authors who were not from Europe or America, the three countries cited as 'other' were Australia, Brazil and South Africa, with no mention of Canada (Williams et al. 2014). This phenomenon could be due to a couple of factors, including that the Canadian identity is not separated from the American identity on the global stage of engineering education. On the other hand, it could also be due to the slower evolution of the field of engineering education in Canada, reflected by the later timing of the changes to CEAB accreditation requirements. There is a natural emphasis on those requirements in Canadian research that was also present in American EER and in countries such as Australia, albeit fifteen years ago. As a result, Canadian research is perhaps not as relevant on a global scale as it might have been in the previous decade.

Hence, although engineering education researchers in Canada are sharing their work nationally, there is the need to more vigorously enter into the present, revolutionary, global conversation. Canadian engineering education researchers who are abreast of engineering education developments on a global scale are encouraging their fellow Canadian engineering education researchers to observe the trend in America (and globally) towards a more scholarly, scientific, and internationally connected field of engineering education inquiry (Borrego 2006; Froyd and Lohmann 2014), and to reflect that trend in Canadian EER (Frank et al. 2011). Work that informs accreditation decisions and examines the role of the graduate attributes in engineering education must go beyond what has already been researched, and offer new insights into this relevant area.

iii. A Discipline-Based Education Research

Ultimately, EER may be characterized as discipline-based education research (Borrego and Bernhard 2011) that is still transitioning into an increasingly interdisciplinary and scholarly field of scientific inquiry (Froyd and Lohmann 2014). The research and pedagogical processes that engineering educators are presently employed in are heavily characterized by accepted pedagogical practices found within the discipline of education, as well as other more established, traditional fields (Borrego and Bernhard 2011; Fortenberry 2014; Froyd and Lohmann 2014; Johri and Olds 2014; Johri, Olds and O'Connor 2014; Newstetter and Svinicki 2014; Roth 2014; Streveler et al. 2014). Due to few individuals trained in both education and engineering disciplines, the founded partnerships between researchers in engineering education and education are vital (Olds, Moskal, and Miller 2005; Borrego and Newswander 2008; Borrego and Bernhard 2011). The combination of established principles and practices of educational assessment with educational theories are informing the shifting engineering curriculum and engineering educators' approach to research and assessment (Olds, Moskal, and Miller 2005; Borrego and Bernhard 2011). This study reflects the use of educational assessment practices in an engineering context, addresses assessment as a vital area of EER, and examines the CEAB graduate attributes in a globally relevant and novel way.

1.1 Research Context and Problem

Globally, engineering accreditation boards have moved away from a quality assurance model focused on documenting inputs to an outcomes-based model concentrated on assessing and improving students' learning (Rogers 2000; Prados, Peterson, and Lattuca 2005; Oliver 2013). Accredited engineering programs are now required to demonstrate that their students are competent in a number of areas (Davis et al. 2002; Olds, Moskal, and Miller 2005). For Canadian accredited programs, the Canadian Engineering Accreditation Board (CEAB) has identified 12 graduate attributes that accredited engineering programs must demonstrate that their engineering students have competence in:

1. A knowledge base for engineering (also referred to in this thesis as: Knowledge base for engineering)
2. Problem analysis
3. Investigation
4. Use of engineering tools
5. Design
6. Individual and teamwork
7. Communication skills
8. Professionalism
9. Impact of engineering on society and the environment
10. Ethics and equity

11. Economics and project management
12. Lifelong learning

Canadian institutions seeking CEAB accreditation are responsible for developing learning outcomes and using outcomes-based pedagogic practices to afford students the opportunity to demonstrate their knowledge, skills, attitudes, values, and behaviours in these 12 areas (Rogers 2000; Frank et al. 2011; Frank and Fostaty-Young 2011; McCahan, Romkey, and Allen 2011; Engineers Canada 2014). This requires that accredited programs develop systematic and valid curricula, and outcomes-based pedagogical strategies and assessment tools that are constructively aligned with their educational objectives and teaching methodologies (Biggs 1999; McGourty, Besterfield-Sacre, and Shuman 1999).

Accreditation changes were born out of the movement to re-conceptualize engineering and educate the Engineer of 2020 (National Academy of Engineering 2004) in order to meet the growing demands of our complex, troubled, fast-paced, technologically driven world. As recounted by Goldberg and Summerville (2014), reports such as *Rising Above the Gathering Storm* (National Academies) and *Engineering for a Changing World: The Millennium Project* (Duderstadt) reflect this growing, urgent need to revolutionize engineering education. Today, less than two short years away from the Engineer of 2020, engineering educators are still looking for revolution. As Pellegrino (2017) describes, educators are seeking ‘the Holy Grail’ of education to instill in students a ‘high level of competency given the nature of life and work in the 21st century.’ They are contemplating how to design pedagogies for the Engineer of 2050 (i.e., the Engineers of 2050 Workshop at CEEA-ACEG 2017), and are even looking beyond the research and into narratives in order to reignite the passion for, and the transformative potential of, education (Goldberg and Summerville 2014). Terms such as Goldberg and Summerville's (2014) 'whole new engineer' and the 'T-shaped professional' are emphasizing the development of both the professional and technical skillsets required for the engineer today (Miller et al. 2014). In engineering, these comprise of the technical skills unique to the engineering profession, such as engineering knowledge and use of engineering tools, problem analysis, investigation, and design, coupled with the intrapersonal and interpersonal skills required of graduates to work successfully, ethically, and professionally, and to communicate effectively in multidisciplinary teams while negotiating an environmentally and socially challenging, culturally complex, diverse world. Hence, the improvement and development of engineering programs that support the authentic education of the 'whole engineer' replete with the knowledge, skills, attitudes, values, and behaviours necessary to tackle the fast-paced, technically complex, ever-changing 'wicked problems' (Simon 1976, as quoted in Radcliffe 2006, p. 263) of the 21st century is the quagmire of engineering education today.

To some extent, thus far in Canada, due to the pressures of accreditation, approaches to this problem could be generalized as singular efforts to teach and assess the CEAB graduate attributes by consecutively locating, and individually and proportionately attending to each attribute on the list. This is done despite acknowledgment by the Washington Accord that whilst all attributes are important, they should not necessarily be appointed equal weight (International Engineering Alliance 2013, p. 4). Problematic in this approach is the tendency through separation to treat attributes in isolation, when authentically they 'overlap and are entwined' (Oliver 2013, p. 453).

When this study was conceived, there was limited evidence of EER that investigated the relative importance or interconnectedness of the attributes required for engineers in order to make sense of how they manifest in stakeholders' respective engineering worlds. Some examples of work in that area include Nguyen 1998; Robinson et al. 2005; Male, Bush, and Chapman 2011a and 2011b; Passow 2012; and Oliver 2013. Understanding the interconnectedness of engineering competencies is critical because this is how competencies authentically emerge when employed in solving the 'messy' problems in the real world (Stephenson, 1998 as quoted in Oliver 2013, p. 454), and therefore, ideally, it is how the attributes should manifest in engineering curricula. Most literature on assessment in engineering education focuses on one or at the most, a few engineering competencies /attributes, to explore how they are best taught and assessed in the educational setting. Very little research focuses on how they are understood conceptually. This indicates the probability that most attributes are likely being taught and assessed in isolation (Smith et al. 2005; Litzinger et al. 2011; Yadav et al. 2011), with the methods and motivation informed by the established engineering education environment and propelled by accreditation.

As stated, one could argue that isolating engineering competencies in engineering curricula is an inauthentic, and therefore potentially less effective way of teaching and assessing the student engineer today. In order to consistently and effectively design engineering curricula, faculty, students, and other engineering stakeholders need to have a clear and common understanding of what the graduate attributes are, what their relative importance is, and a shared conceptual understanding of how the graduate attributes manifest in practice. These understandings will help engineering educators form a comprehensive, complete, and holistic picture of how the engineering competencies should be authentically taught and assessed in the engineering educational environment. This will facilitate in engineering students the authentic development of all required competencies in preparation for engineering professional practice. In other words, the measure of the content validity of engineering programs in regards to the relative importance and interconnections of the graduate attributes needs to be evaluated.

In an important piece of research entitled, 'Which ABET Competencies Do Engineering Graduates Find Most Important in their Work?', Passow (2012) presents the results of a seven-year survey that asked engineering graduates to value each of the ABET General Criterion 3: Student Outcomes (i.e., the 11 learning outcomes required at the time for engineering undergraduates by the American accreditation board, ABET) in relation to their professional careers. In the study, Passow (2012) found that no matter the engineering discipline, graduates ranked teamwork, communication, data analysis, and problem solving as the top used competencies/attributes in their disciplines. (The lowest ranked competencies were contemporary issues, design of experiments, and understanding the impact of one's work.) Passow (2012) concluded, that among other things, 'faculty…should consider placing special emphasis on the 'top cluster' competencies.' At the time, this idea was unique in the body of literature, with the only other research in the area by Nguyen (1998), who conducted a survey with academics, industry members, and students to determine 'the essential generic and specialist skills and attributes…for a modern engineer' (p. 65), and Male, Bush, and Chapman's research (2011a, 2011b) (Passow and Passow 2017). Passow's (2012) work paved the way for a new direction in EER to explore how engineering stakeholders conceptually understand or 'cluster' the graduate attributes.

It was not until the recently published work by Pons (2016), where he explores what are considered the 'professional skills' in engineering in the context of engineering project management, that the idea of 'clusters' of engineering attributes – to this researcher's knowledge – surfaced again. Coming to the same conclusion as Passow (2012), Pons shows evidence that engineering competencies naturally cluster together, and suggests that this occurrence should be further explored. This is vital research as there are few areas in the literature where the linear list of engineering graduate attributes is considered and arranged conceptually (exceptions are found in the work of Hanrahan 2008, see Figure 2.2, and Nelson 2014, see Figure 2.3), which among other considerations, is essential to inform a holistic approach to curricula design in pursuit of the educational development of 'the whole engineer' (Goldberg and Summerville 2014).

Finally, there has also been some new international research on the concept of the relative importance of engineering competencies published within the last year (e.g., Pons 2016; Ebrahiminejad 2017; Passow and Passow 2017). In their recent study, Passow and Passow (2017) not only focus on the relative importance of engineering competencies across engineering disciplines and practice contexts, they underscore the essential importance of the research in designing engineering curricula (p. 475).

Adding to the limited work in this area (e.g., Nguyen 1998; Male, Bush, and Chapman 2011a and 2011b; Passow 2012; Pons 2016; Passow and Passow 2017), this doctoral research explores how Canadian engineering stakeholders rate the relative importance of, and dependencies of the CEAB graduate attributes. These data are then used to evaluate the content validity of an engineering program in order to inform authentic outcomes-based engineering education pedagogical practices. This is novel, as despite the recent research on the relative importance of engineering attributes and call to explore the clusters of the attributes, in this researcher's experience, there appears to be no such studies in Canada, and none where the content validity of engineering programs is evaluated using engineering competencies as a measure.

The premise behind this research is that faculty need to have a clear and common understanding of how the graduate attributes manifest for Engineers-in-Training (EITs) in the field at the beginning of their career, as this is the point at which newly graduated engineering students will first employ the graduate attributes in practice. The relative importance of each of the CEAB graduate attributes to the practice of EITs, as well as a shared understanding of if and how these attributes depend on other attributes, will apprise engineering educators which graduate attributes to emphasize in the engineering curriculum, and whether the graduate attributes should be taught and assessed in clusters or whether they can be taught and assessed authentically in isolation.

In keeping with the new accreditation requirements that state all engineering constituents must be involved in the continual improvement process (Davis et al. 2002; Olds, Moskal, and Miller 2005; Prados, Peterson, and Lattuca 2005), and for the sake of best assessment practices, the understandings and perceptions of the relative importance and dependencies of the graduate attributes need to be explored across the different engineering stakeholder groups. Three of the most probable stakeholders are undergraduate students, faculty members, and engineering industry members (Pons 2016). This will inform engineering stakeholders whether all groups share a common understanding of the graduate attributes, or whether more work needs to be done in this area. Ultimately, this research needs to be done as part of the continual improvement process for engineering education in Canada.

1.2 Research Design, Objectives, Scope, and Research Questions

The overarching objective of this exploratory case study was to investigate the CEAB graduate attributes are emphasized in the engineering programs in the Faculty of

Engineering at the University of Manitoba to reflect their reported importance by key stakeholders. The purpose is to inform the improvement and development of authentic outcomes-based engineering curricula by: (i) determining the relative importance of the CEAB graduate attributes; (ii) evaluating the content validity of an engineering program; and (iii) developing a conceptual and/or theoretical understanding of the CEAB graduate attributes to inform engineering curricular design.

The University of Manitoba is a large research university located in Winnipeg, Manitoba, Canada. Its Faculty of Engineering houses four engineering departments and offers Bachelor of Science degrees in five disciplines: Biosystems, Civil, Electrical, Computer, and Mechanical Engineering. It is the oldest engineering school in Western Canada, and each program is accredited by the CEAB, with the latest six-year accreditation earned through to June 30, 2019 (Beddoes 2017). In the year that the data were collected for this study, there were approximately 91 engineering faculty members, 235 senior students in their capstone year, and 70 Manitoba industry members who belonged to Friends of Engineering in the Faculty of Engineering at the University of Manitoba. These were the stakeholders that comprised the population and scope for this exploratory case study.

The study was designed in two phases. In Phase 1, the relative importance and dependencies of the CEAB graduate attributes for EITs at the beginning of their career as perceived by University of Manitoba senior engineering undergraduate students, engineering faculty, and local Manitoba engineering industry stakeholders were established. In Phase 2, the Department of Biosystems was used as a case study to evaluate the content validity of the program as measured by the relative importance findings from Phase 1. In Phase 1, a closed-ended ratings questionnaire was employed, and a teaching faculty questionnaire and program and accreditation documents were used to collect data for Phase 2. The data were qualitatively analyzed using descriptive and inferential statistics and are reported on in this thesis.

The study was guided by these research questions:

RQ 1.0 Absolute and Relative Importance of the CEAB Graduate Attributes

RQ 1.1 What is the perceived absolute importance of each CEAB graduate attribute across all engineering stakeholders (i.e., students, faculty, and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 1.2 What is the perceived relative importance of each CEAB graduate attribute across all engineering stakeholders (i.e., students, faculty, and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 1.3 How much does the perceived absolute importance of each CEAB graduate attribute vary between each engineering stakeholder group (i.e., students vs. faculty vs. industry)?

RQ 1.4 How much does the perceived relative importance of each CEAB graduate attribute vary between each engineering stakeholder group (i.e., students vs. faculty vs. industry)?

RQ 2.0 CEAB Graduate Attribute Dependencies

RQ 2.1 What is the perceived dependency of each of the 12 CEAB graduate attributes on every other CEAB graduate attribute for all engineering stakeholders (i.e., students, faculty, and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 2.2 How much does the perceived dependency of each CEAB graduate attribute on every other CEAB graduate attribute vary between engineering stakeholder groups (i.e., students vs. faculty vs. industry)?

RQ 2.3 How do the perceived similarities of the CEAB graduate attributes cluster together across all engineering stakeholders?

RQ 3.0 Program Content Validity

RQ 3.1 For each CEAB graduate attribute, how similar are the percentages of course content coverage to the percentages of course assessments in the Biosystems engineering program?

RQ 3.2 In the Biosystems engineering program, how do the percentages of course content coverage and course assessments of the CEAB graduate attributes compare with their perceived relative importance by all engineering stakeholders?

In addition to discussing the findings as relevant to the Faculty of Engineering at the University of Manitoba, the findings from this study will be compared to the international research presently being conducted on engineering student competencies and their application in engineering practice in the profession.

1.3 Research Assumptions

For Phase 1 of this study, it was assumed that:

- All stakeholders, despite their stated level of familiarity with the CEAB graduate attributes, were able to define the graduate attributes in a similar way from the list they were provided of the CEAB definitions;

- The 12 CEAB graduate attributes are required in engineering practice for an EIT;
- There are only 12 graduate attributes; there are no missing graduate attributes;
- Participants rated the frequency and criticality of the CEAB graduate attributes and the dependencies of the graduate attributes while specifically thinking about an EIT at the beginning of his/her career;
- Participants' ratings of the CEAB graduate attributes were based on their individual perceptions and experiences;
- The perceptions and experiences of engineering faculty, students, and industry were informed by their stakeholder role, by their experiences or lack of experiences in engineering practice, and by the engineering discipline and/or industry with which each stakeholder identified; and
- Participants who completed the questionnaire (part one, part two, or both part one and two) did so with integrity.

For Phase 2, it was assumed that:

- All participants who filled out the instructor questionnaire defined the terms, 'teaching' and 'assessing' in a similar way, basing their understanding on the exemplars that were specified for each term in the questionnaire;
- All participants who filled out the instructor questionnaire in response to the course(s) they teach in the biosystems engineering program did so with integrity; and

- The relative importance of the graduate attributes as perceived by engineering stakeholders should be reflected in the engineering curriculum in order to demonstrate program content validity.

1.4 Significance and Contributions of the Study

Research has shown that there is a growing awareness of the value of outcomes-based pedagogical practices, not only for enhancing student learning (Heinricher et al. 2002), but also for enriching program quality (Prados, Peterson, and Lattuca 2005). Canadian engineering instructors are comparatively new to outcomes-based education teaching and assessment practices, and to the formalization of the CEAB graduate attributes in our curricula, which is now an accreditation requirement (Frank et al. 2011). As Male, Bush, and Chapman (2011b) corroborate, 'The accreditation criteria are significant to the decisions made by people driving change in engineering education programs, evaluation methods, and even the foci of benchmarking exercises. Therefore it is critical that the nature of generic engineering competencies required by engineers graduating in [name of country] is understood well by accreditation developers, accreditation panels and engineering educators' (p. 147).

There is an absence of a significant Canadian body of rigorous research on the relative importance of the CEAB graduate attributes, the dependence of one graduate attribute on another, and the content validity of engineering programs based on these measures. This research addresses these gaps, and through this process, makes these contributions:

- Enables stakeholders to become cognizant of, and attend to their own knowledge about the graduate attributes, which will benefit stakeholders as they are responsible for teaching, learning, and assessing the knowledge, skills, attitudes, values, and behaviours that comprise the graduate attributes, either through delivery of curricula (faculty), developing competencies (students), or assessing competencies (faculty and industry);

- Enlightens University of Manitoba engineering stakeholders about the individual and common understandings of engineering faculty, students, and industry members in regards to how the CEAB graduate attributes manifest for EITs at the onset of their careers. Faculty members can use these data to inform their own instruction and consider the constructive alignment of their course objectives, teaching methods, and assessment tools (Biggs 1999, 2013);
- Informs faculty about students' understandings, and aids faculty in exploring, challenging, and/or correcting students' current comprehension and/or potential misconceptions;
- Reveals whether faculty and industry members are aligned in their understandings and perceptions regarding the CEAB graduate attributes, and aids faculty and industry to find common ground in their mutual objective to educate and develop the 'whole engineer'; and
- Fosters the ongoing partnership between local Manitoba Engineering industry members and faculty from the University of Manitoba, and continues the work to create common understandings between these two stakeholder groups to ultimately improve engineering education (Ferens et al. 2014).

The findings from this study have been used to develop a conceptual and/or theoretical understanding of the CEAB graduate attributes to illustrate the relationships amongst them and to inform engineering curricular design. A conceptual understanding of the CEAB graduate attributes is beneficial in that it:

- Propagates an awareness and understanding of the graduate attributes for all engineering stakeholders;
- Illustrates how the competencies that engineering students are expected to acquire are emphasized, and how they interconnect;
- Facilitates students to identify the competencies they can claim as newly graduated engineers, and assists them in communicating their knowledge and skills to industry as they seek employment in the field (Seniuk Cicek, Peto, and Ingram 2016);
- Gives industry a tangible understanding of what competencies they can expect from a newly graduated engineer, a way to identify potentially missing knowledge, skills, attitudes, values, or behaviours, and a way to communicate to both prospective employees and faculty what they are seeking in their EITs; and
- Assists in the improvement and development of engineering curricula by informing educators where and how to emphasize attributes in the curriculum to reflect authentic engineering practice.

By exploring how the University of Manitoba engineering stakeholders' perceive the relative importance and dependencies of the CEAB graduate attributes, University of Manitoba engineering students, faculty, and industry, the greater engineering education community in Canada, including the CEAB, and the international engineering education community will learn how one bounded group of engineering stakeholders' understand engineering competencies for EITs at the beginning of their career; how these understandings communicate importance and reveal structures; how they convey relationships among engineering competencies; what these findings reveal about the various groups of engineering stakeholders and their contexts, motivations and roles; and how these understandings inform the development of outcomes-based curricula and the pedagogical practices of engineering educators. Once it is understood how engineering stakeholders understand the CEAB graduate attributes, engineering educators will have a conceptual/theoretical framework by which to approach teaching and assessing the graduate attributes in a more authentic way. And it is through authentic learning and assessment experiences that students' engagement is increased, and significant learning is fostered (Prince 2004; Smith et al. 2005; Prince and Felder 2006; Oliver Keene and Zimmermann 2007; Litzinger et al. 2011; Yadav et al. 2011).

This research study is novel in a number of ways. Very few research studies on graduate attributes address multiple stakeholder groups simultaneously; specifically the student perspective has not received much attention (Leggett et al. 2004; Pons 2016). This study explored the perspectives of engineering students, faculty, and industry members. This research also addresses all of the graduate attributes rather than a subset of attributes such as the 'professional skills' (e.g., Shuman, Besterfield-Sacre, and McGourty 2005; Pons 2016). There are international studies that have explored the relative importance of engineering competencies (e.g., Robinson et al. 2005; Male, Bush, and Chapman 2010) and a few studies that have explored the relative importance and are calling attention to the significance of clustering them (Male 2010; Male, Bush, and Chapman 2011a, 2011b; Passow 2012; Pons 2016; and Passow and Passow 2017). However, this research is the first that the author is aware of that conducts an exploratory case study to investigate the interrelationships among engineering competencies, as Passow and Passow (2017) confirm from the findings in their systematic literature review (p. 490) (for a more detailed discussion on the relevance of Passow and Passow (2017) to this study, see Section 1.5 *Situating this Work Within Passow and Passow's (2017) Systematic Literature Review: A Contemporary Notion of Engineering*, which follows this section).

Male, Bush, and Chapman (2011b) have completed a rigorous qualitative study on engineering competencies from the perspective of Australian engineers and adapted their findings to a theoretical framework developed by the 'international multidisciplinary Definition and Selection of Competencies (DeSeCo) Project' (p. 147); however, they collected data on relative importance to identify relationships between the competencies and different engineering jobs (p. 148), which is a different design than this study. In addition, Male, Bush, and Chapman's (2011b) attained data by asking participants to rate the importance of each competency (i.e., 'These competencies were rated for importance (1 = not needed; 5 = critical) in two surveys' (p. 148)), and then calculated the relative importance based on these individual ratings. In this research study, the relative importance was calculated by collecting ratings data on the frequency of use *and* the criticality of competence for each graduate attribute. The relative importance was the product of these two ratings. Although this particular method of calculating the relative importance of a competency has been done in other fields, specifically at the University of Manitoba in the Faculty of Medicine (Stutsky, Singer, and Renaud 2012) and in the Faculty of Nursing (Renaud, Forthcoming), this researcher is not aware of it being applied to engineering.

Additionally, this study is using the relative importance data as a measure to evaluate the content validity of an engineering program, which as far as can be discerned by the researcher, is work that has not been done in this field. Furthermore, this researcher is unaware of any research studies that have explored either the relative importance or the interconnectedness of the CEAB graduate attributes in Canada. As Male, Bush, and Chapman (2010) emphasize about their own studies regarding generic engineering competencies, 'rather than making the assumption that findings from overseas studies generalise to Australia, it is prudent to also obtain Australian data' (p. 56). Similarly, it is prudent to obtain CEAB graduate attribute data for Canada.

This research study challenges the list of CEAB graduate attributes, questioning if there are authentically 12 isolated engineering competencies, or if graduate attribute dependencies on other graduate attributes dissolve their linear structure. This study is designed to identify potential clusters of CEAB graduate attributes using a unique quantitative methodological approach in order to develop a conceptual/theoretical understanding from which to design curricula, with the aim that the graduate attributes be taught and assessed as they manifest in engineering practice. This work enables 'harmonizing' the curriculum (Pons 2016, p. 532) by identifying what to emphasize in the curriculum, and uses perceptions of stakeholders, including engineers in practice, to inform curriculum developments, which provides for more authentic education (Passow 2012).

Engineering education is in the midst of a transformation into an interdisciplinary and scholarly field (Froyd and Lohmann 2014). This field needs to become increasingly global. At present, very few Canadian voices are heard and perspectives offered in the international arena of engineering education. This research adds to the growing body of Canadian EER, to Canadian accreditation practices and knowledge, as well as to the global discourse on EER knowledge and methods. Finally, this study is important for constructing a conceptual and/or theoretical understanding of what engineering is to a variety of engineering stakeholders as there is a need for a contemporary understanding of the discipline. As Trevelyan (2014) writes, 'This lack of readily available literature might explain why contemporary notions of engineering have drifted far from the realities of practice and are in urgent need of revision' (p. 36). The findings in this study, supported by the literature, add to the contemporary notion of engineering.

1.5 Situating this Work Within Passow and Passow's (2017) Systematic Literature Review

In a recent publication in *JEE*, a comprehensive systematic literature review is presented that explores which competencies Washington Accord and ABET undergraduate engineering programs should emphasize (Passow and Passow 2017). The study represents the premier systematic review available in this area, contributing to the field by 'Defining the nature of engineering work and the generic competencies required in engineering practice' (p. 504). Fifty-two studies published from 1990–2012 are subject to either a quantitative or qualitative synthesis (p. 475). Over a third of the studies in the review employed methods that 'exceed the rigor of the expert panel process used to develop ABET's learning outcomes, Washington Accord's graduate attributes, and committee reports such as The Engineer 2020: Visions of Engineering in the New Century (National Academy of Engineering, 2004)' (p. 502). By situating the findings from this doctoral research within the context of Passow and Passow's (2017) comprehensive systematic literature review on engineering competencies, this study is strengthened.

Passow and Passow's (2017) findings comprise of engineering stakeholders' perceptions, which are essential for informing curricular improvements, for 'asking respondents to rate the importance of competencies for their own work is more accurate than asking them to rate for a role that is not their own' (p. 502). The authors explain the soundness of considering the perceptions of distinct stakeholders groups to identify similarities and differences amongst perceptions. This research design asked three different groups of engineering stakeholders to rate their perceived importance of the CEAB graduate attributes for Engineer-in-Trainings (EITs) when they first enter the field. Not all stakeholders were close in time and place to the construct that this study was designed to measure. Collecting the perceptions of students, faculty, and industry in this case, and substantiating the data with Passow and Passow's findings, strengthens the findings.

Passow and Passow (2017) highlight the limitations in the studies on engineering competencies thus far, including constraints in sampling, generalizability across disciplines, professional settings and experiences, and changes in the relative importance of competencies as determined by semantics or time (p. 476). This study addresses some of these limitations: It generalizes across different engineering disciplines, specifically Biosystems, Civil, Computer, Electrical and Mechanical engineering, across different educational levels, and across different engineering practice settings and experiences, as stakeholders represented a variety of senior engineering students, engineering faculty, and Manitoba engineering industry members.

Passow and Passow's (2017) work purposes to 'answer the practical question of curriculum design: What competencies should undergraduate engineering programs emphasize?' (p. 476). They aim to do this 'across engineering disciplines and work contexts' (p. 476.) This study has a similar purpose, albeit with a marked difference in scope. However, this research study is important because as already discussed, research on competencies needs to be conducted in the context of the program that is being assessed

(Male, Bush, and Chapman 2011a, p. 153). There is a need for this research in the context of the CEAB graduate attributes and Canadian engineering programs.

Differently than Passow and Passow's (2017) design, which is a comprehensive, global, systematic literature review of published research, this work is a case study bounded by University of Manitoba engineering senior student, faculty, and Manitoba industry members, with data collected via a closed-ended ratings questionnaire. The data are considered unique to this specific case, but are generalizable (Koro-Ljungberg and Douglas 2008) across Canadian accredited engineering programs with similar cases, and transferable to global engineering education. This research is concerned with the Canadian perspective on student engineering competencies, and analogous with Passow and Passow's (2017) criteria, it includes the comprehensive set of CEAB graduate attributes. This study is the first exploratory case study to investigate the CEAB graduate attributes across engineering disciplines and stakeholders of which this researcher is aware. Situating it comparatively within Passow and Passow's (2017) findings strengthens its global relevance beyond this specific case.

Chapter Summary and Organization of Thesis

The prologue briefly introduced the emergence of the field of engineering education in America, and positioned engineering education in Canada within this broader view. The research context and problem were introduced, and the study design, objectives, scope, and research questions were explained. The research assumptions were enumerated. The significance of this study and the research contributions that it will make locally to the Faculty of Engineering at the University of Manitoba, nationally, to Canadian engineering educators, and globally, to international engineering educators and to the field of engineering education, have been presented. The study is situated within the findings from Passow and Passow's (2017) comprehensive, systematic literature review.

The balance of this thesis is organized in this way: Chapter Two is a Review of the Literature, and is organized into three parts: (1) The Emergence of Engineering Education, Engineering Program Accreditation, and the Influence of ABET; (2) Assessment in Engineering Education; and (3) Assessing the CEAB Graduate Attributes. Chapter Three presents the study methods, which includes the research design and methodology; research site; research participants, methods, and measures; data analysis; study quality, ethics approval; and timing and length of study. Chapter Four presents the findings, organized by the study phases; and Chapter Five discusses the relevance of the findings within the context of the research literature, and the implications of the findings for curricular design within the Biosystems Engineering program, the Faculty of Engineering, and accredited engineering programs in general. This is followed by a discussion of the limitations, recommendations, and next steps. Chapter Six concludes the thesis with a summary of the work and a postscript. The References and Appendices follow.

Chapter Two: Literature Review

Chapter Two contains the Literature Review within which the context for this thesis is set. It is comprised of three sections: The first part discusses the emergence of engineering education, the influence of America and the development of the ABET student learning outcomes, changes to engineering accreditation, the Washington Accord graduate attributes, changes to ABET Criterion 3, the Canadian Engineering Accreditation Board (CEAB), and the influences of accreditation changes on Canadian engineering programs. The second part is a comprehensive overview of assessment as it pertains to engineering education and its significance due to the requirements of accreditation and the demands in today's increasing culture of accountability. It includes a discussion on the power and purposes for assessment, the paradigm shift in assessment, types of assessment, constructive alignment, assessment tools, limitations of indirect assessments, recommendations and cautions for assessments, the role of engineering stakeholders in assessment, the importance of a common language and understanding, and the gaps in understanding in assessment. The third section focuses on assessing the CEAB graduate attributes, considers the 'traditional' versus the 'professional skills,' discusses the gaps in the conceptual understanding of the graduate attributes, and the relative importance and interrelationships of the graduate attributes.

2.1 The Emergence of Engineering Education, Engineering Program Accreditation, and the Influence of ABET

The emergence of engineering education as a field or discipline in its own right was partly influenced by a new accreditation culture, which was born out of a mandate for accountability and the urgent call for reformation in engineering education (see Prologue). ABET, the body responsible for accrediting American (and other) college and university programs in applied science, computing, engineering, and engineering technology (ABET 2017), responding to a number of reports and movements to disrupt the engineering curricula and make room for reform, was the first body to introduce a list of engineering student learning outcomes. These encompassed a set of individually assessable competencies that were deemed essential for all engineers, and for which engineering programs were responsible for teaching and assessing. This was in 1996. Other accreditation bodies followed, with the Washington Accord and CEAB making similar changes in 2004-2005 and 2009 respectively (see Figure 2.1).

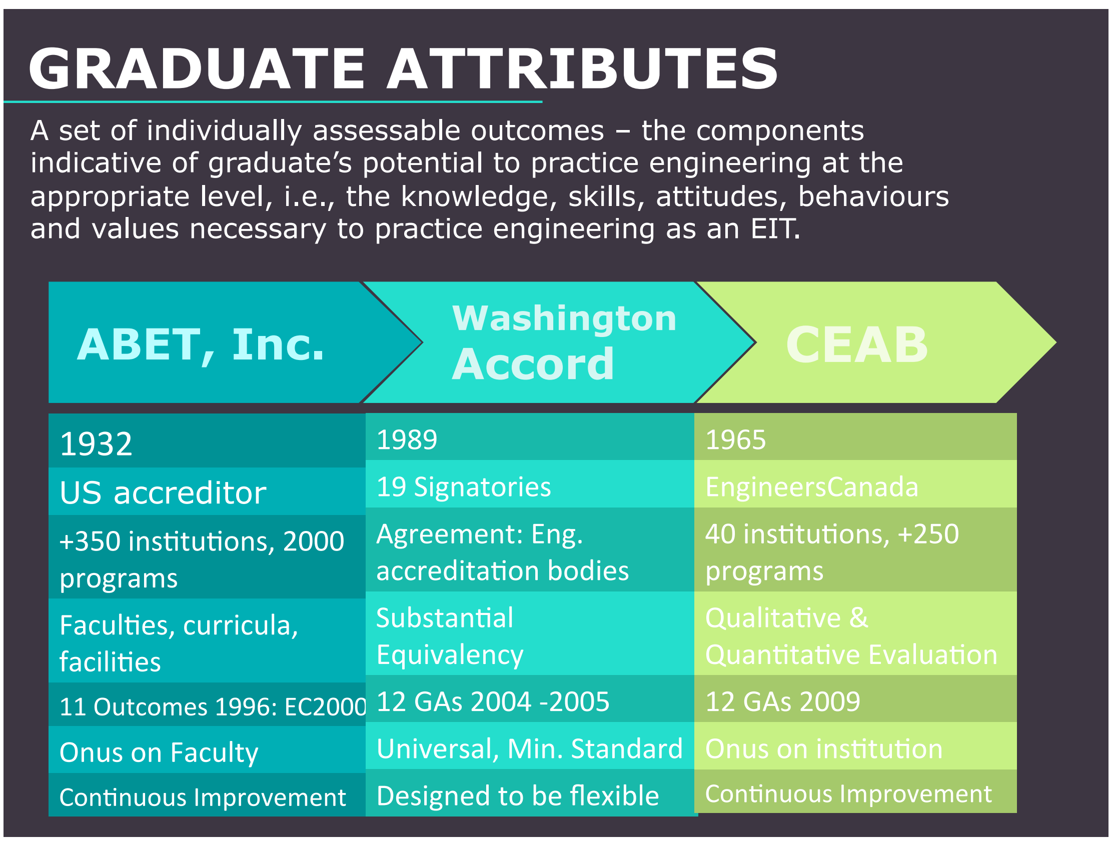


Figure 2.1. Comparative view: ABET, Washington Accord, CEAB (Seniuk Cicek 2015).

The first section of this Literature Review will discuss the emergence of engineering education, engineering accreditation, and the influence of ABET.

2.1.1 The Emergence of Engineering Education as a Field of Research and Inquiry

Today, engineering education is viewed as a recognized field of research and inquiry that draws on a number of established disciplines, including education, learning sciences, cognitive and social sciences, and research in education in physics, chemistry and other sciences to enhance engineering practice and teaching (Olds, Moskal, and Miller 2005; Steering Committee NEERC 2006; Jesiek, Newswander, and Borrego 2009; Borrego and Bernhard 2011; Case and Light 2011; Fortenberry 2014; Froyd and Lohmann 2014; Johri and Olds 2014; Johri, Olds, and O'Connor 2014; Newstetter and Svinicki 2014; Roth 2014; Streveler et al. 2014). The growing importance of the field of engineering education is reflected in its numerous journals and associations, Ph.D. graduate degree programs and university departments in several prestigious American universities (Wankat 2004; Jesiek, Newswander, and Borrego 2009; Borrego and Bernhard 2011; Johri and Olds 2014), and the increasingly enlarging global community of engineering education researchers (Fortenberry 2014; Froyd and Lohmann 2014; Johri and Jesiek 2014; Johri and Olds 2014). Despite the strong presence of engineering education today, it was only a few years ago that Borrego (2007) questioned whether engineering education was indeed a discipline, and certainly felt that it was 'pre-paradigmatic.' In 2011, she called it 'a discipline coming of age' (Borrego and Bernhard 2011). Froyd and Lohmann (2014) agree that engineering education is still in transition, as it becomes an increasingly interdisciplinary and scholarly field of rigorous scientific inquiry.

2.1.1.1 The American Influence

The historical emergence of engineering education can be traced back to the period between 1890-1910, when in America the Society for the Promotion of Engineering Education (SPEE) (presently the American Society for Engineering Education, ASEE) was founded. The interest centered on the development of curriculum and innovative pedagogy (Froyd and Lohmann 2014). It has been only in the last 15–20 years in America that the field has formally emerged as a critical research discipline in its own right, with an increased demand for, and emphasis on an interdisciplinary and scientifically driven foci (Fortenberry 2014; Froyd and Lohmann 2014; Case and Light 2011). This change was due to a number of factors, including the funding of EER by the National Science Foundation (NSF) in America, and the shift in approximately 1996 to an outcomes-based focus by ABET (Besterfield-Sacre et al. 2000; Prados, Peterson, and Lattuca 2005; Fortenberry 2014; Froyd and Lohmann 2014;), which required that students' learning outcomes be assessed. The increased demand for assessment and public scrutiny cultivated the need for EER findings, and enlarged and broadened faculty interest in the field (Fortenberry 2014). It can be argued that a third major influence that emphasized the change of engineering education into a field driven by research and supported by theoretical and empirical frameworks was an issue published in 2005 by the *Journal of Engineering Education* (*JEE*) (Johri and Olds 2014), arguably the most influential journal in engineering education (Wankat 2004). In this particular issue, articles by senior researchers made the case for an increasingly rigorous, scientific approach in EER (Johri and Olds 2014). This general sensibility was repeated in an issue published by *JEE* in January 2011, where the significance of engineering education was argued and lauded, and the call for the ongoing development of EER as a scholarly field was voiced (Borrego and Bernhard 2011; Case and Light 2011; Johri and Olds 2011). Generally, 'events in the early 1990s sparked a spirit of innovation, a torrent of national meetings and workshops, and a worldwide movement toward outcomes-based quality assurance in engineering education' (Prados, Peterson, and Lattuca 2005 as cited in Passow and Passow 2017).

2.1.1.2 The Development of ABET EC 2000

Amendments to the ABET criteria were largely due to a number of American national organizations' independent reports that argued for an increase of synthesis and design, inquiry, problem-solving, and non-technical education in engineering, as well as integrated and experiential learning activities (Fromm 2003; Fink et al. 2005). Additionally, there was a call for early exposure to engineering, interdisciplinary perspectives, a focus on different learning styles, communication, team, leadership and life-long learning skills, social, economic and environmental impact of engineering, a systems approach, and an inclusion of ethics (Fink et al. 2005). These changes were to be informed by cognitive science and educational research. Students were to be educated for life, by teaching them to 'learn how to learn,' and by focusing the educational process on students' learning, rather than instructors' teaching. These changes, first implemented in Drexel University (Fromm 2003) and in four coalition schools (Borrego 2007), can be traced to the present-day ABET EC 2000 criteria (Fromm 2003; Borrego 2007), and were a precursor to the changes implemented to accreditation requirements for engineering programs worldwide. It was the beginning of the initiation to outcomes-based assessment and continuous improvement processes introduced by academic accreditation bodies, industry and government, which have all become part of the lexis of today's engineering education field (Borrego 2007).

2.1.2 Changes to Engineering Accreditation: Outcomes-Based Assessment

The requirements for accreditation for engineering programs have changed in the last 15-20 years. Assessment has grown in importance, as a 'culture of accountability' has swept across the engineering education landscape (Davis et al. 2002). Assessment of student outcomes is being required globally throughout a variety of professions (Olds, Moskal, and Miller 2005). For example, part of the requirements of the Washington, Sydney, and Dublin Accords (International Engineering Alliance 2014), and for accreditation bodies such as ABET (as of 1996) (Fortenberry 2014) and for the Canadian Engineering Accreditation Board (CEAB) as of 2009 (Frank et al. 2011), is characterized by outcomes-based assessment. It is now the responsibility of accredited institutions to show evidence of their graduating students' outcomes, which may be defined as the stated expectations of what a student will learn while in a program (Driscoll and Wood 2007), rather than solely focusing on the inputs of the program itself. In other words, accreditation boards are moving away from a quality assurance model to one focused on assessing and improving the knowledge and abilities of students (Prados, Peterson, and Lattuca 2005). This requires that accredited institutions use systematic and valid methods for measuring students' learning outcomes (McGourty, Sebastian, and Swart 1998). Accredited programs are expected to use outcomes-based assessment practices to demonstrate that their students are competent in a number of attributes identified by the various accreditation bodies, and they are accountable to their numerous stakeholders, including students, parents, faculty, alumni and industry (Davis et al. 2002; Olds, Moskal, and Miller 2005; Prados, Peterson, and Lattuca 2005). The outcomes that accreditation boards expect of graduating engineers are inherent in the attributes that they have identified; for example, ABET General Criterion 3: Student Outcomes (Olds, Moskal, and

Miller 2005; Engineering Accreditation Commission 2016) for ABET accredited programs, and the CEAB 12 graduate attributes for Canadian accredited programs (Franks et al. 2011; Engineers Canada 2014) (see Appendix A.1 for a Comparative View of the CEAB Graduate Attributes and Changes to ABET Criterion 3).

These changes to accreditation have set into motion new foci in EER, one of which concentrates on variant aspects of assessment. For example: approaches to accreditation, program assessment protocols, assessment as it applies to engineering as a pedagogical construct, assessment of students' graduate attribute outcomes, and assessment of, and by engineering stakeholders. *JEE* was analyzed by Wankat (2004) from 1993–2002. The findings showed that *assessment* and *ABET* were popular from 1998–2002, with the most cited reference being *ABET Criterion 2000*. In this same period, there was an increase in papers reporting data, doing assessment, and employing educational or learning theories (Wankat 2004), all of which illustrate the effect of the aforementioned accreditation changes, and the new emphasis on assessment.

Many see America as the leader in, and catalyst for EER. This could be due to the fact that this country has arguably the longest history of engineering education (Froyd and Lohmann 2014). This can also likely be credited to the wealth of funding that American researchers have had access to since the late 1980s through such funding bodies as the NSF (the National Science Foundation) (Fortenberry 2014; Froyd and Lohmann 2014; Johri and Olds 2014). This has allowed for a proliferation of EER and publications, a result of which has seen the field dominated by the voices of American researchers (Williams et al. 2014). This is exemplified in the recently published *Cambridge Handbook of Engineering Education Research* (Johri and Olds 2014), which is edited, as well as predominantly authored by American researchers (e.g., 63 out of 71 of the authors are American).

Due to the influence of America on EER, the study and exploration of the field is often seen through the American lens as a principal framework (Froyd and Lohmann 2014). However, there have been a number of important international engineering accords, including the Washington, Sydney, and Dublin Accords (International Engineering Alliance 2014). Due to the multiple viewpoints represented by the Washington Accord, and signatories' agreement on the Washington Accord Graduate attributes, discussing the graduate attributes from this perspective increases the comprehensive view.

2.1.2.1 Engineering Graduate Attributes: The Washington Accord

The Washington Accord is an international agreement between 19 signatories comprised of accreditation bodies responsible for accrediting engineering degree programmes. The signatories recognize the graduate attributes as 'good practice in engineering education' and the Washington Accord graduate attributes profile exemplars are 'intended to assist growing globalization of mutual recognition of engineering qualifications' (International Engineering Alliance 2017). As such, the Washington Accord works to develop a common ground on which signatories can build or reference their own accreditation standards. By the early 2000s, a number of Washington Accord signatories had or were in the process of implementing student learning outcomes into their engineering curricula requirements as part of a shift to outcomes-based criteria (Hanrahan 2008). As a result of this movement, in 2001 the signatories determined that it would be apropos to develop the Washington Accord Graduate attributes.

According to the International Engineering Alliance (IEA), the fundamental purpose of engineering education is to build a knowledge base and attributes to enable the graduate to continue learning and proceed to the formative development of the competencies required for independent practice (Seniuk Cicek 2015). The Washington Accord is built on the paradigm of 'substantial equivalence' (Hanrahan 2008). Thereby, in defining the attributes for the Washington Accord graduate, performance levels were left undefined, assuming to be determined by the level of problem solving in which the student was engaged. To understand this more clearly, the approach in thinking about the graduate attributes taken by the Washington Accord signatories was to first define the essence of what it means to be an engineer; in other words, describe the knowledge, skills, attitudes, values, and behaviours that capture *engineering*. For Washington Accord signatories, this was encapsulated in three attributes, with problem analysis as the 'core process' of design and investigation (Hanrahan 2008). These three core attributes are then supported by what are known to those familiar with the graduate attributes (e.g., the CEAB graduate attributes or ABET General Criterion 3 student outcomes) as the remainder of the graduate attributes. They are presented as four constructs: (1) Engineering Knowledge, including mathematical, natural and engineering sciences and engineering specialities; (2) Contextual Knowledge, including social, cultural, legislative, health and safety, environmental, and sustainability; (3) Project Management and Finance; and (4) Communication, Teamwork, and Ethics. Hanrahan (2008) developed a conceptual model to illustrate this construct (Figure 2.2):

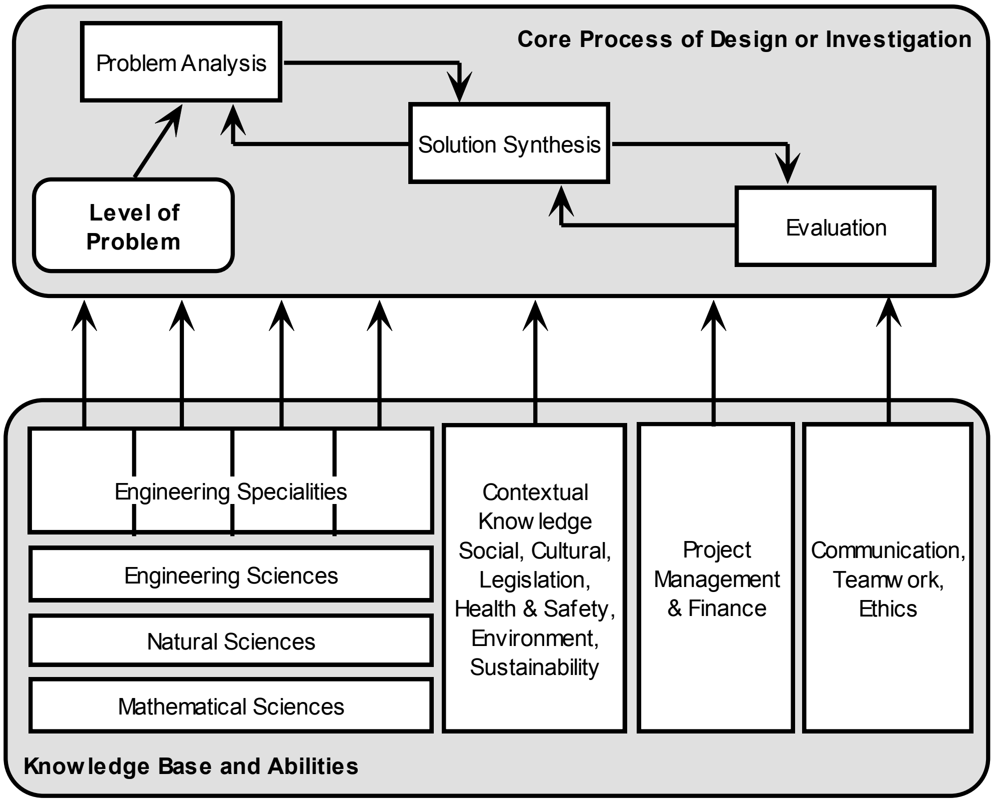


Figure 2.2. A conceptual model of the WA Graduate Attributes (Hanrahan 2008, p. 5). *Used with permission.*

The exit level of the engineering program dictates the student level of performance of the engineering activity, i.e., the problem solving and the competencies engaged from the supporting graduate attributes (Hanrahan 2008). For example, for an engineering education program, expectations are that the graduating student is able to utilize their engineering knowledge and skills to solve complex problems.

The Washington Accord Graduate attributes are supported by the Washington Accord Knowledge Profile (see Appendix A.2), and by the attributes required to solve complex engineering problems and do complex engineering activities. The Washington Accord Graduate attributes are not considered a required standard, but are intended as a guide for engineering programs developing their own outcomes-based criteria (Hanrahan

2008). In 2013 they were 'adopted by the signatories as the exemplar (or reference point) against which substantial equivalence of their own accreditation requirements are to be assessed' (International Engineering Alliance 2014). However, 'the relative emphasis among these competencies has been left for each program to determine' (Passow and Passow 2017, p. 476).

Today, despite agreement by signatories in the Washington Accord on the 12 graduate attributes essential for development in engineering students, outcomes-based criteria and student learning outcomes are continuing to evolve. ABET, characteristic of their established role as leaders in engineering education, has recently undergone a process to make changes to their student learning outcomes.

2.1.2.2 New Developments: Changes to ABET Criterion 3: Student Learning Outcomes

Already leaders in identifying learning outcomes for engineering education, as demonstrated by the Washington Accord's adoption of outcomes-based criteria, ABET has continued to break new ground in this capacity. In 2015, they underwent a process to revise their EC 2000 student learning outcomes.

The struggle engineering educators documented as having with the EC 2000 learning outcomes, namely that certain outcomes were difficult to define and measure, such as multi-disciplinary teamwork, global competencies, environment and sustainability, professional responsibility, contemporary issues, use of engineering tools, a broad education, and lifelong learning, drew the attention of ABET. In 2015, ABET proposed changes to their Criterion 3 outcomes, with the first go-round reducing the 11 outcomes to six by merging two outcomes (i.e., Problem Analysis with Knowledge Base for Engineering) and eliminating four other outcomes, including Impact of Engineering, Lifelong Learning, A Knowledge of Contemporary Issues, and Use of Engineering Tools. Additionally, reference to Professionalism was removed from Criteria 3.f, and the outcome for Teamwork was expanded to include references to Project Management. ABET cited effecting transparent assessment and encouraging innovation as reasons for the changes.

Responses to ABET's initial reorganization of Criterion 3 were swift and divided, with the reactions of opposition characterized by alarm (Seniuk Cicek, Ingram, and Friesen 2016). One camp decried the reduction of student outcomes to only ones deemed 'necessary' to engineering, and in particular, strongly rejected the removal of all references to educating engineering students with a focus on developing a broad education, an aptitude for life-long learning, a knowledge of contemporary issues, an understanding and commitment to professional responsibility, and most importantly, developing global and multidisciplinary competencies (Riley 2016). The new condensed list of six was dubbed 'Watered-Down Gen Ed for Engineers' (Flaherty 2015). They argued that ABET was reducing the competitive edge of American engineering students; that today's engineer needs to be able to work in diverse, multi-disciplinary global communities; and that if not required, missing attributes would not be emphasized – disputing ABET's notion that reducing attributes would generate pedagogical innovation. The opposing camp contended that a reduced list of outcomes would increase program innovation, while at the same time remove outcomes difficult to assess (Flaherty 2015; Rogers 2015). ABET responded to critics by ensuring changes were still in the early stages, and argued that ABET's standards having been adopted worldwide was implicit of ABET's commitment to multidisciplinary global competencies (ABET 2016).

After that first reorganization, ABET proposed a second one, comprised of seven learning outcomes (Engineering Accreditation Commission 2016; Seniuk Cicek, Ingram, and Friesen 2016). Lifelong learning reappeared with a new definition, focusing almost exclusively on the information literacy aspects of the attribute, effectively removing any implications that lifelong learning would incorporate or require reflecting on, identifying, and characterizing one's self as a learner. Since then, this definition (and the one for Design) was reworked, and the 2016 General Criterion 3: Student Outcomes had its first delegation reading, and was waiting on public review and comment before the process proceeded (ABET 2016). With the exception of contemporary issues and use of engineering tools, although the list was reduced, the seven learning outcomes contained most of the elements of the original 11 criterion. However, contemporary issues (3.j) and engineering tools (3.k) remained expunged. (See Appendix A.1 for a comparative view of changes to ABET Criterion 3.)

Presently, as of October 17, 2017, ABET has approved their 2018–2019 Criteria for Accrediting Engineering Programs. Significantly, they have gone back to requiring 11 learning outcomes. They are:

(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

(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.

Fundamentally, ABET arrived back at the 11 outcomes that were first named in 1996, with the only difference being an expansion of (c) the design outcome and (h) the broad education outcome (ABET 2017; Felder and Brent 2003, p. 8). The professional outcry that erupted when ABET first chose to reduce the outcomes has evidently stayed the process. This speaks to the importance that engineering educators place on all of the engineering competencies for professional practice, even the outcomes that are difficult to teach and/or assess, or seem less traditional than others.

Notwithstanding the recent activity regarding the changes to ABET EC 2000, there is much less emphasis today on the topics of graduate attributes and assessment in the leading engineering education journals, especially from American authors. There is still some evidence of the influence of the changes incurred by accreditation bodies seen globally from international researchers. Publications in journals such as the *International Journal of Engineering Education (IJEE),* the *European Journal of Engineering Education (EJEE)* and the *Global Journal of Engineering Education (GJEE)* have authors from around the world publishing on accreditation and assessment topics. However, the flurry of papers from American authors on accreditation topics spurred by outcomes-based criteria has subsided. The focus of accreditation and assessment was prominent in America over ten years ago, and now American researchers have forged ahead with new research interests and questions. In the area of engineering outcomes, this quest has become identifying the competencies that are required for engineers in practice by surveying engineering stakeholders (Passow 2012) and conducting systematic literature reviews (Passow 2012; Passow and Passow 2017; Ebrahiminejad 2017). This underscores how America is ahead of many countries, in particular Canada, when it comes to engineering education and EER. Canada's accreditation criteria were only changed in 2009, and at the national annual Canadian conferences in engineering education held between 2014-2017, accreditation and assessment were prominent topics.

2.1.3 The Canadian Engineering Accreditation Board (CEAB)

The Canadian Engineering Accreditation Board (CEAB) was formed in 1965 by Engineers Canada (Peters 2007). The mandate was robust:

I. Identify programs whose graduates are prepared to enter the profession of engineering
II. Develop accreditation criteria, processes, and procedures
III. Monitor Quality assurance
IV. Support Continuous improvement (Peters 2007)

As of 2007, there were over 250 accredited engineering programs in Canada, housed by 40 institutions of higher-learning, and representing 70 fields of engineering study and 55,000 students, of which approximately 10,500 graduate each year. The CEAB evaluation criteria comprise two elements: a qualitative evaluation the environment of the program, and a quantitative and qualitative evaluation of the engineering curriculum. CEAB is a signatory of the Washington Accord (Peters 2007).

2.1.3.1 The Influence of Recent Accreditation Changes on Engineering Education in Canada: Outcomes-Based Education

In 2009, the Canadian Engineering Accreditation Board (CEAB) initiated an outcomes-based approach for engineering curriculum development and assessment (Frank et al. 2011; Frank and Fostaty-Young 2011; Wolf and Stiver 2011). Canadian engineering programs, traditionally offering courses designed using inputs-based systems (Wolf and Stiver 2011), are now, similar to ABET and other international accredited institutions, responsible for developing transparent objectives, learning outcomes that can be measured, assessments of students knowledge, skills attitudes, values, and behaviours, and feedback for continual improvement of engineering education (Davis et al. 2002; Frank and Fostaty-Young 2011; McCahan, Romkey, and Allen 2011).

Previous to the newly adopted outcomes-based assessment approach, Canadian engineering schools evaluated their programs by documenting inputs, which typically included tracking time spent in a lab, classroom and tutorial contact hours, and personnel, such as number of sessional instructors, instructors with PhDs, and professors on tenure track. Among other input data, programs were (and still are) required to measure Accreditation Units (AUs), and record the hours devoted to engineering fundamentals such as design, math, and science. Today, the accreditation focus has shifted away from what the program is doing to what the students are doing (Almarshoud 2011).

Outcomes-based education is a process that continually focuses on student learning and demands institutions to be accountable to the evidence of the learning

(Driscoll and Wood 2007). Outcomes-based systems are designed to isolate, gather, examine, and report data for evidence of student learning (Seniuk Cicek 2015). Outcomes are the parts of a student's development that an institution endeavors to impact through their educational programs and procedures (Soundarajan 2002). They are 'statements that describe what students are expected to know and be able to do by the time of graduation' (Peters 2007). The outcomes of a student's education is affected by who they are when they come into an institution, what they experience both in their courses and as a result of the program, and how all of those experiences and influences work together to form their understanding of, and attitudes towards learning overall, and in particular, towards engineering (Rogers 2000). The outcomes that are required of Canadian engineering graduates are identified by the 12 CEAB graduate attributes, and can be linked to the ABET Criterion 3 Student Outcomes and the Washington Accord Graduate attributes. They are:

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

12. Lifelong learning

The graduate attributes are meant to guide faculty in equipping students with the knowledge, skills, attitudes, values, and behaviours required to function efficiently and successfully in a multifaceted and changeable world (Passow 2012). Research shows that there is a growing awareness of the value of outcomes-based pedagogical practices, not only for enhancing student learning (Heinricher et al. 2002), but also for enriching program quality (Prados, Peterson, and Lattuca 2005). This same awareness is growing in engineering education in Canada, coupled with the pressure of the outcomes-based assessment of the CEAB graduate attributes required for accreditation. A group of Science and Technology Scholars from Concordia University who are housed in the Centre for Engineering in Society (CES) in Quebec, explain the impact of the CEAB graduate attributes and the increased pressures embroiled in attaining CEAB accreditation:

> Efforts are being made by Concordia's engineering faculty (indeed engineering departments across Canada) to comply with new CEAB accreditation requirements. By 2014, all accredited engineering departments in Canada must demonstrate that their graduates possess a series of outcome attributes encompassing technical skills and social awareness. Further, to achieve accreditation from the CEAB, engineering programs must demonstrate that there is a process in place to assess program outcomes and that the results of these assessments are applied to the further development of the program. Most readers are likely familiar with the inclusion of 'non-technical' graduate attributes, such as an 'understanding of the impact of engineering on society' and 'professional and ethical responsibility'. What makes the CEAB attributes interesting is, first, that their implementation creates what we will argue can be understood as a 'constitutional moment' in engineering education in Canada. Second, the CEAB, unlike other accrediting bodies such as Accreditation Board for Engineering and Technology in the USA, is enmeshed in and carries significant authority within a 'closed', regulated professional practice within Canada. CEAB is a constituent of Engineers Canada, which in addition to controlling accreditation through the CEAB, also controls the obligatory licensure process for all engineers in Canada (through its constituent provincial professional societies). Thus, the new graduate attributes outlined by the CEAB are taken very seriously by engineering departments across Canada. (Caron et al. 2014, p. 46)

2.1.3.2 The Influence of Recent Accreditation Changes on Engineering Education in Canada: Continual Program Improvement

The outcomes-based pedagogy born out of the new CEAB accreditation criteria is meant to be a dynamic process: a continuous cycle of assessment and program improvement (Davis et al. 2002; Soundarajan 2002; Fredericks Volkwein et al. 2004; Moskal 2008, p. 125; Almarshoud 2011; Dew, Lavoie, and Snelgrove 2011; McCahan, Romkey, and Allen 2011). To achieve this, Canadian accredited institutions are faced with the challenge of creating new curricula – as the most successful curricula are redesigned – with the graduate attributes as the focus for development (Felder and Brent 2003; Passow 2012). They are responsible for gathering feedback from all of their engineering stakeholders, including faculty, students, alumni, and industry. They must create and implement an assessment protocol to evaluate attainment of the program's educational objectives and the accreditation outcomes mandated (Rogers 2000; Soundarajan 2002). These assessment results must ideally be used to incur program improvement (Rogers 2000; Soundarajan 2002; Davis et al. 2006; Lathem, Neumann, and Hayden 2011; Popp, Levy, and Barrie 2012). Program improvement is the ultimate goal of outcomes-based education (Soundarajan 2002) and the new accreditation obligations. Otherwise, there is the danger that the process will turn into a large data collection and archiving exercise, futile for sustaining any enhancement for educational purposes, and reminiscent of the 'bean counting' mechanisms of the previous accreditation requirements (Sarin 2000; Prados, Peterson, and Lattuca 2005). Unfortunately, the reality is that engaging all faculty members in a program overhaul is at best, difficult, at worst unachievable (Oliver 2013; Caron et al. 2014). To achieve a true cycle of program assessment and improvement, it is integral that most faculty members buy into the process (Shaeiwitz, 1996). To attain faculty buy-in, and an effective cycle of program assessment and improvement, a fundamental understanding of assessment is paramount.

2.2 Assessment in Engineering Education

As highlighted by James Pellegrino (2017) during his Educational Research and Methods (ERM) Division Distinguished Lecture at the ASEE annual conference in Columbus, Ohio, research on assessment is vital and relevant:

> There is an evolving science of learning and assessment that incorporates ideas about the development of disciplinary knowledge and the nature of competence. It has major implications for all aspects of schooling from pre-kindergarten through post-secondary education – design of curriculum, instruction, assessment, and faculty professional development. It provides a basis for knowing when, how and why to use various instructional strategies; it can guide intelligent design and use of new curricular materials as well as information technologies.

This section presents a discussion on assessment from a variety of angles. In it, the power of assessment, purposes for assessment, types of assessment, educative assessment, assessment tools, limitations of perceptions in assessments, recommendations and cautions in the use of assessment tools, the role of engineering educators in assessment, the importance of a common language and understanding when it comes to assessment, diagnostic assessment, and the gaps in understanding assessment are considered.

2.2.1 The Power of Assessment

As engineering programs across the world shift to outcomes-based assessment practices, a pedagogical understanding of, and purpose for, assessment is critical. Olds, Moskal, and Miller (2005) argue that assessment on a macro-scale is the catalyst to advance engineering education. Indeed, assessment that is precisely and meticulously constructed can be seen as one of higher education's 'most powerful tools' (Maclellan 2001). Assessments of high quality will result in useful information to propel the field forward. On the other hand, 'Inadequate or poorly constructed assessments can cause educators to pursue ineffective paths, resulting in the loss of time, money, and energy' (Olds, Moskal, and Miller 2005). Within the classroom, on a micro-scale, insufficient or inadequately designed assessments that demand little of students' cognitive abilities can result in superficial or 'rote learning'; whereas high-quality assessments in which students perceive the need to understand the material in order to succeed can result in deeper learning (Maclellan 2001). Assessments that are not properly aligned with learning objectives and teaching methods do little to support student learning or accurately reflect student knowledge, skills, attitudes, values, and behaviours, which is the ultimate goal of outcomes-based education. CEAB accreditation demands that engineering programs develop a protocol to assess the outcomes of their graduating students as exemplified in the graduate attributes, and that the results of the assessments are used for the purpose of program improvement (Frank and Fostaty-Young 2011) for the ultimate goal of enhancing student learning. As demonstrated in the literature (Soundarajan 2002; Moskal 2008; Dew, Lavoie, and Snelgrove 2011), a rigorous and systematic assessment protocol is needed to fulfill these criteria, as assessment is far more valuable when it is continuous as opposed to sporadic (Bailey, Floersheim, and Ressler 2002). In order to accomplish this, the paradigm of assessment must be fully understood.

2.2.2 The Paradigm Shift in Assessment

The changes that assessment has undergone in engineering education in the latter part of the 20th and early 21st century, characterized by a movement away from a measurement model that accentuates individual differences to a standards model that stresses the value of education as a way to foster the development of individuals, is described as a paradigm shift (Rompelman 2000; Maclellan 2001). The driver was for assessment to be consequential, significant, and valuable, and constructed in 'authentic,' 'real world contexts' that reflect human enterprise and achievement. This proposed standards model of assessment has its roots in constructionism/social constructionism, and is supported by the idea that learning is a process of knowledge construction rather than knowledge reproduction, situated in a particular context, and dependent on previous knowledge (Maclellan 2001). This re-conceptualization of assessment is still relevant today.

One could argue that engineering education is still in the throes of the measurement model of assessment as found in, and supported by traditional curricula design, despite the efforts being made in the field towards outcomes-based assessment as a result of the outcomes-based accreditation requirements. The standards model is the more desirable model in education because it works to reflect what one has learned (Maclellan 2001). Ultimately, it is the standards model of assessment that fully encompasses the philosophy of outcomes-based education. It is this state of assessment that engineering educators must move towards to truly embrace the new engineering education paradigm required by accreditation.

2.2.3 The Purposes for Assessment

Assessment can be defined as the 'processes that identify, collect, analyze, and report data that can be used to evaluate achievement' (Peters 2007). Assessment traditionally, and prevalently, is purposed to grade or rank students, a summative judgment. This is the reality of higher education, as institutions need to be able to establish students' achievement levels and communicate them to stakeholders, including, and perhaps most vitally, to their students, their students' future employers, and accrediting bodies (Maclellan 2001). However, assessment has – and should have – other purposes, with summative assessment arguably having too much prominence in academia (Boud 1990). One of the overarching purposes of assessment is communication (Liljedahl 2010): communication between students and teachers; teachers and administrators; administrators and Deans; and institutions and constituents, all for the ultimate purpose of fostering student learning. Assessments can and should be used to foster student learning. Indeed, Olds, Moskal, and Miller (2005) believe that the predominant goal of engineering education assessment is to enhance student scholarship. Empirical and anecdotal evidence have shown the positive impact that assessment can have on both instruction and student learning (Gijbels et al. 2005). In order to utilize assessment most effectively, an understanding of how it can be applied is essential.

Assessment can be conceived as formative or summative, in a continuum of feedback (formative) and accountability (summative). These terms were initially introduced by Scriven (1967), and used to distinguish between program improvement (formative) and the holistic evaluation of the educational program. Bloom (1969) can be credited with first using the terms to distinguish the type of student assessment that is administered, the more familiar connotation of formative and summative assessment that is used today (as cited in Bennett 2011). Formative assessment purports to improve learning quality for both students and instructors. Encouraging, responding, and giving feedback purports to students increase their learning effectiveness while they are learning (Boud 1990; Rushton 2005). Formative assessment targets the learning or the instruction for alteration and improvement, usually in the short term (Driscoll and Wood 2007).

Formative assessment can be used diagnostically (Maclellan 2001; Roselli and Brophy 2006), applied at the outset of a course or unit (Maclellan 2001) to inform the instructor and the students what students already know/can do/believe, and what they will be required to know/do/believe in order to successfully demonstrate the learning outcomes in a course; to help inform the instructor and students about students' understanding of various concepts; and to help the instructor match the pace of the course to the abilities of the students. Formative assessment has been shown in the research to be one of the most helpful pedagogical methods to support student learning (Roselli and Brophy 2006), with feedback found to yield the single most influential effect on achievement. It is a means by which to improve identified weaknesses, gaps, or deficits in both learning and in instruction (Rushton 2005). Fundamental to formative assessment is that the feedback is used for improvement; in other words, there is an element of action required for true formative feedback (Rushton 2005; Bennett 2011). The emphasis of formative assessment is considered by some to denote a paradigm shift in assessment, characterized by a culture of assessment rather than testing (Rushton 2005).

Formative assessment is conducive to outcomes-based education. McGourty, Besterfield-Sacre, and Shuman (1999) make an ardent case for formative assessment in response to the movement of the ABET accreditation board to emphasize outcomes-based assessment:

> The very nature of the ABET learning outcomes influences the way that faculty will approach performance assessment and the process of evaluation. Since the demonstration of these outcomes involves both knowledge acquisition and behavior, assessment processes themselves must be active, reflective, and developmental. Faculty needs to become familiar with the wealth of alternative assessment processes that already exist. In general, assessment [i.e., 'feedback'] in the classroom will become more frequent, open-ended, and bilateral between faculty and students. Students also will take a more active role in their own assessment and that of their peers. (p. 6)

At the other end of the continuum, summative assessment represents a summation of students' learning, or an evaluation of the instructor/course/program, and is normally applied at the conclusion of a unit or course, and in the long term (Rogers 2000).

Another way to think about assessment is to categorize it *of, for*, and *as* learning (Manitoba Education, Citizen, and Youth 2006). Assessment *of* learning is a summative assessment of individual student learning, or evaluative assessment of engineering courses, programs, and curricula for program improvement; assessment *for* learning is a formative assessment, with the feedback targeted to help students and instructors reach their potential to ensure that students become proficient in the knowledge, skills, attitudes, values, and behaviours inherent in the targeted outcomes; and assessment *as* learning is metacognitive assessment, which shows students how to assess their own learning, and fosters in them the foundational knowledge, skills, attitudes, values, and behaviours they need to become strong, independent, lifelong learners (Manitoba Education, Citizen, and Youth 2006; Seniuk Cicek, Ingram, and Sepehri 2014b). All of these categories are required of faculty and students today.

Overall, assessment is not a 'one size fits all' problem (Pellegrino 2017). As Pellegrino (2017) tells us, 'Educators at different levels need different information at different [granular] sizes and time scales' [as educators have] 'differing priorities, constraints, and tradeoffs.' The purpose for assessment must be ascertained in order to identify the type of assessment required to most effectively do the job.

2.2.4 The Types of Assessment in Engineering Education

There has been some literature published in engineering education journals devoted specifically to assessment, and how as a concept and methodology it applies to engineering education. A few worth noting include the article by Rogers (2000), who provides definitions for the terminology of assessment and a useful four dimensional framework through which to approach assessment, and another by Moskal, Leydens, and Pavelich (2002), who write about the concepts of validity and reliability as they apply to engineering education assessment. Assessment in engineering education can be used as a process for gathering data or evidence that illuminates course, curricular, or research questions (Olds, Moskal, and Miller 2005); as an assortment of activities designed to give evidence to stakeholders about the influence of educational activities (Rogers 2000); or in a narrower sense, as an assortment of activities designed to measure individual student competencies (Olds, Moskal, and Miller 2005). Assessments can target different dimensions of learning outcomes: the knowledge, skills, attitudes, values, and behaviours inherent in the graduate attributes, for example (Rogers 2000). Students' ability to apply knowledge, organize information, define problems, derive and implement solutions, and students' skills, including their communication, quantitative, inter and intra personal, and critical thinking skills are all areas that require assessment (Fink, Ambrose, Wheeler 2005). As well, the affective traits that students exhibit as a result of their education demonstrated in their behaviours, attitudes, and values also necessitate assessment. These include their goals and aspirations, value systems, and their attitudes towards themselves and others (Rogers, 2000; Fink, Ambrose, Wheeler 2005).

Assessments that are performed on individuals or groups to ensure that the targeted outcomes are being met can be instructor, peer, or self-driven. Courses or programs targeted for assessment to ensure that the stated educational objectives are being met can involve instructor, departments, faculties and/or institutions. Regardless of the specific type being targeted, assessment involves a variety of data-gathering activities (Rogers 2000; Olds, Moskal, and Miller 2005) and its purpose must be clearly defined so that chosen methods are in line with the purpose, and lead to effective data collection.

2.2.5 Constructive Alignment: Educative Assessment

The concept of a 'constructive alignment' between the educational environment and the planned assessments is shown to improve student learning (Biggs 1999, 2013; Gijbels et al. 2005). The goal is to fit assessments to what is being taught in order to measure what students are asked to learn (Gijbels et al. 2005). This constructional alignment is achieved by the practice of 'educative assessment' (Fink, Ambrose, Wheeler 2005), and is fundamental to outcomes-based assessment.

John Biggs coined the term *constructive alignment*, an approach to teaching and learning whose roots can be found in the work of Ralph Tyler, considered 'the father of teaching objectives' (Seniuk Cicek, Ingram, Friesen et al. 2017). It was Tyler who espoused that "'learning takes place through the active behaviour of the student'" (Biggs 2013, as quoted in Seniuk Cicek, Ingram, Friesen et al. 2017). Constructive alignment in the curriculum signifies that what the student is intended to learn and how that learning will take place are identified and communicated *before* teaching occurs. This is characterized as a student-centred approach to learning. Traditionally, higher education is dominated by a teacher-centred approach to education, where the focus is on the content to be ‘delivered,’ rather than on the knowledge, skills, attitudes, values, or behaviours that students are meant to demonstrate (Prince and Felder 2006). The evolution of engineering accreditation requirements to a graduate attributes focus inherently shifts the model of teaching and learning to an outcomes-based approach. Bigg’s constructive alignment provides a framework by which instructors can engage in outcomes-based education (Seniuk Cicek, Ingram, Friesen et al. 2017).

Tailoring assessments to the targeted outcomes expected as a result of the instruction is sound pedagogical practice. It is assessment that goes beyond the sole objective of assigning grades (Maclellan 2001; Fink, Ambrose, Wheeler 2005), and underscores the concept that outcomes are not grades (Rogers 2000). This type of assessment helps instructors make decisions on how to help students master the required material, as well as give direction on how to better students’ comprehension and skill performance. It assists students in improving their scholarship and their understanding of how to learn. Therefore, effective assessment requires more than one action that is tacked on at the end of a unit, term, or course; it requires careful planning and action throughout the complete course process. Effective assessment assimilates and aligns all the major pieces of a course: the learning goals/objectives, the teaching and learning activities, the feedback (formative assessment), the summative assessments, and the outcomes – what students know, can do, how they behave and what they value, once they complete the course (Fink, Ambrose, Wheeler 2005). Effective assessment requires using the appropriate tools.

2.2.6 Assessment Tools in Engineering Education: Measuring Direct and Indirect Sources

As previously discussed, assessment involves an assortment of activities to gather data (Rogers 2000; Olds, Moskal, and Miller 2005), and should be chosen based on the purpose of the assessment. A further important decision required when planning assessment is the type of tool that best fits the assessment purpose. A distinguishing trait of assessment tools is that they are either direct or indirect. (See Appendix B for a comprehensive list of direct, indirect, and published assessment tools.)

2.2.6.1 Direct Assessments

Direct assessments are defined as evaluations of students' work, which is considered a direct product of their learning experiences, also referred to as 'authentic assessment' (Spurlin 2008, p. 60; Spurlin, Rajala, and Lavelle 2008, p. 32). Course-based assessments are traditionally dominated by direct measures of student learning/ performance that specifically relate to course learning objectives/course outcomes. Direct assessments of students' work are produced traditionally in engineering through tests, exams, lab or design reports, projects (Felder and Brent 2003; Jiusto and Di Biasio 2006; Roselli and Brophy 2006; Zafft, Adams, and Matkin 2009), a variety of problem-solving, design-based assignments, as well as standardized tests (Soundarajan 2002; Felder and Brent 2003; Frank et al. 2011). Examples of standardized tests include the Fundamentals of Engineering (FE) Examination (used in America), Concept Inventories (Felder and Brent 2003; Frank et al. 2011), and non-engineering standardized tests such as the GRE (Shaeiwitz 1996; Scales et al. 1998; Felder and Brent 2003). These more traditional forms of assessment are quite often used for the purposes of summative assessment at the completion of a unit, course, or program. Caution is advised when using these types of direct measures of assessment, as although they have traditionally worked very well for inputs-based evaluation, they can be more complicated to use for outcomes-based assessment, as that requires that each question needs to be aligned to a targeted learning outcome, and these tools are not traditionally set up this way (Seniuk Cicek, Ingram, and Sepehri 2014b).

Rubrics are more conducive to outcomes-based assessment (Olds, Moskal, and Miller 2005; Shuman, Besterfield-Sacre, and McGourty 2005; Jiusto and Di Biasio 2006; Roselli and Brophy 2006; Siri Johnson 2006; Yalvac et al. 2007; Hanson and Williams 2008; Olds and Miller 2008, p. 276; Jonassen 2009; Zafft, Adams, and Matkin 2009), and are particularly useful when it comes to assessing students' knowledge, skills, attitudes, values, and behaviours in regard to the graduate attributes. They are an excellent tool for defining attribute foci and indicators, for dividing indicators into a number of performance levels, and for identifying the performance level that indicates the threshold and target, or competency of student learning (Seniuk Cicek et al. 2014). They are catalytic for determining a common language and understanding. Furthermore, when it comes to assessment of student learning and skills, 'the genius of rubrics is that they are descriptive and not evaluative. Of course, rubrics can be used to evaluate, but the operative principle is you match the performances to the description rather than judge it' (Brookhart 2013, p. 4).

Formative assessment is customarily used to improve both instruction and student learning (Rogers 2000), and as such is ideal for continual improvement (Rogers 2000; Soundarajan 2002; Wolf and Stiver 2011; Seniuk Cicek, Ingram, and Sepehri 2013; Seniuk Cicek, Ingram, and Sepehri 2014b). Examples of tools for the purpose of formative assessment include discussions and observations (Felder and Brent 2003; Roselli and Brophy 2006; Yalvac et al. 2007; Hsiung 2010), which are practical and valid assessment tools seldom used in engineering education (Olds, Moskal, and Miller 2005; Seniuk Cicek, Ingram, and Sepehri 2013; Seniuk Cicek, Ingram, and Sepehri 2014b). Other types of formative assessment include instructor and peer feedback (Felder and Brent 2003; Roselli and Brophy, 2006; Yalvac et al., 2007; Hanson and Williams, 2008; Hsiung 2010), which could take on many forms, including written and oral forms, and use language and/or traditionally marking/grading systems or rubrics to provide the feedback.

Student portfolios, also conducive to outcomes-based assessment, can be used as a tool for direct assessment (Heinricher et al. 2002; Felder and Brent 2003; Siri Johnson 2006; Wolf and Stiver 2011). They can be designed in a variety of ways with different objectives, but the aim is for students to showcase evidence of their learning. The process of creating the portfolio encourages student reflection and thereby, deeper learning. Despite the potential of portfolios, they require a concentrated and sustained effort that some faculties have found too ‘labor intensive’ to sustain (McGourty, Sebastian, and Swart 1998).

Student oral presentation reviews, which are intended to evaluate student outcomes during the process, (McGourty, Sebastian, and Swart 1998; Felder and Brent 2003) can be used for assessment, as well as self and peer reviews or feedback (Felder and Brent 2003; Ohland et al. 2005; Hanson and Williams, 2008; Hsiung, 2010). Published examples include the Student Developer, which is an automated feedback instrument created for teams to give members feedback on targeted outcomes (McGourty, Sebastian, and Swart 1998). Questions, such as student-formulated questions about writing assignment (Yalvac et al. 2007); a Metacognitive Questionnaire (Hanson and Williams 2008); Question

Generation (Jonassen et. al 2009); TEQ (Team Effectiveness Questionnaire) (Zafft, Adams, and Matkin 2009); and Lecture-Discussion-Questioning Cycle (Hsiung 2010) are an option. Additionally, writing can be used as an assessment tool. Examples include project reports, research proposals, abstracts, executive summaries, papers, letters, memos and written critiques of documents or oral presentations (Felder and Brent 2003); team-based research papers (Yalvac et al. 2007); structured reflections: written work and journals (Felder and Brent 2003; Colby and Sullivan 2008; Zafft, Adams, and Matkin 2009); case analysis/argumentative essays (Jonassen et al. 2009); and the minute paper (Hsiung 2010).

A unique assessment tool was created by the Department of Chemical Engineering at West Virginia University, called the Majors. These are design projects that are completed by students individually and defended in front of at least two faculty members. It is not unusual for engineering programs to have large design projects, including capstones, as part of the fabric of their assessment protocol. What is interesting about the Majors is that the faculty use the presentation to detect and rectify individual student weaknesses, as well as to identify and correct common student misconceptions (Shaeiwitz 1996), which is another valuable purpose for assessment (Prince 2004; Rover 2005; Prince and Felder 2006).

Several other unique assessment tools exist. One is the use of concept mapping (Walker and King 2003; Besterfield-Sacre et al. 2004). A concept map is a tool in which individuals can graphically organize their ideas and knowledge, as well as theories and concepts (Besterfield-Sacre et al. 2004). It is essentially a flow chart, but rather than using a linear approach to structuring understanding, a conceptual structure of the knowledge is built that is unique to each individual. It is a tool that is conducive to the theoretical perspective of constructivism, for while knowledge is being demonstrated, it is also being built, as consequential connections between concepts and ideas are manifested (Walker and King 2003). A concept map is a unique tool that is ideal for the new generation of engineers: engineers who are faced with a swiftly evolving and complex world full of 'wicked problems' (Simon 1976, as quoted in Radcliffe 2006, p. 263) that require reflective learning and transferable knowledge (Smith et al. 2005; Forgues and Dore 2010; Litzinger et al. 2011; Mukahark et al. 2013). Due to the complexities of today's world, an authentic, constructive, and deep approach to learning is required, where knowledge and understanding can be generated and exchanged. Concept maps enable individuals to practice and hone these deep-learning skills, essential for the new engineering world (Turns and Atman 2000; Forgues and Dore 2010).

All of these tools are examples of direct assessments of students' work.

2.2.6.2 Indirect Assessments

In addition to direct methods of assessment, there are a variety of indirect methods. Indirect methods have another purpose: to explore the perspectives of engineering stakeholders, which are considered vital to the new accreditation process (Seniuk Cicek, Labossiere, and Mann 2013) and a major goal in engineering education (Olds, Moskal, and Miller 2005). Indirect sources of assessment as a measure of stakeholders' perceptions can target a number of areas, including perceived graduate preparedness for the field, perceived importance of the graduate attributes, perceptions of competencies and abilities, as well as retention and transfer rates, and time to degree (Spurlin 2008).

One of the most common indirect assessment methods, particularly in engineering education (Wankat 2004) is the survey (or questionnaire). Survey methods are used to collect data describing specific characteristics of a large group of persons, object or institutions, and may be used in either qualitative or quantitative research designs. They are most helpful when researchers are looking to gather particular facts that describe a large group, when the group is distinct, and when the researcher is interested in the present condition of the group. Data are collected from the members of a sample population, in order to approximate one or more population parameter. Questions for surveys include open-ended and selected response, where the former is summarized or described (qualitative) and the latter is analyzed (quantitative). Surveys can be conducted face-to-face in an interview, over the phone or through mail survey, in which case the instrument is referred to as a questionnaire. The goal, no matter how the survey is administered, is to ensure that all participants comprehend and interpret each question in the exact same way. Surveys must be carefully crafted, with meticulous attention to phrasing, definitions and directions (Jaeger 1997). It is best that the survey instrument is checked for content validity and reliability, which can be done by having the instrument reviewed by a panel of experts, piloting the survey, and constructing the survey using internal validity measures, such as adding negatively worded items (Zhu et al. 2013).

Surveys are often used to gather descriptive statistics in engineering education, which is a beneficial approach when little is understood about the area being researched (Borrego, Douglas, and Amelink 2009), or as a method for gathering data on the perceptions of stakeholders (Olds, Moskal, and Miller 2005). Examples include attitude surveys (Hsiung 2010; Lathem, Neumann, and Hayden 2011), ad-hoc surveys (Loui 2006), or student exit surveys (Schneider and Niederjohn 1995; Scales et al. 1998; Addington and Johnson 1999; Felder and Brent 2003; Lathem, Neumann, and Hayden 2011; Mohamed, Suja, and Ismail 2012; Seniuk Cicek, Labossiere, and Mann 2013;

Seniuk Cicek, Labossiere, and Ingram 2014), where students can rate their own knowledge, skills, attitudes, values, and behaviours at the conclusion of a course, year or program, as well as rate course or program objectives and outcomes, and their perceived importance (Scales et al. 1998; Soundarajan 2002). Surveys or questionnaires can also be used to gather indirect data from alumni, for example, asking alumni to rate their perceived preparedness for the field. Institutions can use surveys to collect data in numerous areas, including degree requisites; contemporary educational praxes; engineering students' educational experiences; trends in student registration; student knowledge growth and retention; student post-graduate incomes; employers' opinions regarding accreditation criteria; minority groups in engineering, including women and their professional training; and longitudinal studies (Borrego, Douglas, and Amelink 2009). Similarly, employer surveys or questionnaires can explore industry's perceptions of new graduates to the field (Shaeiwitz 1996; Soundarajan 2002; Felder and Brent 2003). Surveys have varied and valuable use, especially for the purposes of program assessment and improvement.

Other types of indirect assessment include student evaluations of instructors and instruction (e.g., SEEQs are used at the University of Manitoba), which have been widely used to gather feedback from engineering stakeholders in EER (Puerzer and Rooney 2002; Felder and Brent 2003; Olds, Moskal, and Miller 2005; Roselli and Brophy 2006; Hanson and Williams 2008; Rogers and Goktas 2010); interviews (Shaeiwitz 1996; McGourty, Sebastian, and Swart 1998; Felder and Brent 2003; Hanson and Williams 2008; Zafft, Adams, and Matkin 2009; Lathem, Neumann, and Hayden 2011); and focus groups (Felder and Brent 2003; Lathem, Neumann, and Hayden 2011). Also used for gathering indirect data are published methods of assessment, which include the SDLRS (Self

Directed Learning Readiness Scale), the CDI (Continuing Learning Inventory), and IDEA (Individual Development and Educational Assessment Student Ratings of Instruction System) (Jiusto and Di Biasio 2006); the DTI-2 (Defining Issues Test) (Loui 2006); MBI (Managerial Behavior Instrument) (Zafft, Adams, and Matkin 2009); TESSE (Test of Ethical Sensitivity in Science and Engineering) (Barry and Ohland 2009); National Survey of Student Engagement (E-NSSE), Academic Motivation Scale, and Engineering Attitudes Survey (Frank et al. 2011). All of these instruments work to gather the perceptions of students as a source of indirect assessment.

Course documents and other materials, such as a variety of print, visual or other material products, can be analyzed by researchers to obtain historical or current perspectives, and are another source of indirect assessments. The focus of the analysis can be on the content or on the language and organization of the document, and can be used either as primary or secondary sources of data (Koro-Ljungberg and Douglas 2008; Van Note Chism, Douglas, and Hilson Jr. 2008). Rubrics are one of the tools used to analyze documents and can be either analytic or holistic, with the former using a separate scale for different aspects of the responses, and the latter using a single scale to evaluate the whole response (Leydens, Moskal, and Pavelich 2004). While document analysis is not a direct source of data, systematic reviews can provide a holistic view of a program, locate possible sources of direct data, and illuminate course connections (Office of Institutional Accreditation and Program Assessment 2011).

Overall, there are a number of methods that can be employed to collect indirect data.

2.2.7 The Importance and Limitations of Perceptions Collected in Indirect Assessments

Surveys, questionnaires, and interviews are instruments that assess the perceptions of respondents (Frank and Fostaty-Young 2011) rather than assessing the direct evidence of outcomes themselves (Parsons, Caylor, and Simmons 2005), which is the reason that they are considered indirect sources of data. Perceptions are personal opinions, influenced in an educational context by the way participants view and interpret their learning experiences and goals, the expectations they perceive around the learning, the place from which they experience the learning, the instruction that they experience, and the level of autonomy they have to direct the learning (Maclellan 2001).

Assessing participants' perceptions have limitations. For example, a respondent's personality can change their perceptions. A participant whose orientation is for individual expertise may believe that they have acquired more knowledge and better abilities than their counterparts (Parsons, Caylor, and Simmons 2005), and thereby may have an inflated sense of one's own competence (Kruger and Dunning 1999). Perceptions also differ between respondents who have different primary functions within the educational equation. Case in point, faculty and students often perceive educational efforts and methods differently (Holsapple et al. 2012), which underscores the importance of exploring perceptions when it comes to teaching and assessing the graduate attributes, as the perceptions between different stakeholders, i.e., students, faculty, and industry are likely to be varied. In a study by Maclellan (2001), 81% of faculty surveyed reported that assessment was used to evaluate teaching frequently or sometimes, however, students were not convinced that assessments were frequently used to evaluate teaching at all. In this same study, there was the recognition of differing perceptions of faculty and students as to the role that feedback played in the assessment process. Perceptions between different stakeholders, i.e., students, academic instructors and industry, are likely to be varied, and is a caution to educators that the intended curriculum is not inevitably the learned curriculum (Borrego and Bernhard 2011; Frank and Fostaty-Young 2011).

Due to the variations in different stakeholders' perceptions, it is important to assess them for a comparative view. Data of stakeholders' perceptions regarding engineering competencies are likely to raise questions or concerns that target areas for future investigation, giving insight into potential curricular strengths and weaknesses (Holsapple et al. 2012; Seniuk Cicek, Labossiere, and Ingram 2014). At the very least, the findings will prompt discussions amongst faculty and stakeholders (Maclellan 2001; Seniuk Cicek, Ingram, and Sepehri 2014a), make stakeholders' views transparent, leading to a common understanding regarding required engineering competencies and engineering programs, and ultimately – ideally – program improvement. Additionally, when data are aggregated to compare group performances, the reliability of self-reporting instruments is high, and for the most part felt to be a valid measure of authentic differences between groups (Prados, Peterson, and Lattuca 2005). Therefore, the limitations of perceptions are mitigated in that the stakeholder responses are comparatively analyzed. The importance of discerning potential differences between stakeholder groups, particularly in the educational equation, is beneficial, and helps meet the goal of program improvement.

2.2.8 Assessment Tools for Program Accreditation

Part of the requirements for program accreditation includes the development of measures and the gathering of evidence to demonstrate to what extent student outcomes are realized. Results must be documented and administrators must demonstrate how the findings are being used for program improvement. This necessitates the assessment of all program outcomes and the regular and continuous collection of assessment data. It also requires that all program outcomes are measurable. Assessment data should reflect what students are learning and how well they are learning, and evidence should consist of data gathered using multiple methods and a number of different sources (Spurlin 2008).

Both direct and indirect assessment measures can be utilized for program assessment, but many accreditation bodies mandate that program assessment contains evidence of direct assessments, and does not depend wholly on indirect assessments. Therefore, assessments from courses are commonly used to provide data for assessment at the program level. However, it is essential that in order to demonstrate best practices in program assessment, multiple assessment methods be developed for each outcome. Additionally, new accreditation methods support a wider perspective for program assessment and improvement that includes engineering stakeholders' views. This requires the use of indirect assessments. Using both direct and indirect assessments for program evaluation triangulates findings by verifying findings from two or more sources and methods of data collection. Triangulation creates a holistic picture of what extent students are meeting an outcome, and is effective using both direct and indirect measures (Spurlin 2008).

There are a number of resources that document common assessment methods and effective assessment tools that are used to demonstrate assessment of student learning outcomes. Spurlin (2008) examined several assessment plans used in engineering programs across America, and lists several assessment methods for each of the ABET competencies. Moore, Cupp, and Fortenberry (2004) reviewed 58 published sources and identified 65 tools used for assessment. Schachterle, Demetry, and Orr (2009) cite several assessment tools when discussing quality assurance in engineering education. The Joint

Task Force on Engineering Education (1996) also lists assessment methods in their Assessment White Paper. All of these sources were used to create a table of assessment tools for measuring the ABET competencies, and were cross-referenced by a number of other sources to create a common list of assessment methods. The table is divided into direct, indirect, and published sources, and is based on the ABET competencies (a) – (k) that were applicable pre 2015, and can be found in Appendix B.

Direct methods of assessment commonly used to measure the ABET competencies (a) – (k) (pre 2015) that were found in the literature include projects/design projects, especially from Capstone design projects, which are cited as one of the most universal assessment tools in essentially all engineering programs. Also prevalent are assignments, technical products created in Capstone courses, design competitions, experimental tasks/laboratory evaluations, reports, exams, tests, questions, observations, portfolios/webfolios, contracts, essays, writing assignments, journals, presentations, debates/discussions, interactive case studies, communication of graphic skills, information literacy skills, rubrics, student self evaluations/self reports, peer evaluations/ratings and external stakeholder reviews/reports. Most of these methods are course-based assessments, which are normally already found embedded in the educational structure, and therefore are considered a less burdensome method for both faculty and students (Schachterle, Demetry, and Orr 2009). Common indirect measures include surveys, questionnaires, student interviews, focus groups, and rates/time measures. Most authors are cautious regarding the use of indirect measures, particularly the survey. They are considered restricted by the fact that they are used to collect students' perceptions/opinions about students' abilities, which is unavoidably subjective data (Spurlin 2008; Schachterle, Demetry, and Orr 2009). However, they are feasible when significant numbers of participants respond, they are shown to be reliable when used comparatively (Prados, Peterson, and Lattuca 2005), and as discussed above, when the data are used as one of the sources in a group of direct sources to triangulate the findings (Moskal 2008; Spurlin 2008).

Published assessment instruments were numerous, and comprised of the Fundamentals of Engineering Examination, the Professional Engineer License exam, concept inventories, California Critical Thinking Skills Test, national surveys, the Continuing Learning Inventory, the Continual Development and Educational Assessment Student Ratings of Instruction System, the Managerial Behavior Instrument, as well as measures for information literacy and lifelong learning, ethics, equity, multiculturalism, and teamwork. The strength of published tools is that they are normally valid and reliable, and often can be found documented in the literature. However, published tools are not individually designed for specific programs, which could be a limitation. Therefore, like indirect assessment methods, they too should be triangulated with other data (Moskal 2008; Spurlin 2008).

Most assessment tools can be used to assess more than one outcome, therefore it is necessary to be cognizant of which outcome is being targeted. As well, it is essential that the outcome be defined for the specific program that is being assessed. For example, many engineering programs in America define the outcome, lifelong learning, as information literacy skills, and design their assessments accordingly (Spurlin 2008). However, another method of measuring lifelong learning is the published assessment tool, SDLRS (Self Directed Learning Readiness Scale) (Jiusto and Di Biasio 2006; Spurlin 2008; Wertz et al. 2013), which measures students' metacognitive aspects of lifelong learning. A third method is to use graduate/alumni employment histories and acceptances into graduate school. These examples demonstrate that it is the definition of the attribute that should inform the choice of assessment tool.

2.2.9 Recommendations and Cautions for Use of Assessment Tools in Engineering Education

There are some recommendations and cautions when it comes to the development and implementation of assessment tools. Firstly, it is advised to test assessment methods on a small scale, thus having the opportunity for refinement before implementing on a large scale (Shaeiwitz 1996). Pilot tests are essential to ensure that the instructions and purpose of the instrument are clear to potential participants. Another area to consider is motivating students and other participants to respond to assessment instruments as honestly and thoroughly as they are able in order to ensure the most accurate results (Scales et al. 1998). A third consideration is ensuring that the assessment tool is constructed to measure the outcome, and that the competency level is established *before* the assessment is conducted. Linking the outcome to the assessment tool after the fact is inauthentic outcomes-based assessment (Soundarajan 2002; Seniuk Cicek, Labossiere, and Mann 2013). A further concern is that outcomes-based assessment requires precision, and the level of detail that one applies can be excruciatingly tedious, an extraordinary expenditure of time that will not necessarily be beneficial to either student or faculty (Seniuk Cicek, Ingram, and Sepehri 2013). It is necessary when embarking on outcomes-based assessment to decide to what extent the outcomes are going to be measured, for example, how granular or broad the assessment strokes should be, so that the effort equals the improvement of teaching and learning.

Caution is also advised concerning the reliability and validity, or lack thereof, of the survey as an assessment tool. Evidence of inconsistency and wide-range of responses in student exit, faculty, and alumni surveys point to the care with which these results should be used (Soundarajan 2002). However, when data are aggregated to compare group performances, the reliability of self-reporting instruments is high, and for the most part is felt to be a valid measure of authentic differences between groups (Prados, Peterson, and Lattuca 2005). This supports the use of the survey method for meeting the objective of this study.

A further potential weakness in surveys or any instrument where participation is optional and anonymous is the fact that self-selection can become a factor in the findings that are obtained (Lavrakas 2008). Survey respondents may be motivated by heightened emotion, whether positive or negative, which can bias the results. Those who participate in surveys are most likely different from those who refuse or those who the researcher does not succeed in locating. Therefore, a low survey response rate can lead to considerable bias error (Jaeger 1997). Another weakness is cited in the superficiality of the information gathered in surveys and questionnaires (Maclellan 2001), particularly those instruments that do not utilize open-ended techniques. All these potential limitations are why it is crucial to have a comprehensive assessment protocol, one that does not rely solely on the results of a single instrument (McGourty, Sebastian, Swart 1998; Driscoll and Wood 2007; Spurlin 2008), as viewing data comparatively with other data will strengthen the findings (Gliner, Morgan, and Leech 2009).

2.2.10 The Role of Engineering Stakeholders in Engineering Education Assessment

Part of the requirements in the new outcomes-based accreditation process is to involve all engineering stakeholders in the institution's outcomes-based assessment and continual improvement process (Engineers Canada 2014); this is indicative of the institution's commitment to accountability (Wolf and Stiver 2011). As discussed, indirect assessment data should be gathered from faculty, students, alumni, and industry members in order to triangulate direct assessments. However, there are other valuable reasons for involving the engineering community. By providing opportunity for feedback, faculty demonstrates its partnership, goodwill, and accountability to their engineering stakeholders (Ferens et al. 2014). Students provide indispensible feedback as consumers of their education, and given the opportunity, relish the chance to be part of the discussion that leads to program improvement and gives them some autonomy in the course of their own learning (Seniuk Cicek, Labossiere, and Ingram 2014; Seniuk Cicek et al. 2015; Seniuk Cicek, Ingram, Friesen et al. 2017). They are also the least represented stakeholder voice in published research (Pons 2016), a situation that should be remedied. Faculty members, who are integral to the improvement process, are more likely to buy in to outcomes-based assessment if their own perceptions and expectations are heard (Driscoll and Wood 2007). And industry provides indispensible front-line feedback as they are the stakeholders hiring engineers, and therefore are in the unique position to assess the competencies of new engineering graduates post-graduation at the pivotal juncture when engineering graduates leave their program and enter the field (Shaeiwitz 1996; Soundarajan 2002; Prados, Peterson, and Lattuca 2005). They provide indispensible perspective on the competencies essential for engineering practice. Industry perspectives are additionally significant as the majority of engineering graduates proceed to work in industry (Ferens et al. 2014; Graduate Recruitment Bureau 2014; Ebrahiminejad 2017).

2.2.11 The Importance of a Common Language and Understanding for Assessment in Engineering Education

Part of the success of any new initiative is the establishment of a common language and a shared understanding amongst stakeholders (McGourty, Sebastian, and Swart 1998; Rogers 2000). This is especially so when the goal is to create faculty buy-in when founding an assessment protocol. A common language leads to a shared understanding and the development of a common set of expectations (McGourty, Sebastian, and Swart 1998). Unclear or dissimilar understandings of what 'assessment' means can sabotage the installation of a successful assessment protocol (Rogers 2000).

Further, a collective language that supports the comprehension and expectancies of students and faculty is essential, especially when assessing student outcomes. Indeed, this is an area of particular importance when considering, as previously discussed, that there is a history of research that indicates that students and faculty do not share similar perceptions in regards to pedagogical methods and practice (Maclellan 2001). This has even greater emphasis when it comes to assessment, where large differences in the perceptions of students versus faculty were found when their perceptions of efficacy and usefulness of assessments of learning were explored (Holsapple et al. 2012).

The significance of establishing a common language extends to other engineering stakeholders as well. Research shows that while academics and industry are striving to establish a shared understanding in regards to employability skills for graduates, there is still a chasm between the two groups (Lowden et al. 2011). The same holds true for the language academics use compared to industry (Engeler Newbury 2010). If the language of academics and industry are different, then it is quite possible that the expectations will differ as well (Ferens et al. 2014).

It is fundamental to understand faculty, students, and other engineering stakeholders' expectations and perceptions when it comes to the 12 CEAB graduate attributes and the development of reliable and valid assessment practices, and language will be the conduit. How each of these groups defines, understands, and recognizes the attributes must be established in order to validly and reliably assess student attribute competencies (Holsapple et al. 2012). In the end, understanding the differences between how each of the engineering stakeholders defines the essential concepts in engineering will create fusion between the groups and lead to a deeper appreciation for, and insight into the profession of engineering (Heller et al. 2010), ultimately supporting the development of valid and authentic engineering curricula. This is a research objective of EER that is essential to pursue, and it underscores the core motivation of this research study.

2.2.12 The Gaps in Understanding Assessment

Finally, despite some of the foundational work being done in education and engineering education on assessment, Maclellan (2001) has shown that the student conception of assessment is disheartening: they do not utilize assessment to help improve their learning, and seem to have a limited understanding of what assessment actually is. The same may be true for instructors in engineering education. As Pellegrino (2017) points out, 'A common problem is that the program designs, instructional activities, and assessment strategies we use in higher education often do not lead to the desired student outcomes.'

Due to the recent shift to an outcomes-based engineering education focus in Canada, the relative newness of a formal field of EER, and the traditionally limited emphasis on best pedagogical practices for secondary educators, it would seem likely that engineering instructors' understanding of assessment is quite possibly limited to assessment's traditional summative role: i.e., purposed to determine a summary grade for students. The ubiquitous role assessment should take in an outcomes-based education model is possibly beyond many faculty members' experiences, and therefore present use.

Nevertheless, CEAB accreditation demands that engineering programs develop a protocol to assess the outcomes of their graduating students as exemplified in the graduate attributes, and that the results of the assessments are used for the purpose of program improvement (Frank and Fostaty-Young 2011), with the ultimate goal of improving student learning. In other words, accreditation ultimately requires summative assessments, yet the motivation is to foster student learning. A rigorous and systematic assessment protocol is needed to fulfill these criteria (Bailey, Floersheim, and Ressler 2002; Soundarajan 2002; Spurlin 2008; Dew, Lavoie and, Snelgrove 2011). Engineering educators and administrators are working on this, and learning as they go. Increasing the efficiency and effectiveness of the accreditation assessment process will help stakeholders collect meaningful data, and use these data to facilitate improvement and enhance engineering education for engineering students. Establishing stakeholders' understandings of the relative importance and dependencies of the CEAB graduate attributes will enable the determination of the content validity of our engineering programs by this measure, and inform the effective development of outcomes-based program curricula and assessment protocols. This is what this study proposes to do.

2.3 Assessing the CEAB Graduate Attributes

As stated by Passow and Passow (2017), 'Under Washington Accord or ABET accreditation requirements, faculty must envision, collectively articulate, and prioritize the competencies that students should gain from their educational program to prepare for life and myriad career paths' (p. 475). Attributes have been identified by engineering stakeholders around the world that represent the knowledge, skills, attitudes, values, and behaviours (Scales et al. 1998; Rogers 2000) that are intended to prepare engineering graduates more completely for employment (Passow 2012). In a profession that has become progressively global (Dupuis and St. Pierre 2013), and a world that has become increasingly complex, supporting students to effectively develop the competencies required for the 21st century is a vitally important endeavor.

This is also true for Canadian accredited engineering programs. As part of accreditation, engineering faculties across Canada are required to assess the 12 graduate attributes defined by CEAB. These are:

1. A knowledge base for engineering
2. Problem analysis
3. Investigation
4. Use of engineering tools
5. Design
6. Individual and teamwork
7. Communication skills
8. Professionalism
9. Impact of engineering on society and the environment
10. Ethics and equity

11. Economics and project management
12. Lifelong learning

Curiously, these attributes are presented to engineering program constituents as they are presented here: in a list. As Pons (2016) states about engineering competencies compiled in lists: 'Lists are useful, but still have several limitations' (p. 535). He describes the hazards of these limitations insightfully, with particular significance to the field of engineering, where problem solving is the heart of the profession:

> There is a lack of integration, in that the lists treat the topics as independent entities. Instead, it is reasonable to expect that the topics could be clustered, but those associations are unknown. This is important because otherwise a curriculum risks being merely a disparate string of topics, when what we really want from a didactic perspective is to create in the graduate an integrated set of skills that can be applied to solve complex problems. Complex problems are those with many internal dependencies, and are not amenable to simplistic piecemeal solution approaches. (Pons 2016, p. 535)

Despite this, there has been very limited evidence in the literature of other ways of thinking about or grouping the graduate attributes. The most obvious treatment of the graduate attributes that varies from this linear presentation is to divide them into two groups: the first five considered the 'traditional' or the 'technical' skills, and the latter seven considered the 'professional' (Shuman, Besterfield-Sacre, and McGourty 2005) or higher order skills (Bishop, Nespoli, and Parker 2012). This is an understandable conceptionalization, as the two sets of skills are perceived to require different conditions and present diverse challenges in terms of teaching and assessing (Shuman, Besterfield-Sacre, and McGourty 2005). This is likely due to the fact that most engineering educators, when graduate attributes/student outcomes were first introduced, had not been formally required to teach and assess many of the professional skills, nor really identify with them.

There is a historical and long standing identification with what are considered the 'traditional' skills of engineering, and for some, competencies that are considered to be on the outside of this tradition are disregarded (Caron et al. 2014), or perhaps even perceived as a threat to the epistemological tradition of engineering. This next section deliberates on the traditional versus professional engineering skills, the gaps in engineering education assessment knowledge and research, the relative importance and interrelationships of the graduate attributes, and clustering the graduate attributes.

2.3.1 'Technical' Versus 'Professional' Engineering Skills

When the recent changes were made to accreditation, in addition to the shift from inputs to outcomes, there was a new concentration on the development of a broader set of professional skills for engineering students (Radcliffe 2005) as represented in the latter seven CEAB graduate attributes (Seniuk Cicek, Ingram, and Sepehri 2014b):

- Individual and teamwork
- Communication skills
- Professionalism
- Impact of engineering on society and the environment
- Ethics and equity
- Economics and project management
- Lifelong learning

This is also true of ABET's student learning outcomes, where, even through several recent reiterations, the importance of fostering communication skills, teamwork, and group problem-solving skills have continued to be stressed as part of their educational paradigm

(Fredericks Volkwein 2004; Seniuk Cicek, Ingram, and Sepehri 2014b). Engineering stakeholders have corroborated to underscore the importance of these skills – both in their historical efforts to revolutionize the engineering curriculum (see Chapter 2 Section 2.1 *The Emergence of Engineering Education, Engineering Program Accreditation, and the Influence of ABET*) and in the research following their implementation. For example, in Passow's study (2012), when alumni from a variety of engineering disciplines ranked teamwork and communication as two of the four most used attributes in their professional careers (Seniuk Cicek, Ingram, and Sepehri 2014b), and in Passow and Passow's (2017) research, where they determined after a comprehensive systematic review that 'Engineers' technical work is inseparably intertwined with team-player collaboration' (p. 475). Similarly, in a literature review conducted by Male, Bush, and Chapman (2011a) in the context of their research on Australian engineering student competencies, they found that 'Communication, teamwork, management, personal/attitudinal skills and attributes, problem solving and ability to learn were rated as highly important' for Australian engineering stakeholders (p. 153).

Despite these findings and the emphasis on the professional skills in the new engineering paradigm, there is a lot of literature that cites the persistent resistance to these competencies in engineering. Witness this discussion of the technical versus professional skills in a CEAB accredited institution:

> Perhaps predictably, there is a well respected contingent of very senior faculty members who perceive, or at least rhetorically posit, a dichotomy between technical and soft skills. Soft skills in this dichotomy neither enhance students' ability to put technical knowledge into context nor teach students professionally useful skills, but do threaten to dilute the integrity of technical education. We have found that discussion of the social and ethical attributes is too often only 'window dressing', thinly veiling the entrenched technical and technocratic views of engineering education. (Caron et al. 2014, p. 46)

In these authors' experience, the implicit separation of the 'technical' and 'soft' skills in the list of CEAB graduate attributes is damaging, both for faculty who are responsible for teaching the perceived 'softer' parts of the curriculum, and for students who are not being given the chance to perceive – and thereby, likely develop – the fundamental role these competencies play in the work of engineers today. These authors proposed teaching a combined sustainability and ethics course, and discerned that some department members felt that faculty members relegated to teaching the 'soft skills' in engineering were not capable of teaching what were deemed the technical skills. The authors, commenting on the rejection of their proposal, stated: 'Not only did this discount the research and academic qualifications of CES [Centre for Engineering in Society] faculty, but also defined sustainability as a technical subject. This is an old and ongoing schism within engineering education and the new CEAB graduate attributes are perhaps best seen as the latest discursive rubric under which that contestation is played out' (Caron et al. 2014, p. 46). However likely that this is an isolated case – for example, this researcher who has taught engineering communication in a faculty of engineering has not had this experience, in fact, quite the opposite – this case points to the tension that underlies the group of engineering competencies. Trevelyan (2014) further discusses the harmful potential of this tension:

> Even though engineers would readily associate lack of proficiency in a technical skill with inadequate education, there is a widespread view within the engineering community that communication can be learned merely by practice, without formal instruction. Formal instruction, when employed, tends to be resisted by students (e.g. Paretti, 2008). As long as communication retains its label as a non-technical, generic skill, outside the theoretical framework of engineering, this is likely to continue.
>
> Another aspect is the consistency with which the "non-technical'' label is assigned to any social interaction, even management activity within engineering. This is an intriguing assumption contradicted by observations from the workplace

> that reveal that the content of engineers' social interactions, especially in the workplace, is dominated by technical issues.
>
> Further, while there is continuing debate within engineering schools on the extent to which science fundamentals and mathematics should be taught by engineers, there is little if any debate on the extent to which relevant aspects of social sciences should be taught by engineers. To the extent that liberal arts, social sciences and humanities are part of an engineering curriculum (accepted often with considerable reluctance from engineering academics), such teaching is almost invariably sourced outside engineering faculties. This reinforces the notion that they lie outside the accepted framework of engineering knowledge. (p. 37)

This tension between 'real engineering' and tasks that prevent or get in the way of 'real engineering' – i.e., tasks that require the 'professional' skills – is also noted by Robinson et al. (2005):

> There is evidence to suggest that not only are engineers aware of this distinction between technical and non-technical work, but that the competing demands of each cause tension. For example, the mechanical design engineers interviewed by Perlow and Bailyn (1997) classified such technical work as 'real engineering' (p. 232) and contrasted this with the managerial and administrative tasks, required by their organisation, that prevented them from doing such work. (p. 126).

Even though this tension is real in the field, as supported in the literature, the importance of what are considered the professional skills have emerged repeatedly in the research as vital for successful engineering work today. For example, in a study determining the competencies for design engineers, Robinson et al. (2005) list a variety of professional competencies not traditionally associated with design engineering, including teamwork, leadership, management, communication, planning, innovation, and business savvy (p. 124). They go on to explain that both empirical studies and ethnographic studies have revealed the importance of the 'non-technical' engineering skills, *even* in design engineering, where the stereotype is 100% design (p. 124-125) (emphasis added). Indeed, design engineering has been shown to be such a social process, that some researchers even make a distinction between social-world and object-world engineering (Robinson et al., 2005 p. 125).

Male, Bush, and Chapman's (2011b) study 'confirmed the interrelated nature of competencies,' and supports the holistic assessment of them (p. 152). Their conclusion from their extensive research on engineering competencies is that engineers should 'celebrate' their 'broader' competencies, including their personal, interpersonal, business, community, environmental, and people skills (p. 152). Sunthonkanokpong (2011) reiterates this. He points to a number of attributes required for engineers to be successful in the 21st century, characterizing engineers who are 'lifelong learners,' problem solvers, 'socio-technical,' 'dynamic/agile/resilient/flexible, [with] high ethical standards and a strong sense of professionalism, good communication skills with multiple stakeholders, [who] possess strong analytical skills, exhibit practical ingenuity; posses creativity, and business and management skills; [and] leadership abilities' (p. 160). He cites forthcoming changes in engineering that will require engineers to adapt using these capacities, including globalization, the downsizing of large companies, the growth of entrepreneurialism, the shift to a 'services' economy, and the increase of technology (Sunthonkanokpong 2011, p. 160).

In Male's (2010) work examining the literature on engineering competencies in Australia, New Zealand, Europe and America, she recurrently found that communication and teamwork were rated as top engineering competencies (p. 32). In addition to these were 'professionalism and attitudes such as integrity and commitment; ability to learn; management, a customer focus and business skills; leadership; sourcing and analysing information; and an interdisciplinary approach' (p. 33). Overall, she concluded that developing what she terms as 'generic' engineering competencies has 'met with barriers' and that to improve these biases the separation of engineering competencies by technical and 'other' knowledge and skills needs to stop (p. 25). She writes, 'Faulkner found that the tendency for engineers to classify the work of engineers into technical work, which is seen as the "real" engineering work, and non-technical work, which is not seen as engineering, is both flawed and harmful to the profession (p. 39). She makes a case for a 'holistic' approach to integrating all the required knowledge, skills, attitudes, values and behaviours required for a comprehensive, global approach to engineering be adopted.

Passow and Passow (2017) concur with the importance of coordinating competencies' (p. 500), stressing that 'The most striking finding in this systematic review is that technical competence is inseparably intertwined with effective collaboration' (p. 491). This concept of the interconnection of engineering competencies is essential to the findings from this comprehensive literature review. The authors emphasize this importance: 'All engineering is, of necessity, *both* technical and social… *Good* engineering (as in engineering which is effective) demands the thorough integration of these elements in ways that *transcend* conventional dichotomies' (p. 491) (emphasis in original). They explain how the division between the competencies is in actuality illogical, as these skills are invariably entwined in every day practice: 'The knowledge mobilized in the course of engineering . . . is never "just technical" with "the social" bolted on. Rather, these two dimensions are in a very practical sense inseparable. . . . Since the two are inseparable in everyday engineering practice, the boundaries drawn between them are inevitably arbitrary' (p. 491).

Even if the threat to engineering identity is not the motivation, there is limited evidence of engineering educators embracing this raised level of professional competencies as demonstrated in the research literature; there is more evidence of engineering instructors teaching and assessing the perceived 'technical' skills (e.g., knowledge of engineering; problem analysis; design; investigation, and use of engineering tools) than the professional skills (Shuman, Besterfield-Sacre, and McGourty 2005; Ingram, Seniuk Cicek, and Sepehri 2012; Seniuk Cicek, Ingram and Sepehri 2013; Seniuk Cicek, Ingram, and Sepehri 2014b). This could be due in part to the unfamiliarity with, and possible difficulties inherent in the task of teaching and assessing the professional skills (Jiusto and Di Biasio 2006; Loui 2006; Yalvac et al. 2007; Colby and Sullivan 2008; Hanson and Williams 2008; Barry and Ohland 2009; Jonassen et al. 2009; Zafft, Adams, and Matkin 2009; Seniuk Cicek, Ingram and Sepehri 2014b). When Shuman, Besterfield-Sacre, and McGourty (2005) published their research on the EC 2000 skills required for ABET accredited institutions, *The Professional Skills: Are They Being Taught? Are They Being Assessed?*, they concluded that although good work was being conducted, more work was definitely required in this regard. They particularly noted ineffective assessing for teamwork, ethics and equity, professionalism, and lifelong learning.

Motivated by the work of Shuman, Besterfield-Sacre, and McGourty (2005), this researcher conducted a literature review of *JEE* issues from 2006-2011 (unpublished) to determine if, since the advent of this article, publications on the teaching and assessing of the professional skills had increased, which would be one indication that more work was being done in the area. A search of *JEE*'s electronic database completed in January 2011 resulted in 12 papers being selected that fit the criteria (see Appendices C.1 and C.2 for a list of these papers and targeted student learning outcomes). This is not many, especially considering that Shuman, Besterfield-Sacre, and McGourty (2005) determined that in the area there was much work left to be done. Within these 12 papers, ethics was the attribute most commonly discussed, receiving attention in five papers, and impact of engineering was least common (one paper). Communication skills and lifelong learning, and teamwork were discussed in three and two papers respectively.

The same concerns that Shuman, Besterfield-Sacre, and McGourty (2005) voiced in their article regarding the assessment of the ABET professional skills were essentially shared by the authors published in the subsequent six years. Generally, effective teaching and assessment methods for teamwork were still required. Lifelong learning continued to be viewed as an outcome much better suited to assessment *a priori* (Shuman, Besterfield-Sacre, and McGourty 2005), leaving engineering educators with the conundrum of designing ways to teach and assess lifelong learning while students are in their programs. Very little was written about understanding the impact of engineering on society and the environment or on knowledge of contemporary issues. Both of these outcomes remained elusive in the *JEE* literature. The strongest voices were heard from researchers calling for much-needed work in the area of teaching and assessing ethics in engineering. In the *JEE* literature, ethics remained the most discussed yet the most loosely defined of all the professional skills.

Significantly, there were nine papers published on the assessment of the ABET professional skills in *JEE* in the year 2005, including the Shuman, Besterfield-Sacre, and McGourty (2005) article. The substantial decrease in papers published on the professional skills in *JEE* over this short period of years is perhaps a result of the call during that same year (2005) for engineering education researchers to increase their scientific rigor and place more emphasis on theoretical and empirical frameworks in EER (Johri and Olds 2014). Perhaps the study of assessing the professional skills is regarded as action research, which has been cited as a less-used methodology in EER (Case and Light 2011), and less theory-driven research. Regardless of the reason, assessing the professional skills has been elusive in the most prominent journal of engineering education since 2005, yet these are the competencies that are being repeatedly shown to be in the top clusters of desired engineering competencies, and engineering educators are still grappling with how to effectively teach and assess them.

Overall, the professional skills – both how engineering stakeholders perceive them, and how they are taught and assessed – are a compelling area for research. In addition, how the professional skills relate to the technical skills, how engineering competencies are interconnected and interdependent, and how relatively important each of the graduate attributes are in engineering practice are important understandings that until this research, had yet to be explored specifically in Canada for the CEAB graduate attributes.

2.3.2 The Gaps in The Conceptual Understanding of the CEAB Graduate Attributes

An individual's conceptual understanding is defined by Streveler et al. (2014) as 'the collection of his or her concepts, beliefs, and mental models' where concepts 'are pieces or clusters of knowledge,' beliefs are 'propositional relationships between concepts,' and mental models 'are groups of meaningfully related beliefs and concepts that allow people to explain phenomena and make predications' (p. 83). The CEAB graduate attributes lend themselves to conceptual consideration. For example, Shuman, Besterfield-Sacre, and McGourty (2005) suggest that several of the professional skills are best taught and assessed together. Passow (2012) also advises that 'clusters' of competencies should be considered, an idea echoed by Pons (2016). Up until recently, there was a dearth in the research in this area. For example, as discussed in the previous section, in the review of

JEE from 2006-2011 to explore whether the professional skills were being taught and assessed, 11 out of the 12 articles that met the criteria focused exclusively on one or two student outcomes, with the 12th article focusing on only three outcomes (see Appendices C.1 and C.2). During this time period, there were no articles published that considered the conceptual or theoretical understanding of all of the engineering competencies. This research is only beginning to emerge internationally, with emphasis on the explorations of the relative importance of engineering competencies by Leggett et al. (2004), Male (2010), Male, Bush, and Chapman (2011a, 2011b), Pons (2016), Ebrahiminejad (2017), Meenakshi and Mohanty (2017), and Passow and Passow (2017), and initial descriptions of interrelationships among competencies by Male, Bush, and Chapman (2011a, 2011b); Pons 2016; and Passow and Passow 2017.

The same is true in Canadian EER, where much of the focus is on the 12 graduate attributes as individual components. For example, in the 2014 Canadian Engineering Education Association–Association canadienne de l'éducation en génie national (CEEA-ACEG) annual conference, 31 out of 105 papers published in the proceedings refer to the CEAB graduate attributes. Of those, 27 either refer to the 12 graduate attributes collectively, or to one or a few attributes at a time, treating them in isolation or as separate components within the collective dozen. Twenty-two of these papers do not explicitly acknowledge this treatment (see Appendix C.3). Only in five of these papers do authors hint at, or state the inauthenticity of considering the attributes individually, or refer to potential relationships or connections between attributes (e.g., Buchal et al. 2014; Godri-Politt and Norval 2014; Kishawy et al. 2014; Moazzen et al. 2014; and Nelson 2014). Of those, only Nelson's (2014) paper considers the connections among the graduate attributes, creating a visual to demonstrate the conceptualization (see Figure 2.3).

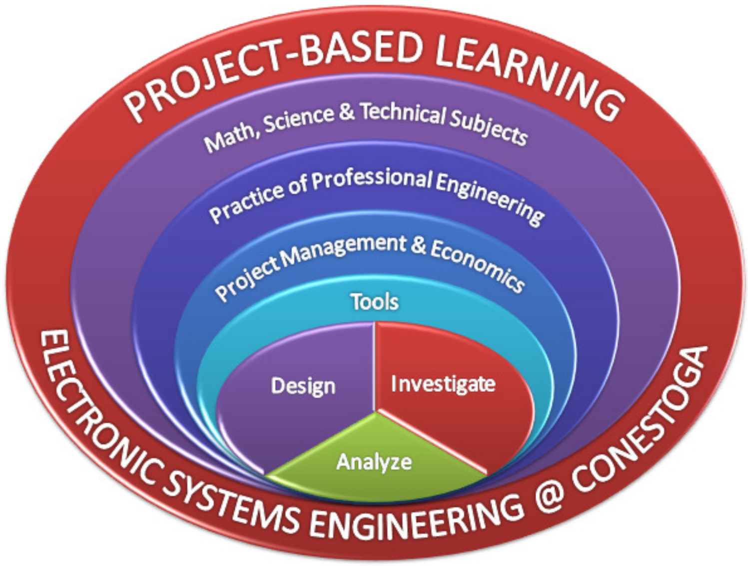


Figure 2.3. PBL model for Electronic Systems Engineering program (Nelson, 2014, p. 3). *Used with permission.*

Nelson's (2014) work is the only example of which the researcher is aware that demonstrates a conceptual consideration of the CEAB graduate attributes. She presents a concentric visual to illustrate how design projects in an engineering course were configured in their engineering program. Design, analysis, and investigation are the three pillars of engineering upon which the instructors build their project. From these pillars, engineering tools, project management and economics, professionalism, and engineering knowledge emerge. Nelson (2014) adds, 'In addition, elements of professional engineering practice such as team work, effective communication of ideas and findings, and adherence to professional, ethical, and legal responsibilities must be incorporated where appropriate.' Nelson's (2014) conception stems from the design of a project-based learning course, and there is no discussion or data in this paper that informs the development of this concept.

Beyond this example, no papers within these CEEA-ACEG publications demonstrate the potential relationship amongst attributes. However, a few authors do acknowledge the potential drawback and inauthenticity of considering the graduate attributes individually: ‘Entertaining individually CEAB graduate attributes in isolation from the others is quite difficult because they are so often interconnected and occur simultaneously’ (Kishawy et al. 2014). Other authors make connections between some of the attributes: ‘assessment of design competence is a complex task due to the fact design process is non-linear and depends on many factors including communication skills, teamwork skills, individual knowledge and skills, and project complexity’ (Moazzen et al. 2014); ‘Risk appears in two of the Graduate attributes: Design and Economics and Project Management’ (Godri-Politt and Norval 2014); and ‘The CEAB graduate attributes also emphasize the engineer’s responsibility to protect the public welfare. The theme appears repeatedly in the attributes [Design, Professionalism, Impact of Engineering on Society and the Environment, and Ethics and Equity]’ (Buchal et al. 2014). These three statements allude to the significance of identifying the relative importance of, and interrelationships between, the CEAB graduate attributes.

Conceptualizing the relative importance and dependencies of the graduate attributes as perceived by engineering stakeholders is necessary for ensuring authenticity for all engineering program curricula. Determining the relative importance of the graduate attributes informs engineering educators about which graduate attributes should be emphasized more, and which less. The relative importance can then be used to evaluate engineering programs; if the relative importance of the graduate attributes as perceived by engineering stakeholders is reflected in the curricula, this is a measure of content validity. As Male (2010) determines, ‘The literature supports a conceptual understanding of "generic engineering competencies" that: integrates generic and engineering-specific aspects and technical and non-technical aspects (p. 41). This is a vital consideration when redesigning or developing new engineering curricula. Engineering educators need to embody authentic outcomes-based education by avoiding teaching and assessing the graduate attributes in isolated, linear, and thereby inauthentic and potentially less-effective ways (Smith et al. 2005; Litzinger et al. 2011; Yadav et al. 2011).

2.3.3 Considering the Relative Importance and Interrelationships of Engineering Competencies: Clustering the Graduate Attributes

As discussed previously, ABET, the recognized accreditation agency for engineering in America, had a list of 11 attributes (pre 2015) that were very similar to the 12 CEAB graduate attributes. In an important piece of research, Passow (2012) presents the results of a seven-year study where engineering graduates were asked to value each of the ABET attributes in relation to their professional careers. In the study, Passow (2012) found that no matter the engineering discipline, graduates ranked teamwork, communication, data analysis, and problem solving as the top used competencies/attributes in their disciplines. The lowest ranked competencies were contemporary issues, design of experiments, and understanding the impact of one's work. Passow (2012) concluded that among other things, 'faculty…should consider placing special emphasis on the 'top cluster' competencies.' Male (2010) calls these clusters 'constellations,' and underscores the relevance of clusters of attributes to all professions, and identifying specific clusters for different engineering roles (p. 38). Male, Bush, and Chapman's (2011b) extensive research in Australia on generic engineering competencies resulted in the development of an 11-factor generic engineering competency model whose competencies are interconnected. Their study ‘confirmed the interrelated nature of competencies’, and supports the holistic assessment of them (p. 152).

New research, published last year in the *European Journal of Engineering Education (EJEE)*, also echoes the importance of clustering the graduate attributes. In a study conducted in New Zealand, Pons (2016) explored the relative importance of the professional skills in engineering management programs and found that some of the competencies naturally clustered in the data, such as communication and project planning (p. 538). Additional research on the relative importance of engineering competencies include a cross-sectional study on generic competencies as perceived by engineering students in India (Meenakshi and Mohanty 2017), and a conference paper examining the competencies required for the workplace through a literature review (Ebrahiminejad 2017). In the former paper, students rank practical knowledge, teamwork, problem-analysis, commitment to work, and problem solving as the top competencies (Meenakshi and Mohanty 2017, p. 51). (Interestingly, students rank social and business context, ethical issues, leadership, knowledge in science and mathematics and written communication as the least important (p. 51), which is a different opinion than found in the literature as perceived by engineers in practice, underscoring the differences in perceptions between stakeholders.) In the literature review, Ebrahiminejad (2017) comes to the same conclusion as Passow (2012), in that communication skills, teamwork, and problem-solving skills are the top desired competencies (p. 9).

As already discussed in this thesis, the comprehensive systematic review recently published in *JEE* by Passow and Passow (2017) that explores which competencies Washington Accord and ABET undergraduate engineering programs should emphasize is one of the most extensive in the area. They underscore the significance of determining the relative importance of engineering student competencies. They state: ‘Specifically, when faculty design a curriculum that ‘support[s] the integration of knowledge, skills… and… values necessary for today’s professional practice’ (Sheppard, Macatangay, Colby, and Sullivan, 2008, p. 5), they need to know the relative importance among the competencies for engineering practice in order to establish specifications’ (p. 476). They identify the significance of this research as determined by America National Engineering Education Research Colloquies of 2016, demonstrating that despite the prominence and urgency given to determining this knowledge, limited publications can be found in the area. In fact, they cite only two publications in this area that meet their research criteria, including Passow (2012) and Male, Bush, and Chapman (2011a), as discussed in this document. Adding substantially to the implications of this doctoral research to establish the relative importance of the CEAB graduate attributes, Passow and Passow (2017) frame the motivation of their study in an engineering product design construct, stating: ‘Engineering faculty should strongly feel the need [to establish the relative importance] as they apply product design principles to curriculum design. That is, before establishing specifications for product design, engineers make a list of ‘what the product has to do’ and then determine the ‘relative importance’ (Ulrich and Eppinger, 1995, p. 54) of items on that list’ (p. 476).

Through their rigorous research process, they identified 16 generic competencies important for engineering practice, which they describe as ‘the essence of engineering practice’ (Passow and Passow 2017, p. 500), which is noteworthy in light of ABET’s recent attempt to reduce their General Criterion 3: Student Outcomes (Seniuk Cicek, Ingram, and Friesen 2016) (see Section 2.1.2.2 for a detailed account of ABET’s proposed changes to their learning outcomes). It is interesting to compare these competencies to the ones adapted from an OECD (Organisation for Economic Co-operation and Development) survey – 16 skills that Pellegrino (2017) put forth in his keynote to engineering educators at the 2017 American Society for Engineering Education (ASEE) Annual Conference and Exposition as competencies that stakeholders likely expect engineering students to be proficient in (see Table 2.1). Although the 21st century skills and competencies are more general than the competencies identified by Passow and Passow (2017), it is worthwhile to note that with the exception of Devise process and Define constraints, two competencies that are both clearly related to engineering practice, six of the competencies that differentiate outstanding engineers from ordinary ones, according to Passow and Passow's research, are listed in the OECD survey (Ananiadou and Claro 2009). Of further consequence for engineering educators, Passow and Passow (2017) 'infer from the results of individual included studies that the pattern of importance ratings indicated in [their findings on the 16 generic engineering competencies important for engineering practice] has remained stable for more than two decades and for various levels of engineering experience' (p. 501).

Table 2.1
Comparison of engineering generic competencies and 21st century skills and competencies.

16 Generic Engineering Competencies for Engineering Practice (Passow and Passow 2017)	**21st Century Skills and Competencies Important for Millennial Learners in OECD Countries (Pellegrino 2017, adapted from Ananiadou and Claro 2009)**
Top Group	1. Creativity/Innovation
Solve Problems (Core)	2. Critical Thinking
Communicate Effectively (D)	3. Problem Solving
Interpret Data	4. Decision Making
Coordinate Efforts (D)	5. Communication
Devise Process (D)	6. Collaboration
	7. Information Literacy
Second Group	8. Research and Inquiry
Take Initiative (D)	9. Media Literacy
Think Creatively (D)	10. Digital Citizenship
Make Decisions (D)	11. ICT (Information and Communication Technology Operations and Concepts)
Additional	12. Flexibility and Adaptability
Measure Accurately	13. Initiative and Self-Direction
Design Solutions	14. Productivity
Gather Information (D)	15. Leadership and Responsibility
Define Constraints (D)	16. Other (please specify)
Apply Knowledge	
Apply Skills	
Take Responsibility	
Expand Skills	

Note. 1. Blue competencies have single match. Red competencies have more than one match. Black competencies have no clear match. 2. OECD – Organisation for Economic Co-operation and Development.
Note for Passow and Passow (2017). Top Cluster–Rated top cluster of importance for engineering practice (quantitative). Second Cluster–Rated just below top cluster of importance for engineering practice (quantitative). Additional–Not rated but part of the 16 generic competencies identified. *Core*–Core activity of engineering (qualitative findings) (p. 495). *D*–'Differentiated between outstanding and ordinary engineering performance' (qualitative).
Note for Ananiadou and Claro (2009). Authors conceptualize framework for 21st century competences in three dimensions: *information* (i.e., research and problem solving skills), *communication* (i.e., effective communication and collaboration), and *ethics and social impact* (i.e., social responsibility and social impact).

Passow and Passow (2017) determined that problem solving is the 'core of engineering practice' (p. 475), which substantiates the Washington Accord's conceptualization of engineering student outcomes (e.g., see Hanrahan 2008, Section 2.1.2.1 *Engineering Graduate Attributes: The Washington Accord*). They established that the technical skills practiced by engineers are fundamentally connected to teamwork, a compelling finding due to the discussion in Section 2.3.1 '*Technical' Versus 'Professional' Engineering Skills* on the general – and at times, even disparaging – treatment of engineering student outcomes that are considered separate from technical, or 'real' engineering work. Passow and Passow (2017) determined that the most critical skill for an engineer is 'coordinating multiple competencies to accomplish a goal' (p. 475) – which harkens to Pellegrino's (2017) theory of transfer being the 'Holy Grail' of education. They state:

> Competencies important for engineering practice differ from required learning outcomes and graduate attributes. We compared the specific competencies that emerged as important in this qualitative analysis to both ABET's learning outcomes and the Washington Accord graduate attributes. The concept of coordinated competencies… – and many of the competencies themselves – differ substantially from the required outcomes and attributes. By listing separate learning outcomes without a unifying portrait… required lists of outcomes and attributes lose the most important concept, which is that in engineering practice, competencies are intertwined and coordinated. (Passow and Passow 2017, p. 492)

The groundbreaking nature of this work is establishing that engineering educators must have a comprehensive understanding on how engineering competencies are connected and interact in engineering practice in order to design authentic learning environments relevant to engineering practice today. Developing a conceptual understanding – or framework – of how the graduate attributes cluster together will inform authentic curricular design. Svinicki (2010) defines a conceptual framework as: 'an interconnected set of ideas (theories) about how a particular phenomenon functions or is related to its parts. The framework serves as the basis for understanding the causal or correlational patterns of interconnections' (p. 5). The importance of a conceptual framework in education is that it allows educators to make informed decisions about developing curricula. Svinicki (2010) makes a skillful case to engineering educators for the importance of using conceptual frameworks for constructing engineering educational systems (i.e., curricula) by employing the metaphor of redesigning a bridge:

> Why should you care about the conceptual frameworks that underlie research on teaching and learning? I propose that you wouldn't consider redesigning a bridge without understanding the underlying principles that support and affect it in the first place. Wouldn't you look to current models of mechanics, materials science, civil engineering, geology, maybe even climatology to inform your questions about its form and function? Those specialties would help you understand the kinds of data to gather, the questions to ask, the variables to consider. They would save you time and effort by focusing your attention on key components that your new design should investigate. They would help you interpret the data you collect and make decisions about what to do at each stage of the process.
>
> The same is true for redesigning educational systems. The underlying models for education come from psychology, sociology, communications, and other behavioral sciences. Just as models from the disciplines listed in the previous paragraph would in engineering, the models in the fields in this paragraph will help researchers in engineering education to save time and effort and to ask reasonable questions informed by what is known about the influences on human learning. (p. 5)

Having a conceptual understanding/framework in which to position educational decisions enables engineering educators to make informed choices in constructing and improving engineering curricula. By developing a conceptual understanding/framework of how the graduate attributes manifest in engineering practice that is informed by the professional judgment of engineering stakeholders, engineering educators can design curricula to teach and assess the graduate attributes in a manner that mirror authentic engineering work. This provides for more authentic education (Passow 2012; Pons 2016) and functions to 'harmoniz[e] the curriculum' (Pons 2016, p. 532).

A conceptual/theoretical understanding of how the CEAB graduate attributes manifest in engineering practice facilitates the achievement of a common understanding among stakeholders of what is important in regards to the development of engineering competencies. Moreover, collecting data on the dependencies of the graduate attributes from multiple engineering stakeholder perspectives enables the identification of potential differences in understandings amongst engineering faculty, students, and industry members, thus identifying where more work is needed to come to a common understanding, and facilitating faculty, students, and industry stakeholders coming together to enhance engineering education.

Pellegrino (2017) refers to this ability to draw on the necessary knowledge and skills required in each situation as ‘21st century competencies’ – the cognitive, interpersonal, and intrapersonal skills that can be ‘taught and learned in ways that promote effective transfer.’ Passow and Passow (2017) emphasize that ‘Engineering education could better coordinate competencies as in engineering practice’ (p. 499), which is an essential purpose of this study.

As shown, the idea of determining the relative importance of, and clustering engineering competencies as introduced by studies such as those done by Male (2010), Male, Bush, and Chapman (2011a, 2011b), and Passow (2012), and renewed by Pons (2016) and Passow and Passow (2017) is unique in the body of engineering education literature, and paves the way for a new direction in the research to explore how engineering stakeholders conceptually understand the graduate attributes. Research is required that explores how Canadian engineering stakeholders rank and cluster the CEAB graduate attributes in order to evaluate engineering program content validity, and inform outcomes-based engineering education pedagogical practices. Determining the relative importance of each of the CEAB graduate attributes, and exploring how stakeholders' rate the dependency of pairs of the attributes will help define stakeholders' conceptual understanding of them, and potentially lead to the formation of a conceptual/theoretical framework. Determining stakeholders' conceptual understanding will apprise the efficient and meaningful development of engineering curricula, as curricula can be re/designed to reflect how the graduate attributes naturally and authentically cluster in engineering practice.

Chapter Summary

Chapter 2 contained the Literature Review within which the context for this thesis is set. It was comprised of three sections: The first section discussed the emergence of engineering education, and the influence of America and the development of the ABET student learning outcomes, changes to engineering accreditation, the Washington Accord graduate attributes, changes to ABET Criterion 3, the Canadian Engineering Accreditation Board, the influences of accreditation changes on Canadian engineering programs. The second discussed assessment in engineering education, including the power and purposes for assessment, the assessment paradigm shift, types of assessment, constructive alignment, assessment tools, including surveys, limitations of indirect assessments, recommendations and cautions for assessments, the role of engineering stakeholders in assessment, the importance of a common language and understanding, and the gaps in understanding. The third section focused on assessing the CEAB graduate attributes, considering traditional versus professional skills, the gaps in the conceptual understanding of the graduate attributes, and considering the relative importance and interrelationships of the graduate attributes. Chapter Three presents the methods.

Chapter Three: Methods

This chapter frames this exploratory case study by explaining the research design, methodology and epistemological perspective. This is followed by the presentation of the methods divided into three sections: participants, measures, and data analyses. Lastly, the study quality, ethics procedures and approval, and timing and length are addressed.

3.1 Research Design, Methodology, and Epistemological Perspective

This is an exploratory case study. The overarching objective of this study is to investigate how the emphasis on the CEAB graduate attributes in the Faculty of Engineering programs at the University of Manitoba reflects the reported importance of the graduate attributes by key stakeholders. The case is bounded by place and the individuals of interest (Van Note Chism, Douglas, and Hilson Jr. 2008), specifically the engineering students, faculty, and industry members associated with the Departments of Biosystems, Civil, Electrical and Computer, and Mechanical Engineering in the Faculty of Engineering at the University of Manitoba. In Phase 1 of this study, the researcher is concerned with what the various engineering stakeholders perceive regarding the relative importance of the CEAB graduate attributes and the dependencies of one CEAB graduate attribute on another. The graduate attributes are considered a general phenomenon because all accredited Canadian engineering programs are responsible for ensuring that, vis-à-vis their individual programs, their graduates demonstrate the knowledge, skills, attitudes, values, and behaviours that are demarcated in them. Therefore, the findings of this study are particularly relevant to other accredited engineering programs within Canada. Phase 2 focuses on evaluating the content validity of the Biosystems Engineering program, which can be considered an intrinsic case study (Creswell 2013, p. 100).

The epistemological and theoretical perspectives that underscore this research have been explicitly considered and delineated because this approach has been called for by engineering education researchers in an effort to increase the rigor of work, and thereby add to the scholarship of the field (Wankat 2004; Olds, Moskal, and Miller 2005; Borrego 2007; Koro-Ljungberg and Davis 2008; Borrego and Bernhard 2011; Case and Light 2011; Johri and Olds 2011; Johri and Olds 2014) (also see Section i: *The Current State of Engineering Education Research in America*). Research designs and the methods used to gather and analyze data do not – and should not – function independently of the epistemological and theoretical perspectives; the epistemological perspective should be consciously grounded in a chosen theoretical framework through which the nature of truth is seen and described (Koro-Ljungberg and Douglas 2008).

There are a number of diverse epistemologies that have been simplified here into two types to invite comparison: positivism/post positivism and situational perspectives (Koro-Ljungberg and Douglas 2008; Van Note Chism, Douglas, and Hilson Jr. 2008; Case and Light 2011). The former is generally characterized by a deductive approach, while situational perspectives can be characterized by an inductive style (Koro-Ljungberg and Douglas 2008). Positivism/post positivism holds the perspective that there is a single, absolute truth or reality (positivism), or that there is a single, falsifiable, fragmented truth or reality (post positivism) (Koro-Ljungberg and Douglas 2008). On the other hand, situational perspectives accept that there are multiple, subjective, constructed, holistic or fragmented (for post structuralism) realities (Tonso 1996; Koro-Ljungberg and Douglas 2008).

In research with a positivistic/post positivist perspective, researchers strive to remain removed from their subjects. Their subjectivity is seen in the development of their hypothesis and targeted variables (Koro-Ljungberg and Douglas 2008). Positivism/post positivism research strives for 'nomological' generalizability and operates by the necessity for a statistically representative sample (Case and Light 2011). In other words, the findings apply to the greater population (Koro-Ljungberg and Douglas 2008) and generalizations are time and context-free (Tonso 1996). This objective is at the centre of many of the rudiments (adequate sample size, random assignment) of positivistic/post positivist research (Koro-Ljungberg and Douglas 2008).

Generally, quantitative research tends to adopt a positivistic/post positivist approach, characteristic of most engineering and scientific research (Leydens, Moskal, and Pavelich 2004; Koro-Ljungberg and Douglas 2008; Van Note Chism, Douglas, and Hilson Jr. 2008; Borrego, Douglas, and Amelink 2009), while qualitative research normally assumes a situational position (Borrego, Douglas, and Amelink 2009). However, elements of positivism can be found in research strategies that are situational (Van Note Chism, Douglas, and Hilson Jr. 2008), and vice a versa.

Olds, Moskal, and Miller (2005) underscore the importance of rigorous research methods that best suit the research questions. Descriptive methods communicate the current state of a phenomenon, and may be served by qualitative, quantitative, or mixed methods designs (Olds, Moskal, and Miller 2005; Koro-Ljungberg and Douglas 2008). Common methods for collecting data for descriptive designs include surveys, questionnaires, focus groups and interviews. Olds, Moskal, and Miller (2005) value descriptive research designs for engineering education because the questions that they explore lead to understanding of engineering stakeholders, one of the major goals of EER.

This research design is a descriptive exploratory case study investigating engineering stakeholders' perceptions of the CEAB graduate attributes through the intersection of the CEAB definitions and participants' own understandings of, and experiences with the knowledge, skills, attitudes, values, and behaviours that they perceive comprise the attributes as they manifest in the engineering workplace at the beginning of EITs' careers. These understandings are based on the engineering role that stakeholders inhabit, i.e., engineering student, engineering faculty, engineering industry member, the engineering disciplines that stakeholders identify with in their bounded world, i.e., Biosystems, Civil, Computer, Electrical, Mechanical engineering, and their engineering experiences (Seniuk Cicek, Ingram, Mann, and Renaud 2017), which lends itself to a constructivist perspective. However, the epistemological position underlying the methodology of this research study is positivism, and the data have been collected using survey methods and analyzed using descriptive and inferential statistics. Additionally, although a purposeful sample was sought as appropriate for this case study, so to was an adequate sample size. Therefore, in the approach to data collection and analysis, and in the presentation of the findings, there is the underlying positivistic epistemological perspective that there is a single, absolute truth or reality to how the engineering stakeholders in this case perceive the CEAB graduate attributes. However, the presentation of the data using Bloom's Domain's of Learning as the theoretical framework has a constructivist interpretation, which is characterized by a situational perspective.

The purpose of the study is to inform the improvement and development of authentic outcomes-based engineering curricula by: (i) determining the relative importance of the CEAB graduate attributes; (ii) evaluating the content validity of our engineering programs; and (iii) developing a conceptual/theoretical understanding of the CEAB graduate attributes to inform engineering curricular design. It has two phases. In Phase 1, the relative importance of the CEAB graduate attributes for EITs at the beginning of their career as perceived by University of Manitoba senior undergraduate students in Capstone courses, engineering faculty, and Manitoba industry stakeholders was established. Additionally, the percentage to which every graduate attribute is dependent on, or requires, every other graduate attribute for an Engineer-in-Training (EIT) at the beginning of his/her career as perceived by these same engineering stakeholders was determined. In Phase 2, the Department of Biosystems program was used as an intrinsic case study to evaluate its content validity as measured by the relative importance findings from Phase 1. In Phase 1, a closed-ended ratings questionnaire was employed, and in Phase 2, a questionnaire and program documents were used to collect quantitative data. The study was guided by these research questions:

RQ 1.0 Absolute and Relative Importance of the CEAB Graduate Attributes

RQ 1.1 What is the perceived absolute importance of each CEAB graduate attribute across all engineering stakeholders (i.e., students, faculty, and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 1.2 What is the perceived relative importance of each CEAB graduate attribute across all engineering stakeholders (i.e., students, faculty, and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 1.3 How much does the perceived absolute importance of each CEAB graduate attribute vary between each engineering stakeholder group (i.e., students vs. faculty vs. industry)?

RQ 1.4 How much does the perceived relative importance of each CEAB graduate attribute vary between each engineering stakeholder group (i.e., students vs. faculty vs. industry)?

RQ 2.0 CEAB Graduate Attribute Dependencies

RQ 2.1 What is the perceived dependency of each of the 12 CEAB graduate attributes on every other CEAB graduate attribute for all engineering stakeholders (i.e., students, faculty, and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 2.2 How much does the perceived dependency of each CEAB graduate attribute on every other CEAB graduate attribute vary between engineering stakeholder groups (i.e., students vs. faculty vs. industry)?

RQ 2.3 How do the perceived similarities of the CEAB graduate attributes cluster together across all engineering stakeholders?

RQ 3.0 Program Content Validity

RQ 3.1 For each CEAB graduate attribute, how similar are the percentages of course content coverage to the percentages of course assessments in the Biosystems engineering program?

RQ 3.2 In the Biosystems engineering program, how do the percentages of course content coverage and course assessments of the CEAB graduate attributes compare with their perceived relative importance by all engineering stakeholders?

3.2 Research Site

The research site was the Faculty of Engineering at the University of Manitoba.

The University of Manitoba is located in Winnipeg, Manitoba, in the centre of Canada. Canada's first Western university, it is a large research-doctoral university that is coeducational, nondenominational, and government-supported. It offers over 100 academic programs and professional disciplines including engineering (University of Manitoba 2017a). The Faculty of Engineering at the University of Manitoba offers the only accredited undergraduate engineering degree programs in the province, with the latest six-year accreditation earned from the Canadian Engineering Accreditation Board (CEAB) through to June 30, 2019 (Beddoes 2017). It is comprised of four departments that offer five distinctive engineering degrees, including biosystems, civil, computer, electrical, and mechanical engineering. Admissions for the 2015–2016 academic year (the year data were collected) totalled 346 students, with over 15% international entries (University of Manitoba 2017c). Additionally, the Centre for Engineering Professional Practice and Engineering Education is an academic centre within the Faculty of Engineering that 'collaborates with departments in the Faculty of Engineering and develops and delivers professional practice and design curricula, drawing on the scholarship of teaching [and] learning in engineering and educational collaboration with industry partners' (University of Manitoba 2017d). Among other responsibilities, the Centre is responsible for offering the Engineering Communications courses, where students work in a team-based environment to examine the principles of engineering communications and the strategies that may be used to implement them into a variety of forms to produce deliverables comparable to the engineering workplace. Other programs in the Faculty of Engineering include ENGAP, an engineering access program for students of Indigenous ancestry (University of Manitoba 2017e), and the IEEQ program, a foreign credentials recognition program for internationally educated engineers (University of Manitoba 2017f).

The Faculty of Engineering has a large number of alumni and close ties with local Manitoba Industry members. In May 2008, Friends of Engineering was established, comprised of a group of Manitoba industry members and/or alumni who are committed to a partnership with the University of Manitoba Faculty of Engineering to support excellence in engineering education (Friends of Engineering 2010). The Faculty of Engineering and Friends of Engineering have come together to sponsor a series of industry forums. The industry forums are essentially round table discussions between Manitoba Engineering industry and Faculty of Engineering members, facilitated by the latter. The primary purpose of the University of Manitoba Industry Forums is to continue the ongoing partnership between local Manitoba Engineering industry and academia from the University of Manitoba, and to establish a meaningful link between academia and industry's expectations of engineering graduates with the singular goal of improving engineering education (Ferens et al. 2014). To date, there have been seven industry forums hosted by the Faculty of Engineering at the University of Manitoba, five in which this researcher played a supporting role.

3.2.1 Biosystems Engineering Program

During Phase 2 of the study, the content validity of the Biosystems Engineering program was evaluated using the relative importance ratings from the first phase of the study.

The Biosystems Engineering program is comprised of a variety of courses, some of which are taught within the Department of Biosystems, and others that are taught outside of the department, either within the Faculty of Engineering or in the Arts and Science faculties at the University of Manitoba (see Appendix D for the Biosystems program 5–year model). Unique to the Biosystems program is the fusion of the Engineering Communication course with three of the four Biosystems Design courses, which make up the 'BIOE Design Spine.' These courses are offered sequentially through the four years of the program, one in each year. The outcomes of the Engineering Communication course stand alone alongside the outcomes of these design courses in the effort to further authenticate communication skills for engineering students (see Friesen, Taylor, and Britton 2005 and Mann, Dick, and Ingram 2012 for an account of the inception of this curricular design).

The Biosystems program is comprised of 45 required courses, 35 of which are considered core courses. Here is a description of the program in an email communication sent from Danny Mann, the Department Head of Biosystems Engineering, on July 17, 2017, which explains how the courses are considered in regards to data collection for accreditation purposes, and how graduate attributes are only mapped in the compulsory courses, not in the course electives:

> There are a total of 45 course required to complete the Biosystems Engineering degree. Of these, 35 are considered to be core courses with the remaining 10 courses fitting into 4 categories of electives (i.e., two science electives, three Biosystems design electives, three complementary studies electives and two free electives). The core does include the preliminary year courses (although one of the 12 preliminary year courses is one of the complementary studies electives).
>
> Although the program consists of 45 courses, any analysis of graduate attributes can really only be done on the 35 core courses because we cannot control the diversity of courses that students will take to complete the various electives. In general, this is the approach that I have taken when trying to collect graduate attribute data.

This approach is supported by the research: ‘A third challenge is electives – programs with a high proportion of electives are challenging to map. One solution is to ‘chunk’ the program and map compulsory sections’ (Oliver 2013, p. 455). Of these 35 core courses, 14 courses are taught within the Biosystems program, and 21 are taught outside the department. Therefore, in order to collect data for Phase 2 of this research study, two approaches for collection were required: A questionnaire was designed for the faculty teaching courses within the Biosystems program and within the Faculty of Engineering, and course syllabi and accreditation documents were used to augment these, and to collect data for courses taught outside the faculty.

3.3 Research Participants

This study is an exploratory case study designed to investigate how the CEAB graduate attributes manifest in engineering practice for EITs at the beginning of their careers from Faculty of Engineering at the University of Manitoba stakeholders’ perspectives. The stakeholders were purposefully selected as participants based on their capacity to support the objectives of the study (Van Note Chism, Douglas, and Hilson Jr. 2008; Creswell 2013), and the researcher worked to collect an adequate sample size based on the targeted participant populations (i.e., response rates exceeded 50% of the populations) (see Seniuk Cicek, Ingram, Mann, and Renaud 2017).

As the study was conducted in two phases, the selection and recruitment of participants will be described separately for Phase 1 and Phase 2.

Phase 1

3.3.1 Phase 1 – Participant Selection

Participants for Phase 1 of the study comprised of three University of Manitoba engineering stakeholder groups, with populations representative of the 2015-2016 academic year:

- Engineering Faculty from the Faculty of Engineering: Professors, Instructors, Administrators, and Engineers-in-Residence (N=91)
- Senior year undergraduate engineering students enrolled in Capstone in the Faculty of Engineering (N=235)
- Engineering Manitoba industry members associated with the Faculty of Engineering through Friends of Engineering (N=70) (augmented by industry members associated with Faculty of Engineering industry forum or professional licensure associations – see below)

Faculty members teaching in the Faculty of Engineering were selected, as they are responsible for the design and delivery of engineering curricula, which includes the teaching and assessing of the CEAB graduate attributes. Senior year undergraduate engineering students enrolled in Capstone in the Faculty of Engineering were targeted, as they are close to finishing their engineering programs and transitioning into industry, and thereby are assumed to be the cohort of students more familiar with the graduate attributes and more likely to be thinking about their upcoming experiences as EITs. Manitoba industry members associated with the Faculty of Engineering through Friends of Engineering were chosen, as this group has members who represent a variety of Manitoba engineering industries. As well, industry members who participated in the Faculty of Engineering Industry Forums at the University of Manitoba, and industry who are members of our provincial professional engineer licensure body (formerly known as APEGM, now *Engineers Geoscientists Manitoba*) were also recruited for the study. (For a description of Friends of Engineering and the Faculty of Engineering Industry Forums see Section 3.2 *Research Site*.)

At the time of data capture (mid December 2015 – end of January 2016), there were 91 faculty members in the Faculty of Engineering, 235 senior year undergraduate capstone students from the Departments of Biosystems, Civil, Electrical and Computer, and Mechanical Engineering collectively, and 70 Manitoba industry Friends of Engineering members. All of these stakeholders were recruited.

3.3.2 Phase 1 – Recruitment

Students, faculty and industry engineering stakeholders were recruited as follows.

3.3.2.1 Students

Upon the Education/Nursing Research Ethics Board (ENREB) approval of this research protocol the researcher piloted the Relative Importance and Graduate Attribute Dependency Ratings Form (see Appendices F.1 and F.2) with a small group of senior year engineering students (N=3) from the Faculty of Biosystems in the Faculty of Engineering at the University of Manitoba to evaluate face and content validity of the forms for the engineering student stakeholder group. (See Appendix E.2 for the Pilot Response Form and Appendix F.1 for the Recruitment Letter for Pilot participants.) Changes made as a result of the pilot are described in Section 3.4.1.4 *Piloting the Relative Importance and Graduate Attribute Dependencies Ratings Form*.

The researcher then met with the Department Heads of the four engineering departments – Biosystems, Civil, Electrical and Computer (ECE), and Mechanical Engineering – to inform them about the study, and ask for their support in recruiting their senior year undergraduate engineering students enrolled in Capstone. A recruitment letter approved by ENREB (Appendix F.2) was then sent through three of the Department's administrative staff (Biosystems, Civil, and Mechanical) to all of their senior year undergraduate engineering students enrolled in Capstone informing them of the nature and scope of the study, and requesting their participation in Phase 1. Students who agreed to participate were asked to contact the researcher via email. They were then sent the Letter of Informed Consent (Appendix F.3), the Word document of the Relative Importance and Graduate Attribute Dependency Ratings Form (Appendix E.1), and the link to the form on Survey Monkey. Student participants were asked to sign the informed consent, and complete the ratings form either in the Word document or online, and in the former case, return the form to the researcher via email.

The faculty member responsible for the ECE Capstone requested that the researcher visit his class rather than send the questionnaire electronically, believing that more students would respond. Due to the insignificant amount of questionnaires that were returned by students to the researcher via email, the researcher adopted this protocol for two other engineering departments as well. Thereby, between the late Fall 2015 and early Winter 2016 term, the researcher visited each of the Biosystems, Mechanical, and ECE Capstone classes once each to explain the study to students. (Faculty in charge of teaching the Civil Capstone could not spare the time during class; therefore, Civil students only received the emailed request for participation.) In the case of the Biosystems and ECE classes, the students were given the rest of the class and the choice whether or not to complete the questionnaire.

To maintain ethics protocol, the following steps were taken. The professor and teaching assistants left the classroom once the researcher arrived. Only the researcher remained. This was done so that faculty could not exert any influence on students, as faculty is in a position of power vis-à-vis the participants. Students were given informed letters of consent and explained that they could freely choose to participate or not participate in the study, without consequence or penalty, while being ensured confidentiality from faculty. To further protect students' confidentiality, all students were given copies of the questionnaire, asked to refrain from writing their name or any other identifying information on the pages, and then all asked to return the questionnaires by placing them into a box left by the door of the classroom, regardless of whether they completed the questionnaire or not. The researcher positioned herself on the other side of the classroom from the door to refrain from overseeing the return of the questionnaires and avoid identifying students who did and who did not fill them out, with the intention of further setting participants at ease. As the researcher had never been a faculty member or a sessional instructor at this time, she did not know any of the students or their names; thereby, students' confidentiality was further protected. Despite this, the researcher did not share any information regarding the behaviour of the participants on the research site or the response rates of the questionnaire with the faculty members responsible for the Capstone courses, nor any other persons, whether connected to the Faculty of Engineering or not.

A different approach was taken for distributing the questionnaire to students in the Mechanical Engineering Capstone. These students are traditionally given a graduate attributes exit survey (a survey that this researcher partnered to design in corroboration with the Mechanical faculty member in charge of the Capstone course). In Fall 2016 at the end of the term after the researcher had visited their Capstone class, at the suggestion of the Capstone instructor and in the same manner that is adopted each year in this course, team leaders were given a manilla envelope containing a copy of either the exit survey or the research questionnaire for each of their team members and asked to distribute them outside of the class. Half of the students were given the traditional graduate attribute survey, and the other half was given the *Relative Importance and Graduate Attribute Dependency Ratings Form* for this study. Distribution of the documents was random and anonymous. Students took the questionnaires home. They could choose to fill out the questionnaire or not (i.e., participate or not participate in the study). Team members were instructed to return the questionnaires in sealed manilla envelopes to ensure their confidentiality from faculty. To further ensure the confidentiality of participants, students were asked to refrain from putting their names or any other identifying information on the form, and the research kept the response rates confidential.

Throughout this process, it was made clear to students that the study was optional, and that their choice to participate or not was not linked to their individual evaluations or to their class grades in any way, and would have no consequences, either positive or negative, on them or their status within the faculty. To ensure students' confidentiality in either participating or not participating in the study, all email correspondence following the initial recruitment was conducted through the researcher, and all questionnaires completed by students were completed and collected confidentially as described above. The researcher did not share participants' identities or the response rates with any one, including students' instructors, Department Heads, the researcher's advisor, Dr. Sandra

Ingram, or any other persons either connected or not connected to the Faculty of Engineering. At the time the data were being collected, the researcher had not, and did not teach any courses in the engineering faculty, therefore the researcher was not in a position of power vis-à-vis participants.

3.3.2.2 Faculty

Upon ENREB approval of this research protocol the *Relative Importance and Graduate Attribute Dependency Ratings Form* (Appendix E.1) was piloted with a small group (N=5) of Engineers-in-Residence in the Faculty of Engineering at the University of Manitoba to evaluate the face and content validity of the forms for the engineering faculty and Manitoba industry stakeholder groups (see Appendix E.2 for the Pilot Response Form). Engineers-in-Residences are industry members who, in partnership with industry and the Faculty of Engineering, are hired to teach courses in the faculty designed to meet specific industry needs. They were recruited to pilot the form as they were in the unique position to represent both faculty and industry members. Changes made as a result of the pilot are described in Section 3.4.1.4 *Piloting the Relative Importance and Graduate Attribute Dependencies Ratings Form*.

The researcher then met with the Department Heads of the four engineering departments – Biosystems, Civil, Electrical and Computer, and Mechanical Engineering – to inform them about the study, and ask for their support in recruiting their engineering faculty. Once obtained, a recruitment letter approved by ENREB (Appendix F.4) was sent through each Department's administrative staff to all of their engineering faculty members informing them of the nature and scope of the study, and requesting their participation. Faculty who agreed to participate were sent the Letter of Informed Consent

(Appendix F.5), a Word document with the Relative Importance and Graduate Attribute Dependency Ratings Form (Appendix E.1), and a link to an electronic version of the form on SurveyMonkey. Participants were asked to sign the Informed Consent, and complete the ratings form either in the Word document provided or online, and in the former case, return the form to the researcher via email.

It was made clear to engineering faculty members that the study was optional, and that their participation or their choice not to participate would not be linked to individual evaluations and/or progress reports. To ensure faculty members' confidentiality in either participating or not participating in the study, all email correspondence following the initial recruitment were conducted through the researcher, and the researcher did not share participants' identities with Department Heads or any other persons, including her advisor, Dr. Sandra Ingram, who is a faculty member. Faculty members were (and are) well aware of the new accreditation requirements for Canadian engineering programs. This study was beneficial to all faculty members in regards to these requirements, which among a number of things, necessitates a composite knowledge of the 12 CEAB graduate attributes, evidence of the use of outcomes-based education strategies, and a commitment to, and evidence of, a continual cycle of improvement. Therefore, it was to faculty members' advantage to participate.

3.3.2.3 Industry members

Upon ENREB approval of this research protocol the University of Manitoba liaison for Friends of Engineering sent the recruitment letter to their mailing list. As well, a professor in the Faculty of Engineering who had contact with industry members through the University of Manitoba Industry Forums sent a recruitment letter informing his contacts of the nature and scope of the study, and requesting their participation (Appendix F.6). Additionally, calls for participation were sent through Engineers Geoscientists Manitoba's ENews (Seniuk Cicek, Ingram, Mann, and Renaud 2017).

Industry members who agreed to participate were sent the Letter of Informed Consent (Appendix F.7), and a Word document of, and link to the Relative Importance and Graduate Attribute Dependency Ratings Form (Appendix E.1). They were asked to sign the informed consent, and complete the ratings form either on the Word Document or electronically, and if the former, return the form to the researcher via email. Manitoba industry members were assured that the study was optional, and that their participation or their choice not to participate would not affect their relationship, either positively or negatively, with Friends of Engineering or the Faculty of Engineering. To ensure industry members' confidentiality in either participating or not participating in the study, industry members were asked to direct all correspondence following the initial recruitment through the researcher, and participants' identities were not shared with any other persons, including the researcher's advisor, Dr. Sandra Ingram. Industry members had been made aware of the new accreditation requirements for Canadian engineering programs. This study would potentially benefit industry members in regards to having a voice regarding these requirements. Therefore, it was also to industry members' advantage to participate.

3.3.3 Phase 1 – Participation Rates and Stakeholder Groups

The total number of participants for Phase 1, who responded to the *Relative Importance and Graduate Attribute Dependencies Ratings Form* once data were cleaned, was 220. This included participants who filled out the form in full, as well as participants who filled out either the relative importance section of the form or the dependency section of the form. It also included participants who missed answering part of a question (i.e., they did not choose a frequency rating for Problem Analysis, but chose a criticality rating; or they missed a dependency rating). One of these participants did not identify his/her stakeholder group. As analyses were contingent upon the stakeholder group as the fixed variable, 219 participants' data were analyzed for demographic and graduate attribute familiarity data.

Seven participants identified with more than one stakeholder group, with one participant identifying as student/faculty, one identifying as student/faculty/industry, and five identifying as faculty/industry. Again, as analyses were contingent upon the stakeholder group variable, the researcher had to determine into which group to place these participants. After consideration, it was decided that faculty trumped both student and industry identities (i.e., all seven participants were labeled faculty). This decision was based on the data collected from pilot participants. Five of the pilot participants were Engineers-in-Residence in the faculty. Four of the Engineers-in-Residences who completed the pilot forms, despite having a number of years of industry experience, all identified themselves as faculty. Research participants who labeled themselves as faculty/industry or student/faculty/industry were assumed by the researcher to be Engineers-in-Residence. Therefore, they were ultimately placed into the Faculty stakeholder group, consistent with how the Engineers-in-Residences who piloted the questionnaire identified (see Table 3.1).

Table 3.1
Stakeholder group assigned by researcher.

Stakeholder Group Specified By Participant	Stakeholder Group Assigned By Researcher
Student/faculty	Faculty
Student/faculty/industry	Faculty
Faculty/industry	Faculty
Faculty/industry	Faculty
Faculty/industry	Faculty
Faculty/industry	Faculty
Faculty/industry	Faculty

Overall, when considering each population, percentage of participation for each stakeholder group was approximately 53% students, 51% faculty, and 69% industry (see Table 3.2).

Table 3.2
Phase 1 participation per stakeholder group (Seniuk Cicek, Ingram, Mann, and Renaud 2017).

Stakeholder	Population	N	Response Rate
Students	235	125	53.2%
Faculty	91	46	50.6%
Industry	70	48	68.6%
Total	396	219	55.3%

The participation rates for the Graduate Attribute Absolute and Relative Importance section of the form and the Graduate Attribute Dependencies section were different, as some participants chose to complete only one section of the form, and the researcher had to remove participant responses with large portions of missing data. These participation rates are presented in Section 3.3.5 *Participation Rates for the Relative Importance and Graduate Attribute Dependencies Ratings Form.*

3.3.4 Phase 1 – Participant Demographics and Graduate Attribute Familiarity

On the first page of the questionnaire, in addition to participants selecting their engineering stakeholder identity, participants were asked to delineate their engineering area, number of years as an engineering student, engineer and/or engineering faculty member, and their familiarity with the CEAB graduate attributes. The following sections report on those findings for all participants (N=219).

3.3.4.1 Engineering Area

Participants were given the six options to choose from to characterize their engineering area: *Biosystems, Civil, Computer, Electrical, Mechanical*, and *Other (please specify)*. The *Other* category allowed for participants to specify what 'Other' represented, and included participants who had areas outside of the engineering areas listed (i.e., Chemical and Materials and Engineering Communications), or interdisciplinary areas (i.e., Biosystems/Civil, Electrical and Computer, Biosystems/Mechanical).

Twenty-three participants listed *Other* as their engineering area. Seven of these participants also chose one of the other five engineering areas (*Biosystems, Civil, Computer, Electrical*, or *Mechanical*), and were thereby categorized into the area specified on the questionnaire. Five participants were reassigned into one of the five original engineering areas based on expert opinion (i.e., advice from engineers in the field) as follows: Metallurgical (N=1) (MECH); Chemical and Materials (N=2) (BIOE); Electronics and Hardware (N=1) (Electrical); and Industrial (N=1) (MECH). Six participants listed multidisciplinary engineering areas, and were assigned one of the areas specified on the questionnaire as follows: BIOE/CIVL (N=1) and BIOE/MECH (N=2) were put in BIOE as there were fewer industry members represented in BIOE than in the other two areas; ECE

(N=2) was put into Electrical, as Electrical has the larger population in the ECE department; and Electrical/MECH (N=1) was put into Electrical, as Electrical had less industry participants than Mechanical. Five participants were assigned a new category, ‘Engineering Professional Practice,’ which was a category that emerged from participants’ responses: Design, Engineering Communications, Design Engineering, CE2P2E (Centre for Engineering Professional Practice and Engineering Education), and Computer/Electrical/Project Management (N=1 for each) (see Table 3.3).

Table 3.3
Engineering area reassigned by researcher.

Engineering Area Specified By By Participant	Engineering Area Assigned Researcher
Engineering area on questionnaire + Other	
MECH & Computer Science	MECH
BIOE & not specified	BIOE
CIVL & Environmental Engineering	CIVL
BIOE & Agriculture	BIOE
CIVL & Heavy Construction & Precast Concrete	CIVL
MECH & Aero	MECH
MECH & Manufacturing & Industrial	MECH
Other Engineering Area	
Metallurgical	MECH
Chemical & Materials	BIOE
Chemical & Materials	BIOE
Electronics Hardware	ELE
Industrial	MECH
Multidisciplinary Engineering Area	
ECE	ELE
ECE	ELE
BIOE/CIVL	BIOE
BIOE/MECH	BIOE
BIOE/MECH	BIOE
ELE/MECH	ELE
Other Area	
Design	ENG Professional Practice
CE2P2E	ENG Professional Practice
Computer, Electrical & Project Management	ENG Professional Practice
Engineering Communications	ENG Professional Practice
Engineering Library, Design Eng	ENG Professional Practice

Participants who chose *Other* were re-categorized into one of the five engineering areas already stipulated on the questionnaire or into the new area that emerged from the data, *Engineering Professional Practice*, to emulate the situation in the case: the six engineering areas at the University of Manitoba: Biosystems, Civil, Computer, Electrical, and Mechanical Engineering, and Engineering Professional Practice. Table 3.4 shows the distribution of respondents by area.

Table 3.4
Phase 1 stakeholder participation by engineering area.

Stakeholder	All Areas	BIOE	CIVL	COMP	ELE	MECH	ENG Prof Practice
Student	125 (53.2%)	12	50	16	31	16	0
Faculty	46 (50.6%)	11	7	3	7	14	4
Industry	48 (68.6%)	6	15	5	10	11	1
Total	219	29	72	24	48	41	5
Total %	100%	13.2%	32.9%	11.0%	21.9%	18.7%	2.3%

Biosystems had 13.2% of participants, Civil 32.9%, Computer 11%, Electrical 21.9%, Mechanical 18.7%, and Engineering Professional Practice 2.3%. Overall, Phase 1 participation rates were reflective of student representation in all engineering programs with less than 1% difference between student capacity and Phase 1 participation rates, with the exception of Civil, which was over-represented by 11.8%, and Mechanical engineering, which was underrepresented by 14.2% (see Table 3.5).

Table 3.5
Comparison of student capacity and Phase 1 participation in engineering areas.

Eng Area	Student Capacity	% Participants in Phase 1
Biosystems	48 (13.2%)	13.2%
Civil	77 (21.1%)	32.9%
Computer	39 (10.7%)	11.0%
Electrical	81 (22.2%)	21.9%
Mechanical	120 (32.9%)	18.7%
Eng Prof Practice	0 (0.0%)	2.3%
All programs	365 (100%)	100%

3.3.4.2 Number of Years as Specified Stakeholder

Participants were asked to specify their number of years as an engineering student, engineer, and/or engineering faculty member. It was the researcher’s intention that participants answer this question for the stakeholder group that they labeled themselves as, i.e., student, faculty or industry member. However, many participants filled out this value for each stakeholder group that they identified with. Therefore, to calculate average number of years for each stakeholder group, the researcher used the value that corresponded with the participants' response to the question, *Your Engineering Stakeholder Identity* (see Section 3.3.3 *Phase 1 – Participation Rates and Stakeholder Groups*). Table 3.6 reports the mean number of years for the student, faculty, and industry stakeholder groups respectively, and gives the number of, and range of responses.

Table 3.6
Number of years as specified stakeholder.

Stakeholders	N Respondents	Mean Years	Range of Years
Students	110	4.9	3–8
Faculty	36	15.0	2–42
Industry	36	24.2	2–53

In addition, 23 industry members and nine faculty members identified themselves as Alumni of the University of Manitoba.

3.3.4.3 Participants' Familiarity with the CEAB Graduate Attributes

Participants were asked if they were familiar with the CEAB graduate attributes, and given four answers from which to choose – *No, Somewhat, Yes*, and *Very* (see Section 3.4.1 *The Relative Importance and Graduate Attribute Dependencies Ratings Form – Instrument Development*). Only one participant out of 219 did not select an answer. Table 3.7 demonstrates the results (Seniuk Cicek, Ingram, Mann, and Renaud 2017).

Table 3.7
Participants' familiarity with CEAB graduate attributes (Seniuk Cicek, Ingram, Mann, and Renaud 2017).

Stakeholders	**N**	***No***	***Somewhat***	***Yes***	***Very***
Students	124	61(49.2%)	57(46.0%)	5(4.0%)	1(0.8%)
Faculty	46	2(4.3%)	14(30.4%)	19(41.3%)	11(23.9%)
Industry	48	20(41.7%)	19(39.6%)	9(18.8%)	0(0.0%)
Total	218	83(38.1%)	90(41.3%)	33(15.1%)	12(5.5%)

Forty-nine percent of students either had not heard of the CEAB graduate attributes, or had heard of them but could not recall them. Forty-six percent of students knew a few of the graduate attributes; four percent knew them and could list them, and less than one percent of students were very familiar with the graduate attributes. Four percent of faculty either had not heard of the CEAB graduate attributes, or had heard of them but could not recall them. Thirty percent of faculty were somewhat familiar with the graduate attributes; and fifty percent of faculty were familiar or very familiar with the graduate attributes. Forty-two percent of industry members either had not heard of the CEAB graduate attributes, or had heard of them but could not recall them. Forty percent were somewhat familiar; nineteen percent were familiar, and no industry member perceived that they were very familiar with the CEAB graduate attributes (Seniuk Cicek, Ingram, Mann, and Renaud 2017).

3.3.5 Participation Rates for the Relative Importance and Graduate Attribute Dependencies Ratings Form

Two hundred and seven respondents' data were analyzed for the absolute and relative importance of the CEAB graduate attributes. Twelve respondents' data were removed either because the participants did not respond to that part of the questionnaire (N=3), or because one or more answers to the frequency or criticality of a graduate attribute were left blank (N=9). As a result, nine students, two faculty members, and one industry member were excluded from the analysis. One hundred and sixty-two respondents' data were analyzed for the dependencies of the CEAB graduate attributes. Fifty-seven respondents' data (students N=32; faculty N=6; industry N=19) were removed either because the participants did not respond to that part of the questionnaire at all, or because the majority (i.e., over half) of the answers were left blank (see Table 3.8).

Table 3.8
Response rates for absolute and relative importance and dependency data.

Stakeholder	Population	N= Phase 1	N=Absolute Relative Imp	N=Dependency of GAs
Students	235	125 (53.2%)	116 (49.4%)	93 (39.6%)
Faculty	91	46 (50.5%)	44 (48.4%)	40 (44.0%)
Industry	70	48 (68.6%)	47 (67.1%)	29 (41.4%)
Total	396	219 (55.3%)	207 (52.3%)	162 (40.9%)

Note. 1. Imp = Importance. 2. GAs = Graduate Attributes.

3.3.6 Handling Missing Data in Dependency of CEAB Graduate Attributes Responses

Nineteen participants (11.7% of responses) missed filling out one (N=15), two (N=1), three (N=1) four (N=1) or six (N=1) answers out of 132 answers in their dependency ratings. These omissions were considered unconscious errors likely caused by the repetitive and labour-intensive nature of the instrument. A set of rules was made for dealing with these blank answers (Gliner, Morgan, and Leech 2009, p. 213). The researcher considered all blank answers in relation to the attribute that was depended on. For example, if the answer for what percentage Problem Analysis is dependent on Lifelong Learning was missing, the researcher looked at all of the participant's answers for the dependencies of every other graduate attribute on Lifelong Learning. Then, the researcher looked for patterns in the participant's answers. If all the graduate attributes depended on Lifelong Learning with a value of 50%, the blank answer was filled in with 50% to reflect this pattern. If there was no discernable pattern, the researcher filled in the blank response with the answer that represented the majority of the participant's answers for the dependencies of every other graduate attribute on Lifelong Learning. For example, if the majority of the participant's answers reflected that every other attribute was dependent on Lifelong Learning 50% of the time, that same answer was filled in for the missing answer. Majority was defined as the *single* answer that was chosen more than any other answer. If the participant chose two answers equally, for example four dependencies on Lifelong Learning were 50%, and four dependencies were 75%, the researcher considered the complete set of answers for Lifelong Learning, and chose the midpoint. For example, if the participant's other two answers were lower than the majority of the participant's answers (i.e., 25% or 0%), the researcher chose the lower value in the majority (i.e., 50%) as the midpoint. If the other two answers were higher than the majority of the participant's answers (i.e., 100%), the researcher chose the higher value in the majority (i.e., 75%) as the midpoint. If there was no pattern or majority evident, the researcher chose the answer that the participant used for the inverse dependency, for example, for Problem Analysis on Lifelong Learning, the researcher used the participant's answer for Lifelong Learning on Problem Analysis. The exception to these rules was for one participant who had missed filling out six responses for Lifelong Learning. In this case, all of the participant's other dependencies for Lifelong Learning were 100% (except for one); therefore, 100% was chosen as the response for the missing dependencies in this case.

To make the researcher's judgment transparent, every data set that had a blank filled in by the researcher has been tracked and explained (see Table 3.9).

Table 3.9
Determined responses for missing dependency data.

N	Stakeholder	Missing Response	Determined Response & Justification
1	Student	PA/LL	75% - participant chose 4 out of 10 times for LL
2	Student	PA/KB	75% - participant chose 9 out of 10 times for KB
3	Student	PA/IT	100% - participant chose 6 out of 10 times for IT
4	Student	PA/LL	100% - participant chose 8 out of 10 times for LL
5	Student	DE/LL	75% - participant chose 4 out of 10 times for LL
6	Student	DE/LL	50% - participant chose 8 out of 10 times for LL
7	Student	DE/LL	100% - participant chose 5 out of 10 times for LL
8	Student	DE/LL	75% - participant chose 7 out of 10 times for LL
9	Student	DE/LL	75% - participant chose 7 out of 10 times for LL
10	Student	DE/LL	100% - participant chose 7 out of 10 times for LL
11	Student	DE/LL	75% - participant chose 5 out of 10 times for LL
12	Student	ET/CS	50% - participant chose 6 out of 10 times for CS
13	Student	KB/DE	50% - participant chose 4 out of 10 times for DE
		DE/LL	75% - chose 100% 4 times, chose 75% 4 times, and chose 50% twice – so chose midpoint
14	Student	PA/EP	50% - no obvious pattern; EP/PA had this value
		PA/LL	100% - all participant's LL had this value
		DE/LL	100% - all participant's LL had this value
15	Student	LL/KB, PA IN, DE ET and IT	100% - all other LL had this value except for one
16	Faculty	KB/ET	50% - participant chose 4 out of 10 times for ET
17	Faculty	DE/IN	100% - participant chose 7 out of 10 times for IN
18	Faculty	PA/IN,	50% - chose 0% 3 times, 50% three times, 75% 3 times, so chose the midpoint for IN
		PA/DE	0% - participant chose 5 out of 10 times for DE
		PA/ET	0% - participant chose 5 out of 10 times for ET
		PA/IT	75% - participant chose 3 out of 10 times for IT
19	Industry	EP/PA	50% - participant chose 10 out of 10 times for PA

Note. KB=Knowledge Base for Engineering; PA=Problem Analysis; IN=Investigation; DE=Design; ET=Use of Engineering Tools; IT=Individual and Teamwork; CS=Communication Skills; PR=Professionalism; IE=Impact of Engineering; EE=Ethics and Equity; EP=Economics and Project Management; LL=Lifelong Learning.

Phase 2

3.3.7 Phase 2 – Participant Selection

For Phase 2 of the study, Biosystems faculty members who teach the 14 courses within the Biosystems department were targeted as participants; for courses that are taught by more than one faculty member, the multiple instructors were contacted, but only one questionnaire was required per course. Most of these faculty members have worked with the researcher for the past couple of years to map the CEAB graduate attributes to their courses, and are very familiar with the graduate attributes.

Of the faculty who teach courses required for the Biosystems program that are found outside of the department (N=21), only seven faculty were sought as participants. This is for several reasons. The researcher was reticent to bother individuals to participate in a study that is not directly beneficial to them; some of these faculty members are not familiar with the CEAB graduate attributes, as they are outside of the Faculty of Engineering, and therefore may not be able to reliably complete the questionnaire. Additionally, many of these courses have more than one section and are taught by more than one individual, making it difficult to target participants. Therefore, it was decided that it would be more efficient for the researcher to access the course syllabi and accreditation assessment documents for the courses that are taught outside of the Faculty of Biosystems, and use her professional judgment, corroborated by the Biosystems Department Head and faculty members on the Faculty of Engineering Curriculum Management Committee who are responsible for mapping the graduate attributes and collecting the assessment documents for all of the courses required by the four departments in the Faculty of Engineering for accreditation purposes, to ascertain the percentage of time instructors spend teaching and assessing the targeted graduate attributes in these courses. As a rule, when this information was ascertained from these documents, the assessment information was relegated to the estimated percentage of time spent for both teaching and assessing the graduate attributes in the targeted course. When this information could not be ascertained from these documents, the researcher contacted the faculty responsible for teaching the courses (N=7). In all of these seven cases, these faculty members were from the Faculty of Engineering.

3.3.8 Phase 2 – Recruitment

Upon ENREB approval of the research protocol and completion of Phase 1 of the study and data analysis, an email was sent to Biosystems faculty (N=21) who teach courses that are part of the Biosystems program with the Recruitment and Letter of Informed Consent (Appendix F.8) attached. This letter informed them of the nature and scope of the study and requesting their participation in filling out the *Teaching Faculty Course Content Questionnaire* (Appendix E.3) that was also attached. Faculty members who emailed the researcher a completed questionnaire were taken to be giving their informed consent to participate in the study.

3.3.9 Phase 2 – Participation Rates

All faculty members from the Department of Biosystems (N=14) as well as faculty from the Faculty of Engineering (N=7) who were asked to fill out the *Teaching Faculty Course Content Questionnaire* participated (N=21). The data collected from these questionnaires delineated both the percentage of time spent teaching and assessing the graduate attributes based on faculty members' professional judgment. These data, with the exception of a few cases, were accepted at face value. In two cases, the percentage of time spent assessing each graduate attribute did not equal one hundred percent; for one, the researcher referred to curriculum documents that broke down the assessments in this course, and used those data for the research. For the other, the researcher contacted the instructor again. In another case, the graduate attributes identified by the instructor of the course did not match the accreditation documents. In this case, the researcher contacted the instructor again, as well as faculty responsible for accreditation, and discussed the matter until a consensus was reached.

For the other courses that are taught outside the Department of Biosystems (N=14) – either within the Faculty of Engineering or in the Faculties of Arts and Sciences – the researcher used Faculty of Engineering accreditation documents to ascertain which CEAB graduate attributes were taught and assessed in each course, and the percentage of time spent teaching and assessing each. In these cases, the percentage of assessment for each graduate attribute was delineated in these documents; however, the percentage of time spent teaching these graduate attributes was not. If the researcher could not determine from additional documentation (i.e., course syllabi) the percentage of time spent teaching the graduate attributes, the researcher assumed that the percentage of time spent teaching the graduate attributes was equal to the percentage of assessments for each of the graduate attributes.

3.4 Research Measures

There were three forms of data collection methods, one in Phase 1 and two in Phase 2.

The Relative Importance and Graduate Attribute Dependencies Ratings Form – Phase 1

(1) A closed-ended ratings questionnaire to gather data from engineering stakeholders on the relative importance of the CEAB graduate attributes and the dependency of each CEAB graduate attribute on every other attribute for engineering practice for EITs at the beginning of their careers (Appendix E.1).

The Teaching Faculty Course Content Questionnaire – CEAB Graduate Attributes – Biosystems Engineering Program – Phase 2

(2) A questionnaire to collect data from faculty on the percentage the CEAB graduate attributes were taught and assessed in courses required in the Biosystems engineering program (Appendix E.3).

Program documents – Phase 2

(3) Program documents, including course syllabi available publically on the University of Manitoba website and accreditation assessment spreadsheets, available through the Faculty of Engineering.

3.4.1 The Relative Importance and Graduate Attribute Dependencies Ratings Form – Instrument Development

One close-ended ratings questionnaire was designed for Phase 1 of the research – the *Relative Importance and Graduate Attribute Dependencies Rating Form*. The questionnaire was developed to address three areas: demographic information, relative importance of the graduate attributes, and graduate attribute dependencies.

3.4.1.1 Demographic Information

The demographic information was purposed to delineate the stakeholder group (i.e., student, faculty or industry), reflective of the design of this case study and integral to the analyses of the data. Additionally, participants were asked to identify their engineering area, i.e., *Biosystems, Civil, Computer, Electrical, Mechanical* or *Other*, which represented the engineering programs in the Faculty of Engineering at the University of

Manitoba, and were used to determine if the stakeholder groups were reflective of our faculty composition. Finally, participants were asked to identify their number of years as a student, faculty, EIT or P.Eng., and their familiarity with the CEAB graduate attributes.

The familiarity with the graduate attributes category was designed with a four-item forced choice confidence scale (Polland 2005), giving participants the following classifications to choose from when asked: *Are you familiar with the CEAB graduate attributes?*

No – I haven't heard of them/I've heard of them but can't recall them

Somewhat – I know a few of them

Yes – I know them, I can list them

Yes, very familiar – I know them, I can list them and define them

Findings from these data are reported in the previous Section 3.3.4 Phase 1 – *Participant Demographics and Graduate Attribute Familiarity*, and its three subsections.

3.4.1.2 Relative Importance of the CEAB Graduate Attributes

The second part of the questionnaire was comprised of a ratings questionnaire designed to establish the relative importance of the CEAB graduate attributes for an EIT at the beginning of his/her career by establishing the absolute importance as perceived by engineering stakeholders. For this context, relative importance is defined as the importance of one CEAB graduate attribute relative to the other 11 graduate attributes, expressed as a percentage of the whole. The absolute importance of each graduate attribute was calculated using a 'multiplicative model' where absolute importance was equated to frequency multiplied by criticality (Stutsky, Singer, and Renaud 2012, p. 4).

Participants were asked to rate the frequency and criticality of each of the graduate attributes based on two questions:

> *How often do you think an Engineer-in-Training (EIT) at the beginning of his/her career will perform a task that clearly requires this graduate attribute?*
>
> *What do you think will be the potential effect on workplace performance for an Engineer-in-Training (EIT) at the beginning of his/her career if he/she does not have a sufficient level of competency for this graduate attribute?*

Participants were given a list of the 12 graduate attributes and the CEAB definition for each attribute, along with a 5-point Likert scale for frequency. Participants were asked, *How often do you think an EIT at the beginning of his/her career would perform a task that clearly requires* [insert CEAB graduate attribute]? Participants were given five choices: *Rarely* (1 – 2 times per year)*; Sometimes* (1 – 2 times per month)*; Regularly* (1 – 2 times per week)*; Quite often* (once per day)*;* or *All the time* (several times per day). For the purposes of analysis, each rating was assigned a value from 1 (*Rarely*) – 5 (*All the time*). See Table 3.10.

Table 3.10
Frequency scale (Seniuk Cicek, Ingram, Mann, and Renaud 2017).

1	**2**	**3**	**4**	**5**
Rarely	***Sometimes***	***Regularly***	***Quite often***	***All the time***
1 – 2 times/year	1 – 2 times/month	1 – 2 times/week	Once per day	Several times/day

On the same page, participants were given a 5-point Likert scale for criticality. For criticality, participants were asked, *What do you think the potential effect on workplace* *performance would be of an EIT at the beginning of his/her career who does not have a sufficient level of competency in [insert CEAB graduate attribute]?* Participants were also given five choices: *No consequence* (nothing to correct or repea*t); Minor consequence* (little or no harm, damage or inconvenience; can correct without help); *Moderate consequence* (notable harm, damage or inconvenience; may need help to correc*t); Major consequence* (serious harm, damage or disruption; likely need help to correct); or *Extreme consequence* (irreversible/irreparable harm or damage resulting in injury, death or destruction of material/natural world, and/or reputation). Each criticality rating was assigned a value from 1 (*No consequence*) – 5 (*Extreme consequence*) for analysis. See Table 3.11.

Table 3.11
Criticality scale (Seniuk Cicek, Ingram, Mann, and Renaud 2017).

1	**2**	**3**	**4**	**5**
No consequences Nothing to either correct or repeat	***Minor consequences*** Little or no harm, damage or inconvenience can correct without help	***Moderate consequences*** Notable harm, damage or inconvenience, may need help to correct	***Major consequences*** Serious harm, damage or disruption, likely need help to correct	***Extreme consequences*** Irreversible or irreparable damage resulting in injuries, death or destruction of material or natural world, and/or reputation

The frequency and criticality scales were informed by the work of, and developed under the guidance of, Dr. Robert Renaud (Renaud, Forthcoming; Stutsky, Singer, and Renaud 2012).

3.4.1.3 Dependencies of the CEAB Graduate Attributes

In addition to the relative importance of the CEAB graduate attributes being determined, this study has also been purposed to provide a conceptual/theoretical understanding of the interdependencies of the CEAB graduate attributes as they apply to EITs at the beginning of their career. As established by Passow (2012) and discussed at length in Chapter Two of this thesis, 'faculty…should consider placing special emphasis on the 'top cluster' competencies.' Nguyen (1998), Male (2010), Male, Bush, and Chapman (2011a), Pons (2016), and Passow and Passow (2017) have also suggested that engineering competencies (i.e., graduate attributes) show evidence of naturally clustering together.

The third part of the questionnaire was designed to investigate potential clusters intrinsic in the CEAB graduate attributes. For this research, 'clusters' have been intellectualized as connections or relations between attributes, and 'connections' have been theorized as the 'dependency' of one attribute on another. By establishing stakeholders' professional judgment of the degree to which they feel that one CEAB graduate attribute is dependent on, or requires, another CEAB graduate attribute for use for Engineers-in-Training (EITs) at the beginning of their career, a pattern of perceived dependencies can be determined amongst the graduate attributes.

For this part of the questionnaire, participants were asked to rate the dependency of each of the 12 CEAB graduate attributes on every other CEAB graduate attribute by estimating the degree to which an Engineer-in-Training (EIT) at the beginning of his/her career who is doing something that involves the knowledge, skills, attitudes, values, or behaviours of one graduate attribute, depends on or requires the knowledge, skills, attitudes, values, or behaviours of another graduate attribute. Participants had five choices on which to base their perceptions: *0%, 25%, 50%, 75%,* or *100%*, which were described for participants as *never, seldom, sometimes, often*, or *always depends on/requires*, respectively. Participants were asked to consider each of the 12 graduate attributes in relation to every other graduate attribute in a one-way relationship in this way:

> *Based on your experience, please indicate on a percentage scale that ranges from 100% = total dependency to 0% = no dependency (see [scale] below), the degree to which you feel that the attribute listed on the left is dependent on, or requires, the attribute listed on the right for an Engineer-in-Training (EIT) at the beginning of his/her career*. (Seniuk Cicek, Ingram, Mann, and Renaud 2017)

Engineering stakeholders' perceived dependency for each graduate attribute on every other graduate attribute was determined based on the mean for all stakeholder groups holistically, as well as for each stakeholder group separately (i.e., student, faculty and industry). From these data, analyses were performed to demonstrate how the graduate attributes cluster together.

3.4.1.4 Piloting the Relative Importance and Graduate Attribute Dependencies Ratings Form

Five Engineers-in-Residence and three senior year engineering students from the Faculty of Engineering at the University of Manitoba piloted the ratings form before data collection commenced to evaluate the face and content validity of the form. *Face validity* is defined as 'what a test appears to measure to the untrained eye', and is considered important because 'whether the test is judged relevant to its objectives by respondents, users, or others can affect examinee cooperation and motivation as well as user and public acceptance of the results. Therefore, it is argued, face *in*validity should be avoided whenever possible' (Messick 1987, p. 13). *Content validity*, or evidence based on the content of the measure, demonstrates whether or not the content within the instrument is demonstrative of the intended concept to be measured (Gliner, Morgan, and Leech 2009, p. 166).

During the pilot, the questionnaire was divided into two parts: the relative importance ratings form, and the attribute dependency ratings form. A response form was designed for pilot participants to assist the researcher in determining the face and content validity of the questionnaire, and was used twice, once for each part of the questionnaire (Appendix E.2). The response form asked pilot participants to identify their stakeholder groups (i.e., faculty, student, industry), and to indicate to which part of the questionnaire they were responding. Then the following questions were asked:

1. How long did the form take you to complete (minutes/hours)?

2. Were you confused by any parts of the form? If yes, please describe what confused you.

3. Do you have any questions about any parts of the form?

4. Do you have any suggestions for improvement for any parts of the form?

a. For clarity (to improve your understanding of what you are being asked to do)

b. For efficiency (to improve the productivity of what you're being asked to do, i.e., structure of the form)

5. Do you have any concerns regarding the form?

6. Do you have additional comments?

Several changes were made as a result of the pilot participants' responses. Modification to the phrasing of the demographic question regarding number of years as an Engineer was made to reflect pilot participants' feedback (i.e., participants questioned what specifically was being asked: Number of years as an engineer since graduation, since becoming a P.Eng., or since birth?, etc.). Adjustments to the phrasing of the questionnaire questions were also made. For example, the questionnaire originally asked: How often would a professional engineer perform a task that clearly requires this graduate attribute? This was changed to read: How often do you think an Engineer-in-Training (EIT) at the beginning of his/her career will perform a task that clearly requires this graduate attribute? (Changes underlined.) The question was rephrased to ask participants *what they think* the criticality and frequency of each graduate attribute would be, rather than asking what they know, thus enabling participants to answer even if they had no experience in the field (i.e., a student). Additionally, changing professional engineer to Engineer-in-Training (EIT) at the beginning of his/her career was done to increase the content-related validity of the questionnaire. The purpose of the study is to determine the relative importance of the graduate attributes for the purpose of engineering program validation and improvement, intended to ultimately enhance these competencies in the engineers who graduate from our programs, better preparing them for transition into industry. Therefore, it is the relative importance of the graduate attributes *at the point of transition*: from student to graduate engineer that is of interest, in order to best prepare students for work in industry by emphasizing in engineering curricula the importance of graduate attribute competencies as reported by key stakeholders. Demarcating the engineering profile as an EIT at the onset of an engineering career more clearly met the objectives of the study.

Another change based on pilot feedback was to add an example to the instructions of the Dependency Ratings form to demonstrate how it was intended for participants to think about the question. The example read as follows (Seniuk Cicek, Ingram, Mann, and Renaud 2017):

For example, in the first pair, you should think about the degree to which an Engineer-in-Training (EIT) at the beginning of his/her career who is doing something that involves A Knowledge Base for Engineering depends on, or requires, Problem Analysis.

	100%	75%	50%	25%	0%	
A Knowledge Base for Engineering						Problem Analysis

You are being asked to consider all 12 graduate attributes individually in relation to every other graduate attribute using the following scale:

*100% - Whenever an Engineer-in-Training (EIT) at the beginning of his/her career does something that involves using his/her Knowledge Base it will **always depend on/require** Problem Analysis.*

*75% - Whenever an Engineer-in-Training (EIT) at the beginning of his/her career does something that involves using his/her Knowledge Base it will **often depend on/require** Problem Analysis.*

*50% - Whenever an Engineer-in-Training (EIT) at the beginning of his/her career does something that involves using his/her Knowledge Base it will **sometimes depend on/require** Problem Analysis.*

*25% - Whenever an Engineer-in-Training (EIT) at the beginning of his/her career does something that involves using his/her Knowledge Base it will **seldom depend on/require** Problem Analysis.*

*0% - Whenever an Engineer-in-Training (EIT) at the beginning of his/her career does something that involves using his/her Knowledge Base it will **never depend on/require** Problem Analysis.*

Finally, the percentage symbol was added to each column of the questionnaire where the numeric scale was delineated for increased clarity (Seniuk Cicek, Ingram, Mann, and Renaud 2017).

3.4.2 Teaching Faculty Course Content Questionnaire – Instrument Development

The second purpose of this study was to evaluate the content validity of an engineering program in order to inform the improvement and development of authentic outcomes-based engineering curricula. Ro et al. (2015) describe content validity within the domain of validity:

> According to the American Educational Research Association, the American Psychological Association, and the National Council on Measurement in Education (1999), "Validity refers to the degree to which evidence and theory support the interpretation of test scores entailed by proposed uses of tests" (p. 9). Their joint standards state that the examination of a measure's validity relies on the collection of evidence that is based on test content, response processes, consequences of testing, internal structure, and relations to other variables.
>
> Evidence based on test content refers to the extent to which a scale's items, in the aggregate, constitute a representative sample of the topic's content domain. Do the items reflect what has been defined as "contextual competence" (Suen, 2008; Trochim, 2006)? To answer the question, content experts are consulted and their professional judgment is taken to reflect the degree of what was traditionally called "content validity." (p. 37-38)

In other words, content evidence shows whether or not the content within the instrument is demonstrative of the intended concept to be measured (Gliner, Morgan, and Leech 2009, p. 166). In this research, the content validity of an engineering curriculum is being measured by comparing the overall percentage that each CEAB graduate attribute is taught and assessed in the whole program to the mean relative importance of the graduate attributes as determined by their engineering stakeholders, with the assumption that the more relatively important a graduate attribute is, the more 'representativeness' it should have in the curriculum, thereby establishing a measure of content relevance (Jonsson and Svingby 2007, p. 136).

The rationality of using the graduate attributes as the measure of an engineering program's content validity is due to the agreement by the IEA (2013), of which Canada is a signatory, that the graduate attributes represent the outcomes that one should expect an engineer graduate to have acquired in an accredited engineering program:

> *Graduate attributes* form a set of individually assessable outcomes that are the components indicative of the graduate's potential to acquire competence to practise at the appropriate level. The graduate attributes are exemplars of the attributes expected of a graduate from an accredited programme. Graduate attributes are clear, succinct statements of the expected capability, qualified if necessary by a range indication appropriate to the type of programme. (p. 2)

Consequently, it is relevant to use the CEAB graduate attributes, which CEAB accredited engineering programs are required to demonstrate that their engineering graduates possess: 'The higher education institution must demonstrate that the graduates of a program possess the attributes under the following headings. The attributes will be interpreted in the context of candidates at the time of graduation' (Engineers Canada 2014).

For this study, the researcher is relying on the professional judgment of relevant engineering stakeholders to determine the content of both engineering practice and an engineering program. As Messick (1987) explains:

> Content validity is based on *professional judgments* about the relevance of the test content to the content of a particular behavioral domain of interest and about the representativeness with which item or task content covers that domain. Content validity as such is not concerned with response processes, internal and external test structures, performance differences and responsiveness to treatment, or with social consequences. Thus, content validity provides *judgmental* evidence in support of the domain relevance and representativeness of the content of the test instrument, rather than evidence in support of inferences to be made from test scores. (p. 9) (Emphasis added.)

In the context of this study, the use of the word, 'test' in the above definition is replaced with the word, 'program' – thereby in this work the researcher is measuring the 'relevance of the program content' in an engineering curriculum.

Engineering faculty, senior students, and industry members have determined the relative importance of the CEAB graduate attributes for an EIT at the beginning of his/her career based on their professional judgment of the *frequency* of use of each attribute in practice, and the potential effect on workplace performance for Engineers-in-Training (EITs) at the beginning of their career if they do not have a sufficient level of competency for each graduate attribute (i.e. the *criticality*). Secondly, engineering faculty who teach in the Biosystems program that is being evaluated in this case used their professional judgment to ascertain the percentage of content and assessments that is apportioned for each of the graduate attributes taught and assessed in their courses. Additionally, the researcher corroborated with the Department Head of Biosystems Engineering and faculty members on the Faculty of Engineering Curriculum Management Committee who are responsible for collecting accreditation assessment data, to use professional judgment to ascertain these percentages in courses taught outside of the Department of Biosystems, but required in the program. Thereby, by these methods, the Biosystems Engineering curriculum was investigated to evaluate the content validity of the Biosystems Engineering program, and thus establish whether the CEAB graduate attributes are being emphasized in one engineering program to reflect their reported importance by key stakeholders.

Faculty teaching courses in the Biosystems Engineering program were asked to respond to a brief questionnaire to explore their judgment of what percentage of time they spend teaching and assessing the targeted graduate attributes in their course using the *Teaching Faculty Course Content Questionnaire* (Appendix E.3). Prior to collecting these data, both the Department Head and Associate Department Head of Biosystems piloted the questionnaire to evaluate face and content validity, and the researcher's committee members provided their feedback as well. The form went through several iterations as a result, including removing any information irrelevant to the objectives of the study, such as how long the instructor has taught the course, to adding specific details/examples of what was meant by the terminology used, such as, *course content*. The largest modification made altered how the instructors were asked about the graduate attributes in their courses. Rather than placing the onus on the instructors to list the graduate attributes that they taught and assessed in their courses, the researcher designed each questionnaire to list the targeted graduate attributes for each course based on accreditation documentation and the researcher's previous curriculum-mapping work in the Department of Biosystems. Faculty were asked to confirm if the list was correct; if not, they were asked to cross out any graduate attributes that were not associated with their course, or add any that were yet not listed. This was done in order to streamline and expedite the process for faculty, as the researcher was cognizant of how busy faculty are, and wanted to create a form that would encourage participation due to ease of use.

Following this, faculty was asked to judge what percentage of the content and what percentage of the course assessments was allocated for each of the graduate attributes listed. The final questionnaire was custom-designed for each core course in the Biosystems program. For example, here is the questionnaire for BIOE 2790:

1. Based on the Graduate Attribute table that was developed for BIOE 2790, these CEAB graduate attributes are taught and/or assessed in your course:

Graduate Attribute	**Weight**	**Level I/D/A**
A Knowledge Base for Engineering		I
Problem Analysis		I
Investigation		I

Is the list correct? Yes ______ No ______
(If no, please cross out any graduate attributes that are listed but aren't associated with your course and/or add any graduate attributes that are missing.)

2. In your judgment, when you consider the content covered in this course (i.e., through teaching, readings, homework, and other methods of course content delivery), approximately what percentage of the content is allocated for each of the graduate attributes listed in question 1?

Graduate Attribute	**Percentage of content coverage (where total does not exceed 100%)**
Total:	**</= 100%**

3. In your judgment, when you consider all of the assessment tools used in this course (i.e., any work that students will receive a mark/grade for, including lab reports, homework, tutorials, quizzes, tests, exams, projects, etc.), approximately what percentage of these assessments is allotted to each of the graduate attributes listed in question 1?

Graduate Attribute	**Percentage of assessments (where total does not exceed 100%)**
Total:	**</= 100%**

These data were collected from engineering faculty via email for the purposes of evaluating the content validity of the Biosystems program.

3.4.3 Program Documents

In addition to collecting course content and assessment data using the *Teaching Faculty Course Content Questionnaire* (Appendix E.3), data were gathered for Biosystems program courses from course syllabi that were available publicly on line, and course data that had been collected by the Faculty of Engineering for accreditation purposes. The accreditation documents were made available to the researcher through the Department Head of Biosystems Engineering and were anonymous (there was no information identifying students in these documents, including names, student numbers, etc.).

3.5 Data Analyses

Data analyses were designed specifically to answer the research questions (RQs) that guided the study. Research questions RQ 1.0 and RQ 2.0 guide Phase 1 of the study, and research questions RQ 3.0 guide Phase 2.

Phase 1:

RQ 1.0 Absolute and Relative Importance of the CEAB Graduate Attributes

RQ 1.1 What is the perceived absolute importance of each CEAB graduate attribute across all engineering stakeholders (i.e., students, faculty, and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 1.2 What is the perceived relative importance of each CEAB graduate attribute across all engineering stakeholders (i.e., students, faculty, and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 1.3 How much does the perceived absolute importance of each CEAB graduate attribute vary between each engineering stakeholder group (i.e., students vs. faculty vs. industry)?

RQ 1.4 How much does the perceived relative importance of each CEAB graduate attribute vary between each engineering stakeholder group (i.e., students vs. faculty vs. industry)?

RQ 2.0 CEAB Graduate Attribute Dependencies

RQ 2.1 What is the perceived dependency of each of the 12 CEAB graduate attributes on every other CEAB graduate attribute for all engineering stakeholders (i.e., students, faculty, and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 2.2 How much does the perceived dependency of each CEAB graduate attribute on every other CEAB graduate attribute vary between engineering stakeholder groups (i.e., students vs. faculty vs. industry)?

RQ 2.3 How do the perceived similarities of the CEAB graduate attributes cluster together across all engineering stakeholders?

Phase 2:

RQ 3.0 Program Content Validity

RQ 3.1 For each CEAB graduate attribute, how similar are the percentages of course content coverage to the percentages of course assessments in the Biosystems engineering program?

RQ 3.2 In the Biosystems engineering program, how do the percentages of course content coverage and course assessments of the CEAB graduate attributes compare with their perceived relative importance by all engineering stakeholders?

3.5.1 Phase 1 Data Analyses – Relative Importance and Graduate Attribute Dependencies

Data were collected either online through SurveyMonkey or in a Word document via email. The researcher manually entered questionnaire data that were received on Word documents into SurveyMonkey. Data were then exported into Excel files, and cleaned. Once cleaned, data were exported into SPSS, which was used to calculate all descriptive and inferential statistics.

3.5.1.1 Relative Importance Data Analyses

Engineering stakeholder data were collected on the perceived frequency of a graduate attribute in engineering practice (i.e., how often an Engineer-in-Training (EIT) at the beginning of his/her career will perform a task that clearly requires a graduate attribute) and the perceived criticality of a graduate attribute (i.e., the potential effect on workplace performance for an EIT at the beginning of his/her career if he/she does not have a sufficient level of competency for this graduate attribute). The mean perceived absolute importance of each graduate attribute for all stakeholders collectively, and for each stakeholder group individually (i.e., student, faculty, and industry) was calculated by multiplying the frequency and the criticality data, i.e., $I_i = F_iC_i$ (Renaud, Forthcoming; Stutsky, Singer, and Renaud 2012) (RQ 1.1). The mean percentage of each graduate attribute's absolute importance to the total absolute importance of all graduate attributes was computed to develop an index of relative importance (Stutsky, Singer, and Renaud 2012, p. 4) (RQ 1.2). Absolute importance data were compared using a one-way analysis of variance (ANOVA) to determine if the perceived absolute importance of each CEAB graduate attribute varied between engineering stakeholder groups, and post-hoc t-tests were conducted to discern which groups differed significantly (RQ 1.3). The relative importance data for each graduate attribute for each stakeholder group was compared (RQ 1.4). See Appendix G.1 for a summary of the analyses methods for the absolute and relative importance data.

3.5.1.2 Dependency Data Analyses

In Phase 1 of the study, data were also collected on the dependencies of the graduate attributes. Similar to the relative importance data, both descriptive and inferential statistics were used to analyze these data. Firstly, the mean dependency for each pair of graduate attributes was calculated for all engineering stakeholders, and then individually for student, faculty, and industry stakeholders to determine the perceived dependency of each of the 12 CEAB graduate attributes on every other CEAB graduate attribute for all engineering stakeholders (research RQ 3.1). These data are presented in tables illustrating one-way dependencies of each graduate attribute pair (see Chapter 4, Section 4.1.2 *Graduate Attribute Dependencies*).

Next, data were analyzed to evaluate how much the pattern of perceived dependencies of the CEAB graduate attributes varied between engineering stakeholder groups (i.e., the relative variation) (RQ 2.2). The dependencies of each stakeholder group were each arranged in a column vector of 132 unique values (i.e., 12 graduate attributes each paired with 11 other graduate attributes; like pairs were omitted). To measure the similarity of the patterns of the dependencies, a Pearson two-tailed correlation between the dependency ratings for each pair of stakeholder groups (i.e., student-faculty, student-industry, faculty-industry) was performed. It is important to note that correlations show only the similarity of the profiles between the stakeholder groups, and not how close the profiles are. To measure how close the profiles are, the sum of square differences was calculated for each group and the root mean square was derived to evaluate how close the dependencies were for each pair of stakeholders. These findings were used to determine which stakeholder group would be used for analysis for RQ 2.3.

To answer RQ 2.3 – *How do the CEAB graduate attributes cluster together based on the engineering stakeholders' perceived dependencies?* – data were analyzed using Multidimensional Scaling (MDS). MDS offers a visual representation of proximity data – or 'measures of similarity, closeness, or relatedness etc.' – indicated in a multidimensional space as the distances between points (Borg, Groenen, and Mair 2013, p. 6) (i.e., the closer the points are in space, the higher the similarity between those points). MDS was chosen in order to explore the similarities in the dependencies of the pairs of CEAB graduate attributes, and if and how the graduate attributes cluster in the multidimensional space. To do this, the mean for each pair of graduate attribute dependencies and each opposing pair of graduate attribute dependencies was calculated for all stakeholder groups (i.e., (A→B + B→A)/2 = MEAN) to derive similarity values. All stakeholder groups (i.e., the collective of all three stakeholder groups) were chosen as the unit for analysis as opposed to selecting one or more of the individual engineering stakeholder groups (i.e., student, faculty, or industry), due to the findings from the analysis of variation of pattern of perceived dependencies (RQ 2.2) that there was little relative or absolute variation between the stakeholder groups. Once the values of similarities were calculated, an upper triangular matrix was created to prepare for MDS analysis (see Table 3.12).

Table 3.12
Upper triangular matrix of mean similarity values of engineering stakeholders' perceived graduate attribute dependency ratings for MDS analysis.

KB	PA	IN	DE	ET	IT	CS	PR	IE	EE	EP	LL
.00	75.15	70.05	72.85	68.70	53.60	52.40	50.05	60.55	49.20	55.00	68.15
	.00	78.00	71.45	66.20	60.10	57.25	45.70	60.90	49.50	61.30	61.80
		.00	65.05	63.60	58.35	60.25	49.45	60.75	50.55	56.65	60.65
			.00	71.15	65.05	60.00	53.55	67.90	57.50	66.15	61.60
				.00	49.90	44.75	42.65	48.75	40.20	55.10	64.70
					.00	84.30	79.55	51.25	65.50	68.30	61.55
						.00	78.15	50.35	61.60	64.35	62.00
							.00	67.15	79.55	66.90	65.65
								.00	77.65	61.90	61.05
									.00	60.70	61.65
										.00	58.10
											.00

Note. KB=Knowledge Base for Engineering; PA=Problem Analysis; IN=Investigation; DE=Design; ET=Use of Engineering Tools; IT=Individual and Teamwork; CS=Communication Skills; PR=Professionalism; IE=Impact of Engineering; EE=Ethics and Equity; EP=Economics and Project Management; LL=Lifelong Learning.

The inspection of the resulting scree plot indicated a 2-dimensional solution. (See Appendix G.2 for a summary of the dependencies data analyses methods.)

3.5.2 Phase 2 Data Analyses – Biosystems Engineering Program Content Validity

For Phase 2 of the study, the total percentage of course content coverage and the total percentage of course assessments for every graduate attribute targeted in each core course (N=35) in the Biosystems Engineering program were collected, and then the overall percentages of each were calculated for the program. (i.e., the total sum that each graduate attribute was taught and assessed for each course, multiplied by 100, divided by 3500 (i.e., 35 courses multiplied by 100% each). The data for course content coverage were compared to the data for course assessments to evaluate how similar they are. These data were then compared with the mean perceived relative importance findings of the graduate attributes for all engineering stakeholders to evaluate the content validity of the Biosystems engineering program.

3.6 Addressing Study Quality

Direct assessments (quantitative) should have some degree of reliability, internal, and external validity, objectivity and rigor (Leydens, Moskal, and Pavelich 2004). Several measures were put in place to address study quality, including piloting measures; achieving a 50% participation rate for all stakeholder groups in Phase 1, and a 100% participation rate for all Biosystems faculty in Phase 2; spot-checking manual entries and data for accuracy; and explaining how data were cleaned and missing data were handled.

3.7 Research Ethics Board and University Approval

This study was considered 'minimal risk.' Before implementation, ethics approval was granted through the Education and Nursing Research Ethics Board (ENREB) that governs educational research activity involving human participants for the Fort Gary campus at the

University of Manitoba. In total, three data collection methods were used for the study. All of these undertakings were governed by the ethical regulations and principles of ENREB. All participants were informed of the purpose and context of the study, and the motivations of the researcher. They were provided with detailed descriptions of the research through recruitment and consent letters, and research measures. Participation for all stakeholders was optional and confidential. Participants were asked to give their informed consent before participating. They were assured of confidentiality, provided descriptions of how confidentiality would be upheld, informed that their decision to either participate or not would have no consequences, either positive or negative, on them or their status in the faculty, and that they could withdraw from the study at any time without penalty or consequence. Data from the questionnaire were anonymous, as participants were asked to refrain from identifying themselves on the Word documents, and SurveyMonkey was adjusted so that the IP addresses of electronic questionnaire participants were not captured (Seniuk Cicek, Ingram, Mann, and Renaud 2017).

Participants were given the contact information of the researcher, and invited to contact the researcher with any questions or concerns regarding the study, or with a request to receive a data summary of the findings. They were also given the contact information for the Human Ethics coordinator at the University of Manitoba, and assured that the research had been approved and that ENREB and the University of Manitoba could look into the research to see that it was being conducted in a safe and proper way.

Additionally, permission to University of Manitoba faculty and students was sought from, and approved by, the Office of Institutional Analysis at the University of Manitoba, and from the Dean of Engineering (Seniuk Cicek, Ingram, Mann, and Renaud

2017). Approval certificates and Letters of Consent are included in Appendices E and G, respectively.

3.8 Timing and Length of Study

Ethics approval was granted in September 2015. The *Relative Importance and Graduate Attribute Dependencies Ratings Form* (Appendix E.1) was piloted (Appendix E.2) between September 2015 and November 2015. The form was disseminated and the majority of data for Phase 1 were collected from December 2015 – January 2016. The *Teaching Faculty Course Content Questionnaire* (Appendix E.3) was piloted between June 2017 and July 2017. The questionnaire was disseminated and data were collected for Phase 2 of the study from September 2017 – December 2017. Course syllabi and accreditation documents were collected in September 2017. Data were analyzed between May 2017 and December 2017 (see Table 3.13).

Table 3.13
Timeline for research activities.

Research Measure	Research Activity	Date
ENREB	Approval	Sept 2015
Relative Importance and Graduate Attribute Dependencies Ratings Form	Piloted	Sept 2015 – Nov 2015
Relative Importance and Graduate Attribute Dependencies Ratings Form	Data collection	Nov 2015 – Jan 2016
Teaching Faculty Course Content Questionnaire	Piloted	June 2017 – July 2017
Teaching Faculty Course Content Questionnaire	Data collection	Sept 2017 – Dec 2017
Course syllabi and accreditation Documents	Data collection	Sept 2017
Data Analysis	Analyze data	May 2017 – Dec 2017

The extended length between the collection of the *Relative Importance and Graduate Attribute Dependencies Ratings Form*, the collection of the *Teaching Faculty Course Content Questionnaire,* and the data analysis stage was not an intentional part of the research design, and is not representative of the time required to execute this study if it were to be recreated. This period is rather a reflection of time away from the study, when the researcher was awarded the opportunity to teach Engineering Communications courses full-time in the Faculty of Engineering at the University of Manitoba to fill the position of a faculty member who was on academic leave.

Chapter Summary

This chapter framed this exploratory case study by explaining the research design, methodology and epistemological perspective, and the research site. This was followed by the presentation of the research participants, research measures, and data analyses processes. Finally, the quality, the research ethical considerations, and the timing and length of the study were described. Chapter Four presents the findings.

Chapter Four: Findings

This chapter presents the findings from Phase 1 and Phase 2 of the study. Phase 1 findings indicate the mean absolute and relative importance of the CEAB graduate attributes as perceived by all engineering stakeholder groups in this case (student, faculty, and industry) collectively and individually. A comparative view of the mean absolute and relative importance between stakeholder groups is then offered. This is ensued by the presentation of the perceived dependencies of CEAB graduate attributes across all engineering stakeholder groups, and for each student, faculty, and industry stakeholder group distinctly. Following, the relative and absolute variation in the patterns of perceived dependencies of the CEAB graduate attributes across engineering stakeholder groups are determined, and how the graduate attributes interrelate and cluster in perceptual space are explored.

Phase 2 examines the percentages of course content coverage and course assessments of the CEAB graduate attributes in the Biosystems Engineering program. These data are then compared to the mean relative importance of the graduate attributes as perceived by all engineering stakeholders, and the content validity of the Biosystems Engineering program is evaluated.

4.1 Phase 1

The following section will be a presentation on the data from Phase 1 of the study as collected from the *Relative Importance and Graduate Attribute Dependencies Ratings Form.* Findings will be organized into two parts: the mean absolute and relative importance of the CEAB graduate attributes; and the dependencies of the CEAB graduate attributes. It is important to note that each of these sections of the form had different participation rates, as discussed in Section 3.3.5 *Participation Rates for the Relative Importance and Graduate Attribute Dependencies Ratings Form*.

4.1.1 Absolute and Relative Importance of CEAB Graduate Attributes

Following the demographic information, participants were asked to rate the frequency and criticality of the CEAB graduate attributes on a 5-point scale. The following section reports on the perceived frequency, criticality, absolute importance, and relative importance of the CEAB graduate attributes from the collective perspective of all three engineering stakeholder groups associated with the Faculty of Engineering at the University of Manitoba, and from each individual stakeholder group. The section is organized by these four research questions:

RQ 1.1 What is the perceived absolute importance of each CEAB graduate attribute across all engineering stakeholders (i.e., students, faculty and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 1.2 What is the perceived relative importance of each CEAB graduate attribute across all engineering stakeholders (i.e., students, faculty and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 1.3 How much does the perceived absolute importance of each CEAB graduate attribute vary between each engineering stakeholder group (i.e., students vs. faculty vs. industry)?

RQ 1.4 How much does the perceived relative importance of each CEAB graduate attribute vary between each engineering stakeholder group (i.e., students vs. faculty vs. industry)?

4.1.1.1 Perceived Absolute and Relative Importance of CEAB Graduate Attributes Across All Engineering Stakeholder Groups

For all engineering stakeholders in this case (i.e., students, faculty, and industry) (N=207), the mean perceived absolute importance of the graduate attributes ranged from 9.0 – 16.0 with a mean of 12.3. In mean absolute terms, the graduate attribute, Economics and Project Management was perceived as the least important, and Individual and Teamwork as the most important. The mean relative importance ranged from 6.1% - 10.9% (see Table 4.1).

Table 4.1
Mean absolute and relative importance of the CEAB graduate attributes across all stakeholders (N=207).

CEAB Graduate Attribute	Frequency (F) M(SD)	Criticality (C) M(SD)	Absolute Importance (F*C) M(SD)	Relative Importance (% of absolute importance)
Knowledge Base	3.8 (1.0)	3.5 (0.9)	13.4 (5.5)	9.1%
Problem Analysis	3.7 (1.0)	3.5 (0.9)	13.3 (6.1)	9.0%
Investigation	3.1 (1.1)	3.2 (1.0)	10.7 (6.0)	7.2%
Design	2.9 (1.1)	3.3 (1.0)	10.3 (6.1)	7.0%
Eng. Tools	3.6 (1.0)	3.3 (0.9)	12.2 (5.6)	8.3%
Ind. & Teamwork	4.3 (0.9)	3.6 (0.9)	16.1 (5.8)	10.9%
Communication	4.3 (0.9)	3.7 (0.9)	15.9 (5.8)	10.8%
Professionalism	3.8 (1.2)	3.5 (1.0)	13.9 (6.9)	9.4%
Impact of Eng.	2.7 (1.2)	3.2 (1.1)	9.3 (6.2)	6.3%
Ethics & Equity	3.4 (1.3)	3.6 (1.1)	13.0 (7.3)	8.8%
Eco. & Proj. Mngt.	2.8 (1.0)	3.1 (0.9)	9.0 (5.0)	6.1%
Lifelong Learning	3.2 (1.2)	3.1 (1.1)	10.5 (6.7)	7.1%

4.1.1.2 Perceived Absolute and Relative Importance of CEAB Graduate Attributes for Each Engineering Stakeholder Group

For engineering student stakeholders in this case (N=116), the mean perceived absolute importance of the graduate attributes ranged from 9.8 – 16.9 with a mean of 13.6. In mean absolute terms, the graduate attribute, Economics and Project Management was perceived as the least important, and Individual and Teamwork as the most important. The mean relative importance of the CEAB graduate attributes for students ranged from 6.0% - 10.4% (see Table 4.2).

Table 4.2
Mean absolute and relative importance of the CEAB graduate attributes for student stakeholders (N=116).

CEAB Graduate Attribute	Frequency (F) M(SD)	Criticality (C) M(SD)	Absolute Importance (F*C) M(SD)	Relative Importance (% of absolute importance)
Knowledge Base	3.7 (1.0)	3.5 (0.9)	13.6 (5.8)	8.4%
Problem Analysis	3.9 (1.0)	3.6 (1.0)	14.5 (6.2)	8.9%
Investigation	3.3 (1.1)	3.4 (1.0)	11.9 (6.2)	7.3%
Design	3.2 (1.1)	3.4 (1.0)	11.4 (6.4)	7.0%
Eng. Tools	3.7 (0.9)	3.4 (1.0)	13.0 (6.2)	8.0%
Ind. & Teamwork	4.5 (0.8)	3.7 (1.0)	16.9 (6.3)	10.4%
Communication	4.4 (0.9)	3.8 (1.0)	16.8 (6.1)	10.3%
Professionalism	4.3 (0.9)	3.7 (1.1)	16.1 (6.6)	9.9%
Impact of Eng.	3.1 (1.1)	3.4 (1.1)	11.2 (6.3)	6.9%
Ethics & Equity	3.8 (1.2)	3.8 (1.2)	15.2 (7.3)	9.3%
Eco. & Proj. Mngt.	3.0 (1.0)	3.2 (0.9)	9.8 (4.9)	6.0%
Lifelong Learning	3.7 (1.1)	3.2 (1.1)	12.2 (6.8)	7.5%

For engineering faculty stakeholders in this case (N=44), the mean perceived absolute importance of the graduate attributes ranged from 7.1 – 15.0 with a mean of 11.1. In mean absolute terms, the graduate attribute, Impact of Engineering on Society and the Environment was perceived as the least important, and Communication Skills as the most important. The mean relative importance of the CEAB graduate attributes for faculty ranged from 5.3% - 11.3%, with Communication Skills rated over two times as relatively important (113.2% higher) as Impact of Engineering on Society and the Environment (see Table 4.3).

Table 4.3
Mean absolute and relative importance of the CEAB graduate attributes for faculty stakeholders (N=44).

CEAB Graduate Attribute	Frequency (F) M(SD)	Criticality (C) M(SD)	Absolute Importance (F*C) M(SD)	Relative Importance (% of absolute importance)
Knowledge Base	4.0 (1.0)	3.5 (1.0)	14.3 (5.5)	10.8%
Problem Analysis	3.5 (1.1)	3.5 (1.0)	12.5 (5.4)	9.4%
Investigation	3.1 (1.1)	3.3 (1.0)	10.4 (5.6)	7.8%
Design	2.7 (1.1)	3.2 (1.2)	9.2 (5.7)	6.9%
Eng. Tools	3.4 (1.2)	3.3 (0.9)	11.3 (5.1)	8.5%
Ind. & Teamwork	4.1 (1.1)	3.5 (0.9)	14.5 (5.4)	10.9%
Communication	4.1 (1.1)	3.6 (0.9)	15.0 (5.4)	11.3%
Professionalism	3.3 (1.3)	3.3 (1.0)	11.3 (6.4)	8.5%
Impact of Eng.	2.2 (1.0)	3.0 (1.1)	7.1 (5.1)	5.3%
Ethics & Equity	3.0 (1.3)	3.5 (1.1)	11.2 (7.0)	8.4%
Eco. & Proj. Mngt.	2.5 (1.0)	3.0 (0.9)	7.7 (4.2)	5.8%
Lifelong Learning	2.7 (1.2)	2.9 (1.1)	8.5 (6.1)	6.4%

For engineering industry member stakeholders in this case (N=47), the mean perceived absolute importance of the graduate attributes ranged from 6.7 – 15.5, with a mean of 10. 4. In mean absolute terms, the graduate attribute, Impact of Engineering on Society and the Environment was perceived as the least important, and Individual and Teamwork as the most important. The mean relative importance of the CEAB graduate attributes for industry ranged from 5.4% - 12.5%. The highest relative importance rating was for Individual and Teamwork, which was over two times as relatively more important as Impact of Engineering on Society and the Environment (129.6% higher) (see Table 4.4).

Table 4.4
Mean absolute and relative importance of the CEAB graduate attributes for industry stakeholders (N=47).

CEAB Graduate Attribute	Frequency (F) M(SD)	Criticality (C) M(SD)	Absolute Importance (F*C) M(SD)	Relative Importance (% of absolute importance)
Knowledge Base	3.7 (1.0)	3.2 (0.8)	12.1 (4.6)	9.7%
Problem Analysis	3.4 (1.1)	3.1 (0.9)	11.0 (5.6)	8.8%
Investigation	2.7 (1.2)	2.7 (1.0)	7.9 (4.9)	6.4%
Design	2.6 (1.2)	3.0 (0.9)	8.6 (5.4)	6.9%
Eng. Tools	3.6 (1.0)	3.1 (0.7)	11.3 (4.5)	9.1%
Ind. & Teamwork	4.3 (0.8)	3.6 (0.6)	15.5 (4.4)	12.5%
Communication	4.1 (1.0)	3.5 (0.7)	14.6 (5.2)	11.7%
Professionalism	3.2 (1.3)	3.2 (0.9)	10.8 (6.1)	8.7%
Impact of Eng.	2.2 (1.2)	2.8 (1.0)	6.7 (5.3)	5.4%
Ethics & Equity	2.7 (1.3)	3.3 (0.9)	9.5 (5.8)	7.6%
Eco. & Proj. Mngt.	2.6 (1.2)	2.9 (0.9)	8.1 (5.6)	6.5%
Lifelong Learning	2.7 (1.1)	2.9 (1.0)	8.3 (5.7)	6.7%

4.1.1.3 Comparative View of the Absolute and Relative Importance of CEAB Graduate Attributes Between Engineering Stakeholder Groups

This section is guided by the research questions RQ 1.3 and RQ 1.4 – *How much does the perceived absolute importance and the perceived relative importance of each CEAB graduate attribute vary between each engineering stakeholder group?*

Student stakeholders rated the absolute importance of Problem Analysis ($F(2, 204)=6.36$, $p=.001$) and Communication Skills ($F(2, 204)=3.30$, $p=.024$) as significantly more important than industry stakeholders. Student stakeholders rated Individual and Teamwork as significantly more important than faculty stakeholders ($F(2, 204)=3.12$, $p=.019$). Student stakeholders rated the following graduate attributes as significantly more important than both faculty and industry stakeholders (significance reported for faculty and industry respectively): Design ($F(2, 204)=4.70$, $p=.035$); ($F(2, 204)=4.70$, $p=.007$);

Professionalism (F(2, 204)=16.11, p<.001); (F(2, 204)=16.11, p<.001); Impact of Engineering on Society and the Environment (F(2, 204)=14.02, p<.001); (F(2, 204)=14.02, p<.001); Ethics and Equity (F(2, 204)=13.15, p=.001); (F(2, 204)=13.15, p<.001); Economics and Project Management (F(2, 204)=4.09, p=.013); (F(2, 204)=4.09, p=.043); and Lifelong Learning (F(2, 204)=9.27, p=.001); (F(2, 204)=9.27, p<.001). Both student stakeholders (F(2, 204)=7.99, p<.001) and faculty stakeholders (F(2, 204)=7.99, p=.046) rated Investigation as significantly more important than industry stakeholders. Only Knowledge Base for Engineering and Use of Engineering Tools had no significant differences in their importance ratings between stakeholders (see Table 4.5).

Table 4.5
Comparative view of mean absolute importance of the CEAB graduate attributes for all engineering stakeholders (N=207).

CEAB Graduate Attribute	Students M(SD)	Faculty M(SD)	Industry M(SD)
Knowledge Base	13.6 (5.8)	14.3 (5.5)	12.1 (4.6)
Problem Analysis	14.5 (6.2)^{a}	12.5 (5.4)^{ab}	11.0 (5.6)^{b}
Investigation	11.9 (6.2)^{a}	10.4 (5.6)^{a}	7.9 (4.9)^{b}
Design	11.4 (6.4)^{a}	9.2 (5.7)^{b}	8.6 (5.4)^{b}
Eng. Tools	13.0 (6.2)	11.3 (5.1)	11.3 (4.5)
Ind. & Teamwork	16.9 (6.3)^{a}	14.5 (5.4)^{b}	15.5 (4.4)^{ab}
Communication	16.8 (6.1)^{a}	15.0 (5.4)^{ab}	14.6 (5.2)^{b}
Professionalism	16.1 (6.6)^{a}	11.3 (6.4)^{b}	10.8 (6.1)^{b}
Impact of Eng.	11.2 (6.3)^{a}	7.1 (5.1)^{b}	6.7 (5.3)^{b}
Ethics & Equity	15.2 (7.3)^{a}	11.2 (7.0)^{b}	9.5 (5.8)^{b}
Eco. & Proj. Mngt.	9.8 (4.9)^{a}	7.7 (4.2)^{b}	8.1 (5.6)^{b}
Lifelong Learning	12.2 (6.8)^{a}	8.5 (6.1)^{b}	8.3 (5.7)^{b}

Note. Means with the same superscript or no superscript do not differ significantly. Means with a different superscript differ significantly (p<.05).

Overall, student stakeholders rated all graduate attributes except for Knowledge Base for Engineering as more important than both faculty and industry stakeholders. Faculty stakeholders rated Knowledge Base for Engineering as more important than student stakeholders; industry rated this attribute as less important than both other stakeholder groups. Industry rated all attributes as less important than faculty with the exception of Engineering Tools, which was rated of equal importance, and Individual and Teamwork and Economics and Project Management, which were both rated as more important than faculty ratings. Although not all of these ratings are of significance, the general trend is for students to rate the graduate attributes as more important than the faculty and industry stakeholder groups, and for industry stakeholders to rate the graduate attributes as less important than student and faculty stakeholder groups.

The largest relative importance value derived from the data was ascribed by industry for the attribute, Individual and Teamwork. Students also rated this attribute with the highest relative importance out of all the graduate attributes. Individual and Teamwork was followed by Communication skills for second largest rating, which was rated with the highest relative importance by faculty, and rated as having the second largest importance by both industry and students. Faculty and industry attributed the least relative importance to Impact of Engineering on Society and the Environment. Students attributed the least relative importance to Economics and Project Management (which also had a comparatively lower relative importance for faculty and industry) (see Table 4.6).

Table 4.6
Comparative view of mean relative importance of the CEAB graduate attributes for all engineering stakeholders (N=207).

CEAB Graduate Attribute	**Students**	**Faculty**	**Industry**
Knowledge Base	8.4%	10.8%	9.7%
Problem Analysis	8.9%	9.4%	8.8%
Investigation	7.3%	7.8%	6.4%
Design	7.0%	6.9%	6.9%
Eng. Tools	8.0%	8.5%	9.1%
Ind. & Teamwork	10.4%	10.9%	12.5%
Communication	10.3%	11.3%	11.7%
Professionalism	9.9%	8.5%	8.7%
Impact of Eng.	6.9%	5.3%	5.4%
Ethics & Equity	9.3%	8.4%	7.6%
Eco. & Proj. Mngt.	6.0%	5.8%	6.5%
Lifelong Learning	7.5%	6.4%	6.7%

When interpreting the importance ratings of the CEAB graduate attributes among student, faculty, and industry stakeholders, roughly three groups of low, medium, and high importance ratings can be construed to aid interpretation. All stakeholders rated Individual and Teamwork and Communication Skills in a top group of importance; Professionalism, A Knowledge Base for Engineering, Problem Analysis, Ethics and Equity, and Use of Engineering Tools could be considered in a second group of importance; and Investigation, Lifelong Learning, Design, Impact of Engineering on Society and the Environment, and Economics and Project Management in a third group of importance. Even though the order changes slightly for each individual stakeholder group, the composition of the low, medium and high groups of importance do not; these three groups are found across all, and for each individual (i.e., student, faculty, and industry) engineering stakeholder group. (see Table 4.7).

Table 4.7
Comparative view of the ranked order of mean importance of the CEAB graduate attributes for all engineering stakeholders (N=207).

Groups of Importance	Students	Faculty	Industry
1	Ind. & Teamwork	Communication	Ind. & Teamwork
1	Communication	Ind. & Teamwork	Communication
2	Professionalism	Knowledge Base	Knowledge Base
2	Ethics & Equity	Problem Analysis	Eng. Tools
2	Problem Analysis	Eng. Tools	Problem Analysis
2	Knowledge Base	Professionalism	Professionalism
2	Eng. Tools	Ethics & Equity	Ethics & Equity
3	Lifelong Learning	Investigation	Design
3	Investigation	Design	Lifelong Learning
3	Design	Lifelong Learning	Eco. & Proj. Mngt.
3	Impact of Eng.	Eco. & Proj. Mngt.	Investigation
3	Eco. & Proj. Mngt.	Impact of Eng.	Impact of Eng.

4.1.2 Graduate Attribute Dependencies

Participants were asked to rate the dependency of one CEAB graduate attribute on another CEAB graduate attribute for an EIT at the beginning of her/his career. The following section reports on the CEAB graduate attribute dependencies from the holistic perspective of all engineering stakeholders associated with the Faculty of Engineering at the University of Manitoba in this case, as well as from the perspectives of each individual stakeholder groups, i.e., students, faculty, and industry members. The findings are organized by these research questions:

RQ 2.1 What is the perceived dependency of each of the 12 CEAB graduate attributes on every other CEAB graduate attribute for all engineering stakeholders (i.e., students, faculty and industry) in the Faculty of Engineering at the University of Manitoba?

RQ 2.2 How much does the pattern of perceived dependencies of the CEAB graduate attributes vary between engineering stakeholder groups (i.e., students vs. faculty vs. industry)?

RQ 2.3 How do the perceived similarities of the CEAB graduate attributes cluster together across all engineering stakeholders?

4.1.2.1 Perceived Dependencies of CEAB Graduate Attributes Across All Engineering Stakeholder Groups

For all engineering stakeholders in this case (N=162), the mean perceived dependencies of the CEAB graduate attributes ranged from 40.1% - 88.7% with a mean of 61.4%, with Ethics and Equity having the lowest dependency on Use of Engineering Tools, and Individual and Teamwork having the highest dependency on Communication Skills (see Table 4.8).

Table 4.8
Mean perceived dependency of one CEAB graduate attribute on another CEAB graduate attribute across all engineering stakeholders (N=162).

➔	KB	PA	IN	DE	ET	IT	CS	PR	IE	EE	EP	LL
KB	100% (0.0)	67.4% (27.7)	61.7% (27.6)	58.8% (31.8)	61.6% (28.8)	57.7% (33.2)	54.0% (32.1)	48.9% (33.8)	50.6% (31.8)	49.2% (33.5)	46.6% (29.4)	66.2% (30.5)
PA	82.9% (20.9)	100% (0.0)	77.5% (23.0)	59.6% (30.8)	69.3% (24.8)	65.0% (29.0)	60.5% (29.6)	46.3% (32.6)	55.4% (30.0)	51.5% (33.3)	52.5% (29.5)	58.2% (30.8)
IN	78.4% (24.1)	78.5% (22.1)	100% (0.0)	56.2% (29.4)	66.2% (25.0)	61.3% (29.6)	65.7% (30.3)	53.2% (31.8)	52.8% (30.7)	50.9% (32.8)	50.5% (28.8)	56.0% (30.2)
DE	86.9% (18.9)	83.3% (19.7)	73.9% (26.2)	100% (0.0)	79.3% (22.0)	73.9% (23.4)	70.8% (26.8)	61.1% (30.8)	70.1% (27.7)	64.5% (31.0)	67.6% (28.8)	64.2% (28.4)
ET	75.8% (22.2)	63.1% (25.7)	61.0% (27.2)	63.0% (30.9)	100% (0.0)	49.5% (30.6)	45.2% (30.7)	43.2% (31.8)	42.6% (29.6)	40.3% (32.5)	47.5% (30.4)	64.0% (29.2)
IT	49.5% (32.7)	55.2% (30.5)	55.4% (30.1)	56.2% (33.1)	50.3% (29.4)	100% (0.0)	88.7% (18.5)	82.9% (22.0)	50.0% (29.8)	69.6% (26.5)	61.1% (30.7)	58.6% (31.8)
CS	50.8% (31.2)	54.0% (30.1)	54.8% (32.7)	49.2% (33.5)	44.3% (29.9)	79.9% (26.0)	100% (0.0)	76.1% (27.8)	44.4% (31.0)	58.5% (31.8)	49.8% (33.7)	58.6% (31.6)
PR	51.2% (33.6)	45.1% (33.4)	45.7% (35.2)	46.0% (34.9)	42.1% (34.9)	76.2% (31.1)	80.2% (27.4)	100% (0.0)	68.1% (29.7)	79.2% (25.7)	59.4% (32.3)	62.0% (30.8)
IE	70.5% (26.4)	66.4% (27.8)	68.7% (28.0)	65.7% (30.0)	54.9% (28.5)	52.5% (31.9)	56.3% (33.1)	66.2% (31.8)	100% (0.0)	79.5% (24.8)	60.8% (30.9)	60.8% (30.8)
EE	49.2% (33.0)	47.5% (33.7)	50.2% (34.1)	50.5% (35.2)	40.1% (34.2)	61.4% (33.0)	64.7% (31.2)	79.9% (27.6)	75.8% (29.5)	100% (0.0)	55.2% (33.4)	60.0% (31.9)
EP	63.4% (26.5)	70.1% (27.0)	62.8% (30.4)	64.7% (28.5)	62.7% (26.8)	75.5% (27.2)	78.9% (25.9)	74.4% (27.2)	63.0% (29.1)	66.2% (29.6)	100% (0.0)	63.0% (30.0)
LL	70.1% (29.9)	65.4% (29.6)	65.3% (29.8)	59.0% (32.1)	65.4% (31.8)	64.5% (31.9)	65.4% (31.8)	69.3% (31.3)	61.3% (33.4)	63.3% (32.2)	53.2% (33.2)	100% (0.0)

Note. 1. Standard deviations in brackets. 2. KB=Knowledge Base for Engineering; PA=Problem Analysis; IN=Investigation; DE=Design; ET=Use of Engineering Tools; IT=Individual and Teamwork; CS=Communication Skills; PR=Professionalism; IE=Impact of Engineering; EE=Ethics and Equity; EP=Economics and Project Management; LL=Lifelong Learning. 3. This table depicts one-way dependencies. The values in each cell represent the dependency the graduate attribute in the column on the left has on the graduate attribute in the row across the top. For example, the dependency of KB on PA is 67.4%, whereas the dependency of PA on KB is 82.9%. 4. Lowest and highest dependency score are highlighted.

4.1.2.2 Perceived Dependencies of CEAB Graduate Attributes for Each Engineering Stakeholder Group

For engineering student stakeholders in this case (N=93), the perceived dependencies of the CEAB graduate attributes ranged from 44.6% for Professionalism on Problem Analysis to 89.0% for Individual and Teamwork on Communication Skills, with a mean of 65.4% and a standard deviation of 10.8 (see Table 4.9).

Table 4.9
Mean perceived dependency of one CEAB graduate attribute on another CEAB graduate attribute for student stakeholders (N=93).

➔	KB	PA	IN	DE	ET	IT	CS	PR	IE	EE	EP	LL
KB	100% (0.0)	71.2% (25.0)	68.3% (24.8)	66.9% (28.8)	69.1% (24.8)	67.7% (31.4)	61.3% (32.7)	57.8% (34.0)	56.2% (29.4)	57.3% (31.6)	53.2% (28.6)	69.9% (28.2)
PA	81.5% (23.0)	100% (0.0)	79.0% (21.6)	63.4% (32.9)	70.2% (24.8)	71.2% (28.1)	66.1% (29.4)	52.7% (34.5)	61.3% (29.1)	58.9% (32.7)	55.4% (29.7)	63.4% (28.9)
IN	77.2% (25.7)	79.0% (22.8)	100% (0.0)	61.0% (29.6)	67.7% (25.4)	65.3% (30.2)	69.6% (30.1)	57.3% (31.6)	58.3% (29.8)	54.0% (33.0)	53.2% (29.3)	61.0% (28.7)
DE	88.4% (19.0)	84.9% (20.6)	77.7% (24.9)	100% (0.0)	82.0% (21.6)	78.8% (21.8)	76.9% (24.8)	64.5% (30.0)	75.0% (25.8)	71.0% (30.7)	72.8% (28.0)	69.9% (26.5)
ET	77.7% (21.3)	64.5% (26.9)	64.0% (27.0)	69.1% (29.8)	100% (0.0)	53.0% (30.8)	47.3% (33.3)	47.6% (33.6)	48.1% (30.4)	45.2% (33.6)	55.1% (30.3)	66.9% (29.3)
IT	51.3% (32.8)	58.3% (31.1)	57.3% (29.9)	59.4% (33.2)	54.3% (29.9)	100% (0.0)	89.0% (19.3)	86.6% (21.0)	52.4% (31.5)	71.2% (26.8)	66.7% (28.4)	65.9% (30.1)
CS	50.3% (29.8)	57.8% (29.3)	58.1% (31.7)	53.5% (36.0)	46.0% (30.5)	84.7% (22.4)	100% (0.0)	83.1% (24.8)	46.8% (30.9)	59.9% (31.1)	55.1% (33.7)	64.5% (31.6)
PR	50.8% (34.0)	44.6% (35.3)	46.5% (37.0)	48.4% (36.6)	47.0% (37.7)	83.1% (27.6)	86.8% (21.4)	100% (0.0)	70.2% (28.6)	78.8% (27.1)	68.0% (30.3)	66.4% (31.4)
IE	72.6% (24.2)	70.7% (25.2)	73.1% (25.1)	72.6% (27.4)	58.1% (26.9)	50.8% (32.0)	58.6% (33.7)	62.6% (33.3)	100% (0.0)	80.6% (25.0)	63.7% (31.8)	63.7% (29.6)
EE	53.2% (32.6)	51.3% (33.5)	54.0% (34.2)	56.2% (36.1)	44.9% (36.0)	62.9% (32.7)	67.5% (31.0)	78.5% (27.7)	80.4% (26.0)	100% (0.0)	61.8% (31.2)	65.9% (30.1)
EP	65.9% (26.3)	71.8% (25.6)	67.2% (30.0)	68.0% (28.2)	66.9% (26.1)	79.3% (24.9)	82.8% (25.0)	79.3% (25.7)	65.6% (29.7)	69.1% (29.8)	100% (0.0)	69.6% (29.5)
LL	70.4% (30.2)	71.8% (28.6)	68.8% (30.3)	64.8% (32.0)	74.5% (28.1)	72.3% (30.1)	73.7% (29.3)	75.3% (29.4)	68.5% (31.7)	70.2% (30.5)	61.0% (32.9)	100% (0.0)

Note. 1. Standard deviations in brackets. 2. KB=Knowledge Base for Engineering; PA=Problem Analysis; IN=Investigation; DE=Design; ET=Use of Engineering Tools; IT=Individual and Teamwork; CS=Communication Skills; PR=Professionalism; IE=Impact of Engineering; EE=Ethics and Equity; EP=Economics and Project Management; LL=Lifelong Learning. 3. This table depicts one-way dependencies. The values in each cell represent the dependency the graduate attribute in the column on the left has on the graduate attribute in the row across the top. For example, the dependency of KB on PA is 71.2%, whereas the dependency of PA on KB is 81.5%. 4. Lowest and highest dependency score are highlighted.

For engineering faculty stakeholders in this case (N=40), the perceived dependencies of the CEAB graduate attributes ranged from 31.3% for Knowledge Base on Ethics and Equity to 88.1% for Individual and Teamwork on Communication Skills, with a mean of 53.7% and a standard deviation of 13.5 (see Table 4.10).

Table 4.10
Mean perceived dependency of one CEAB graduate attribute on another CEAB graduate attribute for faculty stakeholders (N=40).

➔	KB	PA	IN	DE	ET	IT	CS	PR	IE	EE	EP	LL
KB	100% (0.0)	60.6% (32.5)	48.8% (31.0)	46.3% (36.1)	47.5% (31.9)	36.3% (32.5)	40.0% (29.3)	32.5% (29.0)	35.0% (33.4)	31.3% (32.4)	33.8% (30.3)	53.1% (34.5)
PA	86.9% (15.0)	100% (0.0)	68.1% (27.1)	55.6% (29.1)	68.1% (24.7)	51.9% (29.1)	47.5% (29.9)	31.9% (27.7)	43.1% (28.3)	36.9% (30.0)	47.5% (28.2)	49.4% (30.7)
IN	80.0% (22.1)	76.3% (24.0)	100% (0.0)	48.8% (29.9)	61.9% (26.5)	47.5% (29.9)	52.5% (29.9)	40.6% (29.8)	40.6% (30.3)	38.8% (29.9)	45.0% (27.9)	46.9% (32.1)
DE	87.5% (16.0)	85.0% (16.8)	71.9% (28.4)	100 % (0.0)	74.4% (22.3)	66.9% (25.6)	66.3% (27.5)	55.0% (32.6)	65.6% (25.7)	56.3% (28.2)	63.1% (26.5)	54.4% (32.0)
ET	72.5% (21.8)	63.1% (23.3)	53.8% (28.1)	51.3% (31.5)	100% (0.0)	37.5% (29.4)	40.0% (26.4)	33.1% (28.5)	32.5% (24.2)	32.5% (28.4)	35.0% (26.4)	55.0% (29.5)
IT	40.6% (33.3)	47.5% (32.4)	48.1% (33.2)	50.0% (35.8)	40.0% (29.3)	100% (0.0)	88.1% (18.8)	80.0% (22.1)	45.6% (29.4)	69.4% (23.7)	56.3% (33.4)	46.9% (32.1)
CS	46.3% (36.1)	45.0% (32.6)	43.1% (34.4)	43.1% (33.0)	35.6% (29.4)	70.6% (33.4)	100% (0.0)	65.0% (31.4)	40.6% (31.9)	53.8% (31.8)	43.1% (34.4)	46.9% (32.1)
PR	45.0% (33.6)	41.9% (31.2)	41.3% (33.8)	40.6% (33.8)	34.4% (31.9)	62.5% (34.0)	66.9% (34.6)	100% (0.0)	62.5% (32.5)	79.4% (24.6)	50.6% (32.8)	54.4% (30.0)
IE	65.6% (32.4)	60.0% (29.9)	60.6% (29.9)	55.6% (32.8)	50.0% (33.0)	47.5% (33.4)	50.0% (32.5)	72.5% (28.2)	100% (0.0)	72.5% (27.0)	56.3% (30.9)	54.4% (33.9)
EE	35.6% (36.6)	38.8% (37.5)	39.4% (35.8)	41.3% (36.1)	31.9% (33.0)	55.6% (36.5)	58.1% (33.2)	78.8% (28.6)	66.3% (36.5)	100% (0.0)	46.3% (34.7)	48.8% (34.4)
EP	56.3% (28.7)	66.3% (27.5)	51.9% (31.2)	60.6% (27.7)	57.5% (26.7)	69.4% (30.2)	72.5% (29.9)	69.4% (30.2)	60.6% (29.4)	60.0% (29.9)	100% (0.0)	48.8% (29.4)
LL	66.9% (30.2)	60.6% (28.8)	64.4% (29.4)	52.5% (32.9)	56.3% (34.3)	50.0% (32.5)	53.8% (34.2)	62.5% (32.5)	53.8% (32.8)	53.8% (31.3)	46.9% (27.8)	100% (0.0)

Note. 1. Standard deviations in brackets. 2. KB=Knowledge Base for Engineering; PA=Problem Analysis; IN=Investigation; DE=Design; ET=Use of Engineering Tools; IT=Individual and Teamwork; CS=Communication Skills; PR=Professionalism; IE=Impact of Engineering; EE=Ethics and Equity; EP=Economics and Project Management; LL=Lifelong Learning. 3. This table depicts one-way dependencies. The values in each cell represent the dependency the graduate attribute in the column on the left has on the graduate attribute in the row across the top. For example, the dependency of KB on PA is 60.6%, whereas the dependency of PA on KB is 86.9%. 4. Lowest and highest dependency score are highlighted.

For engineering industry stakeholders in this case (N=29), the perceived dependencies of the CEAB graduate attributes ranged from 35.3% for Use of Engineering Tools on Ethics and Equity to 88.8% for Individual and Teamwork on Communication Skills, with a mean of 59.0% and a standard deviation of 11.6 (see Table 4.11).

Table 4.11
Mean perceived dependency of one CEAB graduate attribute on another CEAB graduate attribute for industry stakeholders (N=29).

➔	KB	PA	IN	DE	ET	IT	CS	PR	IE	EE	EP	LL
KB	100% (0.0)	64.7% (28.0)	58.6% (25.2)	50.0% (27.5)	56.9% (29.0)	55.2% (25.3)	50.0% (27.5)	43.1% (30.5)	54.3% (30.7)	48.3% (32.0)	43.1% (24.9)	72.4% (27.0)
PA	81.9% (21.0)	100% (0.0)	85.3% (17.1)	52.6% (24.4)	68.1% (25.8)	62.9% (26.4)	60.3% (24.6)	45.7% (26.8)	53.4% (30.4)	48.3% (33.4)	50.0% (30.6)	53.4% (33.9)
IN	80.2% (21.5)	80.2% (16.9)	100% (0.0)	50.9% (25.4)	67.2% (21.2)	67.2% (21.2)	71.6% (26.5)	57.8% (31.4)	51.7% (30.6)	57.8% (32.8)	49.1% (27.9)	52.6% (30.1)
DE	81.0% (21.8)	75.9% (19.5)	64.7% (25.5)	100% (0.0)	77.6% (22.5)	68.1% (22.1)	57.8% (26.8)	58.6% (30.1)	60.3% (32.5)	55.2% (31.6)	56.9% (31.3)	59.5% (25.4)
ET	74.1% (25.4)	58.6% (25.2)	61.2% (25.5)	59.5% (29.4)	100% (0.0)	55.2% (27.9)	45.7% (27.6)	43.1% (27.5)	38.8% (30.3)	35.3% (32.4)	40.5% (29.4)	67.2% (26.8)
IT	56.0% (29.6)	56.0% (23.8)	59.5% (25.4)	54.3% (28.4)	51.7% (24.9)	100% (0.0)	88.8% (15.8)	75.0% (23.1)	48.3% (24.0)	64.7% (29.5)	50.0% (30.6)	51.7% (31.3)
CS	58.6% (27.8)	54.3% (27.6)	60.3% (30.3)	44.0% (22.8)	50.9% (27.1)	77.6% (21.5)	100% (0.0)	69.0% (25.6)	42.2% (30.7)	60.3% (34.4)	42.2% (30.7)	56.0% (26.4)
PR	61.2% (28.0)	50.9% (30.2)	49.1% (31.7)	45.7% (30.7)	37.1% (26.4)	73.3% (32.0)	77.6% (27.0)	100% (0.0)	69.0% (28.9)	80.2% (23.5)	44.0% (29.6)	58.6% (28.6)
IE	70.7% (24.2)	61.2% (31.0)	65.5% (32.3)	57.8% (29.2)	51.7% (26.7)	64.7% (27.2)	57.8% (32.1)	69.0% (31.1)	100% (0.0)	85.3% (18.3)	57.8% (27.6)	60.3% (29.5)
EE	55.2% (23.5)	47.4% (27.0)	52.6% (28.6)	44.8% (27.9)	36.2% (27.2)	64.7% (28.8)	64.7% (28.8)	86.2% (25.5)	74.1% (27.1)	100% (0.0)	46.6% (34.5)	56.9% (30.5)
EP	65.5% (22.6)	69.8% (30.9)	63.8% (28.0)	59.5% (30.2)	56.0% (27.3)	71.6% (28.9)	75.0% (21.1)	65.5% (24.5)	57.8% (26.8)	65.5% (27.9)	100% (0.0)	61.2% (26.4)
LL	73.3% (29.1)	51.7% (29.1)	55.2% (27.0)	49.1% (27.9)	49.1% (30.2)	59.5% (29.4)	55.2% (28.6)	59.5% (32.3)	48.3% (34.7)	54.3% (34.1)	37.1% (34.5)	100% (0.0)

Note. 1. Standard deviations in brackets. 2. KB=Knowledge Base for Engineering; PA=Problem Analysis; IN=Investigation; DE=Design; ET=Use of Engineering Tools; IT=Individual and Teamwork; CS=Communication Skills; PR=Professionalism; IE=Impact of Engineering; EE=Ethics and Equity; EP=Economics and Project Management; LL=Lifelong Learning. 3. This table depicts one-way dependencies. The values in each cell represent the dependency the graduate attribute in the column on the left has on the graduate attribute in the row across the top. For example, the dependency of KB on PA is 64.7%, whereas the dependency of PA on KB is 81.9%. 4. Lowest and highest dependency score are highlighted.

For all three engineering stakeholder groups (i.e., student, faculty, and industry) the top mean dependency pair was Individual and Teamwork on Communication Skills. The lowest mean dependencies were varied between the three groups, with Professionalism on Problem Analysis, Knowledge Base for Engineering on Ethics and Equity, and Use of Engineering Tools on Ethics and Equity chosen by student, faculty, and industry, respectively. However, all three of these pairs involve a 'technical' engineering skill and what may be considered a value-driven 'professional' skill. Students had a smaller range of mean dependency rankings than faculty and industry (12.4% and 9.1% smaller, respectively), with the discrepancy found in the lower end of the values. In other words, on average, students rated graduate attribute pairs of dependencies higher overall than both faculty and industry, with the lowest mean approximately 45%, which corresponds most closely to the statement: *Whenever an Engineer-in-Training (EIT) at the beginning of his/her career does something that involves using his/her [graduate attribute] it will <u>sometimes depend on/require</u> [graduate attribute].* Faculty and industry's bottom rating was closer to 'seldom depends.' Which generally suggests that students perceive that there is least a moderate dependency between most pairs of graduate attributes. All three groups of stakeholders had a top range of almost 90% for their mean dependency ratings, which corresponds to between 'often' and 'always' depends. Students' mean for all dependency ratings was 65.4%, which is closer to 'often' depends and over 10% higher than faculty's 53.7% mean, which is 'sometimes' depends. Industry fell between the two groups, with a 59.0% mean.

4.1.2.3 Variation in the Pattern of Perceived Dependencies of the CEAB Graduate Attributes Across Engineering Stakeholder Groups

A Pearson two-tailed correlation was performed to evaluate how much the pattern of perceived dependencies of the CEAB graduate attributes varied across engineering stakeholder groups using the mean perceived dependency ratings of the pairs of CEAB graduate attributes as the unit of analysis (N=132). The findings suggest that there was not much relative variation in the pattern of perceived dependencies across students, faculty, and industry engineering stakeholder groups, with r=0.87 (student-faculty), r=0.79 (student-industry), r=0.84 (faculty-industry). The patterns of covariation among student, faculty, and industry perceived mean dependencies of the CEAB graduate attributes was shown to be significant at $p < 0.01$ (see Table 4.12).

Table 4.12
Correlations in the pattern of perceived mean dependencies of the CEAB graduate attributes for engineering stakeholders (N= 132).

Stakeholder	Students	Faculty	Industry
Student	--	.87**	.79**
Faculty	.87**	--	.84**
Industry	.79**	.84**	--

Note. **Correlation is significant at the 0.01 level (2-tailed).

The mean squared difference was calculated to evaluate how the pairs of dependencies of the CEAB graduate attributes varied between stakeholder groups. The root mean square for students, faculty, and industry were between 9.0–13.41, with a range from 1–31, suggesting that there was not much variation in the absolute dependencies of pairs of graduate attributes among stakeholders (see Table 4.13).

Table 4.13
Absolute dependencies between engineering stakeholders' perceived dependencies of pairs of the CEAB graduate attributes for engineering stakeholders (N= 132).

Stakeholder Pairs	**Minimum**	**Maximum**	**Root Mean Square**
StuFac	0.1	31.4	13.41
StuInd	0.2	25.4	9.1
FacInd	0.0	19.7	9.0

Note. StuFac–student and faculty; StuInd–student and industry; FacInd–faculty and industry.

Overall, the findings suggest that there is not much variation in the patterns of engineering stakeholder mean dependency ratings of pairs of graduate attribute both relatively and absolutely among stakeholder groups. As a result, the similarities of the graduate attributes and the clusters of the graduate attributes were analyzed using the data derived from all stakeholders (a holistic analysis), rather than from individual stakeholder groups (case analysis).

4.1.2.4 CEAB Graduate Attribute Clusters

Multidimensional Scaling (MDS) was used to evaluate how the perceived similarities of the CEAB graduate attributes cluster together across all engineering stakeholders. A two-dimensionality plot was determined to be appropriate for analysis. Four clusters of attributes can be perceived in four quadrants in the common space when the x and y-axes are set at 0.0 (see Figure 4.1).

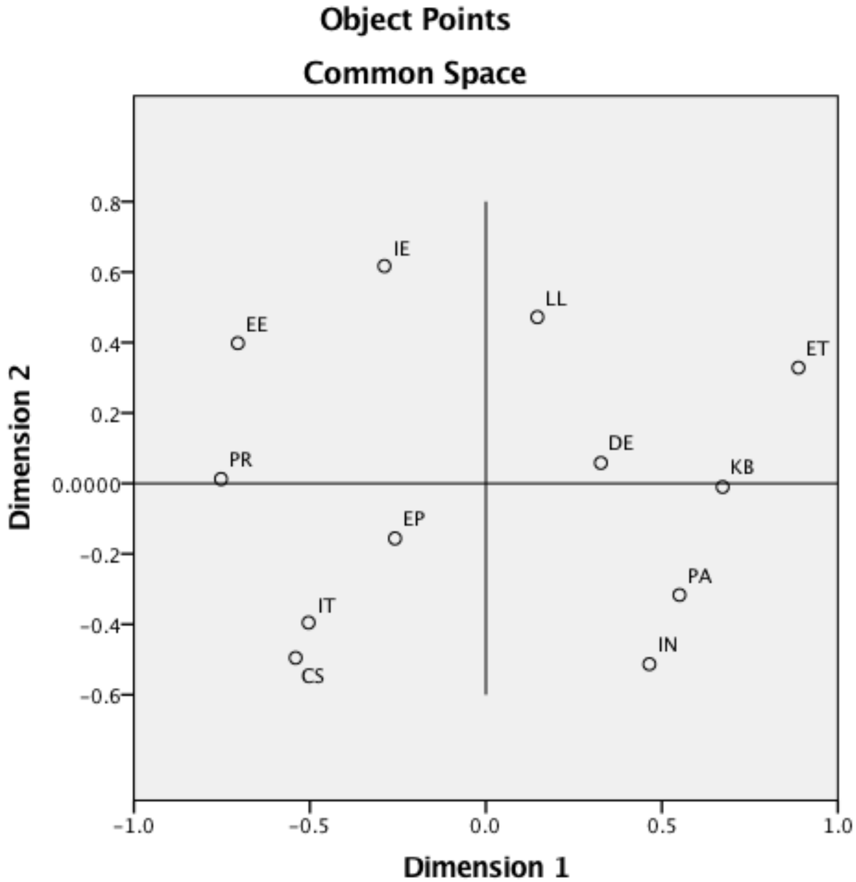


Figure 4.1. Common space of engineering stakeholders CEAB graduate attributes similarity data in a 2-dimensional multidimensional scaling analysis with x and y-axes set at 0.0.

Note. 1. KB=Knowledge Base for Engineering; PA=Problem Analysis; IN=Investigation; DE=Design; ET=Use of Engineering Tools; IT=Individual and Teamwork; CS=Communication Skills; PR=Professionalism; IE=Impact of Engineering; EE=Ethics and Equity; EP=Economics and Project Management; LL=Lifelong Learning. 2. It is important to note that the axes have no intrinsic value: 'the coordinate axes in MDX are simply a device to 'hang' the points within the m-dimensional space' (Jacoby and Ciuk 2014, p. 23). The axes assist in interpreting the dimensions and 'directions' within the space, and in identifying potential clusters (p. 23). MDS is intended for use as an exploratory interpretation of the data, where 'visual inspection is often enough in itself' (p. 23). However, it is recommended to confirm interpretations. In this study, potential cluster interpretations are offered and substantiated by the literature and a reasonable consideration of the engineering curricula.

In the common space, Investigation, Problem Analysis, and Knowledge Base for Engineering are found in the lower right quadrant (quadrant 4), with medium to high values in Dimension 1, and low to medium values in Dimension 2. Communication Skills, Individual and Teamwork, and Economics and Project Management are found in the lower left quadrant (quadrant 3), with a low to medium dimensionality in both Dimensions 1 and 2. Professionalism, Ethics and Equity, and Impact of Engineering on Society and the Environment are found in the upper left quadrant (quadrant 2), with low to medium values in Dimension 1 and medium to high values in Dimension 2. Design, Lifelong Learning and Use of Engineering Tools are found in the upper right quadrant (quadrant 1), with with medium to high dimensionality in both Dimensions 1 and 2.

When considering each dimension, with the addition of the attribute, Lifelong Learning, the attributes that are often considered the more ‘traditional skills’ in engineering are found to have medium to high dimensionality in Dimension 1, occupying the upper and lower right quadrants (quadrants 1 and 4), and what have been conceived as ‘the professional skills’ in engineering have low to medium dimensionality in Dimension 1, and are found in the upper and lower left quadrants (quadrants 2 and 3). When looking at Dimension 2 in the common space, the attributes that have low to medium dimensionality in Dimension 2 comprise of Communication Skills, Individual and Teamwork, Economics and Project Management, Investigation, Problem Analysis, and Knowledge Base for Engineering (quadrants 3 and 4). The attributes that have medium to high dimensionality in Dimension 2 consist of Lifelong Learning, Use of Engineering Tools, Design, Professionalism, Ethics and Equity, and Impact of Engineering on Society and the Environment (quadrants 1 and 2).

Other configurations can be considered: Professionalism, Ethics and Equity, Impact of Engineering on Society and the Environment, Lifelong Learning, Design, and Economics and Project Management have a circular relationship; Investigation, Problem Analysis, Knowledge Base and Use of Engineering Tools have a tangential relationship; and Individual and Teamwork and Communication Skills are closely clustered.

Overall, Individual and Teamwork and Communication Skills, and Problem Analysis and Investigation form the two closest clusters.

4.2 Phase 2

The following section is a presentation of the findings from Phase 2 of the study, where the content validity of the Biosystems Engineering program is evaluated based on the relative importance data from Phase 1. The percentages of course content coverage and course assessments that are allocated for each of the 12 CEAB graduate attributes in the core courses in the Biosystems program based on the professional judgment of the faculty and on the data from accreditation documents are presented. These percentages are compared to the mean relative importance findings data of the graduate attributes based on the perceptions of all stakeholders (discussed in Section 4.1.1 *Absolute and Relative Importance of the CEAB Graduate Attributes*). The analysis was guided by these research questions:

RQ 3.1 For each CEAB graduate attribute, how similar are the percentages of course content coverage to the percentages of course assessments in the Biosystems engineering program?

RQ 3.2 In the Biosystems engineering program, how do the percentages of course content coverage and course assessments of the CEAB graduate attributes compare with their perceived relative importance by all engineering stakeholders?

4.2.1 Teaching and Assessing the CEAB Graduate Attributes in the Biosystems Engineering Program

The following table illustrates the 35 core courses in the Biosystems (BIOE) program, and the percentage of content coverage that each graduate attribute is allocated in each of these courses based on the professional judgement of the course instructors, expert faculty, and accreditation documents. The bottom row demonstrates the overall percentage of content coverage for each graduate attribute for the whole program (Table 4.14).

Table 4.14
Percentage of course content coverage for the CEAB graduate attribute in the BIOE engineering core program (N=35 courses).

CEAB Graduate Attributes	KB	PA	IN	DE	ET	IT	CS	PR	IE	EE	EP	LL
CHEM 1300 Chemistry	100											
COMP 1012 Comp Prog Eng	100											
ENG 1460 Thermal Sciences	25	50			25							
MATH 1510 Applied Calculus	100											
PHYS 1050 Physics	100											
ENG 1430 Eng Design		5	5	40		20	15	8	2		3	2
ENG 1440 Eng Statics (CIVL)	35	60	5									
ENG 1450 Intro Elec &Comp Eng	30	30	2	10	15	5	2		2		2	2
Written Requirement							100					
MATH 1210 C/L Algebra	100											
MATH 1710 Applied Calculus	100											
BIOE 2590 Bio for Engineers	100											
BIOE 2900 Design 1	29			31		1	21	4		4		10
CHEM 1310 Intro Phy Chem	100											
MBIO 1220 Ess. in Microbiology	100											
BIOE 2480 Imp. of Eng on Env.									100			
ENG 2022 Eng CAD Technology	20			50	20		10					
MATH 2132 Math Analysis 2	100											
STAT 2220 Statistics for Eng	100											
BIOE 2110 Trans. Phenom.	50	50										

BIOE 2790 Fluid Mechanics	35	60	5									
MATH 2130 Math Analysis 1	100											
BIOE 2800 Solid Mechanics	90	10										
MECH 2150 Modeling & Num	20	58		5	17							
BIOE 3400 Design of Struc Comp Mach				85								15
BIOE 3590 Mech of Biomatter	65	10	25									
BIOE 3900 Design 2				75	10		10				5	
BIOE 3270 Instru. for BIOE	40	30			25			5				
BIOE 3320 Eng Prop Bio Matter	45		45									10
MECH 3482 Kinematics & Dynamics	25	40	10		25							
CIVL 4460 (ANTH 2430*)						7.5	7.5	15	35	35		
BIOE 4900 Design 3				46	5	4	30	9		0	3	3
BIOE 4240 Grad Project			40			5	45			5		5
BIOE 4950 Design 4				31	23	4	23	4	4		4	7
ENG 3000 Eng Economics		50	25								25	
Total % in program	48.8 %	12.9 %	4.6 %	10.7 %	4.7 %	1.3 %	7.5 %	1.3 %	4.1 %	1.3 %	1.2 %	1.5 %
CEAB Graduate Attributes	KB	PA	IN	DE	ET	IT	CS	PR	IE	EE	EP	LL

Note. 1. KB=Knowledge Base for Engineering; PA=Problem Analysis; IN=Investigation; DE=Design; ET=Use of Engineering Tools; IT=Individual and Teamwork; CS=Communication Skills; PR=Professionalism; IE=Impact of Engineering; EE=Ethics and Equity; EP=Economics and Project Management; LL=Lifelong Learning. 2. Each number represents the percentage of course content coverage. Blank cells = zero. Each horizontal line totals 100%. 3. Students can take CIVL 4460 or ANTH 2430. ANTH 2430 is comprised of 100% IE for both course content coverage and assessments; whereas CIVL 4460 is comprised of IT, CS, PR, IE and EE. These data were calculated using the data from CIVL 4460*.

The following table illustrates the 35 core courses in the BIOE program, and the percentage of assessments that each graduate attribute is allocated in each of these courses based on the professional judgement of the course instructors as collected using the *Teaching Faculty Course Content Questionnaire*, Department Heads familiar with the courses and with Faculty of Engineering accreditation documents, and syllabi and accreditation documents. The bottom row demonstrates the overall percentage of assessments for each graduate attribute for the whole program (Table 4.15).

Table 4.15
Percentage of course assessments for the CEAB graduate attribute in the BIOE engineering core program (N=35 courses).

CEAB Graduate Attributes	KB	PA	IN	DE	ET	IT	CS	PR	IE	EE	EP	LL
CHEM 1300 Chemistry	100											
COMP 1012 Comp Prog Eng	100											
ENG 1460 Thermal Sciences	25	50			25							
MATH 1510 Applied Calculus	100											
PHYS 1050 Physics	100											
ENG 1430 Eng Design		4.5	2	33		11	20.5	12	3		14	0
ENG 1440 Eng Statics (CIVL)	25	70	5									
ENG 1450 Intro Elec &Comp Eng	35	35	5	10	10	5	0		0		0	0
Written Requirement							100					
MATH 1210 C/L Algebra	100											
MATH 1710 Applied Calculus	100											
BIOE 2590 Bio for Engineers	100											
BIOE 2900 Design 1	25			45		5	20	2.5		2.5		0
CHEM 1310 Intro Phy Chem	100											
MBIO 1220 Ess. in Microbiology	100											
BIOE 2480 Imp. of Eng on Env.									100			
ENG 2022 Eng CAD Technology	20			55	20		5					
MATH 2132 Math Analysis 2	100											
STAT 2220 Statistics for Eng	100											
BIOE 2110 Trans. Phenom.	30	70										

BIOE 2790 Fluid Mechanics	34	58	8									
MATH 2130 Math Analysis 1	100											
BIOE 2800 Solid Mechanics	90	10										
MECH 2150 Modeling & Num	20	58		5	17							
BIOE 3400 Design of Struc Comp Mach				91								9
BIOE 3590 Mech of Biomatter	50	20	30									
BIOE 3900 Design 2				75	10		10				5	
BIOE 3270 Instru. for BIOE	30	40			20			10				
BIOE 3320 Eng Prop Bio Matter	45		50									5
MECH 3482 Kinematics & Dynamics	40	40	10		10							
CIVL 4460 (ANTH 2430)						2.5	2.5	15	40	40		
BIOE 4900 Design 3				31	10	7.5	29	3		1.5	9	9
BIOE 4240 Grad Project			42		2.5	7.5	40.5			2.5		5
BIOE 4950 Design 4				33	10	6	29	2	1	1	5	13
ENG 3000 Eng Economics		50	25								25	
Total % in program	47.7 %	14.4 %	5.1 %	10.8 %	3.8 %	1.3 %	7.3 %	1.3 %	4.1 %	1.4 %	1.7 %	1.2 %
CEAB Graduate Attributes	KB	PA	IN	DE	ET	IT	CS	PR	IE	EE	EP	LL

Note. 1. KB=Knowledge Base for Engineering; PA=Problem Analysis; IN=Investigation; DE=Design; ET=Use of Engineering Tools; IT=Individual and Teamwork; CS=Communication Skills; PR=Professionalism; IE=Impact of Engineering; EE=Ethics and Equity; EP=Economics and Project Management; LL=Lifelong Learning. 2. Each number represents the percentage of assessments. Blank cells = zero. Each horizontal line totals 100%. 3. Students can take CIVL 4460 or ANTH 2430. ANTH 2430 is comprised of 100% IE for both course content coverage and assessments; whereas CIVL 4460 is comprised of IT, CS, PR, IE and EE. These data were calculated using the data from CIVL 4460*.

The core course content taught in the BIOE program is found to be comprised of just under 50% Knowledge Base for Engineering, 13% Problem Analysis, just over 10% Design and 7% Communication Skills, approximately 4.5% each of Use of Engineering Tools and Investigation, 4% Impact of Engineering on Society and the Environment, and just over 1% each of Individual and Teamwork, Professionalism, Ethics and Equity, and Economics and Project Management. There are very similar percentages for the assessment of each graduate attribute in the BIOE program, with the largest discrepancy between the teaching and assessing of the graduate attributes found for Knowledge Base for Engineering and Use of Engineering Tools, which are taught approximately 1% more than they are assessed, and Problem Analysis, which is assessed 1.5% more than it is taught. Every other attribute is taught and assessed in the curriculum with a difference of less than 1% (See Table 4.16).

Table 4.16
Comparative view of percentage of course content coverage and percentage of course assessments in the BIOE program.

CEAB Graduate Attributes	Attributes Taught	Attributes Assessed
Knowledge Base	48.8%	47.7%
Problem Analysis	12.9%	14.4%
Investigation	4.6%	5.1%
Design	10.7%	10.8%
Eng. Tools	4.7%	3.8%
Ind. & Teamwork	1.3%	1.3%
Communication	7.5%	7.3%
Professionalism	1.3%	1.3%
Impact of Eng.	4.1%	4.1%
Ethics & Equity	1.3%	1.4%
Eco. & Proj. Mngt.	1.2%	1.7%
Lifelong Learning	1.5%	1.2%

With two exceptions, the ranked order of the graduate attributes based on the course content coverage and course assessments in the BIOE program closely reflects the

CEAB's linear list of the 12 graduate attributes (albeit the order of the 'technical' skills and the 'professional' skills are varied). The exceptions include the relatively larger emphasis on Communication Skills, which is emphasized before Use of Engineering Tools and Investigation, and the relatively larger emphasis on Impact of Engineering on Society and the Environment, which is the top 'professional' skill aside from Communications Skills (and is assessed more than Engineering Tools) (see Table 4.17).

Table 4.17
Ranked order of CEAB graduate attributes based on the course content coverage and course assessments in the BIOE program (N=35 courses).

Ranked Relative Importance	Course Content Coverage (% of time spent teaching)		Course Assessments (% of assessments)	
1	Knowledge Base	48.8%	Knowledge Base	47.7%
2	Problem Analysis	12.9%	Problem Analysis	14.4%
3	Design	10.7%	Design	10.8%
4	Communication	7.5%	Communication	7.3%
5	Eng. Tools	4.7%	Investigation	5.1%
6	Investigation	4.6%	Impact of Eng.	4.1%
7	Impact of Eng.	4.1%	Eng. Tools	3.8%
8	Lifelong Learning	1.50%	Eco. & Proj. Mngt.	1.70%
9	Ind. & Teamwork	1.33%	Ethics & Equity	1.40%
10	Professionalism	1.29%	Ind. & Teamwork	1.27%
11	Ethics & Equity	1.26%	Professionalism	1.27%
12	Eco. & Proj. Mngt.	1.20%	Lifelong Learning	1.20%

4.2.2 The Percentages of Course Content Coverage and Course Assessments of the CEAB Graduate Attributes in the Biosystems Engineering Program Compared to their Mean Perceived Relative Importance by Engineering Stakeholders

Due to the minimal variation between the percentages of course content coverage and course assessments in the data of the graduate attributes in the BIOE program, the findings will be discussed in the context of both.

There was a wide range found in the percentage of course content coverage and course assessments across the graduate attributes in the BIOE program, from 1.2% – 48.8% for teaching, and 1.2% – 47.7% for assessing. This is in sharp contrast to the range of mean perceived relative importance of the graduate attributes ascribed by all engineering stakeholders (i.e., students, faculty and industry), which is between 6.1%– 10.9% (see Table 4.18).

Table 4.18
Comparative view of mean relative importance of the CEAB graduate attributes by all stakeholders with percentage of course content coverage and assessments in the BIOE program.

CEAB Graduate Attributes	Relative Importance All Stakeholders (N=207)	BIOE % of Course Content Coverage	BIOE % of Course Assessments
Knowledge Base	9.1%	48.8%	47.7%
Problem Analysis	9.0%	12.9%	14.4%
Investigation	7.2%	4.6%	5.1%
Design	7.0%	10.7%	10.8%
Eng. Tools	8.3%	4.7%	3.8%
Ind. & Teamwork	10.9%	1.3%	1.3%
Communication	10.8%	7.5%	7.3%
Professionalism	9.4%	1.3%	1.3%
Impact of Eng.	6.3%	4.1%	4.1%
Ethics & Equity	8.8%	1.3%	1.4%
Eco. & Proj. Mngt.	6.1%	1.2%	1.7%
Lifelong Learning	7.1%	1.5%	1.2%

Note. For the purposes of evaluating the content validity of the BIOE program, the mean perceived relative importance for all engineering stakeholders (i.e., student, faculty and industry) was used as the unit of analysis, as opposed to comparing these data to one or more individual stakeholder groups. Before determining this, the mean perceived relative importance was calculated for the newly combined group of faculty and industry stakeholders. This was done because in the mean absolute importance data, faculty and industry only had one significantly different rating, whereas students had 10 significantly different ratings from the other two stakeholders. It was found that the largest difference in the relative importance findings between all stakeholders and faculty and industry stakeholders combined was 1.2%. If the data from the percentages of course content coverage and course assessments were very close to the mean perceived relative importance of all stakeholders, the data could be looked at in this more nuanced way for the purposes of evaluating the program. However, as the BIOE program data are quite varied from the mean perceived relative importance data, it was determined that the analysis could be made using the mean perceived relative importance data of all engineering stakeholders. (The mean perceived relative importance data for the faculty/industry is found in Appendix H.)

When examining the percentage of time spent teaching and assessing the graduate attributes in the Biosystems program in comparison to the mean relative importance of the graduate attributes for all stakeholders, it is found that Knowledge Base for Engineering comprises almost half of the Biosystems program, which is in sharp contrast to its 9% relative importance attributed by stakeholders. This is the attribute that is most skewed in comparison with the relative importance data. Following that, both Problem Analysis and Design are taught and assessed approximately 4% more than its relative importance attributed by stakeholders. The remainder of the graduate attributes are given less weight in the program than their relative importance. The largest of these discrepancies is found for Individual and Teamwork, which is the relatively most important attribute for stakeholders at approximately 11%, and is given just over 1% of attention in the Biosystems curriculum. The same holds true for the attributes, Professionalism, Ethics and Equity, Lifelong Learning, and Economics and Project Management, which are given 8%, 7%, 6%, and 5% less attention respectively than their relative importance suggests. Engineering Tools is given approximately half the time in the curriculum as represented by its relative importance, and Communications Skills and Impact of Engineering on Society and the Environment are given approximately two-thirds of the curricular attention represented by their the relative importance. Generally, Investigation, Design, Communication Skills, Impact of Engineering on Society and the Environment, (and to some extent Use of Engineering Tools and Problem Analysis, at least for teaching content) are the graduate attributes that are given somewhat analogous attention in relation to their mean perceived relative importance. For these comparisons, Problem Analysis and Design are given more emphasis in the BIOE program than their mean relative importance rating warrants, and the rest are given less.

Overall, the ranked order of importance in the Biosystems program as established by percentage of time spent teaching and assessing the graduate attributes is quite varied from the rated order of mean relative importance for engineering stakeholders. For engineering stakeholders, the rated order of mean relative importance can be viewed in three groups (although the mean perceived absolute importance between each group is relatively negligible, with engineering stakeholders varying quite little in their perception of the range of relative importance between attributes, as considered previously). As discussed in Section 4.1.1.3 *Comparative View of the Absolute and Relative Importance of CEAB Graduate Attributes Between Engineering Stakeholder Groups*, all stakeholders rated Individual and Teamwork and Communication Skills in the highest group of importance; Professionalism, A Knowledge Base for Engineering, Problem Analysis, Ethics and Equity, and Use of Engineering Tools could be considered a second group of importance; and Investigation, Lifelong Learning, Design, Impact of Engineering on Society and the Environment, and Economics and Project Management a third group of importance. Even though the order changes slightly for each individual stakeholder group, the composition of the low, medium and high groups of importance do not; these three groups are found across all, and for each individual (i.e., student, faculty, and industry) engineering stakeholder groups.

There is a different composition for the Biosystems engineering program when considering groups of emphasis. For time spent both teaching and assessing the graduate attributes, four groups can be discerned to aid interpretation. Firstly, Knowledge Base for

Engineering is alone in the highest group of emphasis, far removed from all the other graduate attributes with its almost 50% of the program course content coverage and assessments. The next group could be perceived as comprised of Problem Analysis, Design, and Communications Skills, although there is over a 5% discrepancy in this group, from 7.5% – 12.9%. The third group could be perceived as Use of Engineering Tools, Investigation, and Impact of Engineering on Society and the Environment, each with just over 4% emphasis in the program. The fourth group can be interpreted to encompass Lifelong Learning, Individual and Teamwork, Professionalism, and Ethics and Equity, each with between 1% – 1.5% of program course content coverage and assessments (see Table 4.19).

Table 4.19
Comparative view of ranked order of relative importance of the CEAB graduate attributes for all engineering stakeholders with percentage of course content coverage and assessments in the BIOE program.

Ranked Mean Relative Importance for All Stakeholders (N=207)		**BIOE Program % of Course Content Coverage**		**BIOE Program % of Course Assessments**	
Ind. & Teamwork	10.9%	Knowledge Base	48.8%	Knowledge Base	47.7%
Communication	10.8%	Problem Analysis	12.9%	Problem Analysis	14.4%
Professionalism	9.4%	Design	10.7%	Design	10.8%
Knowledge Base	9.1%	Communication	7.5%	Communication	7.3%
Problem Analysis	9.0%	Eng. Tools	4.7%	Investigation	5.1%
Ethics & Equity	8.8%	Investigation	4.6%	Impact of Eng.	4.1%
Eng. Tools	8.3%	Impact of Eng.	4.1%	Eng. Tools	3.8%
Investigation	7.2%	Lifelong Learning	1.5%	Eco. & Proj. Mngt.	1.7%
Lifelong Learning	7.1%	Ind. & Teamwork	1.33%	Ethics & Equity	1.4%
Design	7.0%	Professionalism	1.29%	Ind. & Teamwork	1.27%
Impact of Eng.	6.3%	Ethics & Equity	1.26%	Professionalism	1.27%
Eco. & Proj. Mngt.	6.1%	Eco. & Proj. Mngt.	1.2%	Lifelong Learning	1.2%

When further considering these groups of importance, discrepancies are found with the treatment of Individual and Teamwork, which can be perceived as relegated to the fourth group of emphasis in the Biosystems program (i.e., the ‘bottom’ group of emphasis), whereas Individual and Teamwork is in the highest group of importance for engineering stakeholders. Professionalism and Ethics and Equity are in the bottom group of emphasis in the BIOE program, and in the second highest group of importance (quite close in relative importance to the top group) for engineering stakeholders. Attributes that are more closely aligned in regards to the groups of importance include Investigation and Impact of Engineering on Society and the Environment, which are both found in the third group of emphasis in the BIOE program and in the third group of importance for engineering stakeholders. Interestingly, Design and Communication Skills have inverse values of emphasis, at 10.7% (2^{nd} group) and 7.5% (2^{nd} group) respectively in the BIOE program, and at 7.0% (3^{rd} group) and 10.8% (1^{st} group) mean relative importance for engineering stakeholders. Both however, as shown, are in different groups of importance, with engineering stakeholders placing less importance on Design and more importance on Communication Skills, and the BIOE program placing more equitable emphasis on each.

Overall, with the exception of Communication Skills, the BIOE program emphasizes what have been called the ‘traditional’ skills in engineering, followed by descending emphasis for what have been called the ‘professional’ skills. Engineering stakeholders, on the other hand, place more initial importance on the ‘professional’ skills, i.e., Individual and Teamwork and Communication Skills, followed by a mix of the graduate attributes that does not delineate a clear division between these two labels.

When considering the mean relative importance of the CEAB graduate attributes by all engineering stakeholders in comparison with the percentage of course content coverage and course assessments of the graduate attributes in the BIOE program, program coverage for all of the graduate attributes is somewhat skewed, albeit some more definitively than others. These data suggest that the content validity for the Biosystems engineering program, in regards to the relative importance measure, needs improving.

Chapter Summary

This chapter presented the findings from both phases of the study. Phase 1 findings are a presentation of the mean absolute and relative importance of the CEAB graduate attributes as perceived by all engineering stakeholders in this case holistically, and as perceived by student, faculty, and industry stakeholder groups discretely. A comparative view of the mean absolute and relative importance between stakeholder groups was then offered. This was followed by the presentation of the mean perceived dependencies of CEAB graduate attributes across all engineering stakeholder groups, and for each student, faculty, and industry stakeholder group distinctly. Succeeding, the relative and absolute variation in the patterns of perceived dependencies of the CEAB graduate attributes across engineering stakeholders groups were determined, and how the graduate attributes interrelate and cluster in perceptual space was explored.

Phase 2 evaluates the content validity of the Biosystems Engineering program. The percentages of course content coverage and course assessments of the CEAB graduate attributes were established. These data were then compared to the mean relative importance of the graduate attributes as perceived by all engineering stakeholders, and the content validity of the Biosystems Engineering program was evaluated for this measure. Chapter Five discusses these findings.

Chapter Five: Discussion

This chapter discusses the absolute and relative importance and dependency findings from this study, and considers it within the context of the research literature and in terms of the implications for curricular development. Then the ramifications for the Biosystems Engineering program are considered, and suggestions to improve the content validity of the program in relation to the mean perceived relative importance by engineering stakeholders in this case are presented. Following, implications for the remaining programs within the Faculty of Engineering are deliberated, and relevance of these findings for CEAB accredited engineering programs across Canada and for accredited engineering programs globally is considered. Lastly, the limitations of the study, recommendations, and ideas for further research are raised.

5.1 The Absolute and Relative Importance of the CEAB Graduate Attributes

The following sections discuss the absolute and relative importance of the CEAB graduate attributes as perceived by engineering stakeholders. It is important to keep in mind that the findings show that the differences in mean absolute and mean relative importance between the graduate attributes are not large. Practically speaking, there are no graduate attributes that are well above or below the rest. Due to the similarity in the findings between students, faculty, and industry in regards to the relative importance of the graduate attributes, particularly when considering that all three stakeholder groups allocated the same graduate attributes to three groups of importance (see Section 4.1.1.3 *Comparative View of the Absolute and Relative Importance of CEAB Graduate Attributes Between Engineering Stakeholder Groups*), the data for all stakeholder groups (i.e., students, faculty, and industry) are considered in the discussions on clustering the graduate attributes. However, it is worthwhile to first to look at the differences in the mean absolute importance and dependency ratings, and pay particular attention to students' responses comparatively to faculty and industry's responses to consider if the differences are due to students' perceptions or to students' aspirations. Do these data represent what students conceptualize engineering to be, or what students want engineering to be? The differences in students' responses and potential reasons are discussed first.

5.1.1 The Significant Differences Between Student Versus Faculty and Industry Stakeholders in the Absolute Importance of the CEAB Graduate Attributes: A Millennial Vision?

Overall, student participants rated 10 of the graduate attributes as significantly more important than did faculty or industry participants. The exceptions were Knowledge Base for Engineering and Use of Engineering Tools. Certainly, it is of value to question whether the novice perspective is at play here (Schunn and Nelson 2009), where the tendency to rate the graduate attributes higher could be due to a lack of experience in engineering practice, and thereby the subsequent incapacity to distinguish between more and less important graduate attributes. However, despite potentially a novice perspective at play, it is important to ask whether these differences in absolute importance ratings are due to students' perceptions of what they conceptualize engineering to be, or if these differences are due to students' aspirations of what engineering *should* be. In other words, can these differences be attributed to a 'millennial' vision?

Sheppard, Pellegrino, and Olds (2008) write:

> Educated professionals, such as engineers, with a highly developed understanding of technical matters and a well grounded sense of social responsibility, are arguably among the best equipped to struggle with the complexity of consequences of technological innovation and intervention in our new reality. This should challenge each of us in engineering education to reflect deeply on the significance of integrating ethical reasoning into the learning agenda in a more intentional and holistic manner. (p. 231)

The argument for integrating ethical reasoning into the engineering curriculum has particular relevance when considering that students rated graduate attributes that comprise ethical reasoning and value systems as absolutely and relatively more important than both faculty and industry stakeholders. These included the attributes Professionalism, Ethics and Equity, Lifelong Learning, and Impact of Engineering on Society and the Environment, the first two of which students rated before Knowledge Base for Engineering, Problem Analysis, and Use of Engineering Tools, and the latter which is rated before Investigation and Design.

The 'millennial view' is reflected in the literature, and is an important consideration as engineering educators move forward in designing learning environments that meet the needs and standards of 21st century students. As stated by Beddoes and Friesen (2017) (informed by Engineers Canada 2014), 'Undergraduate students are predominantly Millennials and are a generation of learners who are plugged into information and issues. They expect to practice future engineering careers in ways that match their *values*, which include entrepreneurial, challenge-seeking and community-oriented outlooks' (emphasis added). It is important to recognize that students' perceptions of what is important in engineering emphasizes value-, behaviour-, and attitude-laden attributes over knowledge and skill-based attributes, which could be an important consideration when designing engineering curricula for the new generation of students. It is also an argument for the potential inauthenticity of the list of graduate attributes with its implicit (or perhaps explicit) emphasis of descending importance from the first attribute (Knowledge Base for Engineering) to the twelfth (Lifelong Learning). Students' perceptions in this case need to be explored further to understand why students rated specific graduate attributes as significantly more important than faculty or industry stakeholders.

5.1.2 The Mean Absolute and Relative Importance of the CEAB Graduate Attributes as Perceived by Engineering Stakeholders

A finding that is somewhat surprising although it is reflected in the literature (Male 2010; Passow 2012; Passow and Passow 2017), is that Individual and Teamwork and Communication Skills are the top mean absolute and relative important graduate attributes as perceived by all three stakeholder groups in this study. As presented in Chapter 2, Passow (2012) found engineering graduates ranked teamwork and communication as two out of four of the top used competencies/attributes in their disciplines, which are reflected in these research data. (Data analysis and problem solving were the other top competencies in Passow's (2012) study.) In the literature, Teamwork has been found to be inextricably tied to engineers' technical work (Passow and Passow 2017), which could be one of the reasons for its highest ranked importance, seen in both these data and predominantly in the literature (Male 2010; Male, Chapman and Bush 2011a; Passow 2012; Pons 2016; Passow and Passow 2017). Communication has also been receiving attention in the literature, repeatedly clustered as a top engineering competency, confirming its importance to engineering practice. One of Passow and Passow's (2017) finding in their recent systematic literature review of the importance of the graduate attributes was that ‘engineers spend more than half their work day (55%-60%) communicating’ (p. 491). Robinson et al. (2005) echo this, explaining the necessity of high level communication skills for Design Engineering (p. 125-126), a view arguably transferable to all engineering disciplines.

The lower ranked competencies in Passow (2012) were contemporary issues, design of experiments, and understanding the impact of one’s work. These findings are reflected in this research, with all three groups of stakeholders placing Investigation and Impact of Engineering on Society and the Environment in the lower group of importance. The attribute, Investigation, had the only significantly different rating between faculty and industry, with both faculty and students placing significantly more importance on it than industry. It would be worthwhile to explore this difference further to examine how Investigation is perceived in industry, and whether its close proximity to Problem Analysis suggests that they could be amalgamated.

In the recent follow-up study to Passow (2012) that comprised a meta-analysis of engineering and education databases from 1990 – 2012 resulting in 52 studies selected for a qualitative and quantitative analysis to establish ‘a comprehensive list of generic engineering competencies, their relative importance, and rich descriptions highlighting interrelationships’ (p. 475) (see Section 2.3.3 *Considering the Relative Importance and Interrelationships of Engineering Competencies: Clustering the Graduate Attributes*), Passow and Passow (2017) identify four levels of importance ratings that are statistically discrete (listed in descending order): 1. Problem Solving, Communication, and Teamwork; 2. Ethics and Lifelong Learning; 3. Math, Science, and Engineering Knowledge; Engineering Tools; Experiments and Data Analysis; and Design; and 4. Contemporary Issues and Understanding Impact of one’s work (p. 484). These competencies represent the ABET General Criterion 3 Student Outcomes, which are quite similar to CEAB's 12 graduate attributes, although the former comprise 11 outcomes in which Professionalism is merged with Ethics, and list Contemporary Issues rather than Economics and Project Management (see Section 2.1.2.2 *New Developments: Changes to ABET Criterion 3: Student Learning Outcomes* for a discussion on ABET's required engineering student learning outcomes). If the findings from this research were arranged into four groups of engineering competencies based on the mean relative importance findings in order to relate them to Passow and Passow's (2017) distinct groupings (p. 484), these data would compare. The discrepancies are found in the attributes Lifelong Learning and Use of Engineering Tools, which are located in Passow and Passow's (2017) second and third groupings respectively, but in reverse order for these data. The other variation is that in the findings from this research study, all stakeholders rate Knowledge Base for Engineering in the top group of mean relative importance, whereas in Passow and Passow's (2017) findings, Knowledge Base is found in the third grouping (see Table 5.1).

Table 5.1
Comparative view of ranked order of mean relative importance of the CEAB graduate attributes for all engineering stakeholders and Passow and Passow's (2017) four levels of engineering competencies importance ratings.

Four Levels of Importance Ratings	All Stakeholders Mean Relative Importance	Passow and Passow's (2017) Four Levels of Engineering Competencies Importance Ratings
1	Ind. & Teamwork (10.9%) Communication (10.8%) Professionalism (9.4%) Knowledge Base (9.1%) Problem Analysis (9.0%)	Problem Solving Communication Teamwork
2	Ethics & Equity (8.8%) Eng. Tools (8.3%)	Ethics Lifelong Learning
3	Investigation (7.2%) Lifelong Learning (7.1%) Design (7.0%)	Knowledge Base Eng. Tools Investigation
4	Impact of Eng. (6.3%) Eco. & Proj. Mngt. (6.1%)	Design Contemporary Issues Impact of Eng.

Note. Passow and Passow's (2017) four groups of engineering competencies are demarcated by 'statistically distinct levels of importance ratings…[but] even the bottom cluster competencies are deemed valuable by respondents' (p. 484).

These findings suggest that the stakeholders' perceptions of the relative importance of the CEAB graduate attributes in this case are for the most part, supported by the research. Similar to Passow and Passow's (2017) work, the mean relative importance ratings in this research are close together for all graduate attribute groupings, and thereby, although these represent a mean relative importance of engineering competencies in descending order, all of these graduate attributes (with the exception of Economics and Project Management, which is not listed in Passow and Passow's (2017) clusters, perhaps due to incongruence with ABET's outcomes) are suggested to be of importance to the profession. Subsequently, it would be worth exploring Economics and Project Management further to understand how stakeholders see this graduate attribute fitting into engineering practice. Perhaps this is another graduate attribute that could be amalgamated into the Communication Skills and Individual and Teamwork cluster.

5.2 CEAB Graduate Attribute Dependencies as Perceived by Engineering Stakeholders

An interesting finding in the graduate attribute mean dependency ratings is that all three groups of engineering stakeholders, i.e., students, faculty and industry, chose Individual and Teamwork as having the highest dependency on Communication Skills. These data, in conjunction with their top relative importance ratings in this study and in the research literature, stress the importance of these attributes and the relevance of this pairing within the engineering curriculum. The highest rated dependencies overall (79%–87%) for all engineering stakeholders were found between Design on Knowledge Base for Engineering and on Problem Analysis; Problem Analysis on Knowledge Base for Engineering; Professionalism on Communication Skills and on Ethics and Equity; Individual and Teamwork on Professionalism; Communication Skills on Individual and Teamwork; Impact of Engineering on Society and the Environment on Ethics and Equity; and Ethics and Equity on Professionalism.

At the other end, all three engineering stakeholder groups differed in the pairs of graduate attributes that received the lowest dependency rating. Even so, each pairing in the lowest dependency rankings for all three groups did comprise a ‘value’ attribute – namely, Professionalism or Ethics and Equity. For students, their lowest mean dependency pairing relationship (44.6%) was found to be the value-attribute *on* a technical skill – Professionalism on Problem Analysis; whereas for faculty and industry, it was a technical skill *on* a value-attribute: Knowledge Base for Engineering on Ethics and Equity

(31.3% for faculty); and Use of Engineering Tools on Ethics and Equity (35.3% for industry). When considering this, paired with students' tendency to rate value-attributes higher than faculty and industry, the question of the importance of the value attributes to students, and how they can be conceptualized in the curriculum is again brought to the forefront. This leads to the concept of clustering the graduate attributes.

5.2.1 CEAB Graduate Attributes Clusters

One noteworthy finding in regards to the dependency ratings was the position the graduate attributes occupied in the perceptual space when they were analyzed using MDS. A 2-dimensional solution was indicated on inspection of the plot. In this space, the graduate attributes can be interpreted as distributed into four quadrants, with Individual and Teamwork, Communication Skills, and Economics and Project Management occupying the third quadrant; Problem Analysis, Investigation, and Knowledge Base for Engineering occupying the fourth quadrant; Ethics and Equity, Impact of Engineering on Society and the Environment, and Professionalism occupying the second quadrant; and Design, Lifelong Learning, and Use of Engineering Tools occupying the first (see Section 4.1.2.4 *CEAB Graduate Attribute Clusters*). Within these quadrants, the data suggests that Individual and Teamwork and Communication Skills are closely clustered, as are Problem Analysis and Investigation; and Ethics and Equity and Impact of Engineering on Society and the Environment are in close proximity, as are Design, Lifelong Learning, and Use of Engineering Tools (see Figure 4.1).

Although it necessitated the MDS analysis to arrange the graduate attributes into these groupings, once they were suggested in the findings, the clusters make sense. Within the engineering curriculum at the University of Manitoba, it is the Engineering

Communications course where elements of Individual and Teamwork and Economics and Project Management are taught and assessed. As well, Investigation and Problem Analysis are frequently conceptually linked; and it is reasonable to link Ethics and Equity with Professionalism and with Impact of Engineering on Society and the Environment, particularly when it comes to topics such as sustainability and diversity, which are at the forefront of engineering educational thinking at present. The exception was one specific cluster: Lifelong Learning with Design and Use of Engineering Tools.

This cluster is particularly noteworthy due to the notorious reputation of Lifelong Learning in the research, and the difficulties of an attribute that seems suited to assessment *a priori*. What is interesting is that there are some schools of thought that equate engineering with Design, holding up Design as the mecca of the profession, whereas Lifelong Learning, contrariwise, has in some sense become engineering education's nemesis. Lifelong Learning is the graduate attribute that has given engineering educators the most cause for consternation when it comes to implementing it into the engineering curriculum. In fact, it has caused so much stir that recently, ABET tried to remove it from their list of student outcomes (Seniuk Cicek, Ingram, and Friesen 2016). This was due to the treatment of Lifelong Learning in the literature with puzzlement and angst – how to teach it? How to assess it? (Shuman, Besterfield-Sacre, and McGourty 2005; Jiusto and Di Biasio 2006). Despite these concerns, enough outcry was heard (Waters 2007; Flaherty 2015; Rogers 2015) that ABET reintroduced lifelong learning to their engineering learning outcomes, demonstrating that lifelong learning is evidently considered valuable for engineers and engineering education, and essentially worth the assessment struggle. In fact, the significance engineers have for lifelong learning is evident in the literature from when ABET first proposed lifelong learning as part of Criterion 3 in the 1990s, and historically, long before (Mourtos 2003; Litzinger, Wise, and Lee 2005; Shuman, Besterfield-Sacre, and McGourty 2005; Martinez-Mediano and Lord 2012). Some engineering educators, who argue for the relevance of lifelong learning, consider it the most important of the professional engineering skills (Uziak 2015). Due to the rapidly changing technological and global nature of society (Litzinger, Wise, and Lee 2005; Uziak 2015), the necessity for engineers to adapt quickly and creatively to this swiftly moving 'modern knowledge' 21st century economy (Martinez-Mediano and Lord 2012) requires the skills and behaviours such as those attributed to lifelong learning. These skills and behaviours need to be developed and identified in students while they are in engineering education programs so that when they enter the field, they are well equipped to adapt to and tackle today's global problems (Altuger-Genc and Chassapis 2011; Martinez-Mediano and Lord 2012; Uziak 2015).

Despite its importance, lifelong learning has often been relegated to an 'information literacy' roll and paired with communication skills in engineering curricula as a solution to finding a concrete approach to teaching and assessing this attribute. Passow and Passow (2017) illustrate this by connecting lifelong learning to communication, and then expanding the definition and connecting it to problem solving: 'Besides coordinating efforts, the major reason that practicing engineers communicate is to gather information. In practice, an engineer "seeks information and uses the art of questioning . . . knows when to seek advice . . . [and] validates facts, information, and assumptions" [34, p. 5] (p. 497). Generally in the Faculty of Engineering at the University of Manitoba, Lifelong Learning is linked to communication in the Engineering Communications courses, where the skills of information literacy are taught and assessed in the context of research and producing an engineering research report. However, embedded in Passow and Passow's (2017) definition is the component of solving a problem: 'Gathering information is motivated by the desire to exceed expectations in solving the problem, which is distinct from expanding one's own skills' (p. 497). Engineers do this by using engineering tools, and through the process of design. It is noteworthy that in the findings of this research study, the graduate attribute, Lifelong Learning, occupies the same perceptual space as Design and Use of Engineering Tools. This underscores the importance of lifelong learning and offers another way to conceive it, suggesting an alternative implementation of this attribute in the engineering curriculum. The findings emphasizes *process*, inherent in the knowledge, skills, attitudes, values, and behaviours of Design and Use of Engineering Tools, which are built on the foundation of problem solving. This reminds educators that design is a process, embarked upon to solve a problem, the skills of which have been said to evolve over a lifetime. Clustering Lifelong Learning with Design and Use of Engineering Tools stresses the importance of keeping abreast of the skills and tools of engineering in this multi-faceted, complex, fast-paced, rapidly changing world, in order to successfully solve its problems.

5.2.2 The Argument for the Interconnectivity of Engineering Competencies

One of the objectives of this study was to develop a conceptual/theoretical framework for the CEAB graduate attributes that would inform engineering curricular design and improvement. Rather than listing 12 individual graduate attributes, using these data, engineering educators can conceptualize clusters of knowledge, skills, attitudes, values, and behaviours that can assist thinking about engineering pedagogy and curricular design.

A conception that one might naturally migrate to in interpreting the perceptual space of the graduate attributes as seen in their 2-dimensionality space is by their division on either side of the y-axis. The groupings on the left contain what are often referred to as the 'professional skills,' with the exception of Lifelong Learning, which is found on the right of the y-axis with the other five more 'traditional' engineering skills. This is a division that has been prominent in the literature since the advent of outcomes-based education and corresponding lists of learning competencies that engineering educators suddenly found themselves required to teach and assess. The relegation of some skills to the 'traditional' (or 'hard') skills of engineering, and other skills to the 'professional' (or 'soft') skills in engineering was a natural split in part caused by the familiarity of engineering educators with the latter group of skills, and the unfamiliarity with the former group, as formalized in the engineering curriculum. This caused an uncomfortable pedagogical dilemma, a separation between what was familiar and what was unfamiliar, and subsequently, what some consider somewhat derogatory labeling. For although one could trace the presence of these 'professional' skills in engineering education historically, and they have always been implicit in the hidden curriculum, there was little requirement for formally teaching and assessing these skills in the engineering curriculum pre-outcomes-based assessment movements that began in the 1990s.

However, this conceptualization of these two groups of skills – the traditional and professional – does not sit comfortably with either the mean relative importance data of the engineering stakeholders in this case, nor with the present literature and ways of thinking about 21st century engineering, which stresses the interrelations and decries the division of the graduate attributes into these binary labels. As Sheppard, Pellegrino, and Olds (2008) write: 'It would be naive to treat technical and non-technical challenges and opportunities as separable… Technical and non-technical issues are inextricably and increasingly linked, as the boundary between "autonomous, non-human nature and human generated processes" become increasingly blurred' (p. 231).

In fact, an unexpected finding in the literature was the pattern of concern for the division between the 'technical' and 'professional' skills – not just in how to teach and assess them (Shuman, Besterfield-Sacre, and McGourty 2005), but in the undercurrent (or at times explicit) disregard for the 'professional' skills and their perceived lack of importance compared to the 'technical' skills (Caron et al. 2014 p. 49). Male (2010) acknowledges the denigration of what are perceived of as the less-traditional engineering skills, and suggests that 'Engineering educators should focus on developing "generic engineering competencies" in their students,' arguing that 'Academics' use of the term "generic engineering competencies" will model respect for both aspects of engineering competencies: generic competencies and engineering-specific competencies overcoming the relatively low status of generic competencies in engineering and engineering education cultures' (p. 41). Male, Bush, and Chapman (2011b) debate that engineering educators should be cognizant of not – either consciously or unconsciously – explicitly or implicitly degrading generic competencies that are not perceived as 'real engineering':

> Engineering educators must give their students a realistic understanding of engineering work and the competencies required by engineers, recognizing the significance of work and competencies that are not obviously technical. Engineering educators must be careful not to undermine the importance of competencies by accidentally implying that they are not important through actions or communication… and to assess demonstration of competencies without bias that underrates the importance of these competencies. (p. 151)

Ironically, as already discussed and demonstrated in this thesis, despite the undercurrent of undervaluing generic competencies, the research findings repeatedly suggest that these skills are in the top clusters of attributes required for engineers as perceived by engineering stakeholders. As such, there is a movement for the dissolution of this binary division in engineering competencies. The case Male, Bush, and Chapman (2011b) make for a shift to engineering generic competencies supports both technical and non-technical components, aptitudes required by all engineers across all disciplines in the field (p. 147).

The theme of the interconnectivity of engineering competencies emerged in Passow and Passow's (2017) qualitative findings as well. They found that engineering practice requires 'Coordinating multiple competencies to accomplish a goal' (p. 500). They further state that 'The interrelationships among generic engineering competencies extend beyond the inseparability of technical and collaborative activities' (p. 500). They illustrate this phenomenon in a 'portrait of practice':

> Engineers work in technical contexts to create, implement, and maintain reliable solutions that meet client needs within constraints such as those imposed by technical and manufacturing feasibility, time, budget, business context, codes, regulation, ethics, politics, and impacts on safety, health, the environment, local community, and global society. Engineering work requires technical competence intertwined with effective collaboration because the systems surrounding the "technology-in-the-making" [53, p. 151] are too complex for one person to fully know or implement, making "coordination and overlap . . . both necessary and unavoidable". (p. 492)

If engineering educators consciously refuse to artificially separate the knowledge, skills, attitudes, values, and behaviours essential for engineering work today, engineering educators will move towards a shift in mindset that is required to re-envision engineering curricular design.

Considering the four quadrants defined by the dimensionality that may be interpreted from the MDS common space, the CEAB graduate attributes can be re-conceptualized into four new clusters. The bottom right cluster (quadrant 4) could be termed *Problem Solving Skills*, as problem solving is considered a quintessential engineering skill (Hanrahan 2008) and is a top engineering competency (Passow 2012). This cluster would be comprised of the graduate attributes, Knowledge Base for Engineering, Investigation, and Problem Analysis. The bottom left cluster (quadrant 3), with Communication Skills, Individual and Teamwork, and Economics and Project Management, and the addition of the behavioural elements of Professionalism (i.e., the indicator as defined for the Faculty of Engineering at the University of Manitoba, *exhibits behaviour expected of a Professional Engineer*) could be redefined as the *Interpersonal Skills*, which are demarcated as communication and interaction with people and flagged as one factor for successful employability (SkillsYouNeed 2017). The top left cluster (quadrant 2) could be called *Ethical Reasoning*, a term taken from Sheppard, Pellegrino, and Olds (2008), deemed essential for 21st century engineering, and containing the more cognitive aspects of Professionalism (i.e., the indicators, *understands the role of the engineering profession in society and the responsibility of the Professional Engineer in protection of the public*; and *knows relevant codes, laws and regulations*), along with Ethics and Equity, and Impact of Engineering on Society and the Environment. The upper right cluster (quadrant 1) could be termed *Creativity and Innovation*, the latter which Radcliffe (2005) describes as the 'meta-attribute' for engineers, with both capabilities stressed in the literature as critical engineering competencies (Robinson et al. 2005, p. 128; Male 2010, p. 35). It would encompass the engineering skills Design, Use of Engineering Tools, and Lifelong Learning (see Figure 5.1).

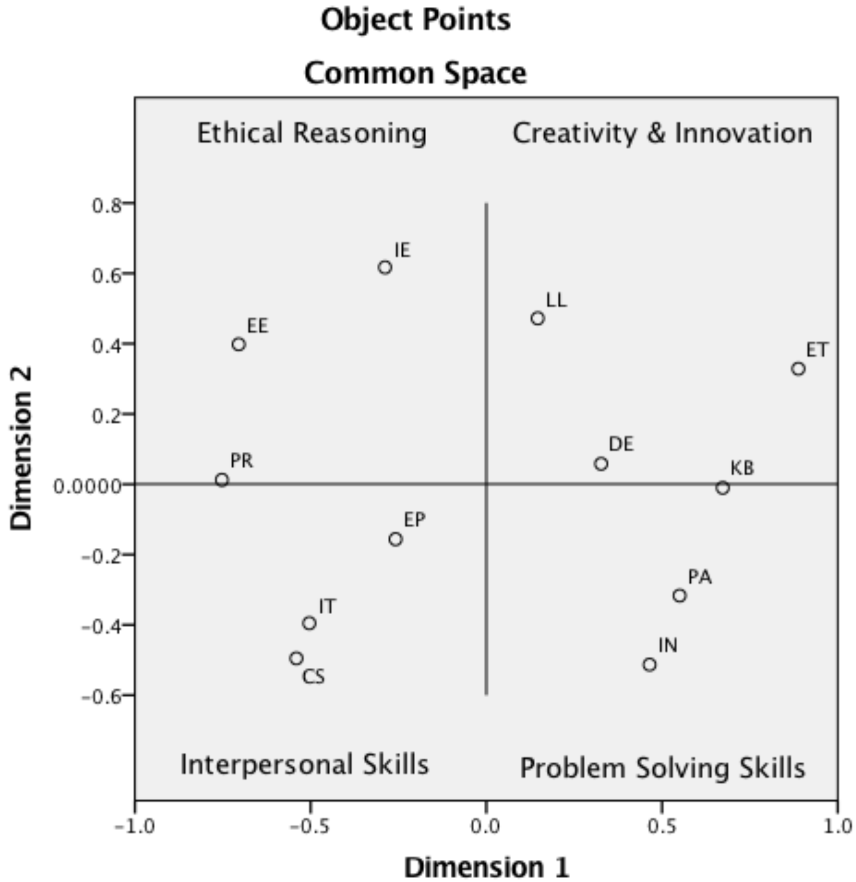


Figure 5.1. Conceptualization of four clusters of engineering competencies in the MDS common space.

Within these clusters, engineering educators can develop the engineering competencies necessary for 21st century practice. As research underscores, engineering educators need to provide authentic educational *experiences* that facilitate students in acquiring *all* the competencies necessary to be successful engineers today: engineers who are ready, willing, and able to tackle 21st century wicked problems, and to be the ambassadors between society and technology, vital as engineering educators face global concerns. Conceptualizing four clusters of engineering competencies rather than 12 listed graduate attributes may help engineering educators focus on designing learning environments using experiential learning that draw on clusters of competencies, rather than implementing curricula that inauthentically isolate engineering knowledge, skills, attitudes, values, and behaviours. As with the stakeholders in this case, who support the interconnection of the graduate attributes, and discussed previously in this thesis, research stresses:

> All engineering is, of necessity, *both* technical and social… *Good* engineering (as in engineering which is effective) demands the thorough integration of these elements in ways that *transcend* conventional dichotomies [50, p. 351 emphasis in original]. The knowledge mobilized in the course of engineering . . . is never "just technical" with "the social" bolted on. Rather, these two dimensions are in a very practical sense inseparable… Since the two are inseparable in everyday engineering practice, the boundaries drawn between them are inevitably arbitrary. (Passow and Passow 2017, p. 491)

All in all, evident in the literature, society's challenges compels new engineering graduates to 'be all things' – knowledgeable, skillful, and emotionally intelligent, showing prowess in cognitive, psychomotor, and affective abilities – which requires curricula that facilitates engineering students to interact with a myriad of knowledge, skills, attitudes, values, and behaviours simultaneously. This recalls the work of Bloom, and his three Domains of Learning, which may be used to theorize the CEAB graduate attributes in the MDS common space.

5.2.3 Bloom's Taxonomies: A Theoretical Framework for Conceptualizing the CEAB Graduate Attributes

Bloom's cognitive taxonomy (Bloom et al. 1956) has been quite prominent in Canadian engineering schools since the advent of the new accreditation graduate attribute requirements (Frank and Fostaty-Young 2011; Harris, Steele, and Russell 2011; Spracklin-Reid and Fisher 2012; Sepehri et al. 2013); similarly in ABET accredited programs (Pimmel 2003). Bloom's Taxonomy of Knowledge arose out of the idea to develop a classification system that reflected people's thinking processes while they were learning. Three domains were identified: Cognitive (knowledge/thinking), Affective (attitude/emotions/feelings), and Psychomotor (kinesthetic/skills), and all versions were eventually published, although the cognitive taxonomy remains by far the most renowned, and is the go-to taxonomy for many educators (Forehand, 2005, p. 42).

It was Bloom's cognitive taxonomy that was used in the Faculty of Engineering at the University of Manitoba when the new outcomes-based accreditation requirements were first introduced as a way to conceive the performance levels for each attribute, equating students' levels of performance to knowledge, comprehension, application, analysis, synthesis, and evaluation. There were difficulties in this. Firstly, there was the implication that higher grades were associated with the higher cognitive abilities; thus, evaluation equated an 'A' grade, notwithstanding the fact that perhaps not all academic performances might require 'evaluation.' Another confusion was whether students should go through all levels of the cognitive taxonomy in all courses through all years of the program, or whether the engineering curriculum should be conceived holistically, with students moving toward 'mastery' as they moved through each year of the program. Thereby, the levels were somewhat ill defined when applied to the curriculum.

Further difficulties arose in the assumption that all components required to competently engage in the knowledge, skills, attitudes, values, and behaviours necessary for each graduate attribute could be conceived and performed in a cognitive structure, including the value-driven attributes such as Ethics and Equity, and the motor-driven skills, such as Use of Engineering Tools. The concern is that although useful when assessing knowledge attributes, Bloom's cognitive taxonomy could be limited when used to describe the skills, values, attitude, and behaviour-based elements of the attributes.

Questions surrounding the relevancy in using the taxonomy in the way it was applied in the Faculty of Engineering curriculum included: (1) Do all levels in the taxonomy exist as a consecutive part of this hierarchy, or do some levels command equal weight? (2) Should Bloom's cognitive hierarchy correspond to the hierarchy of years in the engineering program, or to the hierarchy towards mastery within each course? (3) Do some attributes fit naturally within a particular level of the taxonomy, or should each attribute proceed through all levels, ultimately targeting the highest level, *evaluation*? (4) Do all attributes fit within a cognitive taxonomy?

Perhaps as a result of these concerns, in the Faculty of Engineering at the University of Manitoba, in many cases, the structure of Bloom's as performance levels for assessing students' competencies in the graduate attributes has now given way to the use of a set of graduate attribute rubrics that were developed in the faculty to characterize the knowledge, skills, attitudes, values, and behaviours inherent in the CEAB graduate attributes. These rubrics are structured on four levels of performance: *Strong, Competent, Developing,* and *Needs Work* (Seniuk Cicek, Ingram, Sepehri, Burak et al. 2014). These levels describe the quality of students' competency for performing each indicator, rather than a particular cognitive behaviour.

In this regard, with the history of the use of Bloom's within the Faculty, the researcher did not expect to look to Bloom's taxonomies as a way to theorize this research. However, the clusters of the CEAB graduate attributes in the common space suggest Bloom's three Domains of Learning. The Cognitive and Psychomotor Domains are conceptualized as occupying quadrants 1 and 4. The Affective Domain is conceptualized as occupying quadrants 2 and 3. Further, one can interpret the directionality of the graduate attributes as moving up the y-axis (Dimension 2), which is an evolution from the lower order through to the higher order learning of the Cognitive, Psychomotor and Affective Domains.

For example, consider Bloom's Cognitive Domain. From a constructivist point of view, interacting with the knowledge required of Investigation and Problem Analysis leads to knowing/understanding in engineering (i.e., Knowledge Base for Engineering). This provides a foundation for engaging in Design, and the knowledge required to develop the skills for using engineering tools (Use of Engineering Tools). The knowledge that is acquired through these processes lead to mastery level competencies, which are characteristic of the aptitudes inherent in Lifelong Learning. In this conception, the attributes can be seen to reflect Bloom's new cognitive taxonomy. Students move progressively from lower order Problem Solving Skills to higher order Creativity and Innovation by Remembering, Understanding, Applying, Analyzing, Evaluating, and Creating (see Figure 5.2).

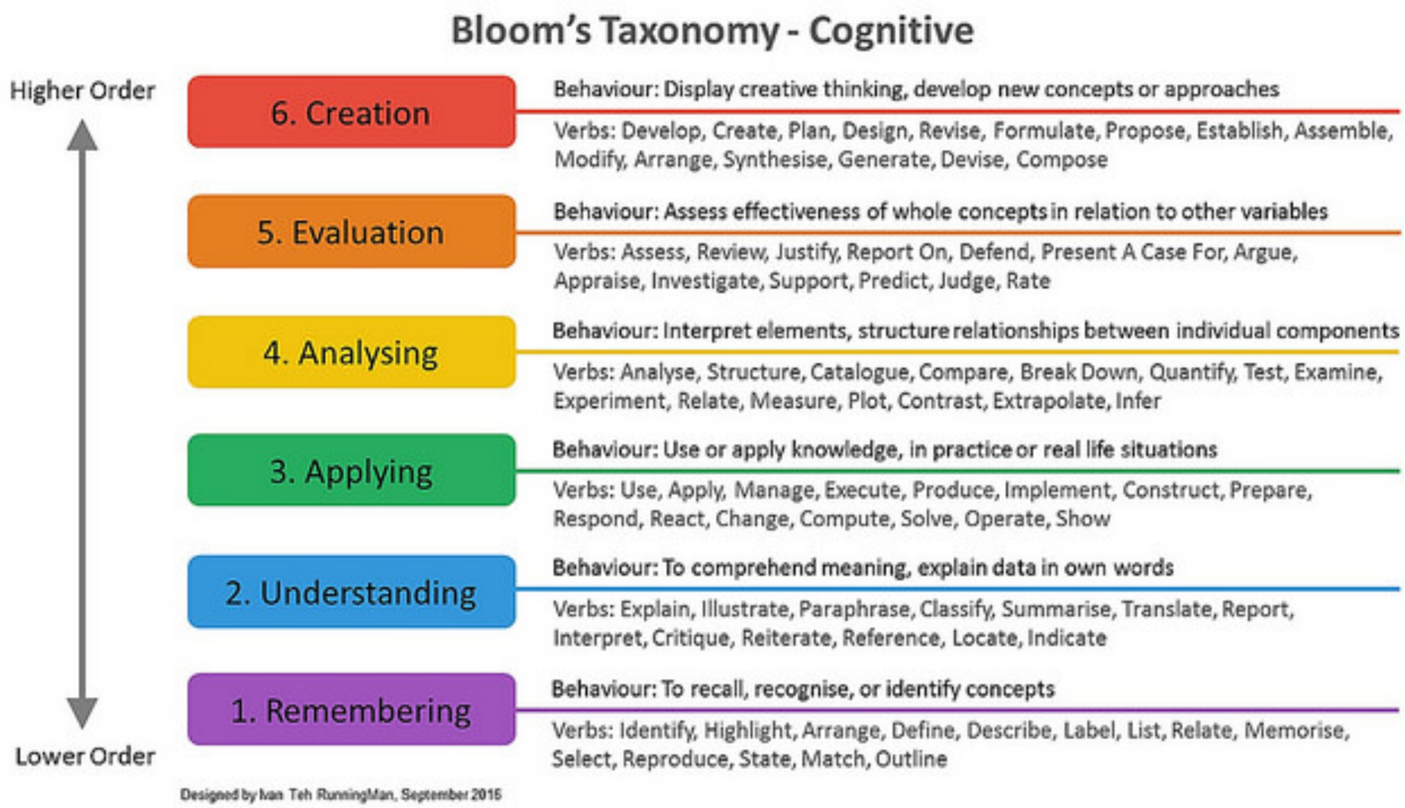


Figure 5.2. Bloom's Taxonomy – Cognitive (Teh 2016).
Used with permission.

Concurrently, through the same quadrants (4 and 1), students are moving vertically through the Psychomotor Domain. They engage in the motor skills required for Problem Solving Skills and Creativity and Innovation using Imitation, Manipulation, Precision, Articulation, and Naturalization. This includes hands-on activities such as: laboratory investigations; executing experiments; prototyping designs; building and demonstrating proof-of-concepts; programming language interfaces, models and/or simulation of systems; measuring and monitoring software and instruments; and using research and information literacy skills (see Figure 5.3).

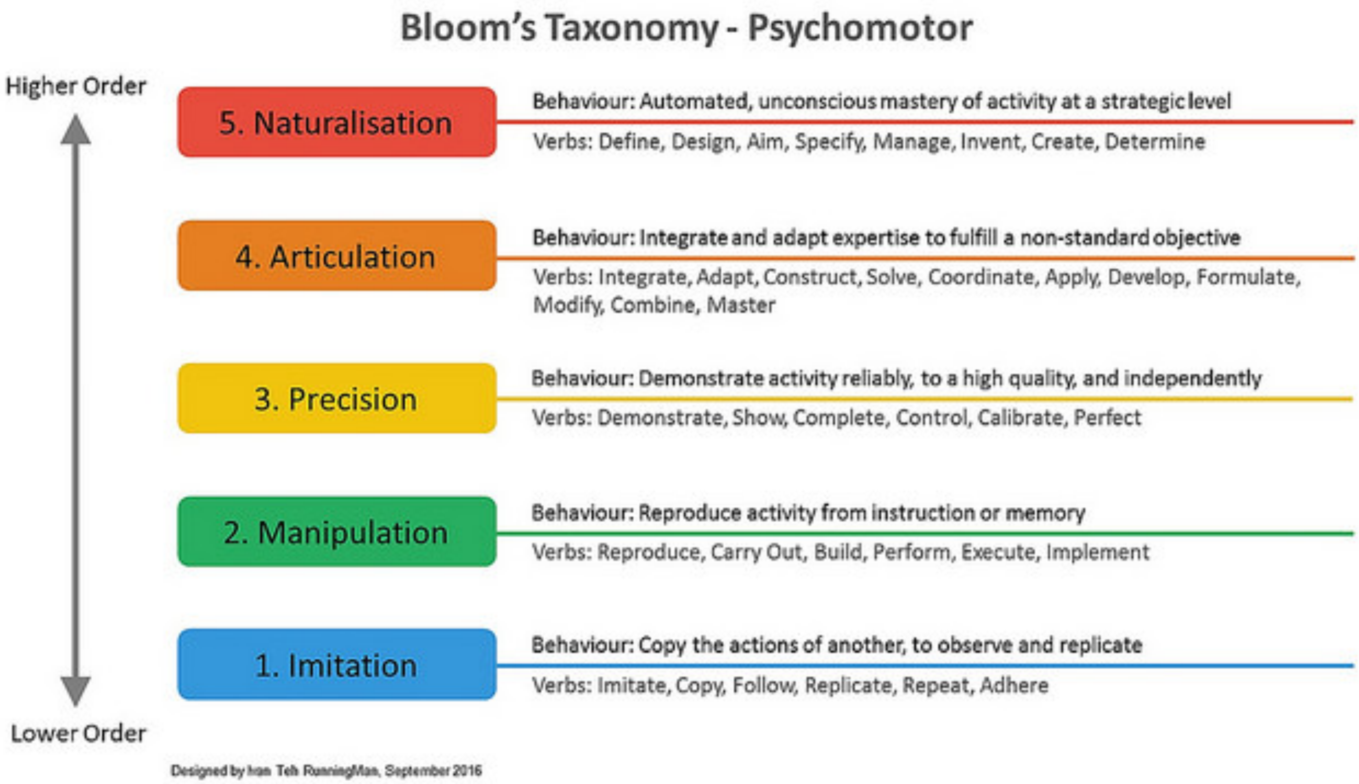


Figure 5.3. Bloom's Taxonomy – Psychomotor (Teh 2016).
Used with permission.

In parallel, and integrated with their cognitive (knowledge) and psychomotor (skills) learning, students move directionally from the bottom to the top of the Affective Domain (quadrants 3 and 2). They learn how to effectively communicate in an engineering community of practice. This includes listening actively, asking meaningful questions, and articulating key ideas (i.e., Communication Skills). They apply and enhance these behaviours to work successfully in teams through fostering a positive team climate; maintaining composure in difficult situations; organizing and managing team members and activities; and evaluating team effectiveness and planning for improvement (i.e., Individual and Teamwork). They employ their teamwork and communication skills to manage authentic engineering projects by understanding clients' needs; evaluating and adapting projects; and applying change management techniques (i.e., Economics and Project Management). All the while, they are assuming responsibility for their own actions and increasing their understanding of what is required in becoming a professional, both in regards to behaviour as well as context-specific Professionalism (i.e., the discipline of engineering, or being a Professional Engineer/P.Eng.). Concurrently, they are honing their personal (moral), company-specific (employment contract), professional, and legal ethical values whilst learning to behave ethically, equitably, and with inclusivity in the profession (i.e., Ethics and Equity) (Hall 2016). Finally, they apply all of their Affective behaviours to their consideration of the Impact of Engineering on Society and the Environment, recognizing the personal (internalizing) and collective responsibility of engineering and its interventions on society and the environment. In attaining competency in Interpersonal Skills and Ethical Reasoning, students practice Receiving, Responding, Valuing, Organizing, and finally Internalizing behaviours in the context of becoming an engineer (see Figure 5.4). (For a comprehensive list of the 12 CEAB graduate attributes and their indicators, and a description of activities that exemplify the indicators and reflect the Cognitive, Psychomotor and Affective Domains of Bloom's taxonomies, see Appendix I: *University of Manitoba Faculty of Engineering Graduate Attribute Indicators and Descriptors*, which have been recently adapted from the *Graduate Attributes and Indicators* developed by Razavinia and Mydlarski (2016) at McGill University.)

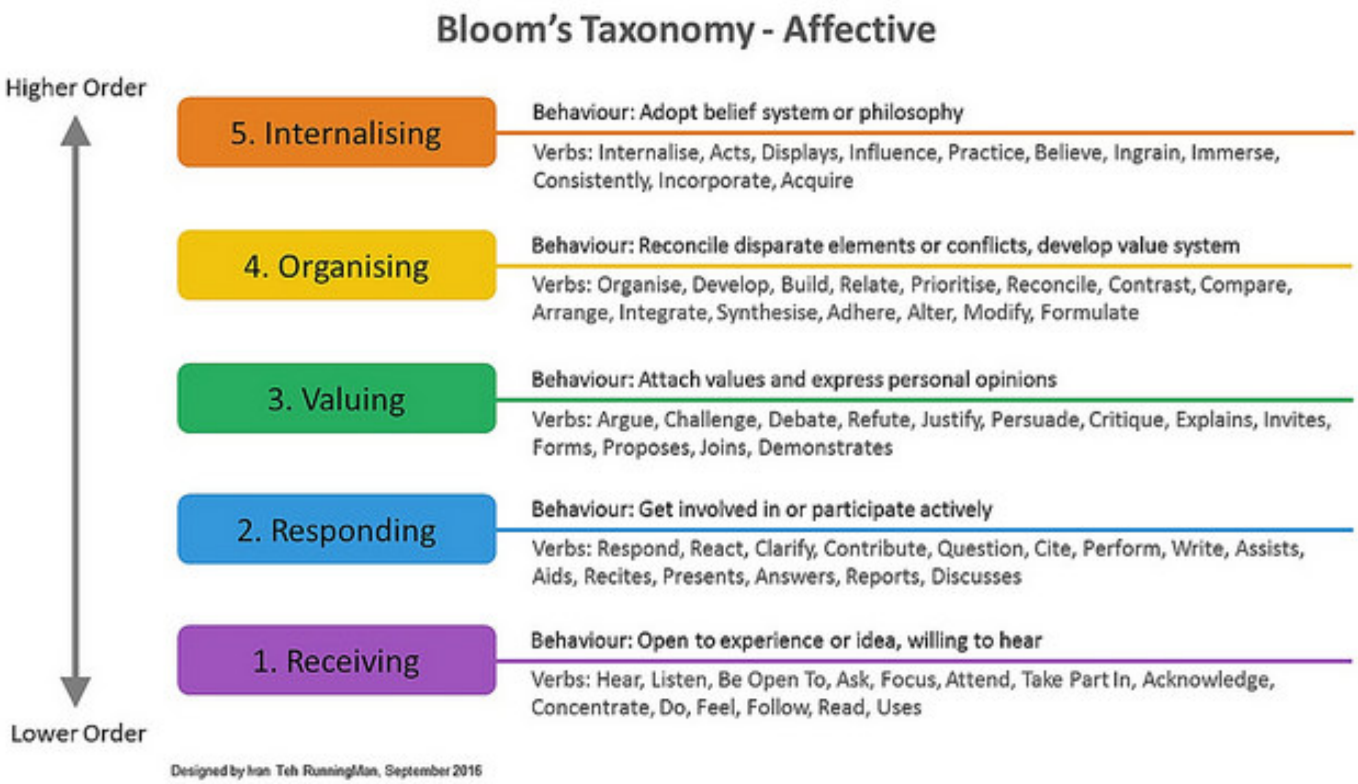


Figure 5.4. Bloom's Taxonomy – Affective (Teh 2016).
Used with permission.

To illustrate the relationship between Bloom's three Domains of Learning and the four CEAB graduate attributes clusters, the MDS 2- common space is re-conceptualized. A triangle is superimposed in the space to represent students' progressive movement from the lower order to the higher order learning domains. The two sides of the triangle, which move upwards from separate points on the base to meet at the vertex, signify students' pathway through the graduate attribute clusters and their related learning domains. The median illustrates the conceptualization of the learning domains on each side of triangle and common space. The left side represents the pathway of the Affective Domain, where students advance through Interpersonal Skills to Ethical Reasoning; the right side represents the pathway of the Cognitive and Psychomotor Domains, where students progress through Problem Solving Skills to Creativity and Innovation. The intersection of both sides of the triangle at the top vertex demonstrates students' completed progression through the four clusters of engineering competencies and related learning domains: at the vertex of the triangle, students have attained graduate attribute competency in Interpersonal Skills, Problem Solving Skills, Ethical Reasoning, and Creativity and Innovation, and are conceptualized as transitioning into their new identity as Engineers-in-Training (see Figure 5.5).

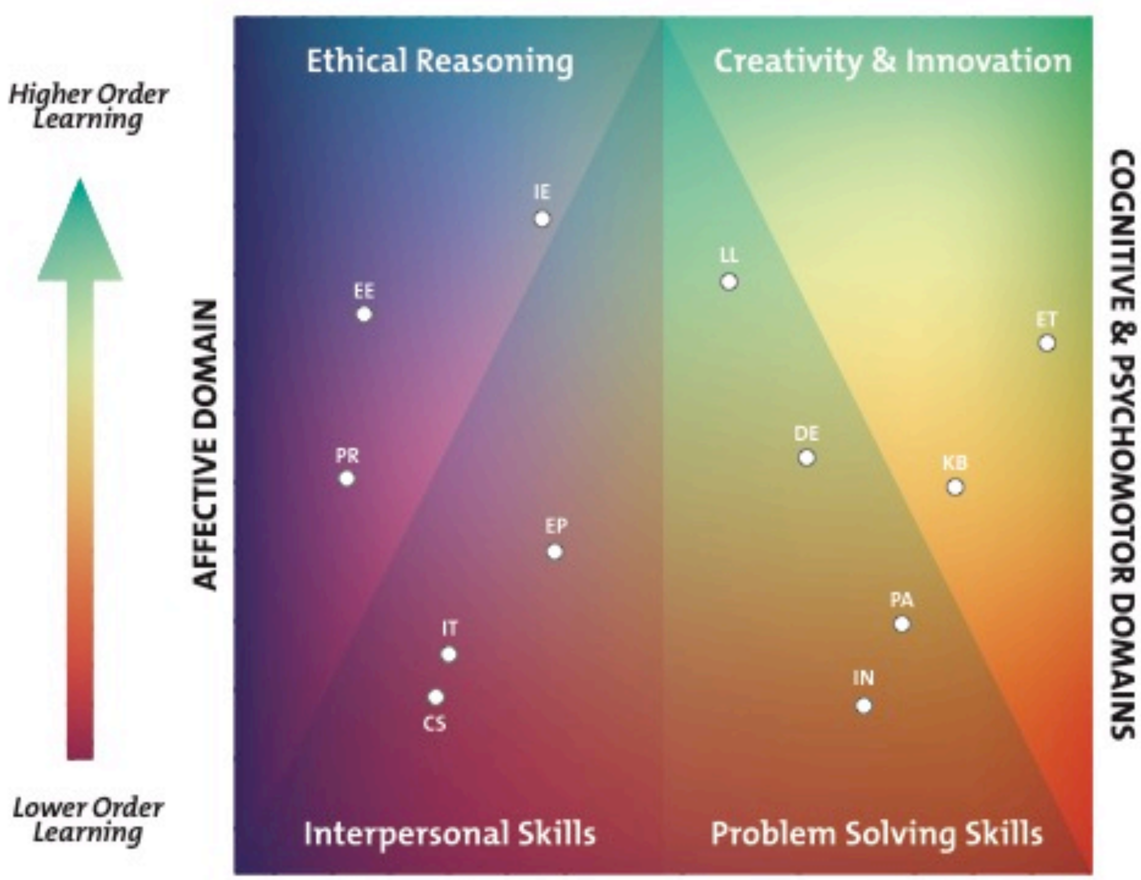


Figure 5.5. Conceptualization of the CEAB graduate attributes through the lower to higher order domains of Bloom's Learning Taxonomies in the MDS common space. *Note. Graphic design attributed to Danielle Anderson, Swish Design and Communication.*

Lifelong Learning, which is found in the Creativity and Innovation cluster in the Cognitive/Psychomotor Domain, is positioned in proximity to the median, towards the higher order Affective Domain. This location aligns with the description of Lifelong Learning found in the literature. Lifelong Learning can be conceived as 'comprised of two facets that [require] two different sets of skills: the 'recognition of the need' requires the skills in the affective domain, while the 'ability to engage' requires the skills in the cognitive domain' (Mourtos 2003 as cited in Seniuk Cicek, Ingram, and Friesen 2016). Furthermore, Lifelong Learning, conceptualized as self-directed learning, comprises a multitude of higher order aptitudes. These are characterized by Litzinger, Wise, and Lee (2005) as 'curious/motivated; methodical/disciplined; logical/analytical; reflective/self-aware; flexible; interdependent/interpersonally competent; persistent/responsible; venturesome/creative; confident; independent/self-sufficient.' They also define Lifelong Learning *skills*, such as highly developed information seeking and retrieval skills; knowledge about, and skills to engage in the learning process; and skills for evaluating and engaging in critical thinking (as cited in Seniuk Cicek, Ingram, and Friesen 2016). These descriptions support the theorization of Lifelong Learning situated in both the Cognitive/Psychomotor and Affective Domains (see Figure 5.5).

Interestingly, in this interpretation, Impact of Engineering on Society and the Environment is positioned above every other graduate attribute, including Lifelong Learning, in what is conceptualized as the higher order Affective Domain of Ethical Reasoning. This signifies the higher order learning required of this graduate attribute. Impact of Engineering on Society and the Environment is given relatively lower importance by the engineering stakeholders in this study comparatively to the other graduate attributes. Conversely, the top three engineering competencies in the literature, Teamwork, Communication Skills, and Problem Solving – the first two of which are rated as the top competencies in these research findings – are found in this theoretical conceptualization in the lower order learning of the common space for the Affective and Cognitive/Psychomotor Domains. This could be due to the foundational importance of these attributes to engineering education. For example, students must be competent with the aptitudes that comprise the Interpersonal Skills and the Problem Solving Skills before they can move on to developing their capacities for the remaining graduate attributes. This interpretation also demonstrates the complexities inherent in the Ethical Reasoning and Creativity and Innovation clusters, which are positioned in the higher order learning of the common space. This theoretical framing of the graduate attribute clusters in lower and higher order learning domains is a way to theorize engineering students' attainment of the graduate attribute competencies found in the Cognitive/Psychomotor and Affective Domains and their subsequent transition from novice to expert. It is worth considering when designing curriculum.

Generally, the theorization of progressing through the lower to higher order learning Cognitive, Psychomotor and Affective Domains in the common space supports the conceptualization of the interconnectivity of the graduate attributes, as the ability to acquire competencies for one graduate attribute is dependent upon the ability to achieve proficiency in another. This is demonstrated by the proximity of each of the clusters to the other clusters. For example, the Problem Solving Skills cluster's contiguity to the Creativity and Innovation cluster; Interpersonal Skills to Ethical Reasoning; and Ethical Reasoning to Creativity and Innovation. Overall, using Bloom's Learning Domains as a theoretical framework for interpreting the CEAB graduate attributes supports 'coordinating competencies' (Passow and Passow 2017, p. 501). It endorses an inverted interpretation of the original linear list of the CEAB graduate attributes, with the numbers 1–12 representing ascension rather than dissention to the higher order learning competencies.

5.2.4 Educating the 'Whole' Engineer: Diversifying Engineering Education

The theoretical conceptualization of the CEAB graduate attributes residing in Bloom's three Domains of Learning – the cognitive, affective, and psychomotor – is particularly relevant in today's vision of the 21st century 'whole' engineer. McGourty, Besterfield-Sacre, M., and Shuman (1999) theorize that

> …a true learning outcome *integrates* the cognitive, attitudinal and behavioural components. True learning outcomes are a demonstration that knowledge does not exist apart from application. In fact, they are tightly coupled. The attitudinal element indicates that the individual not only is capable of doing 'engineering work' but also embodies values of the profession. (p. 3)

Integrating the affective domain with the cognitive and psychomotor domains in support of teaching 'generic competencies' is especially important in cultivating engineering education today as engineering educators move towards diversifying the students whom are attracted to the field, and diversifying the learning environments and the ways of knowing. Examples such as 'indigeneering' (Burgart 2017) engineering knowledge are enabling a richer and deeper understanding of the field, with concepts like sustainable engineering design (Striebig, Ogundipe, and Papadakis 2016, as referenced in Beddoes and Friesen 2017) gaining prominence in today's engineering curriculums. Male, Bush, and Chapman (2011b) emphasize the significance of teaching generic competencies within a diverse engineering framework via variation in engineering programs in order to invite diversification of the types of students who are attracted to, and come in to engineering:

> Engineering educators should design their programs with an understanding that diverse programs and diverse graduates are desirable because different jobs place different importance on the generic engineering competencies. This is one reason that engineering educators should seek to recruit a diverse range of students. Flexibility within programs, or at least diversity among programs, is also recommended. (p. 151)

Communication skills, significantly, are linked to diversity in the literature, as well as to emotional-intelligences. Passow and Passow (2017) offer this broad definition for Communication Skills as an engineering competency: 'Communicate effectively with people that have diverse goals and backgrounds – across disciplines, organizational levels, and organizational boundaries, through listening, oral, written, and graphical means' (p. 497). They underscore the importance of listening, emphasizing that the execution of this skill requires intelligences in interpersonal skills: one's attitude, behaviour, and values for respect. Considering the importance of these multi-faceted generic competencies is how 21st century students become 'whole new engineers' (Goldberg and Summerville 2014). This is the movement that is seen in the social conscious engineers who perceive the role of the engineer as a conduit between technology and society. As stated by Engineers Without Borders (EWB) (2017):

> The engineering profession has a unique and vital role to play in ensuring we move towards the world we want to see—one with more universal equality, sustainability and wellbeing. The reason is engineers play a key role in shaping the relationship between technology and society, which will have massive implications on all aspects of humanity. Technology holds the potential to drive economic development, tackle the sustainable development goals and grand challenges of the 21st century, and even enhance our very humanity through increased connectivity and higher creativity. For the engineering profession to live up to its full potential and guide this relationship, we believe engineers will have to develop new skills and expand their understanding. Through increased socio-technological expertise, the engineering community can enact more impactful leadership.

Trevelyan (2014) shares this vision:

> The links between engineering practice and the physical sciences are unquestioned yet the equivalently strong links between engineering practice and the human sciences seem to be missing. The language of the Grinter report (1955) reflects this separation. Mathematics, physics and chemistry were labeled as the "foundations of engineering curricula''. Inclusion of studies in the humanities, "an acquaintance with the social sciences'', on the other hand, was justified on the basis that a graduate "must be not only a competent professional engineer, but also an informed and participating citizen, and a person whose living expresses high cultural values and moral standards''. This language remains unchanged in engineering academies today where professional skills are widely regarded as non-technical components of engineering, on the curricular margin, yet this is refuted by many of the observations of engineering practice reported in this book that demonstrate that collaboration based on social interactions lies at the core of technical practice. As the Grinter report acknowledged, insights gained from the arts, humanities and social sciences are critical for professional competence. (p. 37)

In order to facilitate engineering students to play a vital societal role, educators must take into account the whole engineer, focusing not only on the cognitive and psychomotor abilities of students, but also on the affective intelligences, and design interconnected, authentic, holistic engineering curricula. Passow and Passow (2017) demonstrate the need to think about engineering competencies with increasing complexity. Rather than distilling the competencies and defining their components, they argue for a far more robust conceptualization of engineering competencies to authentically reflect engineering practice and educate the whole engineer. Engineering stakeholders' perspectives on the dependencies of the CEAB graduate attributes with the groupings of the attributes into four quadrants, theoretically interpreted through the lens of Bloom's cognitive, affective, psychomotor domains, provide a framework through which to do so.

5.3 The Content Validity of the Biosystems Engineering Program

Overall, when comparing the percentages of course content coverage and course assessments for the 35 core BIOE courses to the mean relative importance perceived by all engineering stakeholder groups in this case, the findings suggest that the BIOE program does not have content validity with this measure. The BIOE program emphasizes the Cognitive Domain, i.e., Knowledge Base for Engineering, Problem Analysis, and Design over the Affective Domain, with the exception of Communication Skills, which is accentuated over Investigation and Use of Engineering Tools (the Psychomotor Domain). What is even more noteworthy is that almost 50% of the course content coverage and course assessments in the BIOE program are relegated to Knowledge Base for Engineering. This is in sharp contrast to not only the perceived mean relative importance of all engineering stakeholders in this case, which has a value of 9.1% overall, but also to the literature in the area, which place Knowledge Base for Engineering in the third group of importance for engineering competencies before Problem Analysis, Communication Skills, Teamwork, Lifelong Learning, and Ethics and Equity (Passow and Passow 2017). Also noteworthy is that Individual and Teamwork is given the second lowest attention in the BIOE curriculum, at 1.3%. This is again contrasted sharply with the 10.9% – the top rated mean relative importance – which stakeholders ascribe to it in this case, and to its prominence as an engineering competency in the literature. When the course content coverage and course assessments are positioned in the four clusters of engineering competencies comparatively with the engineering stakeholders and their perceived mean relative importance of the CEAB graduate attributes and with Passow and Passow's (2017) research findings, only Use of Engineering Tools, Investigation, and Economics and Project Management in the BIOE program align with the groups of importance in the other two groups (see Table 5.2).

Table 5.2
Comparative view of ranked order of mean relative importance of the CEAB graduate attributes for all engineering stakeholders, Passow and Passow's (2017) top 4 groups of engineering competencies, and percentage of course content coverage and assessment in the BIOE program.

Four Groups of Relative Importance	All Stakeholders Mean Relative Importance	Passow and Passow's (2017) Top 4 Groups of Eng. Competencies	BIOE % of Course Content Coverage/ Assessments
1	Ind. & Teamwork 10.9% Communication 10.8% Professionalism 9.4% Knowledge Base 9.1% Problem Analysis 9.0%	Problem Solving Communication Teamwork	Knowledge Base 48.8% / 47.7%
2	Ethics & Equity 8.8% Eng. Tools 8.3%	Ethics Lifelong Learning	Problem Analysis 12.9% / 14.4% Design 10.7% / 10.8% Communication 7.5% / 7.3%
3	Investigation 7.2% Lifelong Learning 7.1% Design 7.0%	Knowledge Base Eng. Tools Investigation Design	Eng. Tools 4.7% / 3.8% Investigation 4.6% / 5.1% Impact of Eng. 4.1% / 4.1%
4	Impact of Eng. 6.3% Eco. & Proj. Mngt. 6.1%	Contemporary Issues Impact	Lifelong Learning 1.5% / 1.2% Ind. & Teamwork 1.3% / 1.3% Professionalism 1.3% / 1.3% Ethics & Equity 1.3% / 1.4% Eco. & Proj. Mgt. 1.2% / 1.7%

Note. The BIOE program is ranked by course content coverage.

Other important considerations for the BIOE program include the minimal emphasis on the affective attributes, Professionalism and Ethics and Equity, and the attribute, Lifelong Learning, which are not only rated comparatively higher in relative importance by all engineering stakeholder groups, but are more relatively important particularly to the student stakeholders in this case. Considering increasing the emphasis on these attributes would potentially benefit the program in attracting an even more diverse student population. By appealing to a broader range of potential applicants via the diversification of the competencies perceived as valuable to engineering, the department can enlarge the understanding of what engineering is, and can be (Pawley 2009).

Additionally, although Communications Skills is receiving relatively more weight in the BIOE program than the other affective attributes, students would benefit from increased emphasis, according to the research in this case and the literature. Critical to these findings is the minimal attention given to Individual and Teamwork in the BIOE curriculum, particularly in view of its prominence as a top engineering competency for Industry stakeholders in the literature (May and Strong 2011). It is vital going forward that content coverage of this attribute increases.

Finally, it is evident that Knowledge Base for Engineering has imbalanced impact on the BIOE curriculum when considering the mean relative importance given it in both this case and in the literature. How to de-emphasize the weight of Knowledge Base for Engineering in a curriculum so heavily loaded with this attribute while maintaining the knowledge base necessary for the profession is a fundamental problem that requires solving if the other attributes are to be given the weight that their relative importance suggests. All of these implications are considered in relation to suggestions for improvements in the upcoming Section 5.4.1 *Suggestions for the Biosystems Engineering Program.*

5.4 Implications of the Research for Curricular Design: Preparing Students for Engineering Practice

The overarching implications for curricular design suggested by this study, and supported by the literature, is the concept of clustering the graduate attributes, or as Passow and Passow (2017) state, 'coordinating competencies.' The authors' support what they term as 'a paradigmatic shift' for engineering education curriculum design:

> [The data] revealed three simple, yet paradigm-shifting principles for curriculum design pertaining to coordinating competencies as in practice:
>
> [1] ...engineering work extends far beyond science-based tasks to activities, both technical and social, that are critical to project success, such as controlling scope, error checking in design, and communication…
>
> [2] "Non-technical skills cannot be taught in isolation from the technical context in which they will be used, and . . . integrated projects are a crucial tool for achieving such ends." [49, p. 179]
>
> [3] Engineering education needs a greater connection to practice from the first day…including hands-on problem solving of authentic, ill-structured problems within constraints…iteration…working toward a big picture goal…and realistic social elements …such as working with clients, gathering information, coordinating technical work, work-like writing and speaking, and demonstrating professional behavior. (p. 501)

Whilst their study unequivocally supports this approach to holistic curriculum design in engineering education, and certainly, this thinking requires a shift from traditional approaches in engineering education (Yadav et al. 2011; Seniuk Cicek, Ruth, and Ingram 2013), Passow and Passow's (2017) suggested 'paradigm shift,' while necessary in engineering education, is not novel. The authors are supporting authentic, outcomes-based, active learning pedagogies, which are prevalent in educational paradigms, and although perhaps not as commonly or as extensively used in engineering education, certainly, the shift has begun. What is essential is that these research findings, and research findings globally, are used to support changes to engineering education curricular design and pedagogical practice, as it is the transfer from research to practice that is shown to be wanting in the field (Finelli, Daly, and Richardson 2014).

Indeed, Male (2010) argues that there is a divide between engineering education and engineering practice. She states: '…university engineering educators have a responsibility to society and to engineering students to develop competencies required for engineering work' (p. 26), demonstrating that 'gaps in communication, leadership, and social skills [are] highlighted' (p. 27). Further, she goes on to write, 'A cluster of literature, especially from around the time when outcomes were being introduced in engineering education, has discussed concerns about the focus of engineering education on theory and analysis at the expense of creativity, problem solving, innovation, design, ethics, reflection, and complex systems, as required for engineering practice' (p. 27) and underscores that 'the alignment between engineering education and work has been questioned in several studies' (p. 28).

These concerns are repeated by Passow and Passow (2017), who describe a report entitled, *Educating Engineers: Designing for the Future of the Field* by Sheppard et al. (2008) that details 'the shortcomings of engineering education and set the goal that future curricula prepare students for practice' (p. 504). They quote Sheppard et al. (2008):

> The central lesson that emerged from our study is the imperative of teaching for professional practice – with practice understood as the complex, creative, responsible, contextually grounded activities that define the work of engineers at its best; and professional understood to describe those who can be entrusted with responsible judgment in the application of their expertise for the good of those they serve. (as quoted in Passow and Passow 2017, p. 504)

Undeniably, industry, thus engineering, and thus engineering education are changing:

> …industry has changed from the industrial local [and] national era to the technological international era. It is going to be the post-industrial global era and then the sustainable global [and] local era. As for the eras of engineering education, there was a change from practice-oriented into engineer science based content and then there is going to be a leap into [an] integrative [and] innovative era. (Sunthonkanokpong 2011, p. 161)

Engineering educators need to leap into the era of integration and innovation. The implications for engineering educators can be summed up in the concept, 'Curricular Responsiveness' – '…the idea that a curriculum (the educational program as a whole) must be appropriately responsive to the legitimate expectations, requirements, and interests of stakeholders regarding how the program functions and what it delivers' (Woollacott 2009, p. 258). Research such as this work, and evident in the literature, demonstrate the 'expectations, requirements, and interests of stakeholders.' Our challenge now is to rise to these expectations by using the research findings to re-design our engineering curricula to support engineering practice.

5.4.1 Suggestions for the Biosystems Engineering Program

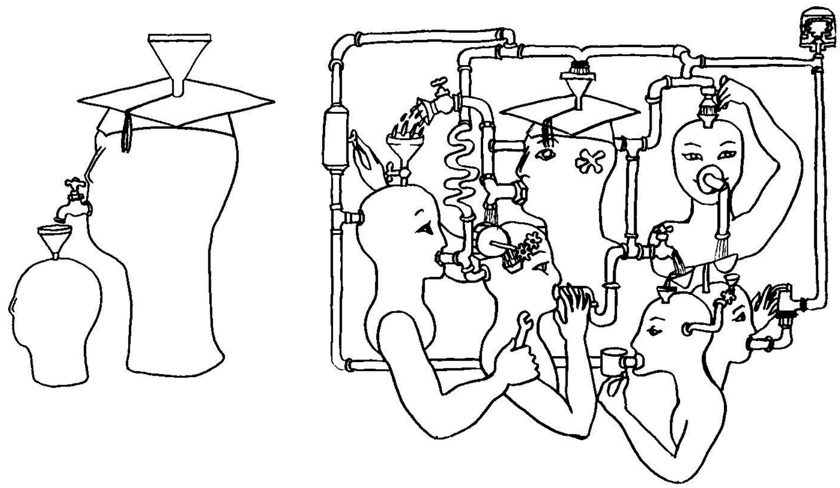
It is important to consider that although the Biosystems Engineering program content coverage and course assessments of the CEAB graduate attributes were largely different than stakeholders' relative importance ratings, this is not a surprising finding. Outcomes-based assessment was only introduced to accredited Canadian engineering programs in 2009. Engineering programs have long historically focused on the knowledge-based and skill-based aptitudes required for engineering. The content validity evaluation of the Biosystems program resulting from this study should be viewed as one tool in which to align the curriculum more closely with the graduate attributes rated as relatively important by key engineering stakeholders as part of the continual improvement process required of CEAB accredited programs. With that in mind, some content and assessment areas in the Biosystems program can be reviewed.

One of the largest implications from the findings for the BIOE program is that Knowledge Base for Engineering is over-represented in the curriculum in comparison to stakeholders' mean relative importance findings – a disparity of almost 40%. This brings to question the importance of the knowledge-based courses to the engineering degree.

There are 12 courses that have course content that is 100% Knowledge Base for Engineering (and one course with 90%). They are all math and science courses. Is the content in all of these courses essential for becoming an engineer? If so, one approach is that they could be perceived as potentially foundational courses and could be separated from the engineering degree itself. Much like at the University of Manitoba, a science degree is (one of) the foundational degrees students earn before they can apply to earn a degree from the Faculty Medicine. Similarly, the Bachelor of Environment Design is the undergraduate degree that precedes a Masters in Architecture, City Planning, Interior Design, Landscape Architecture, or PhD in Design and Planning (University of Manitoba 2017b). Somewhat disingenuously, engineering is touted as a 4-year degree that is in most circumstances, completed in 5 or more years (e.g., Biosystems has a 5-year program model). The Biosystems program could model itself after the Faculty of Architecture at the University of Manitoba, or after the European model of engineering, with a 5-year program that effectively gives students a bachelors and masters degree in the field. In this way, the content-heavy math and science courses that teach and assess Knowledge Base for Engineering could be relegated to a more general, foundational degree, and the other

11 graduate attributes could be concentrated in the engineering degree, whether it be a masters degree or not.

A second approach to the curriculum-heavy knowledge base content in the program could be to re-design the approach to the delivery of the content – effectively using other graduate attributes as a mode by which to learn and demonstrate content through the competencies required for the other targeted attributes, rather than an end unto itself. Attributes such as Investigation, Problem Analysis, Use of Engineering Tools, Communications Skills, and Individual and Teamwork could be employed, which all need more attention in the BIOE curriculum in order to more closely reflect their relative importance to engineering stakeholders. Supporting this, Knowledge Base for Engineering content that is deemed necessary for the Biosystems engineering curriculum could be delivered through active-learning environments, such as project-based and problem-based learning, or cooperative learning. The engineering content would be learned constructively as needed to complete the project or solve the problem, but the knowledge, skills, attitudes, values, and behaviours of the other attributes would be assessed. In this way, students, through engagement with other competencies, would learn the engineering content in an authentic, real-world way, effectively using a knowledge-construction model as opposed to a knowledge transfer model to facilitate learning (see Figure 5.6).



(a) (b)

Figure 1. Two models of the classroom-based teaching learning process, as drawn by Lila Smith in about 1975. (a) "Pour it in" model, (b) "Keep it flowing" model.

Figure 5.6. Conceptualization of a knowledge transfer and knowledge construction models (Smith et al. 2005, p. 89).
Used with permission.

Another consideration for modification would be the treatment of Individual and Teamwork in the BIOE program. Individual and Teamwork is unequivocally the top-rated relatively important attribute for all engineering stakeholders in this case at 10.9%, yet it occupies 1.3% of course coverage in the BIOE program. Certainly, teamwork can be applied to every course, and is in many of the BIOE courses, where students are required to work in teams to accomplish course objectives. The difficulty is in the fact that teamwork is rarely formally and explicitly *taught*, and evidently, rarely assessed. Students spend a lot of time working in teams in engineering – but very little of the curriculum is designated to teach students how to effectively do so. As Individual and Teamwork is found in the data to be clustered closely with Communication Skills, and Communication Skills has more prominence in the BIOE curriculum, it makes sense to look at where

Communication Skills are taught in order to investigate how Individual and Teamwork could have more presence as well.

BIOE, in contrast to every other engineering program offered in the faculty, amalgamated the stand-alone engineering communications course standard for all engineering students into what was called at the time, their Design Trilogy. It was an innovative move within the Faculty that was supported more readily due to BIOE's relatively smaller program. Within a design-based, team-based environment, students are also exposed to the knowledge, skills, attitudes, values, and behaviours characteristic of engineering communications, and required to write reports and do presentations with a design-focus. This focus continues from first year through to final year, when students graduate from writing reports and giving presentations for their instructors and peers in first and second year, to professional communications with their industry sponsors in fourth–fifth year. Through the duration of these courses, students work in teams with their peers, a structure that occupies approximately half of the first and second year courses through one semester, to a structure that dominates the final year. The Design Trilogy – now evolved into the Design Spine – would be the natural place for teamwork skills to be taught and assessed. Students are already required to work in teams; they could explicitly be given the opportunity to formally learn the knowledge, skills, attitudes, values and behaviours required for effective teamwork, and be given feedback on their own aptitudes. The implications of this study highlight the need for emphasis on teamwork in the curriculum; this model would give instructors the opportunity to not only increase Individual and Teamwork, but simultaneously increase Communication Skills to more closely mirror the relative importance it has to stakeholders in this case, and to the engineering field inclusively. Additionally, grouping Individual and Teamwork with

Communication Skills would authentically reflect the clustering found in the research. The aptitudes required of Economics and Project Management could – and should – be taught and assessed here as well.

Another suggestion for modifications to the Design Spine is to increase the Use of Engineering Tools. Problem Analysis and Design already exceed their relative importance rating in their treatment in the curriculum, but Use of Engineering Tools is underrepresented (4.7% content coverage verses 8.3% mean relative importance). The suggestion would be for instructors to have students build prototypes of their designs, and assess students' Use of Engineering Tools competencies. These prototypes could be 2- or 3-dimensional models, such as drawings, 3-D printing, machines, etc. There are also other ways in which students can engage in learning activities using engineering tools. For example, in the newest version of the graduate attribute indicators that have been adapted for the Faculty of Engineering at the University of Manitoba from the *Graduate Attribute and Indicators* developed at McGill University (Razavinia and Mydlarski 2016), *Engineering Tools* are defined as follows:

> *The term "Tools" refers to any equipment, software or resources used in each engineering discipline. A few examples are:*
>
> • *Equipment: Modern engineering tools, prototypes, simplified physical models, laboratory materials*
>
> • *Software: Programming language interfaces, models and/or simulation of systems, measurement and monitoring software and instruments*
>
> • *Resources: Scientific references* (See Appendix I for the complete document.)

Already, students are building small experiments and prototypes in the first and second year BIOE Design courses. As well, the fourth year design course is predominantly occupied with students prototyping their work. Similarly, a full CAD course is being taught as part of the core BIOE program (ENG 2022). So why does Use of Engineering Tools have such a relatively small emphasis in the curriculum? One of the difficulties is that not only are engineering programs under CEAB accreditation required to assess the graduate attributes and provide evidence of students' competencies in these areas, they are also still required for accreditation to count AUs (academic units). Therefore, in many ways, engineering academic programs are somewhat constrained when it comes to curriculum, as the number of AUs controls course content. For example, in BIOE 3900 Design 2, the course had to have a large Design content to meet AU requirements. So even though students are working with Engineering Tools, the course is comprised of 75% Design content, 10% Communication Skills, 5% Economics and Project Management, and only 10% Use of Engineering Tools. The same may be seen for ENG 2022, which one would assume would be 100% Use of Engineering Tools, but is rather 20% that, and 20% Knowledge Base, 55% Design and 5% Communication Skills. Therefore, at times the addition of, or increase of content for, a particular graduate attribute seems an appropriate solution to meet mean relative importance ratings; for other situations, perhaps it is a matter of re-considering which graduate attributes already embedded in the course should and can receive the content and assessment emphasis.

The final suggestion for the Design Spine is to fuse Lifelong Learning into the courses. One of the more surprising findings in these data was the cluster of Lifelong Learning, Design, and Use of Engineering Tools. But on further consideration, it makes sense. A behaviour that the researcher found anecdotally when she was one of the instructors in the BIOE design courses was students' reluctance to research a problem. Their response when asked to look into what was in the literature in regards to their design concepts was that they were taking an *engineering* course, not a *literature* course. This anecdotal finding reflects the treatment of Lifelong learning behaviours in the curriculum – it is relegated to the Communication Skills components of courses, driven by information literacy skills that students often perceive as having little authentic bearing on what they consider important. And yet, when they are genuinely engaged in trying to solve an engineering problem, or develop a design, students are reticent to look beyond their own experiences and that of their peers and/or instructors to guide their thinking. There is a wealth of knowledge that is instantly accessible in today's day and age, which students, of all segments of the population, are likely one of the largest consumers of in other areas of their lives. If engineering educators can harness students' motivation to solve engineering problems by seeking information, Lifelong Learning aptitudes will become rooted in their natural inclination when approaching design. Additionally, employing the use of reflection is a powerful tool for engineers today: "Reflection and the promotion of reflective techniques are becoming more important in engineering education because of the expanding need for diverse, adaptive, broad-thinking, and nimble engineering experts who can respond to the ever-increasing challenges that society faces" (University of Washington 2014). Fusing Lifelong Learning into the Design spine is a natural fit, as the knowledge, skills, attitudes, values, and behaviours that are required of Lifelong Learning are positioned with Design and Use of Engineering Tools – higher order attributes that cluster in the findings.

Another important consideration for the BIOE program is how to meet the mean relative importance levels for the higher order affective attributes, Ethics and Equity and Professionalism. As already discussed, Millennial students are driven by their values, and are motivated by opportunities to engage in professions for the betterment of society.

Moreover, engineering educators arguably have a societal responsibility to integrate 'ethical reasoning' into the engineering curriculum (Sheppard, Pellegrino, and Olds 2008, p. 231). The BIOE program already offers society conscious-driven students opportunities to choose Bioresource, Biomedical, and Environmental specializations. The department attracts relatively more women to their program than the other 4 engineering programs – close to 50% of their student body – which speaks to its capacity to attract and retain a more diverse population. To further this appeal, the BIOE program should consider offering students learning environments that infuse Ethics and Equity and Professionalism in their program, and ultimately, their discipline. A suggestion for this would be to infuse Ethics and Equity into BIOE 2480, which is a course on the Impact of Engineering on Society and the Environment.

In keeping with BIOE's progressive vision and commitment to curricular improvement, BIOE 2480 is a relatively new course in the BIOE program that was added to the curriculum for precisely the same motivation of these suggestions: the attribute, Impact of Engineering on Society and the Environment, was essentially absent in the curriculum. Therefore, BIOE 2480 was designed. It is a course that has the luxury of being recently in development, and therefore offers a golden opportunity for ongoing development. Additionally, in the findings from the data for this research, Impact of Engineering on Society and the Environment is shown to cluster with Ethics and Equity. It is a palpable opportunity for fusion, due to the analogousness found between these attributes, and to the accessibility of this course due to its recent development.

The suggestion for Professionalism is slightly different. It too finds placement in the same quadrant as Impact of Engineering on Society and the Environment and Ethics and Equity, but lies on the x-axis, approximately equidistance to Economics and Project

Management. Professionalism has binary meanings; it can mean professionalism, small *p*, which is captured by its third indicator in the updated University of Manitoba Faculty of Engineer graduate attribute indicators: *PR.3 – Exhibits behaviour expected of a Professional Engineer*, and it can mean Professionalism, which speaks to the engineering discipline, and is described as *PR.1 – Understands the role of the engineering profession in society and responsibility of the Professional Engineer in protection of the public*; and *PR.2 – Knows relevant codes, laws and regulations* (Appendix I). Thereby, this attribute has the potential to be infused in the BIOE curriculum in two ways. Firstly, to target the behavioural aspects of this attribute, one suggestion would be to have a code of professional behaviour that BIOE students are expected to abide by while in the program. This code could quite simply be adapted from the Student Code of Conduct required by the university; however, by explicitly stating and expecting students to abide by this code in all courses throughout the program, students would be aware of, and think about, professionalism and their behaviour, cognizant of practicing these behaviours while in the program. Professionalism can be, and already is, attributed to such behaviours as being on time to class and with assignments, attending class or communicating to relevant parties if one cannot, making meetings and meeting deadlines on projects, etc. A code of conduct would formalize this behaviour across the program. It is also suggested that this indicator in Professionalism be clustered in the Communication Skills, Individual and Teamwork, and Economics and Project Management affective domain, found in the Design Spine.

A recommendation for implementing Professionalism's first and second indicators into the BIOE curriculum (see above) is to create or adopt online modules for this attribute. Thereby, the role of the engineering profession in society and responsibility of the Professional Engineer in protection of the public, and relevant codes, laws and regulations for a Professional Engineer in Manitoba could be communicated to students in an interactive, on-line environment. Already a module such as this has been created for Ethics and Equity at the University of Manitoba, which in fact could be used in conjunction with BIOE 2480 (see Section 5.4.2 *Suggestions for the Faculty of Engineering: Program Enhancements* for a more detailed explanation of the Ethics module); and there are open-access Ethics modules available through the University of Toronto. With Professionalism in Engineering being province-specific, perhaps Engineers Geoscientists Manitoba has the interest in, and the resources to partner with the faculty to create such a learning module for the mutual benefit of both parties.

Finally, it is advised that giving students the choice of taking either CIVL 4460 or ANTH 2430 be considered, as both courses target different graduate attributes. CIVL 4460 covers and assesses Individual and Teamwork, Communication Skills, Professionalism, Impact of Engineering on Society and the Environment, and Ethics and Equity, whereas ANTH 2430 purely targets Impact of Engineering on Society and the Environment. Ideally, both courses should target the same graduate attributes. If this cannot be orchestrated, than perhaps one of the courses should be selected for the program. As Ethics and Equity and Professionalism require more emphasis in the program, CIVL 4460 may be the likely choice. (*Note*. These data have been calculated with CIVL 4460, therefore students who take ANTH 2430 are receiving less course content coverage and assessments in Individual and Teamwork, Communication Skills, Professionalism, and Ethics and Equity, and more in Impact of Engineering on Society and the Environment.)

5.4.2 Suggestions for the Faculty of Engineering: Program Enhancements

The findings from the study do not necessarily support removing any attributes, rather to conceptualize them more holistically in the engineering curriculum, and increase the content and assessment coverage of several of the attributes. The only attribute that one could question in terms of relevance to the group of CEAB graduate attributes would be Economics and Project Management. This is due to it having the lowest mean relative importance rating for all graduate attributes, coupled with its absence in the research in regards to top engineering competencies (Passow and Passow 2017). However, in these research findings, as it is found in the quadrant with Communication Skills and Individual and Teamwork, and as one effective approach to project management is through effective teamwork, it could be easily coordinated with Individual and Teamwork for authentic learning experiences. If faculty disagreed, another approach to exposing students to the knowledge and skills inherent in this attribute could be to offer a 1-year masters or a post-baccalaureate degree that focused solely on this attribute. A second alternative approach could be to offer a certificate that students could earn while in their undergraduate engineering degree, or offer project management as one of the specializations in engineering. As stated previously, this is a graduate attribute worth investigating further to understand its relevance to engineering practice as perceived by stakeholders.

The other attribute that has been the focus of discussion in terms of its individual relevance to the engineering curriculum is Investigation, which some muse could be amalgamated with Problem Analysis. However, even though Investigation is in the third cluster of importance, it is aligned with the literature in this rating. As well, the literature supports Investigation as one of the important engineering competencies. Finally, in this research, Investigation is clustered with Problem Analysis; this finding supports a holistic approach to teaching and assessing the graduate attributes in the program with increasing complexity, as Passow and Passow (2017) suggest, and as these data suggest (see Section 5.2.2 *The Argument for the Interconnectivity of Engineering Competencies*) rather than individualizing the attributes.

Overall, it would be worthwhile to do a content validity study of each engineering program within the Faculty as measured by the mean relative importance of all the engineering stakeholders in this case. Determining how each program aligns with the mean relative importance data would allow specific recommendations for curricular design and improvement for each program. However, if this is not embarked on, there are still recommendations that the Faculty could consider.

The role of the attribute, Individual and Teamwork, could be explored within the Faculty. As discussed, Communication Skills are already taught in a teamwork setting in two courses that are offered to students, one of which is required for their degree. These courses are *ENG 2040: Engineering Communication: Strategies, Practice, and Design*, and *ENG 2030: Engineering Communication: Strategies for the Profession*. As stated, Communication Skills are taught in a teamwork style: teamwork is covered, and to some extent, formally taught and assessed as part of the outcomes of these courses. To increase the emphasis on Individual and Teamwork, both of these engineering communication courses could be re-envisioned so that Communication Skills and Individual and Teamwork are fused more fully, carrying equal weight both for content coverage and course assessments. For example, re-naming the course *Teamwork and Communication Skills: Strategies for the Engineering Profession*. Additionally, Economics and Project Management, the concepts of which again, are utilized in the course to the extent that students are required to communicate their design report processes using Gantt Charts and

Work Based Structure (WBS) models, and at least one guest lecture is devoted to this attribute, could be taught through a teamwork lens, such as Mitacs (2017) does with its project management workshops.

Further suggestions for the Faculty would be to continue to introduce Lifelong Learning information literacy skills in ENG 2040 and ENG 2030, but to pull Lifelong Learning through the programs, fusing it with the Design and Use of Engineering Tools components more fully, including in their Capstone courses, if this is not already done. As suggested in the findings, and as expressed for the BIOE program, Design, Use of Engineering Tools, and Lifelong Learning cluster in the data; thereby, along with an emphasis on Lifelong Learning aptitudes, a continued and increased emphasis on hands-on activities, such as proto-typing designs within the core curriculum would also be worth considering to increase the emphasis on Use of Engineering Tools. Relevantly, this is something that was suggested by Mechanical students as needed in the Mechanical Engineering program, during the student focus groups. These were conducted in a study designed to examine fourth year engineering student perceptions of the CEAB graduate attributes in the mechanical engineering program in 2014 (Seniuk Cicek, Labossiere, and Ingram 2015).

A final, general suggestion for all the programs in the Faculty would be to seriously look at the affective higher order attributes, such as Professionalism and Ethics and Equity, which are found to be relatively important to all stakeholders in this case, and even more so for students. As discussed in the previous section, the Centre for Engineering Professional Practice and Engineering Education enlisted an Engineer-in-Residence (EIR) in the Faculty and an undergraduate student to design an E-module for Ethics and Equity (Kavanagh, Laberinto, and Ruth 2016). A similar module for

Professionalism would be worth considering. An additional approach to increasing the weight of these attributes into the curriculum would be to host a seminar series once a month, where a guest speaker from industry would be invited to share real-world engineering ethical and professional dilemmas and their outcomes, followed by facilitated small-group discussions within the student audience. It could be mandatory for students to attend the seminar series as part of their core requirements. It is important to note that this suggestion also came out of the data from the focus groups that were conducted with senior level Mechanical engineering students in 2014 (Seniuk Cicek, Labossiere, and Ingram 2015). This further demonstrates engineering students' commitment to Ethics and Equity and Professionalism, and their desire to see these topics have greater representation in the engineering curriculum.

Overall, increasing the presence of the less emphasized CEAB graduate attributes through holistic infusion in the engineering curricula in the Faculty of Engineering at the University of Manitoba with the dominant graduate attributes will balance the representation of the engineering competencies whose mean relative importance by all stakeholders in this case are comparatively even. Giving attention to the engineering competencies that are integral for students to successfully negotiate the 21st century and all of its intricate, grand problems, could further peak the interest of today's Millennials in engineering as a discipline, and potentially increase the diversity of the students who seek to enter the field. The increased emphasis on the affective engineering competencies will go a long way in arming society with engineers who comprise the aptitudes to be conduits between society and technology, a necessary position to tackle today's fundamental issues. (See Appendix J for a Conceptualization of the Engineering Education Ecosystem.)

5.4.3 Transferability for Other Engineering Programs

The findings in this study are generalizable within the context of a specific case; in other words, if another institution shares similarities to this case in the context of this research study, these data may be directly applicable to other engineering programs. For example, if the research site and characteristics of the engineering stakeholders are similar in other Canadian institutions with accredited engineering programs (e.g., large research university, comparable student population, same or similar engineering areas, similar engineering industries as found in Manitoba), these data may directly inform those programs. If these similarities are not shared, then the data may be used comparatively or corroboratively to individual institutions' own findings regarding the graduate attributes in their engineering programs. Similarly, these data can be used for comparative and corroborative purposes in engineering programs in nations around the world that are signatories of engineering alliances (e.g., IEA), and under similar accreditation umbrellas, who are doing their own research in engineering competencies, outcomes-based pedagogy, and engineering curriculum design and improvement. As well, the design of the study itself is transferable: the methodology and methods can be recreated.

5.4.4 Impact for Engineering Education in Canada and Globally

Engineering education is transforming into a more interdisciplinary and scholarly research field (Borrego and Bernhard 2011; Case and Light 2011; Johri and Olds 2011; Froyd and Lohmann 2014). Engineering education researchers are calling for the area to become increasingly global. Currently, very few Canadian voices are heard in the international research (Wankat 2004; Williams et al. 2014). There is a demand for more EER that explores stakeholder understandings, framed by the appropriate theoretical and epistemological perspectives (Olds, Moskal, and Miller 2005; Borrego 2007; Borrego, Douglas, and Amelink 2009; Borrego and Bernhard 2011; Case and Light 2011). Determining engineering stakeholders' perceptions of the relative importance and dependencies of the graduate attributes in the Faculty of Engineering at the University of Manitoba, evaluating the content validity of the Biosystems engineering program in the context of the relative importance ratings, and developing a conceptual framework and theoretical understanding of the graduate attributes, offers a Canadian perspective in the global discourse on engineering education.

5.5 Limitations and Recommendations

There were a number of limitations to the study design that should be recognized, which are also important considerations for adapting this study for future use. This is followed by recommendations made in the context of the findings in this study.

5.5.2 Limitations of the Study Design

There were limitations inherent in the questionnaire methods design of the study, as well as in collecting data that were specific to this research site, though not uncommon to studies that involve human participation. Some of these limitations were expected, as they are characteristic of the questionnaire method used, for example, procuring a significant participation rate. Other impediments were specific to the research site, such as institutional controls in place for surveying faculty and student. The researcher worked to mitigate the constraints, as described. For limitations that were not mitigated, recommendations are made for future research employing these methods.

5.5.2.1 Difficulty in Procuring Research Participants

It is well known that it can be difficult to obtain participants, particularly to complete questionnaires. Success in participant recruitment can be affected by two prevailing factors: Participant motivation and external factors.

Procuring adequate participant response rates is a typical challenge of survey/questionnaire methods (Polland 1998, 2005; Oliver 2013). It is difficult to enlist participation, particularly from individuals who are already extremely hardworking and have limited excess time, or who may not entirely see the value in the research. In this study, senior Capstone students, faculty, and industry members were targeted. Tremendously busy individuals, who although 'stakeholders' in the research, may not have fully comprehended or agreed with the benefits of the study. Laying the groundwork for stakeholder buy-in (Shaeiwitz 1996; McGourty, Sebastian, and Swart 1998) goes a long way in helping to motivate participants and alleviate some of the indifferent, or potentially negative attitudes that are associated with questionnaires/surveys. Professional development and opportunities for conversations around the objective and purposes of the research, a well-timed and less onerous method for administering the ratings form, and timely feedback given to, and solicited from participants are all essential for developing stakeholder interest (Seniuk Cicek, Ingram, and Sepehri 2013).

For this study, obtaining participants required several processes. Firstly, studies at the University of Manitoba involving humans have to be approved by ENREB, the office responsible for research involving human subjects (University of Manitoba 2017g). The procedures that are required to recruit participants for research studies are complex and often involve a multi-step process. Therefore, notwithstanding that the research instrument (i.e., the *Relative Importance and Graduate Attribute Dependencies Ratings Form*) is already time-consuming, potential participants must read through recruitment and consent documents before they can agree to participate. Although it is reasonable that research involving humans must have procedures in place to protect the rights and welfare of participants, this structure that is in place for all human research, including 'minimal risk' studies is a potential barrier for procuring participants in educational research.

To mitigate this, it is suggested to try to streamline the documentation and thereby, the procedural steps required. For example, for the second phase of this study, the Recruitment Letter and the Letter of Informed Consent (Appendix F.8) that were required by ENREB were amalgamated, so that participants received the Letter of Recruitment and Consent at the same time that they received the teaching faculty questionnaire. This effectively reduced the multiple steps required for individuals to participate down to one. Response for this part of the study was fairly rapid for the majority of participants, and the reduced recruitment process was likely one factor.

Additionally, specifically for seeking participation from student, faculty, and industry stakeholders as in this case, a study design that seeks participation in a face-to-face manner proved to be more successful than electronic recruitment, such as email. A departmental meeting planned around recruiting and completing the ratings form could be effective for collecting data, for example; a classroom visit as described in this study for the same purpose, proved successful; and an industry forum, as mentioned in this study, and described more fully in Ferens et al. (2014), could be designed with a form-filling component, followed by round table discussions.

In addition to obtaining approval from ENREB, anyone seeking to survey faculty or students at the University of Manitoba must be approved by the Office of Institutional Analysis. This is in place to monitor surveying activities on campus to ensure that faculty and students are not over-surveyed, particularly as the institution itself has their own surveys that they disseminate throughout the year. In this study, the researcher did not know about this office when she began collecting data, which invariably caused an interruption in the data collection process. It is recommended for any parties interested in emulating this study that potential institutional policies are considered, and the timing of the data collection is carefully planned to optimize participant responses (for example, collecting data from university stakeholders at the beginning or end of a term, when teaching responsibilities are especially busy, is not optimal). Once ethics and institutional applications are approved, and data collection begins, the survey/questionnaire must be conducted in the approved window of time.

Overall, one should be well aware of all ethical and institutional requirements in conducting human research in the targeted site, and be sure to execute these procedures efficiently and accurately, by planning for these factors in the initial study design.

5.5.2.2 Survey Fatigue

Survey fatigue was a potential limitation in the design of the *Relative Importance and Graduate Attribute Dependencies Ratings Form*. The first part of the form, the Relative Importance of the CEAB graduate attributes, was only two pages. Participants could fill this out in 10–15 minutes, a timeframe that can be motivating for potential research participants. Unfortunately, the second part of the questionnaire – the graduate attribute dependency form – was cumbersome and repetitive. It comprised of six pages, each with approximately 20 rows that the participant was required to fill out. As well, this part of the form was supplemented by one page of intensive directions. For this part of the questionnaire, participants were required to choose the percentage that one attribute depended on another attribute, given 5 choices (i.e., 0%, 25%, 50%, 75%, 100%), eleven times for each of the 12 attributes. Thus, participants had to fill out 132 rows answering this same question repeatedly. The design and cumbersome nature of this form could definitely incite survey fatigue and/or participant duplicity, thus biasing the data.

In future, the researcher would recommend considering separating part 1 (the relative importance) and part 2 (the graduate attribute dependency) of the ratings form to create two instruments. The design of the instrument for this study was complex, and somewhat unnecessary, as the data for both parts 1 and 2 were analyzed separately. Although a complicated analysis could be completed using both sets of data, it was not done for this study, thereby leaving no pertinent reason to combine the forms (except for the benefit of requesting participation once rather than twice, which could be dealt with by seeking permission for both instruments at once; see Section 5.5.2.1 *Difficulty in Procuring Research Participants*). In fact, it might be beneficial to determine the relative importance first, before seeking information on the dependencies of the graduate attributes. If it was found that one or more graduate attributes were not relatively important, or conversely were substantially more relatively important than the others, the design of the dependency form could be changed to reflect this finding.

Overall, it would have likely greatly increased participation if participants were only required to fill out a two-page relative importance questionnaire that took between 10–15 minutes (although the same limitations would remain for the graduate attribute dependency form). Fortunately, for this study, an adequate number of participants were procured, resulting in a data set that could be confidently used to measure the content validity of the BIOE program, construct a conceptual/theoretical framework of the graduate attributes, and make recommendations for both the BIOE program specifically, and programs in the Faculty of Engineering more generally. However, it could be potentially damaging to program improvement efforts if a study of this nature was executed and did not result in sufficient participant rates. Time and effort are valuable commodities; one would not want to risk spending stakeholders' time and effort without procuring a sufficient rate of return, as it could be difficult to acquire these participants again. Stakeholders' feedback is extremely valuable, and opportunities for acquiring it formally are not limitless, and must be chosen carefully.

Another recommendation to reduce potential respondent bias for the dependency section of the questionnaire would be to create a couple of different versions of the same questionnaire, each using altered orders of the CEAB graduate attributes in order to account for survey fatigue. This was recommended in this study, but as the questionnaire was transferred into SurveyMonkey, and the respondent populations were not large enough to have multiple mailing lists for the same stakeholder groups, the study design did not invite using multiple links to the survey. However, in hindsight, different versions could have been made for the Word versions of the form that were distributed to participants.

5.5.2.3 Self-Selection Bias

A potential weakness in questionnaires where participation is optional and anonymous is self-selection bias. Such bias can result when participants are given the choice to participate or not; in such cases, participants may not be a true representation of the target population (Lavrakas 2008). Survey respondents may be motivated by heightened emotion, whether positive or negative, which can bias the results. Those who participate in surveys/questionnaires are most likely different from those who refuse or those who the researcher does not succeed in locating; therefore, a low response rate can lead to considerable bias error (Jaeger 1997). Self-selection bias cannot be prevented; however, procuring a significant participant response rate will mitigate the effect. In this study, an adequate response rate was secured. Additionally, when data are aggregated to compare group performances, as was done in this research, the reliability of self-reporting instruments is high, and for the most part felt to be a valid measure of authentic differences between groups (Prados, Peterson, and Lattuca 2005).

5.5.2.4 Missing Graduate Attributes: An Additional Question for Participants

In hindsight, the researcher would recommend adding one more question to the *Relative Importance and Graduate Attribute Dependencies Ratings Form*. Participants should be asked if, from their perspective, there are any graduate attributes missing from the list of CEAB graduate attributes.

There was an assumption in the completeness of the 12 CEAB graduate attributes when this study was designed. Moreover, there has been a great focus in the past year on ABET's crusade to reduce student learning outcomes (Seniuk Cicek, Ingram, and Friesen 2016), not increase them. In ABET's motivations and in the literature (Oliver 2013), this tendency towards reduction seems to be a reaction to the disgruntlement of those who struggle with having not only to teach, but to assess these complex attributes. However, this movement was met with resistance.

In the recently published research that is being driven by the needs of engineering practice in the 21st century, there is a call for increased complexity in the lists of engineering competencies, rather than reduction (Passow and Passow 2017). In the literature, it is clear that there are a number of attributes that are perceived as missing from numerous accreditation lists. These include competencies such as innovation (Radcliffe 2005; Robinson et al. 2005, p. 128), entrepreneurship (Radcliffe 2005; Robinson et al. 2005; Male, Bush, and Chapman 2011b), creativity (Male 2010, p. 35), critical thinking, initiative (Woollacott 2014, p. 268), decision-making (Passow and Passow 2017, p. 497), the coordination of multiple competencies to accomplish a goal (p. 492), devise process (which is connected to project management) (p. 498), and intra and interpersonal skills, such as empathy and the ability to work with people (Woollacott 2014, p. 269). Indeed, through their systematic literature review that spanned reports, studies and job postings over 22 years, Passow and Passow (2017) found that there are 16 competencies relevant to engineering (see Table 2.1 *Comparison of engineering generic competencies and 21st century skills and competencies).* Asking stakeholders if there are any graduate attributes missing from the list of 12 CEAB graduate attributes would be worth pursuing in future research. This is a question the researcher would advise adding to this questionnaire if recreated.

5.5.2.5 Recommendations

One of the chief recommendations that arises from this research is to re-conceptualize the CEAB graduate attributes from a linear list into a framework that supports 'coordinating competencies' to emulate engineering practice (Passow and Passow 2017, p. 504). Suggested by these findings is a clustering of the CEAB graduate attributes into four quadrants: Interpersonal Skills, Problem Solving Skills, Ethical Reasoning, and Creativity and Innovation. These quadrants support a hierarchical passage through the Cognitive, Psychomotor, and Affective Domains of learning that comprise the progressive fusion of the knowledge, skills, attributes, values, and behaviours of the engineering competencies, the 12 CEAB graduate attributes. This framework could be used as a tool for curricular development, and for educating engineering stakeholders, i.e., students, faculty, and industry, about the graduate attributes, and their inherent interconnectivity.

Additionally, the determination of the content validity of engineering programs as measured by the mean relative importance of relevant engineering competencies, which in Canada are the CEAB graduate attributes, is recommended. This is endorsed for the purposes of improving and designing engineering curricula that is authentic, engaging, and relevant through the authentic representation of the engineering knowledge, skills, attitudes, values, and behaviours required in engineering professional practice.

The methods employed in this doctoral study – i.e., consulting engineering stakeholders to understand how best to conceptualize engineering competencies – are recommended as one approach to strategizing curricular change in engineering programs, particularly in accredited engineering programs. Some engineering educators struggle with designing learning opportunities for aptitudes required of engineering competencies, for example, such as for Lifelong Learning. When consulting with stakeholders, engineering educators may be offered a different, and sometimes new perspective about the relevance and interconnections of engineering competencies in practice. Informing educational decisions with the experience and knowledge of stakeholders who are experts in their fields will assist engineering educators in making the decisions required for program improvement. It is particularly important to consult with engineering students and understand where their values lie. Honing in on the values that are important to engineering students is one way to attract a more diverse student population into engineering, and expand what it means to be an engineer, and what it looks like to practice engineering in the field.

As Passow and Passow state, ‘In the absence of evidence… about what competencies are important for engineering practice, faculty must rely on either expert panel statements, primary studies, or their own speculations about what competencies are important in different practice settings in which they have no work experience’ (p. 502). Obtaining the evidence for curricular change can be acquired through local engineering stakeholders in each case, and the resulting diversity of perspectives, gleaned through differentiated stakeholders’ views, will support faculty in their efforts to continually improve their engineering curriculums for the ultimate purpose of enhancing and diversifying engineering education.

5.6 Next Steps

Originally, this study was designed as an explanatory mixed methods case study. Phase 1 and 2 are as described in this thesis, but there was another phase planned (formerly known as Phase 2 but now conceptualized as Phase 3), which was a qualitative exploration of the quantitative data through an industry forum, and stakeholders’ interviews and/or focus groups. One industry forum was conducted in December 2015, where preliminary findings from this research were discussed, and upon industry members’ recommendation, used as the impetus to accrue more participants to complete the *Relative Importance and Graduate Attribute Dependencies Ratings Form*. Stakeholder interviews and/or additional focus groups have yet to be conducted. Due to the extensive findings that resulted from the first two phases, it was decided to focus on these for this thesis, and pursue the qualitative phase as a next step. This will help construct understandings on how and why the relative importance and dependencies of the graduate attributes were interpreted as they were, and how participants understand the findings. This will fill another perceived gap in the literature in regards to using a focus group methodology in this context (Male, Bush, and Chapman 2011b).

Specific areas that are of interest for further study include:

- Exploring whether students perceive engineering as pertaining to their mean relative importance rating, i.e., their relatively higher ratings of Professionalism and Ethics and Equity comparable to the faculty and industry stakeholder groups, or if they aspire for engineering to be this way.
- Exploring what Lifelong Learning is to engineering stakeholders, how and why it clusters with Design and Use of Engineering Tools, and how stakeholders envision it can be manifest in the curriculum.
- Exploring the importance attributed to Individual and Teamwork and Communication Skills over other engineering competencies – for example, why are these attributes rated relatively more important than Knowledge Base for Engineering?
- Exploring the role of Investigation in the engineering field, and thus, in the engineering curriculum. Should it be separated from Problem Analysis?
- Exploring Economics and Project Management as an engineering competency. How does this graduate attribute manifest in engineering practice? How should it manifest in the engineering curriculum?
- Exploring if stakeholders perceive any missing attributes.
- Exploring stakeholders' responses to the conceptual and theoretical framework developed using the findings from this study.

Passow and Passow (2017) recommend: 'future work [should] set aside additional measurement of the importance of competencies, and focus on how to remake, or redesign, undergraduate engineering programs to better prepare students for life and work after graduation, and on how to assess students' development of generic engineering competencies' (p. 504). Collecting data in order to further understand the findings from stakeholders' perspectives will continue to support the improvement and re-design of engineering curricula.

Regardless of the approach taken, 'what engineers do is increasingly and intimately involved in creating and shaping this multi-faceted and highly integrated world. In other words, engineering and engineers have never mattered more' (Sheppard, Pellegrino, and Olds 2008, p. 231). Everything that can be done as engineering educators to make engineering curricula relevant, authentic, and engaging for students in order to substantially prepare them for the world today is a grand, and necessary engineering challenge (Sunthonkanokpong 2011, p. 161) that is critical to the well being and future of society.

Chapter Summary

This chapter discussed the absolute and relative importance and dependency findings from this research, and their repercussions contextualized by the literature to curricular development. The implications for the Biosystems Engineering program were considered, and suggestions to improve the measure of content validity of the BIOE program in relation to the mean perceived relative importance by engineering stakeholders in this case were presented. Following, implications for the remaining programs within the Faculty of Engineering were deliberated, and relevance of these findings for CEAB accredited engineering programs across Canada and for engineering programs under accreditation umbrellas globally were considered. Lastly, limitations of the study, recommendations, and ideas for further research were raised. Chapter Six concludes the thesis.

Chapter Six: Conclusions

This thesis presented an exploratory case study of the relative importance of the CEAB graduate attributes, their dependencies on one another from the perspectives of student, faculty, and engineering stakeholders associated with the Faculty of Engineering at the University of Manitoba, and the evaluation of the content validity of the Biosystems Engineering program. Approached through a positivistic epistemological perspective, the research questions and quantitative questionnaire method were designed to examine whether the CEAB graduate attributes are emphasized in our engineering programs to reflect their relative importance as determined by key stakeholders for an EIT at the being of her/his career. The purpose of the study was to inform the improvement and development of authentic outcomes-based engineering curricula by: (i) determining the relative importance of the CEAB graduate attributes; (ii) evaluating the content validity of an engineering program; and (iii) developing a conceptual/theoretical understanding of the CEAB graduate attributes to inform engineering curricular design.

The study was designed in two phases. In Phase 1, the relative importance and dependencies of the CEAB graduate attributes for Engineers-in-Training (EITs) at the beginning of their career as perceived by University of Manitoba senior engineering undergraduate students, engineering faculty, and local Manitoba industry stakeholders were established. In Phase 2, the Department of Biosystems was used as a case study to evaluate the content validity of the program as measured by the CEAB graduate attribute relative importance findings from Phase 1. Phase 1 employed a closed-ended ratings questionnaire, and a teaching faculty questionnaire and program and accreditation documents were used to collect data for Phase 2. The data were analyzed using descriptive and inferential statistics and were reported on in this thesis.

The relative importance findings were for the most part, reflective of the literature. The mean relative importance ratings in this research are comparatively close for all CEAB graduate attributes, and all graduate attributes are suggested to be comparatively important to the engineering profession. The graduate attribute dependency findings demonstrated some understandings that are reflected by the literature, as well as new understandings for how the CEAB graduate attributes cluster together, and how the clusters may be theoretically interpreted. The content validity findings yielded relevant understandings of how the Biosystems Engineering program are emphasizing the CEAB graduate attributes in the curriculum differently than how they are perceived as relatively important by their stakeholders.

Specifically, this study determined that:

(1) All of the 12 CEAB graduate attributes are considered to be relatively important across engineering stakeholders in this case. Student stakeholders place significantly more mean relative importance on the majority of the graduate attributes than faculty and industry stakeholders, including the higher order affective attributes, Professionalism and Ethics and Equity. The findings in this research are closely related to the relative importance of engineering competencies as found in the literature, with the exception of Knowledge Base for Engineering, which our stakeholders emphasized more.

(2) The top graduate attribute dependency for all engineering stakeholders in this case is Individual and Teamwork, which is perceived to *often – always* depend on, or require Communication Skills. The affective higher order attributes, Professionalism and Ethics and Equity, are found in the least dependent pairings. The graduate attributes cluster

together in four groups, in a framework that can be theoretically conceptualized using Bloom's three Domains of Learning: Cognitive, Psychomotor, and Affective. Clusters of attributes are interpreted as (i) the *Interpersonal Skills*, which comprise of Communication Skills, Individual and Teamwork, Economics and Project Management, and the professional behaviour indicator in Professionalism; (ii) the *Problem Solving Skills*, that include Investigation, Problem Analysis, and Knowledge Base for Engineering;
(iii) *Ethical Reasoning*, comprised of a subset of the Professionalism indicators, Ethics and Equity, and Impact of Engineering on Society and the Environment, and (iv) *Creativity and Innovation*, which includes Design, Lifelong Learning, and Use of Engineering Tools. The graduate attributes can be interpreted as moving directionally through lower to higher order learning domains.
(3) The Biosystems Engineering program has a low degree of content validity as measured by the mean relative importance of the graduate attributes by all engineering stakeholders in this case, and as substantiated by the literature. Knowledge Base for Engineering is given the imbalanced attention of almost half of the BIOE curriculum; Individual and Teamwork is given relatively diminutive attention at just over 1% of the curriculum, while in both the literature and these research findings it is chosen as a top engineering competency. The higher order affective attributes, Professionalism and Ethics and Equity, and the higher order attribute, Lifelong Learning, are given minimal attention in the curriculum, all out of balance with the attributed mean relative importance of all stakeholders in this case and in the literature, and particularly out of line with student stakeholders' perspectives.

This doctoral research presents findings regarding the relative importance and dependencies of the CEAB graduate attributes from University of Manitoba engineering stakeholders' perspectives. It can be used by engineering faculty at the University of Manitoba, and by engineering programs both nationally and internationally, for a deeper understanding of engineering competencies as they manifest in engineering practice, and for the improvement and design of undergraduate engineering curricula to enhance engineering education, and theoretically attract a greater, and more diverse population to the study and practice of engineering.

Postscript

In regards to the interdisciplinary nature of the field of engineering education, Borrego and Bernhard (2011) write this summary in their article, 'The Emergence of Engineering Education Research as an Internationally Connected Field of Inquiry':

> Fundamentally, though, engineering education is an interdisciplinary area of study which draws upon a wide range of more traditional fields. Fortenberry, Sullivan, Jordan, and Knight (2007, p. 1175) explain that "Discipline-based education research [like EER] seeks to marry deep knowledge of the discipline with similarly deep knowledge of learning and pedagogy" (McDermott, 2004; Shulman, 1986). All branches of engineering, social and cognitive psychology, sociology, education, ethnic studies, women's studies, international relations, and other STEM or STEM education disciplines were all mentioned specifically by AGCEER [Advancing Global Capacity for Engineering Education Research] participants on six continents discussing the expertise needed for EER (Borrego, Beddoes et al., 2009). Experts from outside of engineering bring valuable research skills and perspectives. Their training for EER usually means becoming familiar with the engineering setting, including values, norms, and language (Borrego [and] Newswander, 2008). One of the many benefits of this "outsider" perspective is that they may notice underlying assumptions that are not evident to engineers. They are also able to maintain a greater degree of objectivity when this is needed for a quantitative study or a project evaluation (Borrego, 2006). (p. 100)

This thesis is the culmination of the work of one 'outsider,' who had the fortuitous opportunity to learn about, and engage in, engineering education research. It is the researcher's modest hope that this work provides value for the engineering educators in the Faculty of Engineering at the University of Manitoba, and universally, to engineering educators in the field.

References

ABET. 2017. "About ABET." *ABET*. http://www.abet.org/about-abet/

ABET. 2017. "Criteria for Accrediting Engineering Programs." *ABET*. http://www.abet.org/wp-content/uploads/2017/12/E001-18-19-EAC-Criteria-11-29-17-FINAL_updated1218.pdf

ABET. 2016. "Proposed EAC Criteria Changes Released For Public Review And Comment." *ABET*. http://www.abet.org/blog/news/proposed-eac-criteria-changes-released-for-public-review-and-comment/

Abu-Mulaweh, H. I. 2005. "An Assessment of ABET Programme Outcomes (a) to (k)." *World Transactions on Engineering and Technology Education* 4 (2): 263-267. http://www.wiete.com.au/journals/WTE&TE/Pages/Vol.4,%20No.2%20(2005)/22-AbuMulaweh12.pdf

Addington J. S., and R. A. Johnson. 1999. "Incorporating the Design and Use of Surveys with Other Engineering Assessment Methods Under Criteria 2000 Guidelines." In *Proceedings of the American Society for Engineering Education Annual Conference*, 21 pp., 20–23 June. Charlotte, NC. www.scopus.com

Almarshoud, A. F. 2011. "Developing a Rubric-Based Framework for Measuring the ABET Outcomes Achieved by Students of Electric Machinery Courses." *International Journal of Engineering Education*, 27 (4): pp. 1–8. https://www.researchgate.net/publication/264672284_Developing_a_Rubric-Based_Framework_for_Measuring_the_ABET_Outcomes_Achieved_by_Students_of_Electric_Machinery_Courses

Altuger-Genc, G., and C. Chassapis. 2011. "Fostering Lifelong Learning in a Capstone Design Environment: An Implementation Assessment." In *41st Annual ASEE/IEEE Frontiers in Education Conference*, 12–15 October. Rapid City, SD.

Ananiadou, K., and M. Claro. 2009. "21st Century Skills And Competences for New Millennium Learners In OECD Countries." Edu Working Paper No. 41. EDU/WKP(2009)20. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=edu/wkp(2009)20&doclanguage=en

Atman, C. J., R. S. Adams, and J. Turns. 2000. "Using Multiple Methods to Evaluate a Freshmen Design Course." In *30th Annual ASEE/IEEE Frontiers in Education Conference*, October, Kansas City, MO. http://ieeexplore.ieee.org.proxy1.lib.umanitoba.ca/search/searchresult.jsp?newsearch=true&queryText=Atman%2C+C.J.%2C+Adams%2C+R.+S.%2C+.AND.+Turns%2C+J.+.LB.2000.RB..+Using+Multiple+Methods+to+Evaluate+a+Freshmen+Design+Course

Bailey, M., R. B. Floersheim, and S. J. Ressler. 2002. “Course Assessment Plan: A Tool For Integrated Curriculum Management.” *Journal of Engineering Education* 91 (4): 425–434. doi: 10.1002/j.2168-9830.2002.tb00728.x.

Barry, B. E., and M. W. Ohland. 2009. “Applied Ethics in the Engineering, Health, Business, and Law Professions: A Comparison.” *Journal of Engineering Education* 98 (4): 377–388. doi: 10.1002/j.2168-9830.2009.tb01034.x.

Beddoes, J. 2017. “Faculty of Engineering: Welcome from the Dean of Engineering.” *University of Manitoba.* http://umanitoba.ca/faculties/engineering/welcome/index.html

Beddoes, J., and Friesen, M. 2017. *NSERC Chair in Design Engineering for Sustainable Development and Enhanced Design Integration.* PIN 145215. University of Manitoba.

Bennett, R. E. 2011. “Formative Assessment: A Critical Review.” *Assessment in Education: Principles, Policy and Practice* 18 (1): 5–25. https://kclpure.kcl.ac.uk/portal/files/9119063/Black2009_Developing_the_theory_of_formative_assessment.pdf

Besterfield-Sacre, M., J. Gerchak, M. Lyons, L. J. Shuman, and H. Wolfe. 2004. “Scoring Concept Maps: An Integrated Rubric for Assessing Engineering Education.” *Journal of Engineering Education* 93 (2): 105–115. doi: 10.1002/j.2168-9830.2004.tb00795.x.

Besterfield-Sacre, M., L. J. Shuman, H. Wolfe, C. J. Atman, J. McGourty, R. L. Miller, B. M. Olds, et al. 2000. “Defining the Outcomes: A Framework for EC 2000.” *IEEE Transactions on Engineering Education* 43 (2): 100–110. https://www.researchgate.net/profile/Larry_Shuman/publication/3050606_Defining_the_outcomes_A_framework_for_EC-2000/links/53db98fd0cf216e4210bf942/Defining-the-outcomes-A-framework-for-EC-2000.pdf

Biggs, J. 1999. “What the Student Does: Teaching for Enhanced Learning.” *Higher Education Research and Development* 18 (1): 57-75. http://dx.doi.org/10.1080/0729436990180105

Biggs, J. 2013. “Constructive Alignment in University Teaching.” *HERDSA Review of Higher Education* 1: 5–22. https://www.tru.ca/__shared/assets/Constructive_Alignment36087.pdf

Bishop, W., O. Nespoli, and W. Parker. 2012. “Rubrics for Accreditation and Outcomes Assessment in Engineering Capstone Projects.” In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp. Winnipeg, MB. June 17-21.

Bloom, B. S., M. D. Engelhart, E. J. Furst, W. H. Hill, and D. R. Krathwohl. 1956. *Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook 1: The Cognitive Domain, 1st Edition*. New York: Longmans, Green and Co.

Borg, I., P. J. F. Groenen, and P. Mair. 2013. *Applied Multidimensional Scaling*. Heidelberg: Springer.

Borrego, M. 2007. “Development of Engineering Education as a Rigorous Discipline: A Study of the Publication Patterns of Four Coalitions.” *Journal of Engineering Education* 96 (1): 5–18. doi: 10.1002/j.2168-9830.2007.tb00911.x.

Borrego, M., and J. Bernhard. 2011. “The Emergence of Engineering Education Research as an Internationally Connected Field of Inquiry.” *Journal of Engineering Education,* 100 (1): 14–47. doi: 10.1002/j.2168-9830.2011.tb00003.x.

Borrego, M., E. Douglas, and C. Amelink. 2009. “Quantitative, Qualitative and Mixed Research Methods in Engineering Education.” *Journal of Engineering Education* 98 (1): 53–66. doi: 10.1002/j.2168-9830.2009.tb01005.x.

Borrego, M., and L. K. Newswander. 2008. “Characteristics of Successful Cross-Disciplinary Engineering Education Collaborations.” *Journal of Engineering Education* 97 (2): 123–134. doi: 10.1002/j.2168-9830.2008.tb00962.x.

Boud, D. 1990. “Assessment and the Promotion of Academic Values.” *Studies in Higher Education* 15 (1): 101-111. http://onlinelibrary.wiley.com/doi/10.1016/0307-4412(90)90252-J/abstract

Brookhart, S. M. 2013. *How to Create and Use Rubrics for Formative Assessment and Grading*. Alexandria: ASCD.

Buchal, R. O., N. Billingsley, A. Bullock and P. Poulin. 2014. “The Lac-MéGantic Train Disaster as a Basis for a Design Project that Emphasizes Safety.” In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 6 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Burgart, D. 2017. *‘Indigeneering’ the Engineering Profession: An Introduction*. A Workshop sponsored by the Centre For Engineering Professional Practice And Engineering Education, Faculty of Engineering, University of Manitoba, 21 March 2018.

Caron, B., G. Gopakumar, D. Dysart-Gale, and M. Harsh. 2014. “Navigating a Constitutional Moment: Reflecting on Implementing Graduate Attributes in Canadian Engineering Education.” *Engineering Studies* 6 (1): 44–61. http://dx.doi.org/10.1080/19378629.2014.905790

Case, J. M., and Light, G. 2011. “Emerging Methodologies in Engineering Education Research.” *Journal of Engineering Education* 100(1): 186–210. doi: 10.1002/j.2168-9830.2011.tb00008.x.

Colby, A., and W. M. Sullivan. 2008. “Ethics Teaching in Undergraduate Engineering Education.” *Journal of Engineering Education* 97 (3): 327–338. doi: 10.1002/j.2168-9830.2008.tb00982.x.

Creswell, J. W. 2013. *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*, 3rd ed. L.A.: Sage.

Davis, D. C., S. W. Beyerlein, and I. T. Davi. 2006. "Deriving Design Course Learning Outcomes from a Professional Profile." *International Journal of Engineering Education* 22(3): 439–446.

Davis, D. C., K. L. Gentili, M. S. Trevisan, and D. E. Calkins. 2002. "Engineering Design Assessment Processes and Scoring Scales for Program Improvement and Accountability." *Journal of Engineering Education* 91 (2): 211–221. doi: 10.1002/j.2168-9830.2002.tb00694.x.

Dew, S. K., M. Lavoie, and A. Snelgrove. 2011. "An Engineering Accreditation Management System." In *Proceedings of the 2nd Annual CEEA Conference (CEEA2011): The Evolution of Engineering Education*, pp. 6, 6–8 June. St. John's, NL: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/328

Driscoll, A. and S. Wood. 2007. *Developing Outcomes-based Assessment for Learning-centered Education: A Faculty Introduction*. Sterling, VA: Stylus.

Dupuis, D., and C. St. Pierre. 2013. Assessing Graduate Attributes as Described by CEAB: An Exploratory Study in a First Year Design Course. In *Proceedings of the Canadian Engineering Education Conference (CEEA)*, 7 pp., 17-20 June. Montreal, QC: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/477

Ebrahiminejad, H. 2017. "A Systematized Literature Review: Defining and Developing Engineering Competencies." In *Proceedings American Society for Engineering Education ASEE's 123rd Annual Conference and Exposition: Jazzed About Engineering Education*, 12 pp., 26–29 June. New Orleans, LA.

Engeler Newbury, B. 2010. "Speaking in Tongues: The Gap Between Academic Language and Industry Language." In *Language in the Disciplines: Disciplinary Discourses and the Embedding of Academic Literacy Skills Within Programs, an Academic Literacy Teaching and Research Network (ALTAR) Symposium,* 14 November. Hawthorn, Victoria, AU.

Engineering Accreditation Commission. 2016. "Comparison of Proposal Submitted in 2015 to Proposal Submitted in 2016." *ABET*. http://www.abet.org/wp-content/uploads/2016/08/EAC-Side-By-Side-Criteria.pdf

Engineers Canada. 2014. "Canadian Engineering Accreditation Board Accreditation Criteria and Procedures." *Engineers Canada.* http://www.engineerscanada.ca/sites/default/files/2014_accreditation_criteria_and_procedures_v06.pdf

Engineers Canada. 2014. *Engineers Canada Annual Report: Canadian Engineers For Tomorrow: Trends in Engineering Enrolment and Degrees Awarded, 2009-2013.* Canada: Engineers Canada. https://www.engineerscanada.ca/sites/default/files/enrolmentreport2013-en-3.pdf

EngineersCanada. 2017. "About Engineers Canada." *Engineers Canada.* https://engineerscanada.ca/about/about-engineers-canada

Engineers Without Borders. 2017. "Evolving Engineering: Unlocking the higher potential of the engineering profession to contribute to society." *Engineers Without Borders Canada*. Accessed 17 December 2017. https://www.ewb.ca/en/showcase/evolving-engineering/

Felder, R. M., and R. Brent. 2003. "Designing and Teaching Courses to Satisfy the ABET Engineering Criteria." *Journal of Engineering Education* 92 (1): 7–25. doi: 10.1002/j.2168-9830.2003.tb00734.x.

Ferens, K., J. Seniuk Cicek, N. Sepehri, W. Kinsner, J.P. Burak, A. Parker, D. McNeill, et al. 2014. "Industry Forum III: Towards a Common Language" In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Finelli, C. J., S. R. Daly, and K. M. Richardson. 2014. "Bridging the Research-To-Practice Gap: Designing an Institutional Change Plan Using Local Evidence." *Journal of Engineering Education* 103 (2): 331-361. doi: 10.1002/jee.20042.

Fink, D. L., S. Ambrose, and D. Wheeler. 2005. "Becoming a Professional Engineering Educator: A New Role For a New Era." *Journal of Engineering Education* 94 (1): 185–194. doi: 10.1002/j.2168-9830.2005.tb00837.x.

Flaherty, C. 2015. "Watered-Down Gen Ed for Engineers?" *Inside Higher Ed.* https://www.insidehighered.com/news/2015/06/26/faculty-members-criticize-proposed-changes-gen-ed-accreditation-standards-engineers

Forehand, M. 2005. "Bloom's Taxonomy." In *Emerging Perspectives On Learning, Teaching, and Technology*, edited by M. Orey. Global Text Project. Creative Commons Attribution 3.0 License. Zurich: Jacobs Foundation. https://textbookequity.org/Textbooks/Orey_Emergin_Perspectives_Learning.pdf

Forgues, D., and S. Dore. 2010. "Three Cases in Using Concept Maps." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 5 pp., 7–9. June. Kingston, ON: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/338

Fortenberry, N. L. 2014. "Foreword." In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, xxv–xxvi. New York: Cambridge University Press.

Frank, B., and S. Fostaty-Young. 2011. “What Can Our Students Do: Year 2 of Graduate Attribute Assessment at Queen’s University.” In *Proceedings of the 2nd Annual CEEA Conference (CEEA2011): The Evolution of Engineering Education*, pp. 6, 6–8 June. St. John’s, NL: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/328

Frank, B., S. McCahan, C. K. Watts, S. Fostaty-Young, P. Ostafichuck, P. Wolf, and N. Saleh. 2011. “Engineering graduate attribute development (EGAD) project.” In *Proceedings of the 2nd Annual CEEA Conference (CEEA2011): The Evolution of Engineering Education*, pp. 3., 6–8 June. St. John’s, NL: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/328

Fredericks Volkwein, J., L. R. Lattuca, P. T. Terenzini, L. C. Strauss, and J. Sukhbaatar. 2004. “Engineering Change: A Study of the Impact of EC2000.” *International Journal of Engineering Education* 20 (3): 318–328. https://www.researchgate.net/profile/Lisa_Lattuca/publication/228578808_Engineering_Change_A_Study_of_the_Impact_of_EC2000/links/09e415143200528ae1000000.pdf

Friends of Engineering. 2017. “Our Purpose.” *Friends of Engineering.* http://www.friendsofengineering.ca/mission/

Friesen, M., Taylor, L. and Britton, R. 2005. A qualitative study of a course trilogy in Biosystems engineering design. *Journal of Engineering Education* 94(3): 288-296.

Fromm, E. 2003. “The Changing Engineering Education Paradigm.” *Journal of Engineering Education* 92 (2): 113–121. doi: 10.1002/j.2168-9830.2003.tb00749.x.

Froyd, J. E. “Assessing and Developing Capabilities to Analyze Broader Contexts for Engineering Practice.” In *Proceedings of the 2005 ASEE/AaeE 4th Global Colloquium*. 26–29 September. Star City, Sydney. Australiahttp://www.foundationcoalition.org/home/keycomponents/assessment_eval/2005-Jun-20_Paper_Global_Societal_Impact_v2.pdf

Froyd, J., and Lohmann, J. R. 2014. “Chronological and Ontological Development of Engineering Education as a Field of Scientific Inquiry.” In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 3–26. New York: Cambridge University Press.

Gijbels, D., F. Dochy, P. Van den Bossche, and M. Segers. 2005. “Effects of Problem-Based Learning: A Meta-Analysis From the Angle of Assessment.” *Review of Educational Research* 75 (1): 27–61. http://arno.unimaas.nl/show.cgi?fid=15855

Gliner, J. A., G. A. Morgan, and N. L. Leech. 2009. *Research in Applied Settings*, *2nd ed*. New York: Routledge.

Graduate Recruitment Bureau. 2014. “Engineering Graduate Career Profile.” Industry Profiles, 2014. Accessed 12 April 2014. http://www.grb.uk.com/engineering-industry-profile

Godri-Politt, K. and G. W. Norval. 2014. "A Module for Teaching Risk Management." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 1 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Goldberg, D. E., and M. Summerville. 2014. "A Whole New Engineer: The Coming Revolution in Engineering Education." Michigan: ThreeJoy.

Hall, J. 2016. *Lecture: Ethics and Engineering*. Given by author during ENG 2030: Engineering Communication: Strategies for the Profession, 7 November 2016. SAFE Work Manitoba.

Hanrahan, H. 2008. "The Washington Accord: History, Development, Status and Trajectory." In *7th ASEE Global Colloquium On Engineering Education*, 9 pp. Cape Town, South Africa
19–23 October.

Hanson J. H., and J. M. Williams. 2008. "Using Writing Assignments To Improve Self-Assessment And Communication Skills In An Engineering Statics Course." *Journal of Engineering Education* 97 (4): 515–529. doi: 10.1002/j.2168-9830.2008.tb00997.x.

Harris, J., A. Steele, and D. Russell. 2011. "Progress on Defining the CEAB Graduate Attributes at Carleton University." In *Proceedings of the 2nd Annual CEEA Conference (CEEA2011): The Evolution of Engineering Education*, pp. 5., 6–8 June. St. John's, NL: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/328

Heinricher, A. C., J. E. Miller, L. Schachterle, N. K. Kildahl, V. Bluemel, and V. Crawford. 2002. "Undergraduate Learning Portfolios for Institutional Assessment." *Journal of Engineering Education* 91 (2): 249–253. doi: 10.1002/j.2168-9830.2002.tb00699.x.

Heller, R. S., C. Beil, K. Dam, and B. Haerum. 2010. "Student and Faculty Perceptions of Engagement in Engineering." *Journal of Engineering Education* 99 (3): 253-261. doi: 10.1002/j.2168-9830.2010.tb01060.x.

Holsapple, M., D. Carpenter, J. Sutkus, C. Finelli, and T. Harding. 2012. "Framing Faculty and Student Discrepancies in Engineering Ethics Delivery." *Journal of Engineering Education* 101 (2): 169–186. doi: 10.1002/j.2168-9830.2012.tb00047.x.

Hsiung, C. M. 2010. "Identification of Dysfunctional Cooperative Learning Teams Based on Students' Academic Achievement." *Journal of Engineering Education* 99 (1): 45–54. doi: 10.1002/j.2168-9830.2010.tb01041.x.

Ingram, S., J. Seniuk Cicek, and N. Sepehri. 2012. "The Attribute Assessment Process at the University of Manitoba." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., 17-21 June. Winnipeg, MB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/399

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

International Engineering Alliance. 2014. "25 Years of the Washington Accord." *International Engineering Alliance.* http://www.ieagreements.org/accords/washington/

International Engineering Alliance. 2017a. "Accords: Washington Accord." *International Engineering Alliance*. http://www.ieagreements.org/accords/washington/

International Engineering Alliance. 2017b. "Home." *International Engineering Alliance*. http://www.ieagreements.org

Jacoby, W. G., and D. J. Ciuk. 2014. *Multidimensional Scaling: An Introduction*. http://polisci.msu.edu/jacoby/research/scaling/intromds/Jacoby-Ciuk,%20MDS,%20V2,%2010-29-14.pdf

Jaeger, R. M. 1997. "Survey Research Methods in Education." In *Complementary Methods for Research in Education*, 2nd ed., edited by R. M. Jaeger, 449-483. Washington: American Educational Research Association.

Jesiek, B., L. Newswander, and M. Borrego. 2009. "Engineering Education Research: Discipline, Community or Field?" *Journal of Engineering Education* 98 (1): 39-52. doi: 10.1002/j.2168-9830.2009.tb01004.x.

Jiusto, S., and Di Biasio, D. 2006. "Experiential Learning Environments: Do They Prepare Our Students to be Self-Directed, Lifelong Learners?" *Journal of Engineering Education* 95 (3): 195–204. doi: 10.1002/j.2168-9830.2006.tb00892.x.

Johri, A., and B. Jesiek. 2014. "Global and International Issues in Engineering Education." In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 655–672. New York: Cambridge University Press.

Johri, A., and B. M. Olds. 2011. "Situated Engineering Learning: Bridging Engineering Education Research and the Learning Sciences." *Journal of Engineering Education* 100 (1): 151–185. doi: 10.1002/j.2168-9830.2011.tb00007.x.

Johri, A., and B. M. Olds. 2014. "Introduction." In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 1–2. New York: Cambridge University Press.

Johri, A., B. M. Olds, and K. O'Connor. 2014. "Situative Frameworks for Engineering Learning Research." In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 47–66. New York: Cambridge University Press.

Jonassen, D. H., D. Shen, R. M. Marra, Y. H. Cho, J. L. Lo, and V. K. Lohani. 2009. "Engaging and Supporting Problem Solving in Engineering Ethics." *Journal of Engineering Education* 98 (3): 235–254. doi: 10.1002/j.2168-9830.2009.tb01022.x.

Jonsson, A., and Svingby, G. 2007. "The Use of Scoring Rubrics: Reliability, Validity and Educational Consequences." *Educational Research Review* 2: 130-144. doi:10.1016/j.edurev.2007.05.002.

Kavanagh, L., K. Laberinto, and D. Ruth. 2016. "Exposing Engineering Students To Ethical Challenges: A Web-Based Learning Module." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 6 pp., 19–22 June. Halifax, NS: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/588

Kishawy, H. A., T. Sidhu, R. Pop-Iliev, M. A. Rosen, D. Zhang and Q. H. Mahmoud. 2014. "Meeting the Outcome-Based CEAB Accreditation Criteria: Engineering Programs at UOIT." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., June 8-11. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Koro-Ljungberg, M., and E. P. Douglas. 2008. "State of Qualitative Research in Engineering Education: Meta-Analysis of JEE Articles, 2005-2006." *Journal of Engineering Education* 97 (2): 163–175. doi: 10.1002/j.2168-9830.2008.tb00965.x.

Kruger, J. and Dunning, D. 1999. "Unskilled and Unaware of it: How Difficulties in Recognizing One's Own Incompetence Lead to Inflated Self-Assessments." *Journal of Personality and Social Psychology* 77 (6): 1121–1134. https://www.avaresearch.com/files/UnskilledAndUnawareOfIt.pdf

Lathem, S., M. Neumann, and N. Hayden. 2011. "The Socially Responsible Engineer: Assessing Student Attitudes of Roles and Responsibilities." *Journal of Engineering Education* 100 (3): 444–471. doi: 10.1002/j.2168-9830.2011.tb00022.x.

Lavrakas, P. J. 2008. "Self-Selection Bias." In *Encyclopedia of Survey Research Methods*. SAGE. http://dx.doi.org.uml.idm.oclc.org/10.4135/9781412963947

Leggett, M., A. Kinnear, M. Boyce, and I. Bennett. 2004. "Student and Staff Perceptions of the Importance of Generic Skills in Science." *Higher Education Research and Development* 23 (3), 295–312. doi: 10.1080/0729436042000235418.

Leydens, J. A., B. M. Moskal, and M. Pavelich, M. 2004. "Qualitative Methods Used in the Assessment of Engineering Education." *Journal of Engineering Education* 93 (1): 65-72. doi: 10.1002/j.2168-9830.2004.tb00789.x.

Liljedahl, P. 2010. "The Four Purposes of Assessment." *Vector*: 7–12. http://www.peterliljedahl.com/wp-content/uploads/Four-Purposes-of-Assessment1.pdf

Litzinger, J. A., L. R. Lattuca, R. G. Hadgraft, and W. C. Newstetter. 2011. "Engineering Education and the Development of Expertise." *Journal of Engineering Education* 100 (1): 123–150. doi: 10.1002/j.2168-9830.2011.tb00006.x.

Litzinger, T. A., Wise, J. C., and Lee, S. H. 2005. "Self-Directed Learning Readiness Among Engineering Undergraduate Students." *Journal of Engineering Education* 94 (2): 215–221. http://onlinelibrary.wiley.com/doi/10.1002/j.2168-9830.2005.tb00842.x.

Lord, M., E. J. Berger, N. N. Kellam, E. L. Ingram, D. M. Riley, D. T. Rover, N. Salzman, and J. D. Sweeney. 2017. "Talking About a Revolution: Overview of NSF RED Projects." In *Proceedings American Society for Engineering Education ASEE 2017 Annual Conference and Exposition*, 25–28 June. Columbus, OH. https://peer.asee.org/talking-about-a-revolution-overview-of-nsf-red-projects.pdf

Loui, M. C. 2006. "Assessment of an Engineering Ethics Video: Incident at Morales." *Journal of Engineering Education* 95 (1): 85–91. doi: 10.1002/j.2168-9830.2006.tb00879.x.

Lowden, K., S. Hall, D. Elliot, and J. Lewin. 2011. *The Employers' Perceptions of Employability Skills of new Graduates*. London: Edge Foundation. https://www.kent.ac.uk/careers/docs/Graduate_employability_skills%202011.pdf

Maclellan, E. 2001. "Assessment for Learning: The Differing Perceptions of Tutors And Students." *Assessment and Evaluation in Higher Education* 26 (4): 307–318. http://strathprints.strath.ac.uk/2427/

Male, S. 2010. "Generic Engineering Competencies: A Review and Modelling Approach." *Education Research and Perspectives* 37 (1): 25 – 51. http://erpjournal.net/wp-content/uploads/2012/07/ERPV37-1_Male-S.-2010.-Generic-Engineering-Competencies.pdf

Male, S. A., M. B. Bush, and E. S. Chapman. 2010. "Perceptions of Competency Deficiencies in Engineering Graduates." *Australasian Journal of Engineering Education,* 16 (1)**,** 55–68. https://www.researchgate.net/profile/Sally_Male/publication/292363499_Perceptions_of_competency_deficiencies_in_engineering_graduates/links/58c939a24585157512315d48/Perceptions-of-competency-deficiencies-in-engineering-graduates.pdf

Male, S. A., Bush, M. B. and Chapman, E. S. 2011a. "An Australian Study of Generic Competencies Required by Engineers." *European Journal of Engineering Education* 36 (2): 151–163. http://dx.doi.org/10.1080/03043797.2011.569703

Male, S. A., M. B. Bush, and E. S. Chapman. 2011b. "Understanding Generic Engineering Competencies." *Australasian Journal of Engineering Education* 17 (3), 147–156. http://dx.doi.org/10.1080/22054952.2011.11464064

Manitoba Education, Citizen, and Youth. 2006. *Rethinking Classroom Assessment with Purpose in Mind: Assessment for Learning, Assessment as Learning, Assessment of Learning.* Winnipeg, MB: Manitoba Education, Citizenship, and Youth. http://www.edu.gov.mb.ca/k12/assess/wncp/rethinking_assess_mb.pdf

Mann, D. D., K. J. Dick, and S. A. Ingram. 2012. "Recent Enhancements to the Biosystems Engineering Design Trilogy at the University of Manitoba." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., 17-21 June. Winnipeg, MB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/article/view/4636

Martinez-Mediano, C., and Lord, S. M. 2012. "Lifelong Learning Competencies Program for Engineers." *International Journal of Engineering Education* 28 (1): 130–143. https://www.researchgate.net/publication/233867546_Lifelong_Learning_Competencies_Program_for_Engineers

May, E., and D. Strong. 2006. "Is Engineering Education Delivering What Industry Requires?" In *Proceedings of the 2nd Annual CEEA Conference (CEEA2011): The Evolution of Engineering Education*, pp. 9., 6–8 June. St. John's, NL: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/328

McCahan, S., L. Romkey, and G. Allen. 2011. "Development of the Graduate Attribute Quality Assurance Process at the University of Toronto." In *Proceedings of the 2nd Annual CEEA Conference (CEEA2011): The Evolution of Engineering Education*, pp. 6., 6–8 June. St. John's, NL: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/328

McGill University. 2017. "Graduate Attributes and Indicators: Detailed/Program Specific Descriptions." McGill University. https://www.mcgill.ca/engineering/files/engineering/graduate_attributes_and_indicators_detailed_list.pdf

McGourty, J., Besterfield-Sacre, M., and Shuman, L. 1999. "ABET's Eleven Student Learning Outcomes (A-K): Have We Considered the Implications?" http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.489.5441&rep=rep1&type=pdf

McGourty, J., C. Sebastian, and W. Swart. 1998. "Developing a Comprehensive Assessment Program for Engineering Education." *Journal of Engineering Education* 87 (4): 355–361. doi: 10.1002/j.2168-9830.1998.tb00365.x.

Meenakshi, S., and S. Mohanty. 2017. "Importance Versus Achieved: A Cross-Sectional Study on Engineering Students' Perception on Generic Attributes." *Journal of Engineering Education Transformations* 31 (1): 48-55. ISSN 2349-2473, eISSN 2394-1707.

Mello, N., D. Di Biasio, and R. Vaz. 2007. "Fulfilling ABET Outcomes by Sending Students Away." In *Proceedings American Society for Engineering Education ASEE 114th Annual Conference and Exposition,* 7 pp., 24-27 June. Honolulu, Hawaii. http://www.wpi.edu/Images/CMS/News/500_FULFILLING_ABET_OUTCOMES_BY_SENDING_STUD.pdf

Messick, S. 1987. "Validity." *ETS Research Report Series* 1987 (2): i – 208. Princeton: Education Testing Service. doi: 10.1002/j.2330-8516.1987.tb00244.x.

Miller, C., L. Geraci, J. Jong, L. Qing, C. Hickman, and S. Kuchta. 2014. *Design Thinking: Business Programs: Industry Future Series*. Education Advisory Board: COE Forum: The
Advisory Board Company. https://www.scribd.com/document/323254125/Design-Thinking-Business-Programs-White-Paper

Mitacs. 2017. "Foundations of Project Management I." *MITACS*. https://www.mitacs.ca/en/foundations-project-management-i

Moazzen, I., M. Miller, P. Wild, L. Jackson and A. Hadwin. 2014. "Engineering Design Survey." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Mohamed, A. H., F. B. Suja, and A. H. Ismail. 2012. "Graduate Students' Perspectives on Study Environment Based on Exit Survey." *Asian Social Science* 8 (16): 200–208. www.scopus.com

Moore, P. D., S. M. Cupp, and N. L. Fortenberry. 2004. "Linking Student Learning Outcomes to Instructional Practices – Phase II." In *Proceedings ASEE/IEEE Frontiers in Education Conference*. 20–23 October. Savannah, GA. http://ieeexplore.ieee.org.proxy1.lib.umanitoba.ca/search/searchresult.jsp?newsearch=true&queryText=Linking+Student+Learning+Outcomes+to+Instructional+Practices+–+Phase+II.

Moskal, B. M. 2008. "Using Assessment Results for Improving Student Learning." In *Designing Better Engineering Education Through Assessment*, edited by J. E. Spurlin, S. A. Rajala, and J. P. Lavelle, 117–148. Sterling: Stylus.

Moskal, B. M., J. A. Leydens, and M. J. Pavelich. 2002. "Validity, Reliability and the Assessment of Engineering Education." *Journal of Engineering Education* 91 (3): 351–354. doi: 10.1002/j.2168-9830.2002.tb00714.x.

Mourtos, N. J. 2003. "Defining, Teaching and Assessing Lifelong Learning Skills." In *33rd Annual ASEE/IEEE Frontiers in Education Conference*. 6 pp., 5–8 November. Boulder, CO. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.501.8223&rep=rep1&type=pdf

Mukahark, N., N. Wahid, Z. I. Rizman, M. A. Ali, M. A. Aris, E. A. Kadir, and G. K. S. Nair. 2013. "Industry's Feedback of New Diploma Program in Industrial Engineering." *World Applied Sciences Journal* 23: 103-108. http://www.idosi.org/wasj/wasj23(eemcge)/18.pdf

National Academy of Engineering (U.S.) (NAE). 2004. "Engineers of 2020: Visions of Engineering In The New Century." Washington: National Academies Press.

National Science Foundation. 2017. "About the National Science Foundation: NSF at a Glance." *National Science Foundation.* https://www.nsf.gov/about/

NCSS. 2017. "Multidimensional Scaling." Chap. 435 in *NCSS Statistical Software*. NCSS, LLC. https://ncss-wpengine.netdna-ssl.com/wp-content/themes/ncss/pdf/Procedures/NCSS/Multidimensional_Scaling.pdf

Nelson, N. 2014. "Achieving Graduate Attributes Through Project-Based Learning." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Newstetter, W. C., and M. D. Svinicki. 2014. "Learning Theories for Engineering Education Practice." In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 29–46. New York: Cambridge University Press.

Nguyen, D. Q. 1998. "The Essential Skills and Attributes of an Engineer: A Comparative Study of Academics, Industry Personnel and Engineering Students." *Global Journal of Engineering Education* 2 (1): 65–75. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.124.1502&rep=rep1&type=pdf

Office of Institutional Accreditation and Program Assessment, 2011. "Data Sources for Outcomes Assessment." University of Texas at Austin. https://www.nyu.edu/content/dam/nyu/academicAssessment/documents/Resource%20Library/University%20of%20Texas%20Arlington_Direct%20vs.%20Indirect%20Evidence%20Handout.pdf

Ohland, M. W., R. A. Layton, M. L. Loughry, and A. G. Yuhasz. 2005. "Effects of Behavioral Anchors on Peer Evaluation Reliability." *Journal of Engineering Education* 94 (3): 319–326. doi: 10.1002/j.2168-9830.2005.tb00856.x.

Olds, B., and R. L. Miller. 2008. "Using Formative Assessment for Program Improvement." In *Designing Better Engineering Education Through Assessment*, eds. J. E. Spurlin, S. A. Rajala, and J. P. Lavelle, 266–284. Sterling, VA: Stylus.

Olds, B., B. Moskal, and R. L. Miller. 2005. "Assessment in Engineering Education: Evolution, Approaches and Future Collaborations." *Journal of Engineering Education* 94 (1): 13–25. doi: 10.1002/j.2168-9830.2005.tb00826.x.

Oliver, B. 2013. “Graduate Attributes as a Focus for Institution-Wide Curriculum Renewal: Innovations and Challenges.” *Higher Education Research and Development*, 32 (3), 450–463. http://dx.doi.org/10.1080/07294360.2012.682052.

Oliver Keene, E., and S. Zimmermann. 2007. *Mosaic of Thought: The Power of Comprehension Strategy Instruction, 2nd ed.* Portsmouth: Heinemann.

Parsons, C. K., E. Caylor, and H. S. Simmons. 2005. “Cooperative Education Work Assignments: The Role of Organizational and Individual Factors in Enhancing ABET Competencies and Co-Op Workplace Well-Being.” *Journal of Engineering Education* 94 (3): 309–317. doi: 10.1002/j.2168-9830.2005.tb00855.x.

Passow, H. 2012. “Which ABET Competencies do Engineering Graduates Find Most Important in Their Work?” *Journal of Engineering Education* 101 (1): 95–118. doi: 10.1002/j.2168-9830.2012.tb00043.x.

Passow, H. J., and C. H. Passow. 2017. “What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review.” *Journal of Engineering Education* 106 (3): 475–526. doi: 10.1002/jee.20171.

Pawley, A. 2009. “Universalized Narratives: Patterns in how Faculty Members Define ‘Engineering.’” *Journal of Engineering Education* 98 (4): 309–319. doi: 10.1002/j.2168-9830.2009.tb01029.x.

Pellegrino, J. 2017. “The Integration of Teaching, Learning and Assessment: A Design-Based Approach*.” Educational Research and Methods (ERM) Distinguished Lecture*. Presented at ASEE’s 124th Annual Conference and Exposition: *Where Engineering Education Takes Flight*, 28 June. Columbus, OH.

Peters, R. 2007. “Engineering Accreditation in Canada and Proposed Changes: as Presented to the Examining Board of Professional Engineers and Geoscientists of Newfoundland and Labrador.” https://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0CCIQFjABahUKEwjt6OuG0fnIAhUGWh4KHZ3iChE&url=http%3A%2F%2Fwww.engr.mun.ca%2Faccreditation2010%2FDennisPresentation.ppt&usg=AFQjCNETOL0OKyr3-JbuqMpD8y4RYNs__w

Pimmel, R. L. 2003. “Student Learning Of Criterion 3 (a)–(k) Outcomes with Short Instructional Modules and the Relationship to Bloom’s Taxonomy.” *Journal of Engineering Education* 92 (4): 351–359. doi: 10.1002/j.2168-9830.2003.tb00780.x.

Plumb, C., and C. Scott. 2002. “Outcomes Assessment of Engineering Writing at the University of Washington.” *Journal of Engineering Education* 91 (3): 333-338. doi: 10.1002/j.2168-9830.2002.tb00711.x.

Polland, R. J. 1998, 2005. *Essentials of Survey Research and Analysis*. http://www.pointk.org/resources/files/Guidelines_on_Essentials_of_Survey_Research.pdf

Pons, D. 2016. "Relative Importance of Professional Practice and Engineering Management Competencies." *European Journal of Engineering Education* 41 (5): 530–547. doi: 10.1080/03043797.2015.1095164.

Popp, A. B., D. C. Levy, and S. Barrie. 2012. "Rationalizing Relationships Between The Various Sets Of Learning Outcomes As A Data Driven Mapping Strategy." *International Journal of Engineering Education* 28 (4): 966–981. http://researchdirect.uws.edu.au/islandora/object/uws%3A40394

Powers, T. A., J. Sims-Knight, R. Topciu, S. C. and Haden. 2002. "Assessing Team Functioning in Engineering Education." In *Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition*, 16–19 June, Montreal, QC. http://www.foundationcoalition.org/publications/journalpapers/asee2002/assessing_team_functioning_in_engineering_education.pdf

Prados, J. W., G. D. Peterson, and L. R. Lattuca. 2005. "Quality Assurance of Engineering Education Through Accreditation: The Impact of Engineering Criteria 2000 and Its Global Influence." *Journal of Engineering Education* 94 (1): 165–184. doi: 10.1002/j.2168-9830.2005.tb00836.x.

Prince, M. J. 2004. "Does Active Learning Work? A Review of the Research." *Journal of Engineering Education* 93 (3): 223–231. doi: 10.1002/j.2168-9830.2004.tb00809.x.

Prince, M. J., and R. M. Felder. 2006. "Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases." *Journal of Engineering Education* (95) 2: 123–138. doi: 10.1002/j.2168-9830.2006.tb00884.x.

Puerzer, R. J., and David M. Rooney. 2002. "The Alumni Survey as an Effective Assessment Tool for Small Engineering Programs." *Journal of Engineering Education* 91 (1): 109–16. doi: 10.1002/j.2168-9830.2002.tb00679.x.

Qualters, D. M., T. C. Sheahan, E. J. Mason, D. S. Navick, and M. Dixon. 2008. "Improving Learning In First-Year Engineering Courses Through Interdisciplinary Collaborative Assessment." *Journal of Engineering Education* 97 (1): 37–45. doi: 10.1002/j.2168-9830.2008.tb00952.x.

Radcliffe, D. F. 2005. "Innovation as a Meta Attribute for Graduate Engineers." *International Journal of Engineering Education* 21: 194–199. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.157.9426&rep=rep1&type=pdf

Radcliffe, D. F. 2006. "Shaping the Discipline of Engineering Education." Journal of Engineering Education 95 (4): 263 – p 264. doi: 10.1002/j.2168-9830.2006.tb00901.x.

Razavinia, N., and L. Mydlarski. 2016. "Graduate Attributes and Indicators: Detailed/Program Specific Descriptions." *Accreditation Resources: Graduate Attribute Indicators.* Faculty of Engineering, McGill University. Accessed on 18 October 2016. http://www.mcgill.ca/engineering/faculty-staff-resources/accreditation/accreditation-resources

Renaud, R. Forthcoming. "Assessing the Content Validity of a Clinical Competency Exam in Nursing." University of Manitoba.

Riley, D. 2016. "Mind the Gap – What the ABET Crisis Can Teach Us about Connecting Research and Practice." *Educational Research and Methods (ERM) Distinguished Lecture*. Presented at ASEE's 123rd Annual Conference and Exposition: *Jazzed About Engineering Education*, 28 June. New Orleans, LA.

Ro, H. K., D. Merson, L. R. Lattuca, and P. T. Terenzini. 2015. "Validity of the Contextual Competence Scale for Engineering Students." *Journal of Engineering Education* 104 (1): 35–54. doi 10.1002/jee.20062.

Robinson, M. A., P. R. Sparrow, C. Clegg, and K. Birdi. 2005. "Design Engineering Competencies: Future Requirements and Predicted Changes in the Forthcoming Decade." *Design Studies* 26 (2005): 123–153. doi:10.1016/j.destud.2004.09.004.

Rogers, G. 2000. "EC2000 and Measurement: How Much Precision is Enough?" *Journal of Engineering Education,* 89 (2): 161–166. doi: 10.1002/j.2168-9830.2000.tb00510.x.

Rogers, J. 2015. "Jamie Rogers, ABET president, explains the reasoning behind proposed changes to Criteria 3 and 5." *ABET*. http://www.abet.org

Rogers, S. W., and R. K. Goktas. 2010. "Exploring Engineering Graduate Student Research Proficiency with Student Surveys." *Journal of Engineering Education* 99 (3): 263–278. doi: 10.1002/j.2168-9830.2010.tb01061.x.

Rompelman, O. 2000. "Assessment of Student Learning: Evolution of Objectives in Engineering Education and the Consequences for Assessment." *European Journal of Engineering Education* 25 (4): 339–350. doi: 10.1080/03043790050200386.

Roselli, R.J., and S. P. Brophy. 2006. "Effectiveness of Challenge-Based Instruction in Biomechanics." *Journal of Engineering Education* 95 (4): 311–324. doi: 10.1002/j.2168-9830.2006.tb00907.x.

Roth, W. M. 2014. "The Social Nature of Representational Engineering Knowledge." In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 67–82. New York: Cambridge University Press.

Rover, D. T. 2005. "Centered on Education Research." Journal of Engineering Education 94 (1): 195–197. doi: 10.1002/j.2168-9830.2005.tb00838.x.

Rushton, A. 2005. “Formative Assessment: A Key To Deep Learning?” *Medical Teacher* 27 (6): 509–513. https://doi.org/10.1080/01421590500129159

Sarin, S. 2000. “Quality Assurance in Engineering Education: A Comparison of EC-2000 and ISO-9000.” *Journal of Engineering Education* 89 (4), 495–501. doi: 10.1002/j.2168-9830.2000.tb00557.x.

Scales, K., C. Owen, S. Shiohare, and M. Leonard. 1998. “Preparing for Program Accreditation Review Under ABET Engineering Criteria 2000: Choosing Outcome Indicators.” *Journal of Engineering Education* 87(3): 207-210. doi: 10.1002/j.2168-9830.1998.tb00342.x.

Schachterle, L., C. Demetry, and J. Orr. 2009. “Quality Assurance in Engineering Education in the United States.” In *Engineering Education Quality Assurance: A Global Perspective*, edited by A. S. Patil, and P. J. Gray, 163-180. New York: Springer. doi: 10.1007/978-1-4419-0555-0_13.

Schneider, S. C., and R. J. Niederjohn. 1995. “Assessing Student Learning Outcomes Using Graduating Senior Exit Interviews and Alumni Surveys.” In *Proceedings of the ASEE/IEEE American Society for Engineering Education Annual Conference*, 5 pp., 1–4 November. Atlanta, GA. www.scopus.com

Schunn, C. D., and M. M. Nelson. 2009. “Expert-novice Studies: An Educational Perspective.” In *Psychology of Classroom Learning: An Encyclopedia*, edited by E. M. Anderman, and L. H. Anderman. Detroit: Macmillan Reference USA/Gale Cengage Learning.

Seniuk Cicek, J. 2015. *CEAB Graduate Attributes: History, Initiative, Changes and Implications*. Educational Seminar for IEEE EduManCom Chapter, Winnipeg Section. Faculty of Engineering, University of Manitoba.

Seniuk Cicek, J., S. Ingram, and M. Friesen. 2016. “On Becoming an Engineer: The Essential Role of Lifelong Learning Competencies.” In *Proceedings of the American Society for Engineering Education 123rd Annual Conference and Exposition: Jazzed about Engineering Education*, 17 pp., 26–29 June. New Orleans, LA.

Seniuk Cicek, J., S. Ingram, M. Friesen, and D. Ruth. 2017. “Action Research: A Methodology for Transformative Learning for a Professor and His Students in an Engineering Classroom.” *European Journal of Engineering Education*. doi: 10.1080/03043797.2017.1405242.

Seniuk Cicek, J., Ingram, S., Mann, D., and Renaud, R. D. 2017. “Investigating the Relative Importance of the CEAB Graduate Attributes: Study Design and Initial Findings.” In *Proceedings of the Canadian Engineering Education Association Conference: Innovation and Diversity in Engineering Education (CEEA/ACEG)*, 9 pp., 4–7 June. Toronto, ON: OJS/PKP. https://ceea.ca/en/publications/

Seniuk Cicek, J., S. Ingram, and N. Sepehri. 2013. "The Attribute Assessment Process at the University of Manitoba: Year Two." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA): Leadership in Engineering*, 7 pp., 17–20 June. Montreal, QC: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/477

Seniuk Cicek, J., S. Ingram, and N. Sepehri. 2014a. "The Attribute Assessment Process in the Faculty of Engineering at the University of Manitoba: Year Three." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Seniuk Cicek, J., S. Ingram, and N. Sepehri. 2014b. Outcomes-Based Assessment in Action: Engineering Faculty Examine Graduate Attributes in Their Courses. *International Journal of Engineering Education* 30 (4): 788–805.

Seniuk Cicek, J., S. Ingram, N. Sepehri, J.P. Burak, P. Labossiere, D. Mann, D. Ruth, et al. 2014. "Rubrics as a Vehicle to Define the Twelve CEAB Graduate Attributes, Determine Graduate Competencies, and Develop a Common Language for Engineering Stakeholders." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 6 pp., 8-11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Seniuk Cicek, J., P. Labossiere and S. Ingram. 2015. "Examining Fourth Year Engineering Student Perceptions of Graduate Attribute Competencies: Year Three." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 8 pp., May 31–June 3. Hamilton, ON: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/544

Seniuk Cicek, J., P. Labossiere, and S. Ingram. 2014. "Examining Fourth Year Engineering Student Perceptions of Graduate Attribute Competencies: Year Two." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 9 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Seniuk Cicek, J., P. Labossiere, and D. Mann. 2013. "Surveying Fourth Year Engineering Student Perceptions of Graduate Attribute Competencies." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA): Leadership in Engineering*, 7 pp., 17–20 June. Montreal, QC: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/477

Seniuk Cicek, J., L. Peto, and S. Ingram. 2016. "Linking Graduate Attribute Competencies to the Canadian Employability Skills: Equipping Students with the Language and Tools for Employability/Career Success." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA/ACEG): Innovation and Design in Engineering Education,* 7 pp., 19–22 June. Halifax, NS: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/588

Seniuk Cicek, J., Ruth, D., Ingram, S. and Friesen, M. 2015. "The Role of Action Research in Influencing a Senior Engineering Professor's Pedagogical Understanding and Creating a Community of Practice for Students." In *Proceedings of the 6th Research in Engineering Education Symposium (REES): Translating Research into Practice*. 9 pp., 13–15 July. Dublin, Ireland.

Sepehri, N., W. Kinsner, J. P. Burak, C. Shafai, U. Annakkage, D. Mann, A. Shalaby, et al. 2013. "The Process of Continual Improvement of Engineering Programs at the University of Manitoba: Now and Next. In *Proceedings of the Canadian Engineering Education Association Conference (CEEA/ACEG),* 7 pp., 18–20 June. Montreal, QC: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/477

Shaeiwitz, J. 1996. "Outcomes Assessment in Engineering Education," *Journal of Engineering Education* 85 (3) 239–246. doi: 10.1002/j.2168-9830.1996.tb00239.x.

Sheppard, S. D., J. W. Pellegrino, and B. M. Olds. 2008. "On Becoming a 21st Century Engineer." *Journal of Engineering Education* 97 (3): 231 – 234. doi: 10.1002/j.2168-9830.2008.tb00972.x.

Shuman, L. J., M. Besterfield-Sacre, and J. McGourty. 2005. "The ABET "Professional Skills" – Can They Be Taught? Can They Be Assessed?" *Journal of Engineering Education* 94 (1): 41–55. doi: 10.1002/j.2168-9830.2005.tb00828.x.

Shuman, L. J., M. F. Sindelar, M. Besterfield-Sacre, H. Wolfe, and R. L. Pinkus. 2004. "Can our Students Recognize and Resolve Ethical Dilemmas?" In *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*, pp. 15, 20–23 June. Salt Lake City, UT. http://faculty.kfupm.edu.sa/COE/mayez/ABET/ABET-PDF/Eng-ethics/ethical-dilema-assessing-outcomes.pdf.

Siri Johnson, C. 2006. "The Analytic Assessment of Online Portfolios in Undergraduate Technical Communication: A Model." *Journal of Engineering Education* 95 (4): 279–287. doi: 10.1002/j.2168-9830.2006.tb00903.x.

SkillsYouNeed. 2017. "Interpersonal Skills*." SkillsYouNeed*. https://www.skillsyouneed.com/interpersonal-skills.html

Smith, K. A., S. D. Sheppard, D. W. Johnson, and R. T. Johnson. 2005. "Pedagogies of Engagement: Classroom-Based Practices." *Journal of Engineering Education* 94 (1): 87–101. doi: 10.1002/j.2168-9830.2005.tb00831.x.

Soundarajan, N. 2002. "Preparing for Accreditation Under EC2000: An Experience Report." *Journal of Engineering Education* 91 (1): 117–123. doi: 10.1002/j.2168-9830.2002.tb00680.x.

Spracklin-Reid, D., and A. Fisher. 2012. "Course-Based Learning Outcomes as the Foundation for Assessment of Graduate Attributes." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 3 pp., 17–20 June. Winnipeg, MB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/399

Spurlin, J. E. 2008. "Assessment Methods Used in Undergraduate Program Assessment." In *Designing Better Engineering Education Through Assessment*, edited by J. E. Spurlin, S. A. Rajala, and J. P. Lavelle, 59–116. Sterling: Stylus.
Spurlin, J. E., S. A. Rajala, and J. P. Lavelle. 2008. "Assessing Student Learning." In *Designing Better Engineering Education Through Assessment*, edited by J. E. Spurlin, S. A. Rajala, and J. P. Lavelle, 23-58. Sterling: Stylus.

Steering Committee of NEERC. 2006. "Special Report: The Research Agenda for the New Discipline of Engineering Education." *Journal of Engineering Education* 95 (4) 259–261. doi: 10.1002/j.2168-9830.2006.tb00899.x.

Streveler, R. A., S. Brown, G. L. Herman, and D. Montfort. 2014. "Conceptual Change and Misconceptions in Engineering Education: Curriculum, Measurement, and Theory-Focused Approaches." In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 83-102. New York: Cambridge University Press.

Striebig, B. A., A. A. Ogundipe, and M. Papadakis. 2016. *Engineering Applications in Sustainable Design and Development.* Boston: Cengage Learning.

Stutsky, B. J., M. Singer, and R. Renaud. 2012. "Determining the Weighting and Relative Importance of CanMEDS Roles and Competencies." *BMC Research Notes* 5 (354): 1-7. doi: 10.1186/1756-0500-5-354.

Sunthonkanokpong, W. 2011. "Future Global Visions of Engineering Education." In *Proceedings of 2nd International Science, Social-Science, Engineering and Energy Conference 2010: Engineering Science and Management*, 160–165. Science Direct: Elsevier. doi: 10.1016/j.proeng.2011.03.029.

Svinicki, M. D. 2010. *A Guidebook on Conceptual Frameworks for Research in Engineering Education*. Rigorous Research in Engineering Education. USA: National Science Foundation. DUE-0341127, DUE-0817461.

The Joint Task Force on Engineering Education Assessment. 1996. *Assessment White Paper: A Framework for the Assessment of Engineering Education*. USA: ASEE. http://www.asee.org/papers-and-publications/publications/Assessment-White-Paper.pdf

Teh, I. 2016. "Bloom's Taxonomy." *Ivan Teh–RunningMan*. http://ivanteh-runningman.blogspot.ca/2016/09/blooms-taxonomy.html

Tonso, K. L. 1996. "Student Learning and Gender." *Journal of Engineering Education* 100 (2): 143–150. doi: 10.1002/j.2168-9830.1996.tb00223.x.

Trevelyan, J. 2014. "Towards A Theoretical Framework For Engineering Practice." In *Engineering Practice In A Global Context: Understanding The Technical And The Social*, edited by B. Williams, F. C. Figueiredo, and J. Trevelyan, 33–60. Boca Raton: CRC Press.

Turns, J. and C. J. Atman. 2000. "Concept Maps for Engineering Education: A Cognitively Motivated Tool Supporting Varied Assessment Functions." *IEEE Transactions on Education* 43 (2): 164–173. doi: 10.1109/13.848069.
University of Manitoba. 2017a. "About the University." *University of Manitoba.* http://umanitoba.ca/about/

University of Manitoba. 2017b. "Faculty of Architecture: Departments and Programs." *University of Manitoba.* http://umanitoba.ca/faculties/architecture/programs/index.html.

University of Manitoba. 2017c. "Faculty of Engineering: Admissions Statistics." *University of Manitoba.* http://umanitoba.ca/faculties/engineering/undergraduate_studies/ugs_admission_statistics.html

University of Manitoba. 2017d. "Faculty of Engineering: Centre for Engineering Professional Practice and Engineering Education: About the Centre." *University of Manitoba.* http://umanitoba.ca/faculties/engineering/departments/ce2p2e/aboutdesign.html

University of Manitoba. 2017e. "Faculty of Engineering: Engineering Access Program (ENGAP): What is ENGAP?" *University of Manitoba.* http://umanitoba.ca/faculties/engineering/programs/engap/prospective/whatis.html

University of Manitoba. 2017f. "Faculty of Engineering: IEEQ. What is the IEEQ?" *University of Manitoba.* http://umanitoba.ca/faculties/engineering/programs/ieeq/whatisieeq.html

University of Manitoba. Forthcoming. "Faculty of Engineering Graduate Attribute Rubrics." *University of Manitoba.*

University of Manitoba. 2017g. "Office of Research Ethics and Compliance: Human Ethics." *University of Manitoba.* http://umanitoba.ca/research/orec/ethics/human_ethics_index.html

University of Washington. 2014. "Consortium to Promote Reflection in Engineering Education." UW Centre for Engineering Learning and Teaching, University of Washington. http://cpree.uw.edu/. Accessed May 4 2018.

Uziak, J. 2015. "Position of the Final Year Project in an Engineering Curriculum." *Global Journal of Engineering Education* 17 (3): 113–118. http://www.wiete.com.au/journals/GJEE/Publish/vol17no3/02-Uziak-J.pdf

Van Note Chism, N., E. Douglas, and W. J. Hilson, Jr. 2008. *Qualitative Research Basics: A Guide for Engineering Educators*. Rigorous Research in Engineering Education. USA: National Science Foundation. DUE-0341127. https://crlte.engin.umich.edu/wp-content/uploads/sites/7/2013/06/Chism-Douglas-Hilson-Qualitative-Research-Basics-A-Guide-for-Engineering-Educators.pdf
Walker, J. M. T., and P. H. King. 2003. "Concept Mapping as a Form of Student Assessment and Instruction in the Domain of Bioengineering." *Journal of Engineering Education* 92 (2): 167–179. doi: 10.1002/j.2168-9830.2003.tb00755.x.

Wankat, P.C. 2004. "Analysis of the First Ten Years of the *Journal of Engineering Education*." *Journal of Engineering Education* 93 (1): 13–21. doi: 10.1002/j.2168-9830.2004.tb00784.x.
Waters, C. 2007. "Work in Progress – Blackboard Tracking, Can This Be a Method of ABET Outcome i Assessment." In *37th Annual ASEE/IEEE Frontiers in Education Conference: Global Engineering: Knowledge Without Borders, Opportunities without Passports*. 10–13 October. Milwaukee, WI. doi: 10.1109/FIE.2007.4417876.

Wertz, R. E. H., S. Purzer, M. J. Fosmire, and M. E. Cardella. 2013. "Assessing Information Literacy Skills Demonstrated In An Engineering Design Task." *Journal of Engineering Education* 102 (4): 577–602. doi: 10.1002/jee.20024.

Williams, B., P. Wankat, P. Neto, and C. Tiago. 2014. "Is Engineering Education Research Global? The Answer May Surprise You." In *Proceedings American Society for Engineering Education ASEE 121st Annual Conference and Exposition,* 8 pp., 15–18 June. Indianapolis, IN.

Wolf, P. and W. Stiver. 2011. "Graduate Attributes: Intentional Mapping and Assessment Portfolios." In *Proceedings of the 2nd Annual CEEA Conference (CEEA2011): The Evolution of Engineering Education*, pp. 4, 6–8 June. St. John's, NL: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/328

Woollacott, L. C. 2009. "Taxonomies of Engineering Competencies and Quality Assurance in Engineering Education." In *Engineering Education Quality Assurance: A Global Perspective*, edited by A. S. Patil, and P. J. Gray, 257–295. New York: Springer. doi: 10.1007/978-1-4419-0555-0_21.

Yadav, A., D. Subedi, M. A. Lundeberg, and C. F. Bunting. 2011. "Problem-Based Learning: Influence On Students' Learning In An Electrical Engineering Course." *Journal of Engineering Education* 100 (2): 253-280. doi: 10.1002/j.2168-9830.2011.tb00013.x.

Yalvac, B., H. D. Smith, J. B. Troy, and P. L. Hirsch. 2007. "Promoting Advanced Writing Skills in an Upper-Level Engineering Class." *Journal of Engineering Education* 96 (2): 117–128. doi: 10.1002/j.2168-9830.2007.tb00922.x.

Zafft, C. R., S. G. Adams, and G. S. Matkin. 2009. "Measuring Leadership in Self-Managed Teams Using the Competing Values Framework." *Journal of Engineering Education* 98 (3): 273–282. doi: 10.1002/j.2168-9830.2009.tb01024.x.

Zhu, J., Y. Li, M. F. Cox, J. London, J. Hahn, and B. Ahn. 2013. "Validation of a Survey for Graduate Teaching Assistants: Translating Theory to Practice." *Journal of Engineering Education* 102 (3), 426–443. doi: 10.1002/jee.20014.

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Appendix A: Engineering Competencies: Comparative Views

Appendix A.1
Comparative View of the CEAB Graduate Attributes and Changes to ABET Criterion

CEAB Graduate Attributes 2009	**ABET EC 2000 (Pre 2015)**	**Proposed Changes to ABET EC 2000 July 2015**	**Submitted in 2015 ABET Criterion 3: Student Outcomes (Engineering Accreditation Commission 2016)**	**Proposed for First Reading in 2016 ABET General Criterion 3: Student Outcomes (Engineering Accreditation Commission 2016)**
1. Knowledge Base	(a) an ability to apply knowledge of mathematics, science, and engineering	Use the principles of science and mathematics to identity, formulate and solve engineering problems	1. An ability to identify, formulate, and solve engineering problems by applying principles of engineering, science, and mathematics.	(1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
3. Investigation	(b) an ability to design and conduct experiments, as well as to analyze and interpret data	Develop and conduct appropriate experimentation and testing procedures, and analyze and draw conclusions from data	3. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.	(3) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
4. Design	(c) an ability to design a system, component, or process to meet desired needs	Apply both analysis and synthesis in the engineering design process, resulting in designs that meet constraints and specifications (including societal, economic, environmental and other factors appropriate to design)	2. An ability to apply both analysis and synthesis in the engineering design process, resulting in designs that meet desired needs.	(2) Ability to apply the engineering design process to produce solutions that meet specified needs with consideration for public health and safety, and global, cultural, social, environmental, economic, and other factors as appropriate to the discipline.
6. Individual & Teamwork	(d) an ability to function on multidisciplinary teams	Establish goals, plan tasks, meet deadlines, manage risk and uncertainty, and	7. An ability to function effectively on teams that establish goals, plan tasks, meet	(7) An ability to function effectively as a member or leader of a team that establishes

		function effectively on teams.	deadlines, and analyze risk and uncertainty.	goals, plans tasks, meets deadlines, and creates a collaborative and inclusive environment.
2. Problem Analysis	(e) an ability to identify, formulate, and solve engineering problems	Use the principles of science and mathematics to identity, formulate and solve engineering problems	1. An ability to identify, formulate, and solve engineering problems by applying principles of engineering, science, and mathematics.	(1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
10. Ethics & Equity	(f) an understanding of professional and ethical responsibility	Demonstrate ethical principles in an engineering context	5. 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 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.
8. Professionalism	(f) an understanding of professional and ethical responsibility		5. 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 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.
7. Communication Skills	(g) an ability to communicate effectively	Communicate effectively with a range of audiences through various media	4. An ability to communicate effectively with a range of audiences.	(4) An ability to communicate effectively with a range of audiences.
9. Impact of Engineering on Society and the Environment	(h) the broad education necessary to understand the impact of engineering		5. An ability to recognize ethical and professional responsibilities in engineering situations and	(5) An ability to recognize ethical and professional responsibilities in engineering situations and

	solutions in a global and societal context		make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.	make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
12. Lifelong Learning	(i) a recognition of the need for, and ability to engage in, lifelong learning		6. An ability to recognize the ongoing need for additional knowledge and locate, evaluate, integrate, & apply this knowledge appropriately.	(6) An ability to recognize the ongoing need to acquire new knowledge, to choose appropriate learning strategies, and to apply this knowledge.
[Contemporary Issues]	(j) a knowledge of contemporary issues			
5. Engineering Tools	(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice			
11. Economics & Project Management		Establish goals, plan tasks, meet deadlines, manage risk and uncertainty, and function effectively on teams.	7. An ability to function effectively on teams that establish goals, plan tasks, meet deadlines, and analyze risk and uncertainty.	(7) An ability to function effectively as member or leader of a team that establishes goals, plans tasks, meets deadlines, and creates a collaborative and inclusive environment

APPENDIX A.2
Graduate Attribute Comparison Table: WA, CEAB and ABET Criterion 3

Differentiating Characteris-tics (IEA):	For Washington Accord Graduate:	Washington Accord Knowledge Profile: A WA Program Provides:	CEAB Graduate Attribute:	ABET Criterion 3 Student Outcomes	Proposed Changes to ABET Criterion 3 (2016)
Engineering Knowledge:	**WA1:** Apply knowledge of mathematics, natural science, engineering fundamentals and an engineering specialization as specified in WK1 to WK4 respectively to the solution of complex engineering problems.	**WK1: A** systematic, theory-based understanding of the **natural sciences** applicable to the discipline.	**1. A knowledge base 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	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
		WK2: Conceptually-based **mathematics**, numerical analysis, statistics and formal aspects of computer and information science to support analysis and modeling applicable to the discipline.			
		WK3: A systematic, theory-based formulation of **engineering fundamentals** required in the engineering discipline.			
		WK4: Engineering **specialist knowledge** that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline.			
Problem Analysis Complexity of analysis	**WA2:** Identify, formulate, research literature and analyse	**WK1: A** systematic, theory-based understanding of the **natural sciences** applicable	**2. Problem analysis**: An ability to use appropriate knowledge and skills to	(e) an ability to identify, formulate, and solve engineering problems	

	complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences. (WK1 to WK4)	to the discipline. **WK2:** Conceptually-based **mathematics**, numerical analysis, statistics and formal aspects of computer and information science to support analysis and modeling applicable to the discipline. **WK3: A systematic**, theory-based formulation of **engineering fundamentals** required in the engineering discipline. **WK4: E**ngineering **specialist knowledge** that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline.	identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.		
Design/ development of solutions: Breadth and uniqueness of engineering problems i.e. the extent to which problems are original and to which solutions have previously been identified or codified	**WA3:** Design solutions for *complex* engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations (WK5)	**WK5:** Knowledge that supports **engineering design** in a practice area.	**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	(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	An ability to apply the engineering design process to produce solutions that meet specified needs with consideration for public health and safety, and global, cultural, social, environmental, economic, and other

			societal considerations.		factors as appropriate to the discipline.
Investigation: Breadth and depth of investigation and experimentation	**WA4:** Conduct investigations of *complex* problems using research-based knowledge (WK8) and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.	**WK8:** Engagement with selected knowledge in the **research literature** of the discipline.	**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	An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
Modern Tool Usage: Level of understanding of the appropriateness of the tool	**WA5:** Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling, to *complex* engineering problems, with an understanding of the limitations. (WK6)	**WK6:** Knowledge of **engineering practice** (technology) in the practice areas in the engineering discipline.	**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.	(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	
The Engineer and Society: Level of knowledge and responsibility	**WA6:** Apply reasoning informed by contextual knowledge to assess societal, health, safety,	**WK7: Comprehension of** the role of engineering in society and identified issues in engineering practice in the discipline: ethics and the professional responsibility of an engineer to public safety; the impacts of engineering activity: economic,	**8. Professionalism:** An understanding of the roles and responsibilities of the	(f) an understanding of professional and ethical responsibility	An ability to recognize ethical and professional responsibilities in engineering

	legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems. (WK7)	social, cultural, environmental and sustainability.	professional engineer in society, especially the primary role of protection of the public and the public interest.		situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
Environment and Sustainability: Type of solutions.	**WA7:** Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering problems in societal and environmental contexts. (WK7)	**WK7: Comprehension of** the role of engineering in society and identified issues in engineering practice in the discipline: ethics and the professional responsibility of an engineer to public safety; the impacts of engineering activity: economic, social, cultural, environmental and sustainability.	**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 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	
Ethics: Understanding and level of practice	**WA8:** Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice. (WK7)	**WK7: Comprehension of** the role of engineering in society and identified issues in engineering practice in the discipline: ethics and the professional responsibility of an engineer to public	**10. Ethics and equity**: An ability to apply professional ethics, accountability, and equity.	(f) an understanding of professional and ethical responsibility	An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must

		safety; the impacts of engineering activity: economic, social, cultural, environmental and sustainability.			consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
Individual and Team work: Role in and diversity of team	**WA9:** Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings.		**6. Individual and team work**: An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	(d) an ability to function on multi-disciplinary teams	An ability to function effectively as a member or leader of a team that establishes goals, plans tasks, meets deadlines, and creates a collaborative and inclusive environment
Com-munication Level of communication according to type of activities performed	**WA10:** Communicate effectively on *complex* engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.		**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.	(g) an ability to communicate effectively	An ability to com-municate effectively with a range of audiences.
Project Management and Finance: Level of management required for	**WA11:** Demonstrate knowledge and understanding of engineering		**11. Economics and project management**: An ability to appropriately incorporate		

differing types of activity	management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, to manage projects and in multi-disciplinary environments.		economics and business practices including project, risk and change management into the practice of engineering and to understand their limitations.		
Lifelong learning: Preparation for and depth of continuing learning.	**WA12:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.		**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 (j) a knowledge of contemporary issues	An ability to recognize the ongoing need to acquire new knowledge, to choose appropriate learning strategies, and to apply this knowledge.

Appendix B: A Comprehensive List of Direct, Indirect, and Published Assessment Tools

Key: ABET Student Learning Outcomes and CEAB Graduate Attributes

ABET EC 2000	CEAB Graduate Attributes
engineering programs must demonstrate that their graduates have: (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; (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; (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 ability to engage in, lifelong learning; (j) a knowledge of contemporary issues; (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	1. Knowledge base for engineering 2. Problem analysis 3. Investigation 4. Design 5. Use of engineering tools 6. Individual and team work 7. Communication skills 8. Professionalism 9. Impact on society and environment 10. Ethics and equity 11. Economics and project management 12. Lifelong learning

Common Assessment Methods for ABET Competencies a-k with Comparative CEAB Graduate Attributes

Assessment Method	Sources
DIRECT MEASURES (COURSE-BASED)	
Projects/Design Projects - Capstone (ABET 3.c/CEAB 4) - Introduction, Junior or Senior Course Design Projects (ABET 3.c/CEAB 4) - Project assessment of student's ability to use tools appropriately (ABET 3.k, 3.a-c/CEAB 5, 1-4) - Internal Student Project Quality Assessment Protocol - Junior Year Interdisciplinary Project (Abroad)	- Spurlin 2008 - Jiusto and DiBiasio 2006 - Zafft et al. 2009 - Moore et al. 2004 - Schachterle et al. 2009 - The Joint Task Force on Engineering Education Assessment, 1996
Assignments - Group Assignments - Graded assignments that assess student's use of analytical software, design tools, CAD programs, robotics (ABET 3.k, 3.a-c/CEAB 5, 1-4) - Analysis Problems: "Open-ended" application of assumptions (ABET 3.b/CEAB 2, 3) - Problem sets	- Colby and Sullivan 2008 - Spurlin 2008 - Schachterle et al. 2009

Technical Products from Capstone Course (ABET 3.c/CEAB 4)	- Spurlin 2008
Design Competitions - Scored work of students entering national design competitions (ABET 3.i,; 3.a-e, 3.g, 3.k./CEAB 1-7, 11, 12)	- Spurlin 2008
Experimental Tasks/ Laboratory Evaluations (ABET 3.c/CEAB 3, 4)	- Spurlin 2008 - Abu-Mulaweh 2005
Reports - Lab Reports (ABET 3.b/CEAB 3) - Technical Reports from capstone courses (ABET 3.f/CEAB 8, 10) - Reports based on case studies (ABET 3.f/CEAB 8, 10) - Project reports - "Lab Report Checklist"	- Mello et al. 2007 - Spurlin 2008 - Moore et al. 2004
Exams - Final exams - National exams - Pre-post exams within courses using normalized gain scores	- Roselli and Brophy 2006 - Qualters et al. 2008 - Spurlin 2008 - Schachterle et al. 2009 - The Joint Task Force on Engineering Education Assessment, 1996
Tests - Calculus, chemistry, physics (ABET 3.a/CEAB 1) - Test the interrelationship of basic science knowledge and engineering knowledge (ABET 3.a/CEAB 1) - Related to ability to to identify and formulate design tasks (ABET 3.e/CEAB 2) -Testing of professional code of ethics and application of code of ethics (ABET 3.f/CEAB 8, 10) - Testing based on case studies (ABET 3.f/CEAB 8, 10) - Students propose solutions to contemporary engineering problems (ABET 3.j; CEAB 9) - Conceptual diagnostic test - Critical Essay Tests	- Shuman et al. 2004 - Hsiung 2010 - Spurlin 2008 - Moore et al. 2004 - Schachterle et al. 2009 - The Joint Task Force on Engineering Education Assessment, 1996
Questions - Question Generation - Lecture Discussion Question Cycle - Test questions - Graded homework on contemporary issues module (ABET 3.j/ CEAB 9)	- Yalvac et al. 2007 - Jonassen et al. 2009 - Hsiung 2010 - Spurlin 2008
Observations - Off-Task Frequency Behavior Observations - By faculty, advisors and industry experts on teams (ABET 3.d/CEAB 6) - Faculty observation of ethical behavior of students (ABET 3.f/CEAB 8, 10) - Use of tools in the field assessed by faculty and industry experts (ABET 3.k, 3.a-c/CEAB 5, 1-4)	- Atman 2000 - Roselli and Brophy 2006 - Yalvac et al. 2007 - Hsiung 2010 - Spurlin 2008
Portfolios/Webfolios - Professional portfolios using course material (ABET 3.f/CEAB 8, 10)	- McGourty et al. 1999 - Froyd 2005 - Siri Johnson 2006

	- Spurlin 2008 - Moore et al. 2008 - The Joint Task Force on Engineering Education Assessment, 1996
Contracts - Signed contracts with students related to ethical behavior (ABET 3.f/CEAB 8, 10)	- Spurlin et la. 2008
Essays - Case Analysis/Argumentative Essays - Students describe what they are learning from their engineering education (ABET 3.i/CEAB 12) - Students show their understanding of the global nature of engineering as well as social, political, and/or economic issues (ABET 3.h/CEAB 9 & 11)	- Shuman et al. 2004 - Plumb and Scott 2002 - Jonassen et al. 2009 - Yalvac et al. 2007 - Spurlin 2008
Writing Assignments (ABET 3.g/CEAB 7) - Minute Paper - Student Reflections (ABET 3.i/CEAB 12) - Freewriting/Loping - Literary critique - Major Research Papers - Team-based Research Paper	- Shuman et al. 2004 - Plumb and Scott 2002 - Colby and Sullivan 2008 - Hsiung 2010 - Spurlin 2008 - Mourtos 2003 - Moore et al. 2004 - The Joint Task Force on Engineering Education Assessment, 1996
Journals (ABET 3.f/CEAB 8)	- Colby and Sullivan 2008 - Zafft et al. 2009 - Moore et al. 2004
Presentations (ABET 3.g/CEAB 7) - Oral - Video Presentations	- McGourty et al. 1999 - Shuman et al. 2005 - Spurlin 2008 - Moore et al. 2008
Debates/Discussions - Graded discussion of current events in engineering and changes to analysis/design procedures (ABET 3.h/CEAB 9 & 11)	- Spurlin et al. 2008
Interactive Case Studies	- Shuman et al. 2004
Communication of Graphical Skills (ABET 3.g/CEAB 7)	- Spurlin 2008
Concept Mapping	- Atman 2000 - Froyd 2005 - Spurlin 2008 - Moore et al. 2004
Information Literacy Skills - Assessment of student's ability to search the Internet or library resources and distinguish quality resources (ABET 3.i/ CEAB 12)	- Spurlin 2008
Rubrics - Used by faculty, industry, students for self and peer assessment - To score specific engineering problems (ABET 3.e/CEAB 2) - California critical thinking rubric (ABET 3.e/CEAB 2)	- Spurlin 2008 - Moore et al. 2004

- To judge design ability based on student presentations; judging by industry (ABET 3.c/CEAB 4) - Rubrics to score ethics essays (ABET 3.f/CEAB 8, 10) - Rubrics on written work – judged for technical ability and writing skills (ABET 3.g/CEAB 7) - Rubrics when viewing student presentations (ABET 3.g/CEAB 7) - Rubrics used by industry for senior-design final-project presentations and reports (ABET 3.g/CEAB 7) - Rubrics for senior design project or course paper (ABET 3.j/CEAB 9)	
Student Self Evaluations/Self Reports - Measure of Aptitude and Perception - Student Developer	- Powers et al. 2002 - Shuman et al. 2004 - Shuman et al. 2005 - McGourty et al. 1999
Peer Evaluations/Ratings - Team members' assessment of other team members (ABET 3.d/CEAB 6) - Student Developer (ABET 3.d/CEAB 6)	- Hsiung 2010 - Spurlin 2008 - McGourty et al. 1999
External/Stakeholder Reviews/Reports - Feedback from Employer Interviews - Co-op Education/Coordinator Reports - External Review - Community Reports on Student Service-Learning Projects - Interviews with Employers - Input from Practicing Engineers	- Shuman et al. 2004 - Abu-Mulaweh 2005 - Moore et al. 2004 - The Joint Task Force on Engineering Education Assessment, 1996
INDIRECT MEASURES	
Surveys - Ad-hoc Survey - Attitude Scale Survey - Alumni Survey (graduates of 3-5 years, every 3-5 years) - Employer Survey - Faculty Survey (every 5-6 years) - Senior Surveys (Exit Survey) - Entry and Exit Surveys - Perception and Attitude Surveys - National Surveys	- McGourty et al. 1999 - Froyd 2005 - Atman 2000 - Roselli and Brophy 2006 - Loui 2006 - Lathem, Neumann and Hayden 2011 - Hsiung 2010 - Spurlin 2008 - Plumb and Scott 2002 - Moore et al. 2004 - Schachterle et al. 2009
Questionnaires -Metacognitive Questionnaire - Team Effectiveness Questionnaire	- Atman 2000 - Hanson and Williams 2008 - Zafft et al. 2009
Students Interviews - Metacognitive Interview - Senior Exit Interviews	- McGourty et al. 1999 - Atman 2000 - Hanson and Williams 2008 - Zafft et al. 2009 - Lathem et al. 2011 - Spurlin 2008 - Moore et al. 2008 - The Joint Task Force on Engineering Education Assessment, 1996

Focus Groups - Student - Industry members	- Lathem et al. 2011 - Spurlin 2008 - Moore et al. 2004
Rates/Time Measures - Retention Rates - Transfer Rates - Time to Degree - Graduate/alumni employment histories/Job Satisfaction and Advancement - Acceptances into graduate school	- Spurlin 2008 - Schachterle et al. 2009
PUBLISHED ASSESSMENT INSTRUMENTS	
The Fundamentals of Engineering Examination	- Abu-Mulaweh 2005 - Spurlin 2008 - Schachterle et al. 2009 - The Joint Task Force on Engineering Education Assessment, 1996
Professional Engineer License exam	- Moore et al. 2004
Concept Inventories	- Moore et al. 2004
California Critical Thinking Skills Test	- Moore et al. 2004
National Surveys - Educational Benchmarking, Inc. (EBI) (Exit Assessment; Alumni Assessment; Employer Assessment) National Survey of Student Engagement (NSSE)	- Schachterle et al. 2009
- *CLI* - Continuing Learning Inventory - *IDEA* - Continual Development and Educational Assessment Student Ratings of Instruction System	- Jiusto and DiBiasio 2006
- *MBI* - Managerial Behavior Instrument	- Zafft et al. 2009
Information Literacy/Lifelong Learning (ABET 3.i/CEAB 12): - *SDLRS* - Measures readiness for self-directed learning - *iSkills* - Measures information and communication technologies competencies - *SAILS* - Measures how to use library resources - *ILT* - Measures how to use library resources - *SKILLS* - Measures learning strategy preferences, given certain scenarios - *ATLAS* - Measures learning strategy preferences	- Wertz et al. 2013 - Jiusto and DiBiasio 2006 - Spurlin 2008
Ethics (ABET 3.f/CEAB 10): - *Cognito System* –Measure intellectual development; adapted for ethics: to recognize and resolve ethical dilemmas. - *Perry's Model of Intellectual and Ethical Development* - *Reflective Judgment (RJ) Model* - Patricia M. King and Karen S. Kitchener - *Defining Issues Test (DIT/DIT-2)* – Rest/Kolberg. To determine subject's moral development level. - *TESSE* - Test of Ethical Sensitivity in Science	- Shuman et al. 2004 - Loui 2006 - Barry and Ohland 2009 - Moore et al. 2004
Equity/Multiculturalism (ABET 3.d, h/CEAB 10, 6) - *IDI* - The Intercultural Development Inventory	- Froyd 2005 - Spurlin 2008

(Bennett) - *MEXQ* - The Multicultural Experience Questionnaire - *DIT* - Defining Issues Test - *DMIS* - Developmental Model of Intercultural Sensitivity	
Teamwork (ABET 3.d/CEAB 6) - *TKT* – Teamwork Knowledge Test (based on Stevens and Campion Teamwork KSA Test) – multiple-choice test constructed to assess individual knowledge regarding a variety of teaming issues - *TPC* – Team Process Checks – 20-item scale assessing team member's evaluation of his/her team functioning across a number of domains - *CATME* – Comprehensive Assessment of Team Member Effectiveness (Ohland, Pomeranz and Feinstein, 2006) - *Team Developer* (now the *Professional Developer*)	- Powers et al. 2002 - Spurlin 2008 - Moore et al. 2004

Appendix C: Engineering Competencies in the Literature

Appendix C.1
Selected *JEE* Articles that Assess the ABET Professional Skills, 2006–2011

N	Date/ Vol (Issue)	Title	Author(s)
1	2006 95 (4)	*The Analytic Assessment of Online Portfolios in Undergraduate Technical Communication: A Model*	C. Siri Johnson
2	2006 95 (4)	*Effectiveness of Challenge-Based Instruction in Biomechanics*	R. J. Roselli and S. P. Brophy
3	2006 95 (1)	*Assessment of an Engineering Ethics Video: Incident at Morales*	M. C. Loui
4	2006 95 (3)	*Experiential Learning Environments: Do They Prepare Our Students to be Self-Directed, Life-Long Learners?*	S. Jiusto and D. Di Biasio
5	2007 96 (2)	*Promoting Advanced Level Writing Skills in an Upper-Level Engineering Class*	B. Yalvac, H. D. Smith, J.B. Troy and P. Hirsch
6	2008 97 (3)	*Ethics Teaching in Undergraduate Engineering Education*	A. Colby and W. Sullivan
7	2008 97 (4)	*Using Writing Assignments to Improve Self-Assessment and Communication Skills in an Engineering Statics Course*	J. H. Hanson and J. M. Williams
8	2009 98 (4)	*Applied Ethics in the Engineering, Health, Business, and Law Professions: A Comparison*	B. E Barry and M. W. Ohland
9	2009 98 (3)	*Engaging and Supporting Problem Solving in Engineering Ethics*	D. H. Jonassen, D. Shen, R. M. Marra, Y. H. Cho, J. L. Lo, V. K. Lohani
10	2009 98 (3)	*Measuring Leadership in Self-Managed Teams Using the Competing Values Framework*	C. R. Zafft, S. G. Adams and G. S. Matkin
11	2010 99 (1)	*Identification of Dysfunctional Cooperative Learning Teams Based on Students' Academic Achievement*	C. M. Hsiung
12	2011 100 (3)	*The Socially Responsible Engineer: Assessing Student Attitudes of Roles and Responsibilities*	S. A. Lathem, M. D. Neumann and N. Hayden

Note. These articles are cited in the References.

Appendix C.2
Student Outcomes in *JEE* Articles, 2006 – 2011

Article/ Author/ Year	Targeted Outcome	Activity	Assessment Method(s)	Author/ Source of Method	Description of Method – Verbatim
The Analytic Assessment of Online Portfolios in Undergrad-uate Technical Commun-ication: A Model /Siri Johnson (2006)	An ability to communicate effectively (3.g)	Online Portfolio	Analytical scoring for 10 separate communication criteria and holistically for one overall portfolio score.	Instructors from New Jersey Institute of Technology & members of Society for Technical Communication	An individual online portfolio that contains students' work for the semester. Open to the internet and hosted on university servers. Faculty and instructors gather each semester to read and assess a random sampling of the portfolios.
Effectiveness of Challenge-Based Instruction in Biomechanics /Roselli & Brophy (2006)	Recognition of the need for, an ability to engage in lifelong learning (3.i)	Challenge-based instruction (CBI) informed by How People Learn (HPL) framework & using STAR (Software Technology for Action & Reflection) Legacy cycle & classroom communication system.	1. In-class formative assessment 2. Observations 3. Surveys 4. Knowledge-based exam questions 5. Rubrics	Roselli & Brophy (2006)/Nation Academy of Science (NAS)/ Cognition & Technology Group at Vanderbilt Peabody College; Bransford et al./Schwartz et al.	1. Classroom communication system; on-line practice environment with diagnostic feedback; small & large group discussions. 2. External observers used the VaNTH Observational System (VOS) to estimate the percentage of class time spent using HPL activities. 3. End of semester survey, "Experiences in and Benefits from This Course"; Student Exit Survey targeting theories & assumptions of the benefits of CBL; end of course evaluations. 4. Created by both the CBI & traditional instructor. 5. The CBI & traditional instructors developed the scoring rubric for each knowledge-based question.
Assessment of an Engineering Ethics Video: Incident at Morales/Loui (2006)	Understand professional & ethical responsibility (3.f)	Students view engineering ethics video, *Incident at Morales*.	6. Ad hoc survey 7. Defining Issues Test (DIT-2)	1. Loui (2006) 2. Center for the Study of Ethical Development at the University of Minnesota, 1970s	1. Five-item survey students take before and after viewing the video. 2. A standard paper-and-pencil multiple-choice test of moral reasoning, administered pre and post-test
Experiential Learning Environments : Do They Prepare Our Students to be Self-Directed, Life-Long	Recognition of the need for, an ability to engage in lifelong learning (3.i)	The Worchester Polytechnic Institute (WPI) Global Studies Program.	1. Self-Directed Learning Readiness Scale (SDLRS) 2. Continuing Learning Inventory (CLI) 3. Individual	1. Guglielmino & Associates 2. N/A 3. IDEA centre at Kansas State University 4. Program Project designed	1. A 58-item Likert-scale self-assessment questionnaire with prompts probing students' attitudes towards learning. One of two major instruments for assessing students' readiness & willingness to

Learners? /Jiusto & Di Biasio (2006)			Development & Educational Assessment Student Ratings of Instruction system (IDEA). 4. Internal student project quality assessment protocol.	by WPI instructors	engage in LLL. 2. The other of two major instruments for assessing students' readiness & willingness to engage in LLL. Not used by Jiusto & Di Biasio. 3. A course self-evaluation product completed at end of a course designed for students to focus on student learning. 4. Faculty assessment of students' final reports analyzed using WPI's internally developed evaluation rubrics. Faculty trained and calibrated reviewers.
Promoting Advanced Level Writing Skills in an Upper-Level Engineering Class/ Yalvac, Smith, Troy, & Hirsch (2007)	An ability to communicate effectively (3.g)	1. Team-based research paper using How People Learn (HPL) approach to Writing Across the Curriculum (WAC) or Writing within the Disciplines (WID) 2. Roleplaying	1. Scoring rubric 2. Feedback/ Questions/ Observation	Yalvac, Smith, Troy, Hirsch (2007)/National Academy text HPL	1. Research papers evaluated by trained, independent coders. The rubric targeted seven areas: (a) organizing and formatting; (b) mechanics, (c) style, (d) clarity and quality of content, (e) synthesis, (f) argumentation, (g) visual thinking (charts and tables). 2. Students received feedback from peers and a teaching assistant after mini-presentation/debate of their research papers. Teaching assistants and students asked questions to clarify outcomes. One researcher attended presentation/debate class to observe.
Ethics Teaching in Undergrad-uate Engineering Education / Colby & Sullivan (2008)	Understand professional & ethical responsibility (3.f)	1. Case studies/Discussion (i.e.) Hyatt Regency walkway collapse & Challenger disaster 2. Student-developed case studies/graded group assignments 3. Structured reflections: written work/journals 4. Oral presentations 5. Community-based learning	Suggestions by authors. Not necessarily what they observed, but rather what they recommend. 1. N/A 2. N/A 3. Shuman et al.'s scoring rubric 4. Shuman et al.'s scoring rubric 5. N/A	Colby & Sullivan (2008)/Shuman et al. (2005)	1 – 5. Generally, the authors recommend using Shuman et al.'s scoring rubric: Students' written responses to ethical decision-making scenarios in engineering practice are coded for 5 components: recognition of dilemma; information; analysis; perspective; and resolution.

		/service learning			
Using Writing Assignments to Improve Self-Assessment and Communication Skills in an Engineering Statics Course/ Hanson & Williams (2008)	An ability to communicate effectively (3.g)/ Recognition of the need for, an ability to engage in lifelong learning (3.i)	Writing Across the Curriculum (WAC)/Writing in the Disciplines (WID) explain-a-problem assignment (a variation of "Documented Problem Solutions" classroom assessment technique)	1. Evaluation rubrics Authors suggested using these assessment methods in future: 2. Metacognitive questionnaire 3. Metacognitive interviews 4. Course evaluations	1. WAC/WID strategies/ Angelo and Cross (1993) 2. Swanson (1990) 3. Paris & Jacobs (1984) 4. N/A	1. During the first term, students were asked to provide one written description of their solution to one homework problem, twice per week. During subsequent terms, students prepared one written description of a homework problem per week. Students were supplied with the 4 criteria. Criteria targeted the professional skills 3.g & 3.i. Instructor used a 3-level grading rubric to assess the 4 criteria. 2. N/A 3. N/A 4. Students commented on their experience with the explain-a-problem assignment; part of assessment for learning.
Applied Ethics in the Engineering, Health, Business, and Law Professions: A Comparison/ Barry & Ohland (2009)	Understand professional & ethical responsibility (3.f)	N/A	Test of Ethical Sensitivity in Science and Engineering (TESSE)	Borenstein et al. (2008)	An assessment tool patterned after the DIT-2, but using scenarios in the context of engineering. Still in development in 2008.
Engaging and Supporting Problem Solving in Engineering Ethics / Jonassen, Shen, Marra, Cho, Lo, & Lohani (2009)	Understand professional & ethical responsibility (3.f)	On-line case-based, problem-centered learning environment, Engineer Your Eye (EYE). 1. Experiment 1: Students use the online learning environment with hyperlinks written as questions to negotiate engineering ethics problems. 2. Students evaluate, create or summarize arguments to the cases.	1. Question generation; case analysis essay 2. Answers to questions; argument-tative essay	1. Jonassen, Shen, Marra, Cho, Lo & Lohani (2009); Dori & Herscovitz (1998); Nussbaum & Kardash (2005); Nussbaum & Schraw (2007). 2. Jonassen, Shen, Marra, Cho, Lo & Lohani (2009); Nussbaum & Kardash (2005); Nussbaum & Schraw (2007); Ferretti, MacArthur, & Dowdy (2000).	1. Two raters using criteria established by Dori & Herscovitz analyzed questions. Four variables were used to assess question generation: question total count; relevant question count; level of questions; relevant higher-order question count. Two raters used a holistic rubric with a 4-point scale to assess the essay based on these components: perspectives of characters; application of various ethical theories; application ethical cannons; generation of alternative solutions; and making decisions. 2. Two researchers assessed quality of responses to questions on a 3-point scale; argumentative essays were assessed using the holistic rubric described for

					Experiment 1; all responses to every cases received a frequency score for each dependent variable; each student's total set of responses for each case was evaluated for overall quality on a 6-point scale emphasizing support for argument, counterclaim identification & justification, & overall clarity & organization.
Measuring Leadership in Self-Managed Teams Using the Competing Values Framework/ Zafft, Adams & Matkin (2009)	Ability to function on teams (3.d)	Self-managed teams worked together to develop a written Request for Proposal (RIP) to renovate the mechanical systems for the local State Fair Grandstand.	1. Grades from final project 2. Managerial Behavior Instrument (MBI) to measure leadership profiles (language & scoring system modified to fit educational team setting & needs of the study) • Self-evaluation • Team member evaluation 3. Team Effectiveness Questionnaire (TEQ) Additional Assessment Methods Suggested: 4. Interviews or journals 5. Evaluating the customer on the performance of the team 6. Make survey available on-line	1. N/A 2. Lawrence, Quinn & Lenk (2003) 3. Adams, Vena & Ulla, 2002 Additional Methods: Adams & Matkin (2009)	1. A scoring matrix with input from students' peers in the form of a peer review evaluation. Components include: 1) clear expectation of thought; 2) depth of coverage; 3) LEEDS Energy Rating analysis & heating & cooling loads; 4) Reasonableness of cost/benefit ratio; 5) Meets the needs of the owner; 6) Creativity & imagination; 7) Grammar, neatness, & professionalism 2. A 360-degree survey that measures behavioral complexity in teams. Participants are asked to evaluate their own leadership profiles & the leadership profiles of each member of their team. Both surveys contain 36 items measuring the leadership profiles of the Competing Values Framework (CVF). Profiles are: Relating to People; Producing Results: Leading Change; and Managing Processes. Once the surveys are assessed, teams are coded as high or low behavioral complexity. 3. Seven items measuring the effectiveness of student teams & students' attitudes towards teams using a five-point Likert scale. 4. Qualitative data to further measure attitude & performance 5. N/A 6. To eliminate survey fatigue & lessen the load of the investigator.
Identification of Dysfunctional	Ability to function on teams (3.d)	Teamwork • Discussion Sessions	1. Minute paper 2. Peer rating system	1. N/A 2. Kaufman, Felder,	1. Student writes how their team is doing and lists any difficulties at the end of

Cooperative Learning Teams Based on Students' Academic Achievement /Hsiung (2010)		• Homework Classes	3. Off-task behavior frequency observations 4. Lecture-discussion-questioning cycle 5. Tests 6. Attitude scale survey	Fuller 3. Hwong et al. 4. Hsiung (2010) 5. Hsiung (2010) 6. Johnson, Johnson, Anderson	class. 2. A confidential rating of the extent to which each of their teammates is (or is not) fulfilling his/her responsibilities. 3. Two observers perform 5 systematic observations of the students during team discussions. Off-task behaviors defined in advance. 4. Instructor poses short questions to randomly selected students during class lectures and discussions to ensure students' accountability. 5. Students are tested individually 4 times on course contents throughout teamwork process. Flowcharts are prepared in advance as a key for assessing each test. Test papers graded independently by two assistants; students verified results. 6. Two peer-academic-support subscale using a 5-point scale: designed to evaluate (i.) the respondent's teammates' attitudes about the respondent, and (ii.) the respondent's perceptions about how teammates feel about him/her.
The Socially Responsible Engineer: Assessing Student Attitudes of Roles and Responsi-bilities/ Lathem, Neumann, Hayden (2011)	Understand professional & ethical responsibility (3.f); understand impact of engineering solutions in global, economic, environmental, and societal context (3.h); knowledge of contemporary issues (3.j)	Coursework in the Civil & Environmental programs in a state university during a 4-year curricular reform period. Specifically, (i) a series of 3 systems courses to replace 3 existing courses; (ii) incorporating service learning into required courses in all 4 years of the program; (iii) incorporating information technology &	1. Quantitative analysis of Student Attitude Survey 2. Qualitative analysis of responses to open-ended survey questions in Student Attitude Survey 3. Qualitative analysis of faculty and student interviews 4. Qualitative analysis of student focus groups 5. Senior Exit Survey	1-4. Lathem, Neumann, Hayden (2011) 5. N/A	1. A quantitative survey instrument designed using ABET's Engineering Criterion 3 defining roles & responsibilities of today's engineers as one of the frameworks. Constructed using a 5-point Likert scale. 2. Qualitative analysis of student responses to open-ended questions in Student Attitude Survey. Researchers developed codes that reflected the professional skills described in ABET Engineering Criteria 3; additional code was found through analysis. 3. Faculty members leading program reform were interviewed twice each during the four years. Students were selected by

		inquiry-based learning into required courses.			stratified random sampling for interviews. Transcripts were analyzed using qualitative methods. 4. Focus group interviews were conducted with senior class of 2008 and 2009. Transcripts were analyzed using qualitative methods. 5. Given at the end of students' senior year; authors reference the results from the Class of 2008.

Appendix C.3
CEEA 2014 Conference Proceedings that Refer to the CEAB Graduate Attributes

Note. These papers (N=22) refer to the 12 graduate attributes collectively, or to one or a few attributes at a time, treating them in isolation or as separate components within the collective dozen, and do not explicitly acknowledge this treatment.

Beach, D., and S. M. McCahan. 2014. "Review of Learning Outcomes Developed for Graduate Attributes." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 1 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Behdinan, K., R. Pop-Iliev, and J. Foster. 2014. "What Constitutes a Multi-Disciplinary Capstone Design Course? Best Practices, Successes and Challenges." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 5 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Brennan, R.W., M. Eggermont, W. Rosehart, A. K. Deacon, N. Larson, and T. A. O'Neill. 2014. "Assessing Life-Long Learning in a First-Year Design and Communication Course." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 4 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Caines, S., L. Lye, and M. R. Hossain. 2014. "Teaching Assistant Training to Enhance Graduate Engineering Education." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 4 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Caines, S., and J. Shirokoff. 2014. "The Development and Teaching of Corrosion Course in an Engineering Program." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 4 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Calderon, F., L. Yu, and T. Willink. 2014. "Using Arts in Engineering to Develop Graduate Attributes in an Outcome-Based Approach." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Dew, S., R. Driver, G. Thomas, M. Mandal, and P. Choi. 2014. "Scalability of a Graduate Attributes and Continuous Improvement Process." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 6 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Ferens, K., J. Seniuk Cicek, N. Sepehri, W. Kinsner, J.P. Burak, A. Parker, D. McNeill, et al. 2014. "Industry Forum III: Towards a Common Language." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Hsiao, A. 2014. "Sustainability Entrepreneurship in Engineering." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 5 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Kaupp, J., and B. Frank. 2014a. "Approaching the Loop: A Brief Review of Effective Practices in Continuous Program Improvement." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 6 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Kaupp, J., and B. Frank. 2014b. "Evaluation of Software Tools Supporting Outcomes-Based Continuous Program Improvement Processes: Part 2." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 10 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Kaupp, J., N. Simper, and B. Frank. 2014. "Triangulated Authentic Assessment in the HEQCO Learning Outcomes Assessment Consortium." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 10 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Kennedy, D., K. Abercrombie, M. Bollo, and J. Jenness. 2014. "Reconciling Graduate Attribute Assessment with Existing Outcome-Based Assessment." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 6 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Lye, L. 2014. "Development and Use of Simulation Apps and Physical Toys for Teaching Experimental Design Principles." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 6 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Mackie, M. L., and D. D. Mann. 2014. "Alumni Survey for University of Manitoba Department of Biosystems Engineering." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 5 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Marasco, E., L. Behjat, and M. Eggermont. 2014. "Engaging First Year Students Through Cross Disciplinary Design Projects." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 4 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Orr, V., S. Barghi, and R. Buchal. 2014. "Process Safety Management Learning Module." In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Peto, L., and C. Geddert. 2014. “Using Career Education to Help Students Build and Articulate Employability Skills.” In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Spracklin-Reid, D., and A. Fisher. 2014. “Curriculum Mapping in Engineering Education: Linking Attributes, Outcomes and Assessments.” In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 1 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Spracklin-Reid, D., C. Koenig, S. Hurley, and P. Phillips. 2014. “Teaching with Technology in Engineering Education.” In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 4 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Spracklin-Reid, D., A. Ryan, and A. Smith. 2014. “Building Relationships Between Engineering and the Trades Through Service Learning.” In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 5 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Stagner, J., and J. Johrendt. 2014. “Mechanical Engineering Capstone Design Course – CEAB Accreditation Outcomes Assessment.” In *Proceedings of the Canadian Engineering Education Association Conference (CEEA)*, 7 pp., 8–11 June. Canmore, AB: OJS/PKP. https://ojs.library.queensu.ca/index.php/PCEEA/issue/view/543

Appendix D: Biosystems Program 5–Year Model

	First Year
1	*Complementary Studies Elective 1*
2	CHEM 1300 Chemistry
3	COMP 1012 Comp Prog Eng
4	ENG 1460 Thermal Sciences
5	MATH 1510 Applied Calculus 1
6	PHYS 1050 Physics
7	ENG 1430 Engineering Design
8	ENG 1440 Engineering Statics
9	ENG 1450 Intro Elec & Comp Eng
10	Written Requirement
11	MATH 1210 C/L Algebra
12	MATH 1710 Applied Calculus 2
	Second Year
13	BIOE 2590 Biology for Engineers
14	BIOE 2900 Design 1
15	CHEM 1310 Intro Physical Chemistry
16	MBIO 1220 Essentials in Microbiology
17	BIOE 2480 Impact of Eng on Environment
18	ENG 2022 Eng CAD Technology
19	MATH 2132 Math Analysis 2
20	STAT 2220 Statistics for Engineers
21	*Complementary Studies Elective 2*
	Third Year
22	BIOE 2110 Transport Phenomenon
23	BIOE 2790 Fluid Mechanics
24	MATH 2130 Math Analysis 1
25	*Science Elective 1 (BIOL 1410 or SOIL)*
26	BIOE 2800 Solid Mechanics
27	MECH 2150 Mech. Eng. Modeling & Numerical (FORMER MATH 2120)
28	*Science Elective 2 (BIOL 1412 or BIOE)*
	Elective Slot
	Fourth Year
29	BIOE 3400 Design of Struc Comp Mach
30	BIOE 3590 Mechanics of Biomatter
31	BIOE 3900 Design 2
32	*Complementary Studies Elective 3*
33	BIOE 3270 Instrumentation for Biosystems
34	BIOE 3320 Eng Prop of Biological Matter
35	MECH 3482 Kinematics & Dynamics
36	ANTH 2430 or CIVL 4460
37	*BIOE Design Elective 1*

	Fifth Year
38	BIOE 4900 Design 3
39	BIOE 4240 Graduation Project
40	*BIOE Design Elective 2*
41	*Free Elective 1*
42	BIOE 4950 Design 4
43	ENG 3000 Engineering Economics (formerly CIVL 4050)
44	*BIOE Design Elective 3*
45	*Free Elective 2*

Appendix E: Research Measures

Appendix E.1
Relative Importance and Graduate Attribute Dependency Ratings Form

Determining the Relative Importance and Dependencies of the CEAB Graduate Attributes: An Explanatory, Mixed-Methods Case Study in the Faculty of Engineering at the University of Manitoba

Notice Regarding Collection, Use, and Disclosure of Personal Information by the University

Your personal information is being collected under the authority of *The University of Manitoba Act*. The information you provide will be used by the University for the purpose of determining the relative importance and level of dependencies of the 12 Canadian Engineering Accreditation Board (CEAB) Graduate Attributes. Your personal information will not be used or disclosed for other purposes, unless permitted by *The Freedom of Information and Protection of Privacy Act* (FIPPA). If you have any questions about the collection of your personal information, contact the Access & Privacy Office (tel. 204-474-9462), 233 Elizabeth Dafoe Library, University of Manitoba, Winnipeg, MB, R3T 2N2.

Engineering Area (check all that apply): Biosystems _____Civil _____ Computer _____ Electrical___ Mechanical _____ Other _____

Engineering Stakeholder Identity (check all that apply):
Student _____ Faculty _____ Industry Member _____ Alumni of U of M _____ Other _____

Number of Years as an Engineering Student/Engineer/Engineering Faculty:
Eng Student: _______ Eng-in-Training (EIT): _______ P.Eng: _______ Eng. Faculty: _____

Are you familiar with the CEAB graduate attributes? (Check one):
___ No - I haven't heard of them/I've heard of them but can't recall them
___ Somewhat - I know a few of them
___ Yes – I know them, I can list them
___ Yes, very familiar – I know them, I can list them and define them

Relative Importance Rating Form – **CEAB Graduate Attributes**

Instructions: Listed below are the 12 Canadian Engineering Accreditation Board (CEAB) graduate attributes, which comprise of the knowledge, skills, behaviors and values that graduating engineers from an accredited Canadian program are required to possess. Based on these CEAB definitions and your experience, **please rate each graduate attribute in terms of its frequency and criticality** as defined on the scales below.

Frequency

How often do you think an Engineer-in-Training (EIT) at the beginning of his/her career will perform a task that clearly requires this graduate attribute?

1	2	3	4	5
Rarely 1-2 times per year	**Sometimes** 1-2 times per month	**Regularly** 1-2 times per week	**Quite often** once per day	**All the time** several times per day

Criticality

What do you think will be the *potential effect* on workplace performance for an Engineer-in-Training (EIT) at the beginning of his/her career if he/she does <u>not</u> have a sufficient level of competency for this graduate attribute?

1	2	3	4	5
No consequence nothing to either correct or repeat	**Minor consequence** little or no harm, damage or inconvenience, can correct without help	**Moderate consequence** notable harm, damage or inconvenience, may need help to correct	**Major consequence** serious harm, damage or disruption, likely need help to correct	**Extreme consequence** irreversible/irreparable harm or damage resulting in injuries, death/destruction of material/natural world, and/or reputation

	CEAB GRADUATE ATTRIBUTES	Frequency	Criticality
1	**A knowledge base for engineering**: Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.		
2	**Problem analysis**: An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.		
3	**Investigation**: An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data and synthesis of information in order to reach valid conclusions.		
4	**Design**: An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.		
5	**Use of engineering tools**: An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.		
6	**Individual and team work**: An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.		
7	**Communication skills**: An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.		
8	**Professionalism**: An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.		
9	**Impact of engineering on society and the environment**: An ability to 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 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	**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.		

Attribute Dependency Scoring Form – **CEAB Graduate Attributes**

Preamble: Determining how each CEAB Graduate Attribute is dependent on the other CEAB Graduate Attributes will inform the improvement and development of engineering curricula.

Instructions: Listed on page 5 are pairs of CEAB graduate attributes (the CEAB definitions for the graduate attributes are provided on page 4). Based on your experience, please indicate on a percentage scale that ranges from *100% = total dependency to 0% = no dependency* (see below), the degree to which you feel that the attribute listed on the left is dependent on, or requires, the attribute listed on the right for an Engineer-in-Training (EIT) at the beginning of his/her career. For example, in the first pair, you should think about the degree to which an Engineer-in-Training (EIT) at the beginning of his/her career who is doing something that involves A Knowledge Base for Engineering **depends on, or requires,** Problem Analysis:

	100%	75%	50%	25%	0%	
A Knowledge Base for Engineering						Problem Analysis

You are being asked to consider all 12 graduate attributes individually in relation to every other graduate attribute using the following scale:

100% - Whenever an Engineer-in-Training (EIT) at the beginning of his/her career does something that involves using his/her Knowledge Base it will **always depend on/require** Problem Analysis.

75% - Whenever an Engineer-in-Training (EIT) at the beginning of his/her career does something that involves using his/her Knowledge Base it will **often depend on/require** Problem Analysis.

50% - Whenever an Engineer-in-Training (EIT) at the beginning of his/her career does something that involves using his/her Knowledge Base it will **sometimes depend on/require** Problem Analysis.

25% - Whenever an Engineer-in-Training (EIT) at the beginning of his/her career does something that involves using his/her Knowledge Base it will **seldom depend on/require** Problem Analysis.

0% - Whenever an Engineer-in-Training (EIT) at the beginning of his/her career does something that involves using his/her Knowledge Base it will **never depend on/require** Problem Analysis.

Mark (✔, X) the column that most closely reflects the degree to which you feel the attribute listed on the left is **dependent on, or requires,** the attribute listed on the right for an EIT at the beginning of his/her career.

	100%	75%	50%	25%	0%	
A Knowledge Base for Engineering						Problem Analysis
A Knowledge Base for Engineering						Investigation
A Knowledge Base for Engineering						Design
A Knowledge Base for Engineering						Use of Engineering Tools
A Knowledge Base for Engineering						Individual and Teamwork
A Knowledge Base for Engineering						Communication Skills
A Knowledge Base for Engineering						Professionalism
A Knowledge Base for Engineering						Impact of Engineering on Society & the Environment
A Knowledge Base for Engineering						Ethics and Equity
A Knowledge Base for Engineering						Economics and Project Management
A Knowledge Base for Engineering						Lifelong Learning
	100%	75%	50%	25%	0%	
Problem Analysis						A Knowledge Base for Engineering
Problem Analysis						Investigation
Problem Analysis						Design
Problem Analysis						Use of Engineering Tools
Problem Analysis						Individual and Teamwork
Problem Analysis						Communication Skills
Problem Analysis						Professionalism
Problem Analysis						Impact of Engineering on Society & the Environment
Problem Analysis						Ethics and Equity

	100%	75%	50%	25%	0%	
Problem Analysis						Economics and Project Management
Problem Analysis						Lifelong Learning
Investigation						A Knowledge Base for Engineering
Investigation						Problem Analysis
Investigation						Design
Investigation						Use of Engineering Tools
Investigation						Individual and Teamwork
Investigation						Communication Skills
Investigation						Professionalism
Investigation						Impact of Engineering on Society & the Environment
Investigation						Ethics and Equity
Investigation						Economics and Project Management
Investigation						Lifelong Learning
	100%	75%	50%	25%	0%	
Design						A Knowledge Base for Engineering
Design						Problem Analysis
Design						Investigation
Design						Use of Engineering Tools
Design						Individual and Teamwork
Design						Communication Skills
Design						Professionalism
Design						Impact of Engineering on Society & the Environment
Design						Ethics and Equity
Design						Economics and Project Management

	100%	75%	50%	25%	0%	
Design						Lifelong Learning
Use of Engineering Tools						A Knowledge Base for Engineering
Use of Engineering Tools						Problem Analysis
Use of Engineering Tools						Investigation
Use of Engineering Tools						Design
Use of Engineering Tools						Individual and Teamwork
Use of Engineering Tools						Communication Skills
Use of Engineering Tools						Professionalism
Use of Engineering Tools						Impact of Engineering on Society & the Environment
Use of Engineering Tools						Ethics and Equity
Use of Engineering Tools						Economics and Project Management
Use of Engineering Tools						Lifelong Learning
	100%	75%	50%	25%	0%	
Individual and Teamwork						A Knowledge Base for Engineering
Individual and Teamwork						Problem Analysis
Individual and Teamwork						Investigation
Individual and Teamwork						Design
Individual and Teamwork						Use of Engineering Tools
Individual and Teamwork						Communication Skills
Individual and Teamwork						Professionalism
Individual and Teamwork						Impact of Engineering on Society & the Environment
Individual and Teamwork						Ethics and Equity
Individual and Teamwork						Economics and Project Management
Individual and Teamwork						Lifelong Learning

	100%	75%	50%	25%	0%	
Communication Skills						A Knowledge Base for Engineering
Communication Skills						Problem Analysis
Communication Skills						Investigation
Communication Skills						Design
Communication Skills						Use of Engineering Tools
Communication Skills						Individual and Teamwork
Communication Skills						Professionalism
Communication Skills						Impact of Engineering on Society & the Environment
Communication Skills						Ethics and Equity
Communication Skills						Economics and Project Management
Communication Skills						Lifelong Learning
	100%	75%	50%	25%	0%	
Professionalism						A Knowledge Base for Engineering
Professionalism						Problem Analysis
Professionalism						Investigation
Professionalism						Design
Professionalism						Use of Engineering Tools
Professionalism						Individual and Teamwork
Professionalism						Communication Skills
Professionalism						Impact of Engineering on Society & the Environment
Professionalism						Ethics and Equity
Professionalism						Economics and Project Management
Professionalism						Lifelong Learning

	100%	75%	50%	25%	0%	
Impact of Eng on Society & the Env						A Knowledge Base for Engineering
Impact of Eng on Society & the Env						Problem Analysis
Impact of Eng on Society & the Env						Investigation
Impact of Eng on Society & the Env						Design
Impact of Eng on Society & the Env						Use of Engineering Tools
Impact of Eng on Society & the Env						Individual and Teamwork
Impact of Eng on Society & the Env						Communication Skills
Impact of Eng on Society & the Env						Professionalism
Impact of Eng on Society & the Env						Ethics and Equity
Impact of Eng on Society & the Env						Economics and Project Management
Impact of Eng on Society & the Env						Lifelong Learning
	100%	75%	50%	25%	0%	
Ethics and Equity						A Knowledge Base for Engineering
Ethics and Equity						Problem Analysis
Ethics and Equity						Investigation
Ethics and Equity						Design
Ethics and Equity						Use of Engineering Tools
Ethics and Equity						Individual and Teamwork
Ethics and Equity						Communication Skills
Ethics and Equity						Professionalism
Ethics and Equity						Impact of Engineering on Society & the Environment
Ethics and Equity						Economics and Project Management
Ethics and Equity						Lifelong Learning

	100%	75%	50%	25%	0%	
Economics and Project Management						A Knowledge Base for Engineering
Economics and Project Management						Problem Analysis
Economics and Project Management						Investigation
Economics and Project Management						Design
Economics and Project Management						Use of Engineering Tools
Economics and Project Management						Individual and Teamwork
Economics and Project Management						Communication Skills
Economics and Project Management						Professionalism
Economics and Project Management						Impact of Engineering on Society & the Environment
Economics and Project Management						Ethics and Equity
Economics and Project Management						Lifelong Learning
	100%	75%	50%	25%	0%	
Lifelong Learning						A Knowledge Base for Engineering
Lifelong Learning						Problem Analysis
Lifelong Learning						Investigation
Lifelong Learning						Design
Lifelong Learning						Use of Engineering Tools
Lifelong Learning						Individual and Teamwork
Lifelong Learning						Communication Skills
Lifelong Learning						Professionalism
Lifelong Learning						Impact of Engineering on Society & the Environment
Lifelong Learning						Ethics and Equity
Lifelong Learning						Economics and Project Management

Note. All rows were of equal height in actual measure.

Appendix E.2
Pilot Response Form

Response Form – Piloting Research Forms

Check what applies:

I represent the following engineering stakeholder:
____ Industry
____ Faculty
____ Student

I am responding to the following form:
____ Relative Importance Rating Form
____ Attribute Dependency Scoring Form

1. How long did the form take you to complete (minutes/hours)?

2. Were you confused by any parts of the form? If yes, please describe what confused you.

3. Do you have any questions about any parts of the form?

4. Do you have any suggestions for improvement for any parts of the form?

    a. For clarity (to improve your understanding of what you are being asked to do

    b. For efficiency (to improve the productivity of what you're being asked to do, i.e., structure of the form)

5. Do you have any concerns regarding the form?

6. Do you have additional comments?

Appendix E.3
Teaching Faculty Course Content Questionnaire

Teaching Faculty Course Content Questionnaire – **CEAB Graduate Attributes – Biosystems Engineering Program**

COURSE: ______________________________________

(For your reference, the graduate attributes and their definitions are listed on p. 2.)

1. Based on the Graduate Attribute Table that was developed for BIOE [number], these CEAB graduate attributes are taught and/or assessed in your course **OR** Based on the accreditation requirements for our engineering program, these CEAB graduate attributes have been identified as being taught and/or assessed in your course:

[List attributes]

Is the list correct? Yes ______ No ______
(If no, please cross out any graduate attributes that are listed but aren't associated with your course and/or add any graduate attributes that are missing.)

2. In your judgment, when you consider the content covered in this course (i.e., through teaching, readings, homework, and other methods of course content delivery), approximately what percentage of the content is allocated for each of the graduate attributes listed in question 1?

Graduate Attribute	**Percentage of content coverage (where total does not exceed 100%)**
Total:	**</= 100%**

3. In your judgment, when you consider all of the assessment tools used in this course (i.e., any work that students will receive a mark/grade for, including lab reports, homework, tutorials, quizzes, tests, exams, projects, etc.), approximately what percentage of these assessments is allotted to each of the graduate attributes listed in question 1?

Graduate Attribute	**Percentage of assessments (where total does not exceed 100%)**
Total:	**</= 100%**

	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 team work**: An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.
7	**Communication skills**: An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.
8	**Professionalism**: An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.
9	**Impact of engineering on society and the environment**: An ability to 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 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	**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.

Appendix F: Letters of Recruitment and Informed Consent – Phase 1

Appendix F.1
Recruitment Letter – Pilot Participants

University of Manitoba

Centre for Engineering Professional Practice and Engineering Education
E2-262 EITC, 75 Chancellors Circle
Winnipeg, MB R3T 5V6
Telephone: 204-474-9722
Facsimile: 204-474-7676
Email: ce2p2e@umanitoba.ca

Faculty of Engineering
Centre for Engineering Professional Practice and Engineering Education

October 14, 2015

RE: Piloting Forms for Doctoral Research – Recruitment Letter for University of Manitoba Engineering Stakeholder Participants (Faculty, Fourth Year/Graduating Students, and Manitoba Industry members)

Dear University of Manitoba Engineering Stakeholder,

Hello, my name is Jillian Seniuk Cicek. I am a PhD Candidate in the Department of Biosystems Engineering at the University of Manitoba, conducting research in Engineering Education. My research advisor is Dr. Sandra Ingram. I am conducting a study to determine the relative importance and the levels of dependencies of the 12 Canadian Engineering Accreditation Board (CEAB) Graduate Attributes, which are required competencies for all engineering students graduating from accredited Canadian engineering programs. You are one of a small group of engineering stakeholders being contacted because you are part of one of the three engineering stakeholder groups associated with the Faculty of Engineering at the University of Manitoba that has been identified for this study. These stakeholder groups include: Engineering Faculty members, fourth year/graduating Engineering students, and Manitoba Engineering Industry members. As a member of one of these stakeholder groups, your input is vital for this study.

I am looking for between 2 – 5 participants from each stakeholder group to provide feedback by piloting the following forms for my study:

1. **The Relative Importance Rating Form**
2. **The Attribute Dependency Scoring Form**

Your participation is voluntary, and greatly needed, and will be held confidential.

The Education/Nursing Research Ethics Board has approved this research. If you have any concerns or complaints about this project, you may contact me, or the Human Ethics Coordinator, at 474-7122, or by e-mail at: XX.

This study presents no known risks to volunteer participants. The information from the study will be used to determine the relative importance and the levels of dependencies of the 12 CEAB Graduate Attributes as perceived by our engineering stakeholders, including Engineering faculty, fourth year/graduating Engineering students, and Manitoba Engineering Industry members. The findings will be used to determine the content validity of the engineering programs at the University of Manitoba. They will also inform curricula improvements and developments, and support the Faculty of Engineering accreditation process.

You have the right to withdraw any of your data or withdraw completely from this study at any time without consequence or prejudice, by telling me in person, through email or via telephone, and I will securely destroy (i.e., securely erase from computer files and shred all paper documents) all data that you have provided for the study. Any disclosures or data that you provide will be held in complete confidence. To assure your confidentiality as a participant in this study, I ask that you please do not provide your name or any other identifying information on the rating and scoring forms, or on the response forms. To further ensure your confidentiality, I will keep all data collected for this study securely in my home office, and all data will be destroyed at the end of the study, not to exceed five years.

Please email me at XX to express your interest in participating. When I receive your email, I will send you a letter of Informed Consent and a copy of the rating, scoring and response forms. It is estimated that completing the forms and providing a response will take approximately 60 minutes of your time.

If you have any questions about this study, please feel free to contact me.

Thank you for considering being one the engineering stakeholder participants for my study. Your input is invaluable.

Sincerely,

Jillian Seniuk Cicek

Jillian Seniuk Cicek

Appendix F.2
Recruitment Letter – Student

UNIVERSITY OF MANITOBA

Centre for Engineering Professional
Practice and Engineering Education
E2-262 EITC, 75 Chancellors Circle
Winnipeg, MB R3T 5V6
Telephone: 204-474-9722
Facsimile: 204-474-7676
Email: ce2p2e@umanitoba.ca

Faculty of Engineering
Centre for Engineering Professional Practice and Engineering Education

December 11, 2015

RE: Recruitment Letter for University of Manitoba Fourth Year/Graduating Engineering Student Stakeholders who have completed a minimum of 110 credit hours

Dear University of Manitoba Fourth Year/Graduating Engineering Students,

Hello, my name is Jillian Seniuk Cicek. I am a PhD Candidate in the Department of Biosystems Engineering at the University of Manitoba, and my research advisor is Dr. Sandra Ingram. I am conducting a study to determine the relative importance and the level of dependencies of the 12 Canadian Engineering Accreditation Board (CEAB) Graduate Attributes, which are required competencies for all engineering students graduating from accredited Canadian engineering programs. The collection of these data will shed light on how University of Manitoba Engineering stakeholder groups understand the graduate attributes, which will ultimately support engineering curricula and program design and improvement, and the Faculty of Engineering accreditation process. You are being contacted by your department on my behalf because you are part of one of the three engineering stakeholder groups associated with the Faculty of Engineering at the University of Manitoba that has been identified for this study. These stakeholder groups include: Engineering Academic Faculty members; Fourth Year/Graduating Engineering Students; and Manitoba Engineering Industry members. As Fourth Year/Graduating Engineering Students, your input is vital for this study.

I am looking for between 49 – 121 participants from your Fourth Year/Graduating Engineering Students who have completed a minimum of 110 credit hours to provide feedback by doing the following:

1. Rating the Relative Importance and the Dependency Levels of the CEAB Graduate Attributes

You may choose to provide this information in one of two ways:

- on a Word Document that I will send to you via email
- on the web-based survey site, Survey Monkey at the following link: https://www.surveymonkey.com/r/9X53D66

Your participation is voluntary, greatly needed, and will be held confidential.

The Education/Nursing Research Ethics Board has approved this research. If you have any concerns or complaints about this project, you may contact me, or the Human Ethics Coordinator at 474-7122, or by e-mail at: XX.

This study presents no known risks to volunteer participants. You have the right to withdraw any of your data or withdraw completely from this study at any time without consequence or prejudice by not submitting the data via SurveyMonkey, or in the case of the Word Document, by telling me in person, through email or via telephone, and I will securely destroy (i.e., securely erase from computer files and shred all paper documents) all data that you have provided for the study. Any disclosures or data that you provide will be held in complete confidence. To assure your confidentiality as a participant in this study, I ask that you please do not provide your name or any other identifying information on the rating and scoring forms, or on the response forms. On SurveyMonkey, I have adjusted the settings so that the IP address of your computer/device is not captured. To further ensure your confidentiality, I will keep all data collected for this study securely in my home office, and all data will be securely destroyed at the end of the study, not to exceed five years.

I have attached a letter of Informed Consent, a Word Document of the Relative Importance and Attribute Dependency Response form, and the link to the survey. Based on pilot trials, it is estimated that completing the form or providing your responses online via SurveyMonkey will take approximately 20 – 30 minutes of your time. I will attend your class on January 15, 2016 to further explain my study. In the meantime, if you have any questions, please feel free to contact me at XX.

Thank you for considering being one of the student stakeholder participants for my study. Your input is invaluable.

Sincerely,

Jillian Seniuk Cicek

Jillian Seniuk Cicek

Appendix F.3
Letter of Informed Consent – Student

University of Manitoba

Centre for Engineering Professional Practice and Engineering Education
E2-262 EITC, 75 Chancellors Circle
Winnipeg, MB R3T 5V6
Telephone: 204-474-9722
Facsimile: 204-474-7676
Email: ce2p2e@umanitoba.ca

Faculty of Engineering
Centre for Engineering Professional Practice and Engineering Education

January 15, 2016

RE: Informed Consent for Fourth Year/Graduating Engineering Student Stakeholders who have completed a minimum of 110 credit hours to rank the relative importance and levels of dependencies of the CEAB Graduate Attributes.

Informed Consent Form Study Title: Determining the Relative Importance and Dependencies of the CEAB Graduate Attributes: An Explanatory, Mixed-Methods Case Study in the Faculty of Engineering at the University of Manitoba
Principal Investigator: Jillian Seniuk Cicek, Ph.D. Candidate, Engineering Education, Centre for Engineering Professional Practice and Engineering Education, E2-262 Information and Technology Complex, 75A Chancellor's Circle, University of Manitoba, Winnipeg, MB R3T 5V6, Canada Telephone: 204-474-9722 Fax: 204-474-7676
Advisor: Dr. Sandra Ingram, Associate Professor and Associate Chair, Centre for Engineering Professional Practice and Engineering Education, E2-262 Engineering and Information Technology Complex, 75A Chancellor's Circle, University of Manitoba, Winnipeg MB, R3T 5V6, Canada
Telephone: 204-474-9722 Fax: 204-474-7676

Dear Engineering Fourth Year/Graduating Student Stakeholder:

I am conducting a study to determine the relative importance and the level of dependencies of the 12 CEAB Graduate Attributes. As a fourth year/graduating student in the Faculty of Engineering at the University of Manitoba who has completed a minimum of 110 hours of your degree, you are one of the engineering stakeholders being recruited for Phase 1 of this study. Forty-nine to 121 students from the five engineering programs

(Biosystems, Civil, Computer, Electrical and Mechanical Engineering) are needed to rank the relative importance and levels of dependencies of the CEAB Graduate Attributes. The letter below tells you more about the study in the formal language required by the Education/Nursing Research Ethics Board. With this letter I formally request your participation in this study, and your written informed consent as a participant.

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The purpose of this research is to determine the relative importance and the level of dependencies of the 12 CEAB graduate attributes.

Should you agree to participate at this time, your participation will involve the following:

1. Rating the Relative Importance and the Dependency Levels of the CEAB Graduate Attributes

You may choose to provide this information in one of two ways:

- on the Word Document attached to this email
- on Survey Monkey at the following link: https://www.surveymonkey.com/r/9X53D66

Based on pilot trials, it is estimated that completing the form or providing your responses online via SurveyMonkey will take approximately 20 – 30 minutes of your time.

Before providing written consent, you should be aware that this study is optional. Your choice to participate or your choice not to participate will not be used to assess you individually in any way: it will not affect your individual assessments or evaluations, or any of your course grades. You also have the right to withdraw any of your data or withdraw completely from this study at any time without consequence or prejudice by not submitting the data via SurveyMonkey, or in the case of the Word Document, by telling me in person, through email or via telephone, and I will securely destroy (i.e., securely erase from computer files and shred all paper documents) all data that you have provided. You should also know that Survey Monkey Inc., whose servers are located outside of Canada in the United States, hosts the survey. The privacy of the information you provide is subject to the laws of those jurisdictions. By participating in this survey you acknowledge and agree that your information will be stored and accessed outside of Canada and may or may not receive the same level of privacy protection.

Any disclosures or data that you provide will be held in complete confidence. To assure your anonymity and confidentiality as a participant in this study, I ask that you please do not provide your name or any other identifying information on the rating and scoring forms. On SurveyMonkey, I have adjusted the settings so that the IP address of your computer/device is not captured. I will keep all data collected for this study securely in my home office, and all data will be securely destroyed at the end of the study (i.e., the survey site and data will be securely erased on SurveyMonkey; my computer files will be securely erased and all paper documents will be shredded), for a period not to exceed five years. No one else, including other students and faculty members from the Faculty of Engineering at the University of Manitoba, and Dr. Ingram, my advisor, will know who does and who does not participate. Only I will know these identities, and I will keep this information confidential.

Minimal risks to participants or third parties are foreseen. Any potential risks to participants are addressed through confidentiality measures. Benefits include increased knowledge and consideration of the CEAB graduate attributes for participants, and the collection of data that will shed light on how each of the stakeholder groups understands the graduate attributes, which will ultimately support engineering curriculum and program design and improvement, and the Faculty of Engineering accreditation process. I should let you know that no compensation is being offered for your participation. If you would like to be entered into a draw for one of four $25 Bookstore gift cards as a token of appreciation for participating in this survey, please email your name to me at XX or check the box at the end of this form, and I will enter your name in the draw.

These data collection activities represent Phase 1 of my research study. Once the findings are analyzed, I will be recruiting engineering stakeholders to take part in one individual interview to explore their understandings of the findings, which will be Phase 2 of my study. If you are also willing to be interviewed to discuss these data, please provide me with your name and email address at XX or check the box at the end of this form. The interview will be scheduled at a time and at a place that is convenient for you. The interview should take approximately 45 – 60 minutes, and refreshments will be provided.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research study and agree to participate as a subject. In no way does this waive your legal rights nor release the researcher, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. My contact information is as follows:

Jillian Seniuk Cicek
Centre for Engineering Professional Practice and Engineering Education
E2-262 Information and Technology Complex, 75A Chancellor's Circle
University of Manitoba, Winnipeg, MB R3T 5V6, Canada
Telephone: 204-474-9722   Fax: 204-474-7676

The University of Manitoba may look at my research records to see that the research is being done in a safe and proper way.

The Education/Nursing Research Ethics Board has approved this research. If you have any concerns or complaints about this project, you may contact me, or the Human Ethics Coordinator at 474-7122, or by e-mail at: XX. A copy of this consent form has been given to you to keep for your records and reference.

Please fill out and sign this form and email it to me at XX or mail/fax/drop off in E2-262 at the Centre for Engineering Professional Practice and Engineering Education office (address above). You may also email/mail/fax or drop off the completed Relative Importance Rating and Attribute Dependency Scoring Form in E2-262 EITC, or choose to participate by inputting your responses via SurveyMonkey. Thank you for agreeing to be a participant for this study.

Sincerely,

Jillian Seniuk Cicek

Jillian Seniuk Cicek

Please sign below to indicate your informed written consent to participate in this study.

I consent to (choose one):

Completing the Relative Importance Rating and Attribute Dependency Scoring Form ______

OR

Completing the survey on SurveyMonkey ______

Participant's Name and Signature: Date:

Researcher's Signature: Date:

Jillian Seniuk Cicek January 15, 2016

To receive a report of the results of this study, please fill out this page and return it to me:

Jillian Seniuk Cicek
Centre for Engineering Professional Practice and Engineering Education
E2-262 Information and Technology Complex, 75A Chancellor's Circle
University of Manitoba, Winnipeg, MB R3T 5V6, Canada
Telephone: 204-474-9722   Fax: 204-474-7676

Name:

I prefer to receive the summary as an (check one):

 E-mail attachment to the following e-mail address:

 Hard copy to the following mailing address:

Please contact me to participate in an interview for Phase 2 of this study:

 Yes, please. You can contact me at:

 No, thanks.

 Undecided at this time.

Please enter me in the draw to win one of four $25 Gift Cards to the University of Manitoba Bookstore (contest rules available upon request):

 Yes, please. You can contact me at the following e-mail address:

 No, thanks.

Appendix F.4
Recruitment Letter – Faculty

Centre for Engineering Professional Practice and Engineering Education
E2-262 EITC, 75 Chancellors Circle
Winnipeg, MB R3T 5V6
Telephone: 204-474-9722
Facsimile: 204-474-7676
Email: ce2p2e@umanitoba.ca

Faculty of Engineering
Centre for Engineering Professional Practice and Engineering Education

December 11, 2015

RE: Recruitment Letter for University of Manitoba Engineering Faculty Stakeholder Participants

Dear University of Manitoba Engineering Academic Faculty,

Hello, my name is Jillian Seniuk Cicek. I am a PhD Candidate in the Department of Biosystems Engineering at the University of Manitoba, and my research advisor is Dr. Sandra Ingram. I am conducting a study to determine the relative importance and the level of dependencies of the 12 Canadian Engineering Accreditation Board (CEAB) Graduate Attributes, which are required competencies for all engineering students graduating from accredited Canadian engineering programs. The collection of these data will shed light on how University of Manitoba Engineering stakeholder groups understand the graduate attributes, which will ultimately support engineering curricula and program design and improvement, and the Faculty of Engineering accreditation process. You are being contacted by your department on my behalf because you are part of one of the three engineering stakeholder groups associated with the Faculty of Engineering at the University of Manitoba that has been identified for this study. These stakeholder groups include: Engineering Academic Faculty members; Fourth Year/Graduating Engineering Students; and Manitoba Engineering Industry members. As Engineering Academic Faculty, your input is vital for this study.

I am looking for between 37 – 67 participants from your Engineering Academic Faculty stakeholder group to provide feedback by doing the following:

1. Rating the Relative Importance and the Dependency Levels of the CEAB Graduate Attributes

You may choose to provide this information in one of two ways:

- on a Word Document that I will send to you via email
- on the web-based survey site, Survey Monkey at the following link: https://www.surveymonkey.com/r/9X53D66

Your participation is voluntary, greatly needed, and will be held confidential.

The Education/Nursing Research Ethics Board has approved this research. If you have any concerns or complaints about this project, you may contact me, or the Human Ethics Coordinator at 474-7122, or by e-mail at: XX.

This study presents no known risks to volunteer participants. You have the right to withdraw any of your data or withdraw completely from this study at any time without consequence or prejudice by not submitting the data via SurveyMonkey, or in the case of the Word Document, by telling me in person, through email or via telephone, and I will securely destroy (i.e., securely erase from computer files and shred all paper documents) all data that you have provided for the study. Any disclosures or data that you provide will be held in complete confidence. To assure your confidentiality as a participant in this study, I ask that you please do not provide your name or any other identifying information on the rating and scoring forms, or on the response forms. On SurveyMonkey, I have adjusted the settings so that the IP address of your computer/device is not captured. To further ensure your confidentiality, I will keep all data collected for this study securely in my home office, and all data will be securely destroyed at the end of the study, not to exceed five years.

Please email me at XX **to express your interest in participating**.

When I receive your email, I will send you a letter of Informed Consent, a Word Document of the Relative Importance and Attribute Dependency Response form, and the survey link. Based on pilot trials, it is estimated that completing the form or providing your responses online via SurveyMonkey will take approximately 20 – 30 minutes of your time.

If you have any questions about this study, please feel free to contact me.

Thank you for considering being one of the Engineering Academic Faculty stakeholder participants for my study. Your input is invaluable.

Sincerely,

Jillian Seniuk Cicek
Jillian Seniuk Cicek

Appendix F.5
Letter of Informed Consent – Faculty

University of Manitoba

Centre for Engineering Professional
Practice and Engineering Education
E2-262 EITC, 75 Chancellors Circle
Winnipeg, MB R3T 5V6
Telephone: 204-474-9722
Facsimile: 204-474-7676
Email: ce2p2e@umanitoba.ca

Faculty of Engineering
Centre for Engineering
Professional Practice and
Engineering Education

January 18, 2016

RE: Informed Consent for University of Manitoba Engineering Academic Faculty Member Stakeholder Participants to rank the relative importance and levels of dependencies of the CEAB Graduate Attributes.

Informed Consent Form Study Title: Determining the Relative Importance and Dependencies of the CEAB Graduate Attributes: An Explanatory, Mixed-Methods Case Study in the Faculty of Engineering at the University of Manitoba
Principal Investigator: Jillian Seniuk Cicek, Ph.D. Candidate, Engineering Education, Centre for Engineering Professional Practice and Engineering Education, E2-262 Information and Technology Complex, 75A Chancellor's Circle, University of Manitoba, Winnipeg, MB R3T 5V6, Canada Telephone: 204-474-9722 Fax: 204-474-7676
Advisor: Dr. Sandra Ingram, Associate Professor and Associate Chair, Centre for Engineering Professional Practice and Engineering Education, E2-262 Engineering and Information Technology Complex, 75A Chancellor's Circle, University of Manitoba, Winnipeg MB, R3T 5V6, Canada
Telephone: 204-474-9722 Fax: 204-474-7676

Dear Engineering Academic Faculty Member Stakeholder:

I am conducting a study to determine the relative importance and the level of dependencies of the 12 CEAB Graduate Attributes. As an Academic Faculty member in the Faculty of Engineering at the University of Manitoba, you are one of the engineering stakeholders being recruited for Phase 1 of this study. Thirty-seven to 67 faculty members from the five engineering programs (Biosystems, Civil, Computer, Electrical and Mechanical Engineering) are needed to rank the relative importance and levels of dependencies of the CEAB Graduate Attributes. The letter below tells you more about the study in the formal language required by the Education/Nursing Research Ethics Board. With this letter I formally request your written informed consent as a participant in this study.

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The purpose of this research is to determine the relative importance and the level of dependencies of the 12 CEAB Graduate Attributes.

Should you agree to participate at this time, your participation will involve the following:

1. Rating the Relative Importance and the Dependency Levels of the CEAB Graduate Attributes

You may choose to provide this information in one of two ways:

- on the Word Document attached to this email
- on Survey Monkey at the following link: https://www.surveymonkey.com/r/9X53D66

Based on pilot trials, it is estimated that completing the form or providing your responses online via SurveyMonkey will take approximately 30 minutes of your time.

Before providing written consent, you should be aware that this study is optional. Your participation or your lack of participation in this study will not be used to assess you individually in any way, and will not have any consequences for you, either positive or negative, in your position as a faculty member. You also have the right to withdraw any of your data or withdraw completely from this study at any time without consequence or prejudice by not submitting the data via SurveyMonkey, or in the case of the Word Document, by telling me in person, through email or via telephone, and I will securely destroy (i.e., securely erase from computer files and shred all paper documents) all data that you have provided. You should also know that SurveyMonkey Inc., whose servers are located outside of Canada in the United States, hosts the survey. The privacy of the information you provide is subject to the laws of those jurisdictions. By participating in this survey you acknowledge and agree that your information will be stored and accessed outside of Canada and may or may not receive the same level of privacy protection.

Any disclosures or data that you provide will be held in complete confidence. To assure your anonymity and confidentiality as a participant in this study, I ask that you please do not provide your name or any other identifying information on the rating and scoring forms. On SurveyMonkey, I have adjusted the settings so that the IP address of your computer/device is not captured. I will keep all data collected for this study securely in my home office, and all data will be securely destroyed at the end of the study (i.e., the survey site and survey data will be securely erased on SurveyMonkey; my computer files will be securely erased and all paper documents will be shredded), for a period not to exceed five years. No one else, including the Department Heads from the Faculty of Engineering at the University of Manitoba and Dr. Ingram, my advisor, will know who does and who does not participate. Only I will know the identities of who does and who does not participate, and I will keep this information confidential.

Minimal risks to participants or third parties are foreseen. Any potential risks to participants are addressed through confidentiality measures. Benefits include increased knowledge and consideration of the CEAB Graduate Attributes for participants, and the collection of data that will shed light on how each of the stakeholder groups understands the graduate attributes, which will ultimately support engineering curriculum and program design and improvement, and the Faculty of Engineering accreditation process. I should let you know that no compensation is being offered for your participation.

These data collection activities represent Phase 1 of my research study. Once the findings are analyzed, I will be recruiting engineering stakeholders to take part in one individual interview to explore their understandings of the findings, which will be Phase 2 of my study. If you are also willing to be interviewed to discuss these data, please provide me with your name and email address at XX or check the box at the end of this letter. The interview will be scheduled at a time and at a place that is convenient for you. The interview should take approximately 45 – 60 minutes, and refreshments will be provided.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research study and agree to participate as a subject. In no way does this waive your legal rights nor release the researcher, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. My contact information is as follows:

Jillian Seniuk Cicek
Centre for Engineering Professional Practice and Engineering Education
E2-262 Information and Technology Complex, 75A Chancellor's Circle
University of Manitoba, Winnipeg, MB R3T 5V6, Canada
Telephone: 204-474-9722 Fax: 204-474-7676

The University of Manitoba may look at my research records to see that the research is being done in a safe and proper way.

The Education/Nursing Research Ethics Board has approved this research. If you have any concerns or complaints about this project, you may contact me, or the Human Ethics

Coordinator at 474-7122, or by e-mail at: XX. A copy of this consent form has been given to you to keep for your records and reference.

Please fill out and sign this form and email it to me at XX or mail/fax/drop off in E2-262 at the Centre for Engineering Professional Practice and Engineering Education office (address above). You may also email/mail/fax or drop off the completed Relative Importance Rating and Attribute Dependency Scoring Form in E2-262 EITC, or choose to participate by inputting your responses via SurveyMonkey.

Thank you for agreeing to be a participant for this study.

Sincerely,

Jillian Seniuk Cicek

Jillian Seniuk Cicek

Please sign below to indicate your informed written consent to participate in this study.

I consent to (choose one):

Completing the Relative Importance Rating and Attribute Dependency Scoring Form ______

OR

Completing the survey on Survey Monkey ______

Participant's Signature: Date:

Researcher's Signature: Date:

Jillian Seniuk Cicek January 18, 2016

To receive a report of the results of this study, please fill out this page and return it to me:

Jillian Seniuk Cicek
Centre for Engineering Professional Practice and Engineering Education
E2-262 Information and Technology Complex, 75A Chancellor's Circle
University of Manitoba, Winnipeg, MB R3T 5V6, Canada
Telephone: 204-474-9722 Fax: 204-474-7676

Name:

I prefer to receive the summary as an (check one):

☐ E-mail attachment to the following e-mail address:

☐ Hard copy to the following mailing address:

Please contact me to participate in an interview for Phase 2 of this study:

☐ Yes, please. You can contact me at:

☐ No, thanks.

☐ Undecided at this time.

Appendix F.6
Recruitment Letter – Industry

UNIVERSITY OF MANITOBA

Centre for Engineering Professional
Practice and Engineering Education
E2-262 EITC, 75 Chancellors Circle
Winnipeg, MB R3T 5V6
Telephone: 204-474-9722
Facsimile: 204-474-7676
Email: ce2p2e@umanitoba.ca

Faculty of Engineering
Centre for Engineering
Professional Practice and
Engineering Education

November 23, 2015

RE: Recruitment Letter for Manitoba Industry Representatives

Dear Manitoba Industry Representative,

Hello, my name is Jillian Seniuk Cicek. I am a PhD Candidate with a focus in Engineering Education at the University of Manitoba. My research advisor is Dr. Sandra Ingram. I am conducting a study to determine the relative importance and the levels of dependencies of the 12 Canadian Engineering Accreditation Board (CEAB) Graduate Attributes. These attributes are required competencies for all engineering students graduating from accredited Canadian Engineering programs. The collection of these data will shed light on how University of Manitoba Engineering stakeholder groups understand the graduate attributes, which will ultimately support engineering curricula and program design and improvement, and the Faculty of Engineering accreditation process. You are being contacted by Dr. Ken Ferens on my behalf because you are the Industry representatives who will be working directly with our engineering graduates, and we value your perspectives and opinions. As a Manitoba Engineering Industry representative, your input is vital for this study.

I am looking for between 33 – 55 participants from your group to provide feedback by:

1. Rating the Relative Importance and the Dependency Levels of the CEAB Graduate Attributes

You may choose to provide this information in one of two ways:

- on a Word Document that Dr. Ferens will send to you via email
- on the web-based survey site, Survey Monkey at the following link: https://www.surveymonkey.com/r/9X53D66

Your participation is voluntary, greatly needed, and will be held confidential. Please complete the survey by Wednesday, December 9, 2015 so that we can analyze the data and present initial findings at the Industry Forum 6.

The Education/Nursing Research Ethics Board has approved this research. If you have any concerns or complaints about this project, you may contact me, or the Human Ethics Coordinator at 474-7122, or by e-mail at: XX.

This study presents no known risks to volunteer participants. You have the right to withdraw any of your data or withdraw completely from this study at any time without consequence or prejudice by not submitting the data via SurveyMonkey, or in the case of the Word Document, by telling Dr. Ferens or me in person, through email or via telephone, and I will securely destroy (i.e., securely erase from computer files and shred all paper documents) all data that you have provided for the study. Any disclosures or data that you provide will be held in complete confidence. To assure your confidentiality as a participant in this study, I ask that you please do not provide your name or any other identifying information on the rating and scoring form. On SurveyMonkey, I have adjusted the settings so that the IP address of your computer/device is not captured. To further ensure your confidentiality, I will keep all data collected for this study securely in my home office, and all data will be securely destroyed at the end of the study, not to exceed five years.

Please email Dr. Ken Ferens at XX to express your interest in participating.

When your email is received, you will be sent a letter of Informed Consent, a Word Document of the Relative Importance and Attribute Dependency Response form, and the link to the survey. Based on pilot trials, it is estimated that completing the form or providing your responses online via SurveyMonkey will take approximately 20 – 30 minutes of your time.

If you have any questions about this study, please feel free to contact Dr. Ferens.

Thank you for considering being a Manitoba Industry representative participant for my study. Your input is invaluable.

Sincerely,

Jillian Seniuk Cicek

Jillian Seniuk Cicek

Appendix F.7
Letter of Informed Consent – Industry

UNIVERSITY OF MANITOBA

Centre for Engineering Professional Practice and Engineering Education
E2-262 EITC, 75 Chancellors Circle
Winnipeg, MB R3T 5V6
Telephone: 204-474-9722
Facsimile: 204-474-7676
Email: ce2p2e@umanitoba.ca

Faculty of Engineering
Centre for Engineering Professional Practice and Engineering Education

December 14, 2015

RE: Informed Consent for Manitoba Industry Representatives to rank the relative importance and levels of dependencies of the CEAB Graduate Attributes.

Informed Consent Form Study Title: Determining the Relative Importance and Dependencies of the CEAB Graduate Attributes: An Explanatory, Mixed-Methods Case Study in the Faculty of Engineering at the University of Manitoba
Principal Investigator: Jillian Seniuk Cicek, Ph.D. Candidate, Engineering Education, Centre for Engineering Professional Practice and Engineering Education, E2-262 Information and Technology Complex, 75A Chancellor's Circle, University of Manitoba, Winnipeg, MB R3T 5V6, Canada
Telephone: 204-474-9722   Fax: 204-474-7676
Advisor: Dr. Sandra Ingram, Associate Professor and Associate Chair, Centre for Engineering Professional Practice and Engineering Education, E2-262 Engineering and Information Technology Complex, 75A Chancellor's Circle, University of Manitoba, Winnipeg MB, R3T 5V6, Canada
Office: 204-474-9722   Fax: 204-474-7676

Dear Manitoba Engineering Industry Member Stakeholder:

I am conducting a study to determine the relative importance and the levels of dependencies of the 12 CEAB Graduate Attributes. Thirty-three to 55 Manitoba Industry Representatives are needed to rank the relative importance and levels of dependencies of the CEAB Graduate Attributes. The letter below tells you more about the study in the formal language required by the Education/Nursing Research Ethics Board. With this letter I formally request your written informed consent as a participant in this study.

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The purpose of this research is to determine the relative importance and the levels of dependencies of the 12 CEAB Graduate Attributes.

Should you agree to participate at this time, your participation will involve the following:

1. Rating the Relative Importance and the Dependency Levels of the CEAB Graduate Attributes

You may choose to provide this information in one of two ways:

- on the Word Document attached to this email
- on Survey Monkey at the following link: https://www.surveymonkey.com/r/9X53D66

Based on pilot trials, it is estimated that completing the form or providing your responses online via SurveyMonkey will take approximately 30 minutes of your time.

Before providing written consent, you should be aware that this study is optional. Your participation or your lack of participation in this study will not be used to assess you individually in any way. You have the right to withdraw any of your data or withdraw completely from this study at any time without consequence or prejudice by not submitting the data via SurveyMonkey, or in the case of the Word Document, by telling me in person, through email or via telephone, and I will securely destroy (i.e., securely erase from computer files and shred all paper documents) all data that you have provided. You should also know that SurveyMonkey Inc., whose servers are located outside of Canada in the United States, hosts the survey. The privacy of the information you provide is subject to the laws of those jurisdictions. By participating in this survey on-line, you acknowledge and agree that your information will be stored and accessed outside of Canada and may or may not receive the same level of privacy protection.

Any disclosures or data that you provide will be held in complete confidence. To assure your anonymity and confidentiality as a participant in this study, I ask that you please do not provide your name or any other identifying information on the rating and scoring forms. On SurveyMonkey, I have adjusted the settings so that the IP address of your computer/device is not captured. I will keep all data collected for this study securely in my home office, and all data will be securely destroyed at the end of the study (i.e., the survey site and data will be securely erased on SurveyMonkey; my computer files will be securely erased and paper documents will be shredded), for a period not to exceed five years. I will keep the identities of those who do and who do not participate confidential, including from my advisor, Dr. Ingram.

Minimal risks to participants or third parties are foreseen. Any potential risks to participants are addressed through confidentiality measures. Benefits include increased knowledge and consideration of the CEAB Graduate Attributes for participants, and the collection of data that will shed light on how each of the stakeholder groups understands the graduate attributes, which will ultimately support engineering curriculum and program design and improvement, and the Faculty of Engineering accreditation process. I should let you know that no compensation is being offered for your participation.

These data collection activities represent Phase 1 of my research study. Once the findings are analyzed, I will be recruiting engineering stakeholders to take part in one individual interview to explore their understandings of the findings, which will be Phase 2 of my study. If you are also willing to be interviewed to discuss these data, please provide me with your name and email address at XX, or check the box at the end of this letter. The interview will be scheduled at a time and at a place that is convenient for you. The interview should take approximately 45 – 60 minutes, and refreshments will be provided.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research study and agree to participate as a subject. In no way does this waive your legal rights nor release the researcher, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. My contact information is as follows:

Jillian Seniuk Cicek
Centre for Engineering Professional Practice and Engineering Education
E2-262 Information and Technology Complex, 75A Chancellor's Circle
University of Manitoba, Winnipeg, MB R3T 5V6, Canada
Telephone: 204-474-9722 Fax: 204-474-7676

The University of Manitoba may look at my research records to see that the research is being done in a safe and proper way.

The Education/Nursing Research Ethics Board has approved this research. If you have any concerns or complaints about this project, you may contact me, or the Human Ethics Coordinator at 474-7122, or by e-mail at: XX. A copy of this consent form has been given to you to keep for your records and reference.

Please fill out and sign this form and email it to me at umseniuk@myumanitoba.ca. Please email me the completed Relative Importance Rating and Attribute Dependency Scoring Form, or choose to participate by inputting your responses via SurveyMonkey.

Thank you for agreeing to be a participant for this study.

Sincerely,

Jillian Seniuk Cicek

Jillian Seniuk Cicek

Please sign below to indicate your informed written consent to participate in this study.

I consent to (choose one):

Completing the Relative Importance Rating and Attribute Dependency Scoring Form ______

OR

Completing the survey on SurveyMonkey ______

Participant's Signature: Date:

Researcher's Signature: Date:
Jillian Seniuk Cicek December 14, 2015

To receive a report of the results of this study, please fill out this page and return it to me:

Jillian Seniuk Cicek
Centre for Engineering Professional Practice and Engineering Education
E2-262 Information and Technology Complex, 75A Chancellor's Circle
University of Manitoba, Winnipeg, MB R3T 5V6, Canada
Telephone: 204-474-9722 Fax: 204-474-7676

Name:

I prefer to receive the summary as an (check one):

☐ E-mail attachment to the following e-mail address:

☐ Hard copy to the following mailing address:

Please contact me to discuss the data from Phase 1 of the study:

☐ Yes, please. You can contact me at:

☐ No, thanks.

☐ Undecided at this time.

Appendix F.8
Letter of Recruitment and Informed Consent – Phase 2

University of Manitoba

Centre for Engineering Professional Practice and Engineering Education
E2-262 EITC, 75 Chancellors Circle
Winnipeg, MB R3T 5V6
Telephone: 204-474-9722
Facsimile: 204-474-7676
Email: ce2p2e@umanitoba.ca

Faculty of Engineering
Centre for Engineering Professional Practice and Engineering Education

RE: Research Study – The Content Validity of the CEAB Graduate Attributes in an Engineering Program: A Quantitative Exploratory Case Study
Principal Investigator: Jillian Seniuk Cicek, Ph.D. Candidate, Faculty of Graduate Studies Department of Biosystems Engineering, E2-376 Information and Technology Complex, 75A Chancellor's Circle, University of Manitoba, Winnipeg, MB R3T 2N2, Canada Office: 204-474-6033
Advisor: Dr. Sandra Ingram, Associate Professor and Associate Chair, Centre for Engineering Professional Practice and Engineering Education. E2-262 Engineering and Information Technology Complex, 75A Chancellor's Circle, University of Manitoba, Winnipeg MB, R3T 5V6, Canada

This recruitment and consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

September 7, 2017

Dear Professor/Instructor,

Hello, my name is Jillian Seniuk Cicek. I am a PhD Candidate in the Faculty of Graduate Studies at the University of Manitoba. For my doctoral research, I am conducting a study to determine the content validity of the Biosystems Engineering curriculum in regards to the Canadian Engineering Accreditation Board (CEAB) graduate attributes. I am contacting you because you are teaching a course that is part of the Biosystems Engineering program.

I am looking for you to provide feedback by doing the following:

> **1. Completing <u>one</u> questionnaire about the CEAB graduate attributes that you teach and assess in your course (questionnaire attached) – estimated time <u>15 minutes</u>.**

This study presents minimal risk to volunteer participants. The information from this study will be used to determine the content validity of the Biosystems curriculum. The findings will be used to inform curricula improvements and developments, and to support the Biosystems' accreditation process.

Your participation is voluntary and will be held confidential. To assure your confidentiality as a participant in this study, I will be the sole recipient of your emails and completed questionnaire. In this way, only I will know who participates and who does not participate, and this information will remain confidential, including from Dr. Mann, Department Head of Biosystems Engineering, and my advisor, Dr. Ingram. If you choose not to participate, I will try to ascertain the information on the questionnaire from your course syllabus that is publically available on the Biosystems Engineering website, and/or from the assessment spreadsheets that you complete at the end of your course that are made anonymous and available to the Faculty of Engineering for accreditation purposes.

<u>Emailing me your completed questionnaire will be taken as your informed consent to participate in this study</u>. You may choose to not answer a question or withdraw from the study simply by not completing the questionnaire.

If you have any questions about this study, or **if you would like to meet with me to fill out the form**, or if you'd like to obtain a summary of the results of the study, please feel free to contact me at XX.

Emailing me your completed questionnaire indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

The Education and Nursing Research Ethics Board (ENREB) has approved this research. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator at 204-474-7122. A copy of this recruitment and consent form has been given to you to keep for your records and reference.

Thank you. Your input is invaluable.

Sincerely,

Jillian Seniuk Cicek

Jillian Seniuk Cicek

Appendix G: Data Analyses Summaries

Appendix G.1
Summary of analyses methods for the absolute and relative importance data

Graduate attribute relative importance research questions and corresponding data analyses.

Absolute Importance RQ1.1 What is the perceived absolute importance of each CEAB graduate attribute across all engineering stakeholder groups (i.e., students, faculty and industry) in the Faculty of Engineering at the University of Manitoba?	DESCRIPTIVE Importance = Frequency * Criticality ($I_i = F_iC_i$) (Renaud, Forthcoming; Stutsky, Singer, and Renaud 2012). Calculate the mean value of each group for each attribute.
Relative Importance RQ1.2 What is the perceived relative importance of each CEAB graduate attribute across all engineering stakeholder groups (i.e., students, faculty and industry) in the Faculty of Engineering at the University of Manitoba?	DESCRIPTIVE Calculate the mean percentages of the absolute importance of each graduate attribute divided by the total absolute importance of all graduate attributes to create an index of relative importance for each graduate attribute (Stutsky, Singer, and Renaud 2012).
Variation of Perceived Absolute Importance Per Stakeholder Group RQ1.3 How much does the perceived absolute importance of each CEAB graduate attribute vary each between engineering stakeholder group (i.e., students vs. faculty vs. industry)?	INFERENTIAL – ANOVA Determine if the mean values differ significantly across the 3 stakeholder groups. POST-HOC t-tests are conducted to identify which groups differed significantly.
Variation of Perceived Relative Importance Per Stakeholder Group RQ1.4 How much does the perceived relative importance of each CEAB graduate attribute vary between each engineering stakeholder group (i.e., students vs. faculty vs. industry)?	DESCRIPTIVE Compare the mean relative importance values.

Appendix G.2
Summary of the dependencies data analyses methods

Graduate attribute dependencies research questions and corresponding data analyses.

Perceived Dependency RQ2.1 What is the perceived dependency of each of the 12 CEAB graduate attributes on every other CEAB graduate attribute for all engineering stakeholders (i.e., students, faculty and industry) in the Faculty of Engineering at the University of Manitoba?	DESCRIPTIVE – DEPENDENCY RATINGS MATRIX The mean dependency rating across participants for each of the 12 graduate attributes. One-way correlation (i.e., $A \rightarrow B \neq B \rightarrow A$).
Variation of Pattern of Perceived Dependencies RQ2.2 How much does the pattern of perceived dependencies of the CEAB graduate attributes vary between engineering stakeholder groups (i.e., students vs. faculty vs. industry)?	PEARSON TWO-TAILED CORRELATION Determine whether the patterns of perceived dependencies for each stakeholder group correlate (relative standing). SUM OF SQUARE DIFFERENCES (SSD) and ROOT SQUARE MEAN Determine whether the pattern of perceived dependencies are more varied or more similar between stakeholders groups (absolute standing).
Graduate Attribute Clusters RQ2.3 How do the perceived similarities of the CEAB graduate attributes cluster together across all engineering stakeholders?	MULTIDIMENSIONAL SCALING Performed by calculating the mean dependencies of each pair and inverse pair of graduate attributes (i.e., $(A \rightarrow B + B \rightarrow A)/2 = MEAN$).

Appendix H: Mean Perceived Relative Importance Data for the Faculty/Industry

Mean Perceived Relative Importance of CEAB Graduate Attributes for Engineering Stakeholder Groups

CEAB Graduate Attribute	All Stakeholders (N=207)	Student Stakeholders (N=116)	Faculty Stakeholders (N=44)	Industry Stakeholders (N=47)	Fac/Ind Stakeholders (N=91)
Knowledge Base	9.1%	8.4%	10.8%	9.7%	10.3%
Problem Analysis	9.0%	8.9%	9.4%	8.8%	9.1%
Investigation	7.2%	7.3%	7.8%	6.4%	7.1%
Design	7.0%	7.0%	6.9%	6.9%	6.9%
Eng. Tools	8.3%	8.0%	8.5%	9.1%	8.8%
Ind. & Teamwork	10.9%	10.4%	10.9%	12.5%	11.6%
Communication	10.8%	10.3%	11.3%	11.7%	11.5%
Professionalism	9.4%	9.9%	8.5%	8.7%	8.6%
Impact of Eng.	6.3%	6.9%	5.3%	5.4%	5.3%
Ethics & Equity	8.8%	9.3%	8.4%	7.6%	8.0%
Eco. & Prj. Mgt.	6.1%	6.0%	5.8%	6.5%	6.2%
Lifelong Learning	7.1%	7.5%	6.4%	6.7%	6.5%

Note. Fac/Ind – Faculty and Industry Stakeholders Groups Combined

Appendix I: University of Manitoba Faculty of Engineering Graduate Attribute Indicators and Descriptors
2017

Sections herein used in whole or part with permission from McGill University.

Razavinia, N., and L. Mydlarski. 2016. "Graduate Attributes and Indicators: Detailed/Program Specific Descriptions." *Accreditation Resources: Graduate Attribute Indicators.* Faculty of Engineering, McGill University. Accessed on 18 October 2016. http://www.mcgill.ca/engineering/faculty-staff-resources/accreditation/accreditation-resources

KB - A knowledge base for engineering

Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.

Indicators	Descriptors
KB.1 – Recalls and defines, and/or comprehends and applies information and concepts in mathematics	• Defines terminology and facts related to university level mathematics • Identifies rules and methodologies • Reproduces solutions to problems, uses correct equations, calculates parameters • States first principles and theories in university level mathematics • Appropriately interprets mathematical terms • Applies theories to simple problems • Shows an in-depth understanding of key ideas and concepts related to university level mathematics e.g. by explaining, translating mathematical concepts into engineering applications
KB.2 – Recalls and defines, and/or comprehends and applies information, first principles and concepts in the natural sciences	• Defines terminology and facts related to university level natural sciences • Identifies rules and methodologies • Shows an in-depth understanding of key ideas and concepts related to university level natural sciences e.g. by explaining engineering concepts using natural sciences
KB.3 – Recalls and defines, and/or comprehends and applies information, first principles and concepts in fundamental engineering science	• Defines terminology and facts related to engineering science fundamentals such as: (to be completed for each program) • Shows appropriate engineering interpretation of scientific terms • Identifies rules and methodologies • States first principles and theories in engineering science fundamentals such as: (to be completed for each program) • Shows an in-depth understanding of key ideas and concepts related to engineering science fundamentals (to be completed for each departments discipline), e.g. by explaining • Uses fundamental engineering science to explain real world phenomena
KB.4 – Recalls and defines, and/or comprehends and applies, first principles and concepts in specialized engineering science	• Defines terminology and facts related to specialized engineering knowledge appropriate to the program such as: (to be completed by each departments discipline) • Identifies rules and methodologies • Applies theories to simple problems • States first principles and theories in specialized engineering knowledge appropriate to the program such as: (to be completed for each departments discipline) • Shows an in-depth understanding of key ideas and concepts related to specialized engineering knowledge appropriate to the program (to be completed for each departments discipline) , e.g. by explaining

PA – 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.

Indicators	Descriptors
PA.1 – Identifies and defines complex engineering problems	• Identifies and/or articulates a problem (i.e., complex engineering problem, open-ended problem) • Understands a problem within a larger context (problem within a problem) • Identifies first principles, relevant information as well as uncertainty and biases in problems • Interprets auxiliary information • Adjusts from known problems to different situations • Derives familiar problems from infrequently encountered problems by simplifying problems, reducing number of variables, and applying assumptions • Formulates solutions, procedures, and methods • Uses order-of-magnitude estimates to obtain fundamental insights into complex engineering problems • Researches for development of solution
PA.2 – Develops and/or implements a strategy to analyze complex engineering problems	• Identify strategies for solving problems (brainstorming, research, trial and error) • Selects and applies appropriate computational procedures • Formulates models and identifies their limitations • Validates credibility of models with first principle analysis
PA.3 – Analyzes and solves complex engineering problems	• Implements practical solutions to address problems • Ability to propose and/or develop solutions to address a problem, and/or create/play with solutions • Ability to recognize and consider assumptions when solving a problem • Ability to analyze, evaluate and select optimal/practical solution, including feasibility and impact • Researches alternative existing solutions • Extracts conclusions from calculations • Evaluates validity of the answers and results • Provides comments to questions posed • Provides recommendation • Demonstrates creative synthesis of solution and creates new alternatives by combining knowledge and information • Predicts and justifies problem outcomes
PA.4 – Evaluates a solution to a complex engineering problem	• Evaluates solution and impact (performance, limitations, risk, cost (time and money), consequences of failure, risk) • Identifies solution methods limitation(s) and sources of error in the solution process

IN – 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.

Indicators	Descriptors
IN.1 – Gathers information (literature review, measurements, experiments, laboratory exercises) and analyzes data	• Identifies problems/issues/topics for investigation • Gathers background information (existing knowledge, research, and/or indications of the problem) • Gather materials and documents information • Analyzes the data • Troubleshoots
IN.2 – Devises and/or implements an appropriate plan / methodology for gathering information required to solve a complex engineering problem	• Selects or develops a methodology or theoretical framework to investigate a problem • States the hypothesis and the research question, clarifies the connection between them, and identifies the variables • Develops and/or follows experimental procedures, controls variables, and records procedural steps on lab report • Ability to record raw data/evidence • Ability to use information from a variety of sources to achieve an intended purpose
IN.3 – Interprets results and reaches appropriate conclusions	• Organizes evidence to demonstrate patterns, and highlight differences and/or similarities • Interprets findings using appropriate theories, and compares them to previous works/values in the literature • Reaches valid conclusions justified by the data and makes recommendations as a result of the investigation • Identifies limitations and measurement error, and/or identifies implications and proposes improvements • Presents data using charts, tables and/or graphs
IN.4 – Understands appropriate safe work procedures during experiments or laboratory exercises	• Attentive to safety • Courteous to others, and tidy in the lab • Obtains WHMIS Certification

DE – 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.

Indicators	Descriptors
DE.1 – Understands the complexities of an open-ended engineering design problem and defines appropriate objectives and constraints	• Understands the nature of the complex/open-ended engineering problems • Defines the functions and objectives • Identifies technical constraints as well as constraints set by factors such as health, safety, engineering standards, etc.
DE.2 – Uses an appropriate design process that considers all relevant factors (i.e., health & safety risks; standards; economic, environmental, cultural and societal considerations)	• Explains the design process including the importance of needs, specifications, concept generation, selection, and evaluation • Presents a problem definition in such a way that the client has full assurance that the proposed solution will be relevant • Selects and clearly states an appropriate scope • Gathers and presents reliable information relevant to the stated problem • Uses idea generation techniques to identify multiple potential solutions • Uses a formal decision-making process to select a single concept • Describes limitations and assumptions and consequences • Imposes realistic limitations on the conceptual design • Generates a conceptual solution to the stated design problem
DE.3 – Develops/implements possible solutions to an open-ended design problem, leading to an appropriate recommendation	• Develops an approach to solve a problem • Select an optimal and practical solution for the problem, considering feasibility (budget, time, etc.) and impact. • Executes a solution to an open-ended problem considering design requirements and pertinent contextual elements • Recognizes and incorporates innovation when considering an idea • Connects, integrates and transforms ideas into solutions • Incorporate new ideas, ways or tactics (alternate, divergent, contradictory and/or potentially high risk perspectives or ideas) when developing a design/approaching an assignment • Makes engineering recommendations • Conceives alternative design solutions that meet most of the desired functions and objectives • Systematically identifies and justifies an appropriate design that satisfies all requirements (functions, objectives, and constraints) and considers implementation issues • Integrates engineering, computer, and mathematical principles to resolve all the constraints involved in the design process to take into account economic, health, safety, social and environmental factors, engineering codes of practice and applicable laws
DE.4 – Devises and implements a plan to evaluate a proposed design solution	• Evaluates/confirms the functioning of the final design • Validates the design against the problem specifications

ET – 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.

Indicators	Descriptors
ET.1 – Uses tools to complete engineering activities	• Identifies and uses relevant tools for an engineering activity • Selects appropriate techniques, modern engineering tools and resources such as: short list of tools that are important and specific to the discipline grouped by software, Modern engineering tools • Demonstrates correct use of modern techniques, testing apparatus, databases, models such as: short list of tools that are important and specific to the discipline grouped by software, Modern engineering tools • Applies modern engineering tools in complex engineering activities
ET.2 – Evaluates and selects appropriate tools for a given scenario	• Describes and explains the principles behind and applicability of engineering tools • Identifies the limitations in the use of engineering tools, and their underlying assumptions
ET.3 – Adapts or creates tools to meet specific analysis or design needs	• Create simple engineering tools, e.g. measurement modules, codes • Understands the adaptability of tools • Combines tools and techniques • Integrates software with physical hardware

The term "Tools" refers to any equipment, software or resources used in each engineering discipline. A few examples are:

• Equipment: Modern engineering tools, prototypes, simplified physical models, laboratory materials

• Software: Programming language interfaces, models and/or simulation of systems, measurement and monitoring software and instruments

• Resources: Scientific references

IT – Individual and teamwork

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

Indicators	Descriptors
IT.1 – Participates in group activities and decision-making	• Contributes ideas to advance work of team • Prepares for, and contributes to, team meetings • Participates and shows interest in discussions and activities • Participate in group decision making • Demonstrates initiative
IT.2 – Contributes equitably to completion of group work	• Carries out individual responsibilities • Shares credit and accepts accountability when working in a team • Contributes an appropriate share of the group's work • Completes assigned tasks on time • Collaborates with other team members
IT.3 – Exhibits appropriate interpersonal skills when interacting with team members	• Fosters a positive and productive team atmosphere and keeps team members working together • Is courteous and respectful with team members • Demonstrates a positive attitude using verbal and non-verbal cues, and tone • Inspires, helps and encourages team members • Identifies, responds to and resolves potentially damaging conflict among team members • Listens to, collaborates with, and champions the efforts of others • Maintains composure in difficult situations • Contributes to the group's effectiveness
IT.4 – Develops or demonstrates leadership skills	• Ability to manage time (estimate, prioritize, establish deadlines/milestones, follow timeline, plan for contingencies, adapt to change) • Ability to lead a team (i) Mentors and accepts mentoring from others; (ii) Demonstrates capacity for initiative while respecting others' roles; (iii) Facilitates others' involvement. (iv) Evaluates team effectiveness and plans for improvements • Appreciates, understands and works equitably and productively with multidisciplinary team members • Provides direction and facilitates achievement of the team's goals • Evaluates team effectiveness and plans for improvement • Gets the most from resources • Motivates team members

CS – 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.

Indicators	Descriptors
CS.1 – Understands, interprets and/or applies principles for effective engineering communication (oral, written and graphical)	• Understands and uses conventions intrinsic to engineering genres (informal-formal reports, logbooks, lab reports, proposals, presentations, memos, emails, business letters, etc.) • Listens actively to a speaker, summarizes key ideas and supporting information • Understands and follows instructions successfully (spoken and/or written) • Gives/writes clear directions or instructions, conveys the sequence of steps and uses clear examples/references • Recognizes and/or constructs meaningful and relevant questions
CS.2 – Designs and produces appropriate engineering documents (i.e., research reports, engineering reports, design documents, graphics)	• Evaluates the speaker/writer, message/purpose and audience (i.e., professional and technical vs. public and nontechnical), and determines the best communication for the task • Identifies and communicates the main idea • Uses and cites information sources (texts, journals, research) correctly and effectively to support the purpose and main idea of the communication, and establish credibiity • Generates materials (examples, statistics, analogies) to support the purpose and main idea of the communication, and establish credibiity • Structures ideas to move logically forward, considering both macro (introduction, paragraphs, sequence of content, conclusion) and micro (sentences, transitions) organization • Uses language that clearly and concisely conveys meaning and supports the purpose of the work • Uses language that is mechanically correct (punctuation, capitalization, spelling, grammar) • Tailors communication by using language that is appropriate for (i) the genre (written, verbal or electronic communications, i.e., texts & emails); (ii) the target audience; (iii) the company/persons that the communicator is representing • Uses graphics (tables, figures and equations) properly to support, explain, interpret and assess communications (citations, position on page, integration, design and support of ideas) • Uses appropriate or precribed formats, which are effectively designed, clearly labeled, neatly and professionally presented

CS.3 – Delivers effective technical presentations	• Articulates strong key ideas and supporting details with clarity and concision (logical sequencing, clear transitions between points, introduction, supporting details and summary) • Uses language that is appropriate for the context, the target audience, and the company/persons that the communicator is representing • Designs, uses and integrates visual aids (slides, illustrations, props, demonstrations) that effectively support and focus the presentation • Is prepared for presentation • Speaks with non-distracting use of aids. • Uses verbal elements to effectively deliver the presentation • Uses non-verbal cues to effectively deliver the presentation • Completes presentation in the allocated time • Adopts an appearance/attire that is appropriate to the presentation (business-casual, formal, etc.) • Transitions smoothly from presentation, listen to, answer and manage questions from the audience

PR – 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.

Indicators	Descriptors
PR.1 – Understands the role of the engineering profession in society and responsibility of the Professional Engineer in protection of the public	• Shows awareness of professional/technical associations in engineering • Understands the role of the engineering profession • Understands the duty of engineers in society, i.e. safeguard life, health, property, economic interests, public welfare or the environment where engineering is concerned • Understands the process for becoming a Registered Professional Engineer • Understands the responsibility of Professional Engineer • Demonstrates an understanding of the protection of the public and its interest in decision-making • Understands the impact of engineering failures
PR.2 – Knows relevant codes, laws and regulations	• Shows awareness and understanding of the codes and acts that govern the Professional Engineer (i.e., Engineers Geoscientists Manitoba Code of Ethics and the Professional Engineering Act of Manitoba), and the primary role of the engineer to protect the public and the public interest • Shows awareness of the acts that govern safety (i.e., Manitoba Workplace Health and Safety Act), and the importance of, and demonstration of, the principles of personal and workplace health and safety
PR.3 – Exhibits behaviour expected of a Professional Engineer	• Exhibits appropriate professional behaviour • Assumes responsibility for own actions

IE – 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 sustainable design and development and environmental stewardship.

Indicators	Descriptors
IE.1 – Understands the social, environmental, economic, health, safety, legal and/or cultural aspects of engineering activities	• Considers diverse (cultural, disciplinary, ethical, etc.) perspectives when investigating engineering impact on society and the environment • Understands global, regional and local societal values applicable to engineering activities • Understands the importance of interactions between environmental, social, health and safety, cultural, legal, and economic factors in both the built and natural environment
IE.2 – Predicts environmental and socio-economic impacts associated with engineering activities	• Considers the impact of engineering interventions (decisions and technology) on society and environment (historical and/or contemporary) • Understands and/or analyzes the uncertainties in the prediction of the interaction of engineering with environmental, social, cultural, legal and economic factors • Uses risk assessment to recommend actions to protect, restore & improve the environment • Identifies and analyzes uncertainties in scientific data or incomplete evidence of adverse impacts
IE.3 – Develops solutions for adverse environmental and/or socio-economic impacts	• Identifies solutions to challenges in society and the environment • Shows awareness of, and the ability to follow the principle steps of Environmental and Social Impact Assessment (ESIA) and of Environmental Management Systems (EMS) • Identifies environmental impacts and knows different methods to estimate environmental impacts of engineering designs in their branch of engineering • Uses a diversity of approaches to "measure" the sustainability of designs (e.g., life cycle analysis, multi-criteria analysis, or monetary valuation)
IE.4 – Understands and/or applies the concepts of environmental stewardship, sustainable design and sustainable development	• Recognizes the personal (individual) and collective responsibility of engineering and its interventions on society and the environment • Understands the concept of sustainable design and development • Understands the three dimensions of sustainable development (social justice, environmental preservation, economic growth), as well as the trade-offs between them, and knows how they affect engineering design/implementation • Recognizes the extent that engineering activities affect the environment and sustainability

EE – Ethics and equity

An ability to apply professional ethics, accountability, and equity.

Indicators	Descriptors
EE.1 – Demonstrates and/or applies knowledge of ethical principles	• Understands the codes of ethics • Analyzes and applies a code of ethics in an engineering situation/activity • Recognizes, understands and applies proper ethical and legal use of intellectual property, copyrighted materials, and research
EE.2 – Appreciates, articulates and/or resolves issues and dilemmas related to ethics and equity	• Exhibits awareness of the ethical and equity-related implications of engineering work • Recognizes equitable issues (ethnicity, gender, age, sexual orientation, faith, geography, socio-economic status, etc.), and acts/behaves with inclusivity • Recognizes and acts on ethical issues (personal, professional and corporate) • Appreciates and articulates issues and dilemmas in following the dictates/requirements of professional ethics • Generates and understands approaches for resolving ethical dilemmas and issues of equity in relation to both professional and substantive ethics • Can discuss and/or apply principles of equity in workplace
EE.3 – Demonstrates individual accountability	• Understands accountability and assumes responsibility for own actions • Recommends actions that are accountable • Can discuss and/or apply principles of professional accountability

EP – 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.

Indicators	Descriptors
EP.1 – Understands concepts of engineering economics	• Comprehends and employs economic principles in the assessment/design an engineering project, including short-term cost vs. long-term value, and determines feasibility • Understands the limitation of economic analysis in an engineering context • Understands the effect of the national/global economy on engineering projects
EP.2 – Understands concepts of project management	• Understands the problem, the client's needs, and is able to propose a plan • Understands the 5 levels of the project management phases, i.e. initiating, planning, executing, monitoring and controlling, and closing the project and can define the necessary tasks for each • Understands project constraints, i.e. cost, time and resources • Understands risk management principles in an engineering context • Understands change management principles in an engineering context • Understands time management principles in an engineering context • Understands the limitation of engineering management techniques
EP.3 – Critically applies management tools and economics principles in engineering projects	• Identifies risks (physical, emotional, monetary, risks of repute, etc.) related to a project considering the probability of occurrence, the severity, and/or mitigation strategies • Estimates time on task, establishes deadlines/milestones, follows timeline, monitors and completes project • Plans for contingencies and adapts to change • Understands and/or meets quality assurance standards • Create and/or adheres to a budget • Evaluates the project and adapts for subsequent projects • Analyzes the economic viability of engineering projects by applying economic tools and principles • Identifies, selects, and uses the appropriate project management tools and understands the limitations of the different tools • Identifies the requirements, assumptions, risks and constraints • Plans the project within the project constraints, creates a schedule, performs risk analysis, considers plans to manage changes • Evaluates cost of alternative approaches, assesses purchases and creates procurement document, reports on project progress, produces deliverables • Applies risk management principles in an engineering project • Applies change management principles in an engineering project

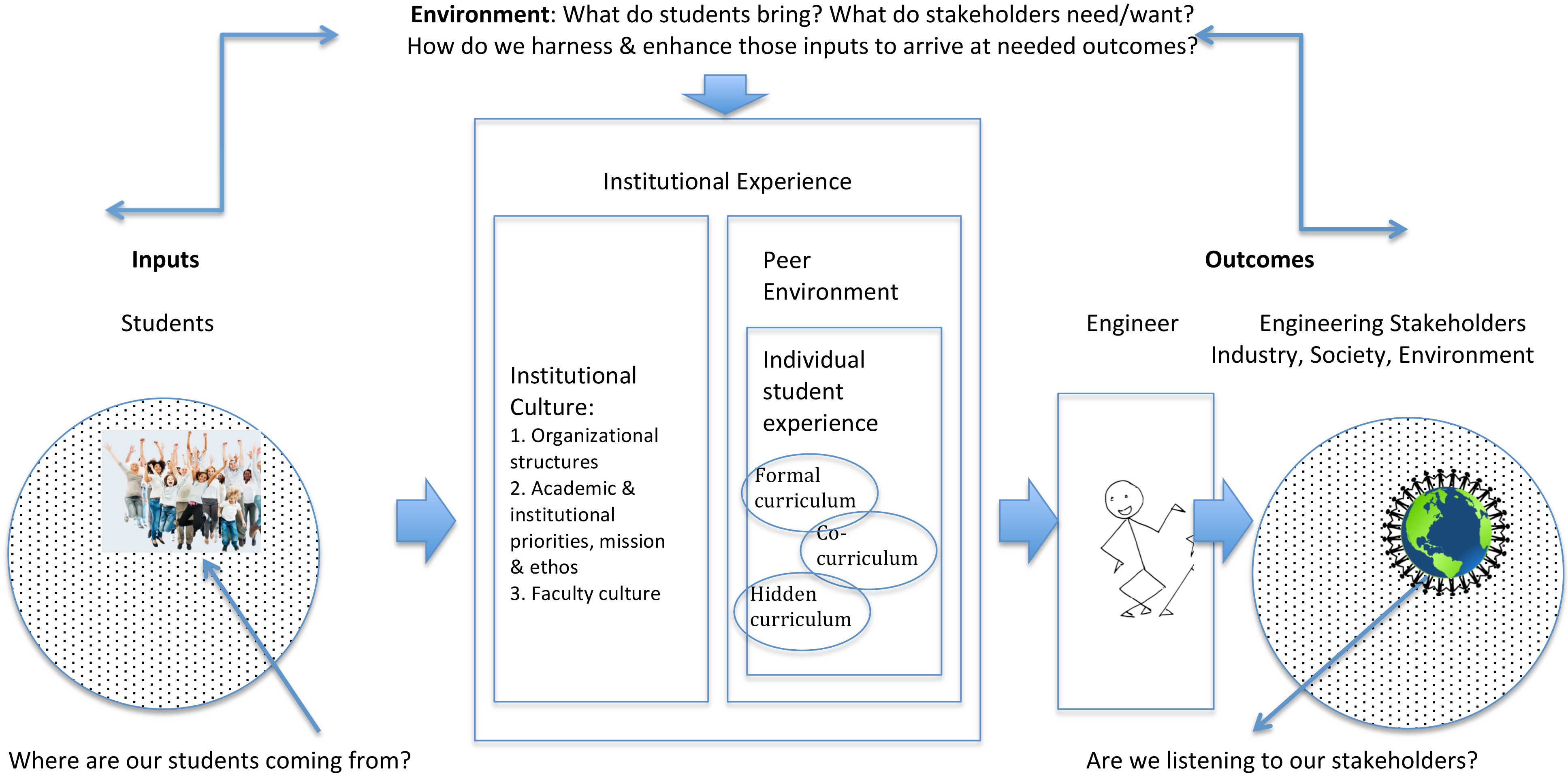
LL – Lifelong learning

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.

Indicators	**Descriptors**
LL.1 – Applies appropriate knowledge to new situations	• Applies prior knowledge, skills and/or behaviors to new situations
LL.2 – Engages in activities to advance knowledge and understands the role of on-going professional development	• Explores a subject/topic in the pursuit of knowledge • Takes initiative; seeks additional opportunities for learning • Engaged in staying current in the chosen field • Constructs meaningful and pertinent questions to guide learning
LL.3 – Learns from successes and mistakes; recognizes limitations	• Accepts and uses constructive feedback • Reflects on experiences/situations, and applies results from reflections to subsequent experiences/situations • Learns from successes and mistakes, and recognizes limitations
LL.4 – Demonstrates research and information literacy skills	• Frames a topic, determines research scope, identifies essential concepts, selects information relevant to chosen topic and define research questions • Uses search strategies and accesses information • Uses criteria to select authoritative information from a variety of reputable sources and critically evaluate sources and information • Identifies and summarizes the main ideas/key concepts found in an information source • Uses information from a variety of sources to achieve an intended purpose • Employs appropriate strategies to cite and reference sources

Appendix J: A Conceptualization of the Engineering Education Ecosystem

(Adapted from Holsapple et al. (2012) – Based on Astin's Inputs-Environments-Outputs (I-E-O) Model (1970, 1993) with expansion from Terenzini & Reason (2005))



Rather than achievement, focus on diversity:

- Diversity of sociodemographic characteristics: cultures, races, genders, religions, socio-economic status
- Diversity of experiences, perspectives, interests
- Diversity of skills & knowledge

To achieve diversity of student population, we need diverse requirements & ways to enter engineering.

Change:

1. Diversity
2. Identity
3. Educate the Whole Engineer

Assumptions of problems, needed improvement:

- Lack of diversity
- Failures of ethics and professionalism
- Poor record of innovation
- Exclusion of non-licensed engineers from profession
- Inflexibility of the academic accreditation system and education model
- Siloing and commoditization of work (EngineersCanada)