ability activity although analysis applications applied approach because between captures category challenges collection concept conceptual connections considers constructs context create critical curriculum described descriptions design development differently directly discuss educators’ elements engage engineers enhance example experiences figure findings following further graduate holistic identified important include individual influence insight instruments interpreted interview knowledge learners learning literature matter meaning methods objectives opportunities orientation participants personal perspectives practicing presented problem process program projects provide qualitative questionnaire questions related relationships requires research responses school science section skills society solving specific structure students’ studying subject support systems teaching theory thesis thinking through transfer undergraduate understandings

About this word cloud: The words above are the 100 most frequently occurring words in my thesis. The words are displayed in a font size representative of their frequency count: the larger the text, the higher the word frequency. This image was generated using the qualitative data analysis package I used for my research.
ABSTRACT

There is a societal need for design education to prepare holistic engineers with the knowledge, skills, and attitudes to innovate and compete globally. Design skills are paramount to the espoused values of higher education, as institutions of higher learning strive to develop in students the cognitive abilities of critical thinking, problem solving, and creativity. To meet these interests from industry and academia, it is important to advance the teaching and learning of engineering design.

This research aims to understand how engineering students learn and think about design, as a way for engineering educators to optimize instructional practice and curriculum development.

Qualitative research methodology was used to investigate the meaning that engineering students’ ascribe to engineering design. The recruitment of participants and corresponding collection of data occurred in two phases using two different data collection techniques. The first phase involved the distribution of a one-time online questionnaire to all first year, third year, and fourth year undergraduate engineering students at three Canadian Universities. After the questionnaire, students were asked if they would be willing to participate in the second phase of data collection consisting of a personal interview. A total of ten students participated in interviews. Qualitative data analysis procedures were conducted on students’ responses from the questionnaire and interviews. The data analysis process consisted of two phases: a descriptive phase to code and categorize the data, followed by an interpretative phase to generate further meaning and relationships.
The research findings present a conceptual understanding of students’ descriptions about engineering design, structured within two educational orientations: a learning studies orientation and a curriculum studies orientation. The learning studies orientation captured three themes of students’ understanding of engineering design: awareness, relevance, and transfer. With this framework of student learning, engineering educators can enhance learning experiences by engaging all three levels of students’ understanding. The curriculum studies orientation applied the three holistic elements of curriculum—subject matter, society, and the individual—to conceptualize design considerations for engineering curriculum and teaching practice.

This research supports the characterization of students’ learning experiences to help educators and students optimize their teaching and learning of design education.
DEDICATION

To

Mom and Dad,

and my sisters, Michelle and Nicole

You inspire me to teach and learn every day.
When I think about how I first became involved in engineering education, it is not surprising that my past experiences have led me directly to where I am today. I remember volunteering in high school at the Ontario Science Centre, an interactive science museum in Toronto, Ontario. The Science Centre has a simple mission: to delight, inform, and challenge. One activity which I volunteered for, involved building balloon rockets with visitors to learn about Newton’s Third Law of Motion: Every action has an equal and opposite reaction. In this educational exercise, engineering design was applied to engage learners and teach a fundamental physics principle. It was that moment—playing with science and sharing in someone else’s learning—that first ignited my passion for engineering education.

This thesis is about creating learning experiences that are engaging and meaningful. I hope to provide a deeper understanding of engineering education, for educators and students to apply in their teaching and learning.

At the end of one of my research interviews, a participant openly asked me: “Why are you doing this? Do you just want to obtain a Degree, or do you actually want to make a difference?” More than anything, I hope this research will make a difference in the education of future engineers—it has, in so many ways, made a difference for me.

Richard J. Aleong

August 2012
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CHAPTER 1

INTRODUCTION

Research in engineering education serves to answer the question “how do we engineer an engineer?” How should educational systems be designed to optimize students’ learning and success in their personal and professional careers, given the constraints on time and resources? In this thesis, I have embraced an interdisciplinary perspective, bringing together the fields of engineering and education to explore the overarching question: How can educators create meaningful learning experiences for engineering students?

Despite one’s disciplinary background, the term ‘engineering education’ can be understood in two ways—as a noun and as a verb—each way having a distinct meaning. As a noun, engineering education is a product. The field of engineering is the subject matter and academics are concerned with how to teach the knowledge, skills, and attitudes required for the engineering profession. On the other hand, understanding ‘engineering education’ as a verb, transforms it into a process—the engineering of education. By treating education as a complex system, educators are trying to design systems to help students learn. I have embraced both perspectives for my research: as a product, I am concerned about engineering design as the subject matter to be taught; as a process, I aim to design educational systems to improve teaching and learning. Understanding engineering education as a product and a process allows educators to appreciate the interdisciplinary and far-reaching challenges facing engineering education in the 21st century.
CHAPTER 1: INTRODUCTION

Although we cannot predict the future economy, change is inevitable: globalization will continue to expand; technology will become more sophisticated; social interactions will become more complex (National Academy of Engineering, 2004, 2005, 2007). These challenges have posed new demands on how we educate engineers. How can educators ensure that engineering graduates are best positioned for a world that is unpredictable?

This thesis offers new insight, from a conceptual understanding of engineering students’ perspectives, for educators to consider in the design of engineering education.

Research Objectives and Questions

The continuous improvement of engineering education is at the heart of this research thesis. How can engineering educators create high quality learning experiences for students? Open-ended design challenges often begin with *insight, observation, and empathy* to deeply understand the needs and actions of the user (Brown, 2009). My approach to improve engineering education is focused on qualitatively understanding how engineering students describe their learning and practice of engineering design. My research was guided by the following question:

*How do undergraduate engineering students understand and make meaning of engineering design?*

To explore the research question, the sub-question was asked:

*How do undergraduate engineering students think about learning and practicing design?*
CHAPTER 1: INTRODUCTION

Under this sub-question, three topics were identified as the areas of thinking to be explored:

1. What are students’ conceptions of design?
2. How do students describe the meaning of design?
3. How do students describe their learning of design?

With this framework, the purpose of this research was to explore the conceptions and relationships found in engineering students’ understanding of engineering design. These research questions served as the foundation of my study—to ignite inquiry and drive exploration. Above all, the objective of this thesis was to provide insight for the design of educational systems to optimize students’ learning of engineering.

Overview of Methodology

To investigate what students think about learning engineering design, a qualitative research approach was undertaken grounded in an interpretivist research paradigm. Qualitative inquiry is appropriate for the purpose of this study because it aims to explore the meaning that individuals assign to a phenomenon. The interpretivist research paradigm recognizes that reality is socially constructed and that each student will have their own way of describing their reality. Through qualitative inquiry, the exploration of how students’ construct their reality is possible, providing educators with a better understanding of engineering students. Data collection methods consisted of two measurement instruments: a one-time online questionnaire and follow-up personal interviews. The measurement instruments asked students to describe their experiences with learning and practicing engineering design. Students in first year, third year, and
fourth year of undergraduate engineering studies, at three Canadian Universities in Ontario, were invited to participate in the one-time online questionnaire. At the end of the questionnaire, students were invited to participate in a personal interview held in the second semester of the academic year. A total of 118 students partially completed the questionnaire, and 10 students participated in a personal interview. Qualitative analysis was conducted through an iterative, four stage process consisting of two phases of analysis: descriptive and interpretative. All of the data collected from students’ responses were coded and categorized to draw meaning from the data. Themes and categories emerged to formulate the research findings and inspire the research discussion.

Thesis Contributions and Implications

This thesis presents applied research in the field of engineering education, contributing to the body of literature on students’ understanding of engineering design. The science of learning is applied to inform educational practice and curriculum development—leading to enhanced student learning.

My thesis offers critical perspectives for engineering educators to consider when thinking about the teaching and learning of engineering design. These considerations and implications are critical for building engineering educators’ pedagogical content knowledge, defined by Shulman (1986) as “the ways of representing and formulating the subject that make it comprehensible to others” (p. 9). Because each student brings different backgrounds and experiences to the classroom, all contributing to what the individual student may already know about the subject, “teachers need knowledge of the strategies most likely to be fruitful in reorganizing the understanding of learners” (p. 9-
10). Shulman states that “pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult” (p. 9). With the knowledge of how students think about engineering design, engineering educators can build their pedagogical content knowledge and optimize teaching strategies. As Dunsmore, Turns, and Yellin (2011) suggested, understanding engineering students’ constructions of the engineering profession “could generate leverage points to foster more effective student understandings of engineering practice” (p. 343).

The implications of my research to enhance student learning are twofold. First, the research captures valuable student feedback on their learning experiences. With this feedback, educators can reevaluate their teaching methods and adapt their teaching practice. Second, and perhaps more importantly, this research provides conceptual insight for engineering educators to position and challenge their teaching practice. With a framework for thinking about teaching and learning in the engineering context, educators can create new learning experiences for students. This view supports the research-based educational approach, where educational research is applied to influence teaching practice.

To facilitate the design of educational systems, I have structured my research findings into two educational orientations: 1) a learning centered orientation and 2) a curriculum centered orientation. The learning centered orientation presents students’ understanding of engineering design within three themes: awareness, relevance, and transfer. I offer these three themes, grounded in concrete evidence from the students’ perspectives, as a way for educators to conceptualize meaningful learning in engineering education. The curriculum orientation focuses on students’ perspectives that speak to the
three elements of holistic curriculum: subject matter, society, and the individual. In these themes, the ways students learn engineering design are presented for consideration in the design of holistic learning systems.

Several authors have provided a comprehensive look at how engineers are taught and curriculum reform to drive the design of engineering education (Sheppard, Macatangay, Colby, & Sullivan, 2009). Design principles are identified and action items are outlined. It is clear what engineering educators can do to improve engineering education—there is a vision and a plan. This thesis provides applied research to support how engineering educators can design learning systems to enhance students’ experiences.

Organization of Thesis

This thesis follows an organizational structure that outlines the situation of engineering education and identifies challenges within the field (Chapter 2), presents my approach to design learning systems (Chapters 3, 4 & 5), and offers insight for application and evaluation of the research findings (Chapters 6 & 7). For a comprehensive understanding of the interdisciplinary challenges facing the field of engineering education, this thesis serves to “tell the whole story” leading up to the specific problems that are addressed by my research. Appreciating the full context of these challenges is important and will help in understanding my approach to offer input to advance engineering education. The research discussion offers implications and insight on applying the research findings to teaching practice.

The overarching objective of this research is to explore ways to design systems to optimize students’ learning of engineering design. Therefore, this thesis is written for a
CHAPTER 1: INTRODUCTION

broad audience within the engineering education community. This thesis is organized into the following chapters:

CHAPTER 2: LITERATURE REVIEW

The literature review serves to position my thesis within the field of engineering education. I outline the challenges and need for design education and provide background theory on educational studies to set the context and approach for my work.

CHAPTER 3: RESEARCH DESIGN - METHODOLOGY, METHODS, AND DATA COLLECTION

This chapter outlines the qualitative methodology I used in my research. The design of my data collection instruments are also discussed as well as the process and limitations of my data collection methods.

CHAPTER 4: RESEARCH ANALYSIS

In this chapter, I discuss the rigorous data analysis that was conducted to make meaning out of the data. I followed a four stage process to code the initial data, and then to generate conceptual themes of meaning. This process was conducted over two phases of analysis: descriptive and interpretative.
CHAPTER 1: INTRODUCTION

CHAPTER 5: RESEARCH FINDINGS

The research findings are presented in two parts representing the two orientations that I have used to make meaning out of my data. The first part is grounded in a learning theory orientation that considers students’ understanding in terms of awareness, relevance, and transfer. The second part applies a curriculum studies orientation to understand the three elements of a holistic curriculum in the engineering context: subject matter, society, and the individual.

CHAPTER 6: DISCUSSION

The discussion of my research findings is structured similarly to the presentation of the research findings for consistency and clarity. My discussion sections highlight ways in which engineering educators can apply the research findings. Readers are challenged to be critical of their own teaching and learning practice.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

To advance the teaching and learning of engineering education, I offer a number of recommendations that have emerged from my research. These recommendations are targeted to various stakeholders within the engineering education community.
CHAPTER 2
LITERATURE REVIEW

To understand how this research fits into the larger framework of engineering education, it is important to set the context in terms of two interrelated educational fields: 1) curriculum studies and 2) learning theory (cognitive studies). This literature review, organized in two parts, will consider how each of these fields provides insight into the complexity of engineering education. Contemporary trends and issues facing engineering design education will be discussed.

Part 1: Positioning Design Education—Insight from Curriculum Studies

In Part 1, I will establish the need for design education to set the context of my work. I utilize a curriculum studies framework to evaluate the current situation of engineering education accreditation. I present the holistic engineering approach as the solution to the challenges engineering education has faced in the past.

Part 2: Teaching and Learning Engineering Design—Insight from Learning Theory

In Part 2, I continue to define my problem and outline the approach of my research to improve engineering design education. From both a curriculum theory and learning theory perspective, I discuss the challenges facing design education in the engineering curriculum. I explore the specific literature and learning theory that are applicable to my core research question.
Part 1

Positioning Design Education

Design is a ubiquitous term in engineering, but may hold varying degrees of ambiguity among engineering practitioners, educators, and students. According to Engineers Canada (2011a), *engineering design* is defined as:

> [the integration] of mathematics, natural sciences, engineering sciences, and complementary studies in order to develop elements, systems, and processes to meet specific needs. It is a creative, iterative, and open-ended process, subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may also relate to economic, health, safety, environmental, societal or other interdisciplinary factors. (p. 18)

It is clear that design is a core activity in the engineering profession. Furthermore, design is intimately linked with learning because the process of design serves to develop students’ abilities in problem solving, critical thinking, and creativity. I approach my research with a holistic design paradigm: considering design not only as the activity of the engineering profession—that is, what engineers do—but also how engineers think and learn. To support my view, I will discuss the relationship between design and higher education, and the impact this relationship has on society.

Higher education espouses to develop students’ ability for problem solving, critical thinking, and creativity—all elements required for effective design. As Koshland (2010) pointed out, a liberal education serves to educate students who are “ready to pursue a complex career path and a rich post-graduate life with skills in critical thinking, analysis, and an appreciation for the complexity of the society in which [they] live” (p. 54). Undoubtedly, design education plays a key role in all forms of higher education.
Ultimately, engineering students will have the skills and ability to tackle complex problems in any situation by effectively working through all aspects of the design process. To emphasize the importance of design thinking in all disciplines of higher education, I agree with the argument made by Simon (1996) that design thinking is core to all professions:

Engineers are not the only professional designers. Everyone designs who devises courses of action aimed at changing existing situations into preferred ones. The intellectual activity that produces material artifacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a state. Design, so construed, is the core of all professional training; it is the principal mark that distinguishes the professions from the sciences. Schools of engineering, as well as schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design. (p. 111)

Sharing the same sentiments around design, Brown (2009) used a very broad approach to design thinking explaining that “the mission of design thinking is to translate observations into insights and insights into products and services that will improve lives” (p. 49).

Wnek and Williamson (2010) argued that engineering lies at the intersection of science and business, to create value for society (p. 137). They further define innovation as “the process that turns an idea into value for the customer and results in sustainable profit for the enterprise” (p. 137). Engineering design can be considered as the process to enable innovation (Natural Sciences and Engineering Research Council of Canada, 2012).

The design thinkers, as referenced above, recognized the importance of design practice to benefit society and build a sustainable future. The current economy, driven by globalization, knowledge, and rapidly changing technology, is placing new demands on
CHAPTER 2: LITERATURE REVIEW - PART 1

the way we train engineers. With the complex and interdisciplinary challenges facing the 21st Century, as identified by the Grand Challenges for Engineering (National Academy of Engineering, 2012), there is a need for design education in all facets of higher learning to foster design thinkers with the ability to drive innovation.

Curriculum Perspectives

I have discussed my position in terms of understanding engineering design and design thinking. With this understanding, I will now discuss educational theory pertaining to curriculum studies to make the connection between engineering design and education.

Contemporary literature on engineering education begins by addressing the challenges facing the engineering profession in the 21st century and the requirements of engineering education to address these challenges. Understanding the history and progress of engineering curriculum provides a basis from which to launch educational improvement initiatives. To set the premise for this thesis, the following sections will present the state of engineering education and the changing paradigms that support the need for research in engineering design education.

To understand the current state and future prospects of engineering education, it is helpful to use a framework from curriculum studies to set the larger context of the problem. By looking at curriculum perspectives first, the push for a paradigm shift to holistic engineering education becomes more meaningful.
Marsh and Willis (2007) defined *curriculum* as “an interrelated set of plans and experiences that a student undertakes under the guidance of the school” (p. 15). Dym (2008) reinforced this view of curriculum in an engineering context, stating that:

> Engineering education is much more than a list of required subjects. Rather, the engineering curriculum should be viewed as the sum of a set of experiences in which future engineers will participate and a set of skills that they will acquire as a result of those experiences. (p. 219)

Although an effective curriculum plan is central to designing effective learning experiences, it is important to note that there are three aspects of curriculum that influence a student’s development: *the planned, enacted, and experienced* (Marsh & Willis, 2007). While the curriculum documents serve the planned curriculum, understanding how students learn promotes better implementation of the enacted curriculum. As well, a deeper look into students’ experiences helps to explain what students actually experience in the classroom. With this broad view, the impact and overarching influence of curriculum on designing learning experiences cannot be understated.

The framework from curriculum studies used in this thesis is that of Marsh and Willis (2007), who presented the three elements of a holistic curriculum: *subject matter, society, and the individual* (p. 25-26) (Figure 1). It is up to curriculum developers to balance each element when designing effective curriculum.
The three elements of curriculum will be discussed to show the implications for engineering education. As well, the challenges of engineering education accreditation will be discussed from the perspective of these three curriculum orientations. Following this discussion, the holistic engineering education approach is presented to meet the needs of engineering curriculum.

Subject Matter

The element of subject matter is concerned with the specific knowledge, skills, and attitudes that encompass the curriculum—that is, what is the content of the curriculum? The Canadian Engineering Accreditation Board (CEAB) sets the general subject matter requirements for accredited engineering schools in Canada. With the ever-expanding knowledge base in engineering, an evaluation of the content to be covered in the engineering curriculum and how schools will manage the growing content should be addressed. Within the engineering curriculum subject matter, this research focuses on engineering design.

Figure 1: The three elements of a holistic curriculum.
CHAPTER 2: LITERATURE REVIEW - PART 1

The view of design as the central creative activity in the engineering profession is held by a number of engineering practitioners and engineering education researchers (Simon, 1996). As Lewin (1979) stated, “the engineer’s chief concern is with the design of artifacts which can achieve certain desired objectives (the specifications) and to establish the necessary properties required by the artifacts to allow them to function correctly to this end” (p. 113). Wiese and John (2003) further captured the important role design plays in engineering: “Engineering is all about applying scientific principles to the design and manufacture of useful items.” (p. 1). Borgford-Parnell, Deibel, Atman (2010) supported the importance of design with the statement that “the design process resides at the heart of engineering practice and therefore, it is critically important that engineering students develop a high degree of understanding and ability in this arena” (p. 748).

Although these statements identify design as core to engineering, the engineering profession has been viewed in the past as a highly technical field grounded in scientific analysis and mathematics. Bowden (2004) described the traditional curriculum experience in the 1960s, “where there was too much emphasis on quantitative problem solving through rote-learned algorithms in isolated contexts” (p. 39). With the rapid increase in technical knowledge and changing technology, engineering educators should be cautious of a curriculum with technical content overload and narrow specialization. As Goldberg (2008) indicated, engineering educators must be hesitant of “the persistence of a Cold War curriculum in an Internet world” (p. 68). He argued that the emphasis on technical science and math knowledge may have worked before, but now the neglect of significant engineering design may be doing students a disservice (p. 68). As Wnek and Williamson (2010) pointed out, “a common body of knowledge and competency has the
risk of quickly becoming a commodity” (p. 138). If engineers are charged with enabling innovation, then a strong foundation in math and science—while required—is not sufficient to accomplish this task. Design education is one way to offer students a differentiated and value added skillset.

**Society**

The element of society is concerned with how the curriculum prepares students to operate within society and meet society’s needs. As Marsh and Willis (2007) questioned:

> Does the curriculum sufficiently reflect a broad range of the cultural, political, and economic characteristics of the social context in which it exists so that the student may fit into the society in the future yet also be able to change that society? (p. 25)

The last paradigm shift in engineering curriculum can be traced back to the post-World War II and cold war era of the 1950s, where math and science research was seen as the way to a country’s technological superiority. This shift is evidenced by the “Report of the Committee on Evaluation of Engineering Education” chaired by L.E. Grinter and published in 1955 by the Journal of Engineering Education (a summary of this report can be found in Harris, DeLoatch, Grogan, Peden, & Whinnery, 1994). The pressure from society at that time highly influenced the curriculum to be scientific-content driven (Dym, 2004; Harris, DeLoatch, Grogan, Peden, & Whinnery, 1994). However, the 21st century has changed the way the world operates and has brought new challenges to society. As such, the engineer’s role must be redefined to meet the demands of a new economy. Societal pressures still place a heavy demand on the engineering curriculum; however, society has shifted aims from the past scientific Cold War era, and now requires a new workforce with diverse skills. This is evidenced in the report by the National

A great deal of the engineering education literature identifies the knowledge, skills, and attitudes required of the future engineer (Schaefer, Panchal, Choi, & Mistree, 2008). These engineering educators call for ‘flat world’ skills, referring to the global economy and ease of cross-continent collaboration. If Canadian engineers are to compete globally and be leaders of innovation, design education is essential to an engineer’s education.

**The Individual**

The element of the individual looks at how the curriculum serves an individual student’s learning needs and interests. Recognizing that each student is unique, Marsh and Willis (2007) acknowledged that “the same curriculum cannot be equally appropriate for all individuals” (p. 28). Engineering education has inherent open-ended learning objectives because of the nature of engineering as a professional undergraduate program. Students may or may not pursue professional engineering licensure after graduation. Therefore, engineering educators must be mindful of how the engineering curriculum appeals to individual learning needs: How does the curriculum prepare students for a wide range of career opportunities?

I have presented the three elements of curriculum as a framework for engineering education development. The paradigm shift in educational reform does not call for drastic changes in what we teach, but how we teach it. I will now discuss how the three elements of curriculum relate to the Canadian Engineering Accreditation Board (CEAB) requirements for accreditation of engineering programs.
Canadian Engineering Accreditation Board – Requirements for Accreditation

In Canada, successfully completing four years of the undergraduate engineering program qualifies students as having met the academic requirements required for licensure as a Professional Engineer. While students must still meet the professional experience requirement and pass the licensing exam, engineering is a unique undergraduate program because it is one of the few professional degrees where the academic requirements can be completed in undergraduate studies. Because of this professional status, the engineering program must be accredited to ensure its quality, integrity, and consistency across all engineering schools in Canada. The Canadian Engineering Accreditation Board (CEAB) is the standing committee of Engineers Canada, the body that certifies Canadian universities to grant engineering undergraduate degrees. Therefore, the CEAB represents the societal stakeholder in engineering curriculum and holds the highest level curriculum document by setting the minimum academic program requirements for Canadian engineering schools.

The most important components of engineering accreditation related to curriculum are the Accreditation Units (AUs) and Graduate Attributes. The CEAB has defined broad categories for the technical content that must be covered in the engineering curriculum. Accreditation Units (AUs) are used to track the number of hours of instruction students receive in course content. The AUs represent the fundamental subject matter of engineering curriculum. One AU is equivalent to 1 hour of class instruction or a fifty-minute lecture and one hour of lab time or tutorial is equivalent to 0.5 AU (Engineers Canada, 2011a, p. 15).
First introduced in 2008, the CEAB has identified twelve graduate attributes that engineering schools must develop in their students. These twelve attributes are listed in Table 1 and emphasize the professional skills and competencies of graduating engineers.

As Bowden (2004) pointed out, these attributes shift the curriculum to be “capabilities-driven,” – considering learning outcomes and serving to answer the question “what should the learner be capable of doing at the end?” (p. 36).

Table 1: Twelve graduate attributes (Engineers Canada, 2011a, pp. 12-13).

<table>
<thead>
<tr>
<th>1. engineering knowledge base</th>
<th>7. communication skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. problem analysis</td>
<td>8. professionalism</td>
</tr>
<tr>
<td>3. investigation</td>
<td>9. engineering impact on society and the environment</td>
</tr>
<tr>
<td>4. design</td>
<td>10. ethics and equity</td>
</tr>
<tr>
<td>5. use of engineering tools</td>
<td>11. economics and project management</td>
</tr>
<tr>
<td>6. individual and team work</td>
<td>12. lifelong learning</td>
</tr>
</tbody>
</table>

The first assessment of compliance with the Graduate Attributes criteria is scheduled to begin in June 2015 (Engineers Canada, 2011a, p. 12). With this upcoming assessment, there is immense pressure from the CEAB for institutions to reform engineering curriculum around the twelve graduate attributes.

It is evident that the CEAB Twelve graduate attributes emphasize professional skills and competencies beyond the technical engineering subject matter covered in the required Accreditation Units. Furthermore, the graduate attributes attempt to capture skills and attitudes that are applicable to all individuals pursuing higher education. The establishment of the twelve graduate attributes shows that CEAB is moving towards a holistic approach to engineering education, recognizing the importance of skill development beyond technical content. It is interesting to see that design is listed as an
attribute in itself; however, from a holistic perspective, design can be considered an over-
arching and all-encompassing attribute (Strong & Fostaty Young, 2010). That is, all of
the other eleven attributes are required to perform effective engineering design.

Current societal needs and the changes in curriculum brought by the CEAB have
positioned engineering educators to adopt a holistic approach towards education. I will
now discuss what holistic engineering education means for students and educators.

**Holistic Engineering Education**

Holistic engineering education balances the curriculum interests of subject matter,
society, and the individual by taking “an integrated, whole-system approach to
education” (Wnek & Williamson, 2010, p. 139). The holistic approach emphasizes the
role of engineers as the enablers of innovation, creating products, services, and systems
for the betterment of society. Although this idea is not new, the holistic approach serves
to bring the essence of engineering as design to the forefront of engineering education.

Engineers in the 21st century must be design-oriented critical thinkers with a
commitment to lifelong learning. Education of a holistic engineer strives to equip
students with the unique skillset to define and solve problems across disciplines,
spanning “technology, law, public policy, sustainability, the arts, government, and
industry” (Grasso & Burkins, 2010, p. 1). As Grasso and Helble (2010) rightly pointed
out, “the broader one’s education and the more ways of thinking to which one is exposed,
the more creative, holistic, and expansive is the solutions space” (p. 87). Though it may
appear that the holistic approach extends the subject matter to include topics not typically
covered in the traditional program, the intent is not to add more content to the already
overloaded curriculum. Instead, the holistic approach redefines the role of both engineers and education with its paradigm shift towards a learner-centered, design-oriented view (Harris & Cullen, 2009, p. 52; Wise, 2010, pp. 231-232; Schaefer, Panchal, Choi, & Mistree, 2008, p. 276). In so doing, the emphasis of technical content is shifted to adopt broader learning objectives that meet the needs of subject matter, society, and the individual. The holistic engineering education approach supports the paradigm shift in not what is taught, but how it is taught.

Summary of Literature Review - Part 1

In the first part of my literature review, I have used a curriculum studies approach that considers the three elements of holistic curriculum to position design within engineering education. Within this curriculum framework, I have addressed the current state of engineering curriculum in relation to the CEAB Accreditation requirements.

The societal and economic demands of the 21st Century have brought new pressures for engineering education. Based on the engineering education literature, design education meets the needs of a holistic engineering curriculum by:

- Recognizing the importance of technical engineering subject matter by bridging theory to practice
- Meeting the needs of society based on the current global economy driven by innovation and creativity
- Addressing the needs of the individual by developing skills applicable for all citizens through the CEAB twelve graduate attributes
The holistic approach to engineering education serves to bring the essence of engineering as design to the forefront of the curriculum. Understanding the past and present engineering curriculum serves to provide insight for future development.
Part 2

Teaching and Learning Engineering Design

In Part 1, I presented how I position design within engineering education and the background information from curriculum studies to set the context for my research. The need for design education was identified to promote holistic engineering education. In Part 2 of the literature review, I will use a learning theory orientation to continue exploring the challenges and needs of design education. In this way, I will show the links between engineering design and student learning—building the foundation for my research design.

Integrating Engineering Science and Engineering Design

Much of the engineering education literature suggests the existence of two camps in engineering education: 1) engineering science and 2) engineering design—what some authors have referred to as the “theory-to-practice” gap (Dym, Agogino, Eris, Frey, & Leifer, 2005; Lamancusa, 2006; Redish & Smith, 2008). These two activities undoubtedly rely on each other and must be integrated together to form holistic engineering. As Lamancusa (2006) stated: “In order to design, one must have a firm grasp of engineering fundamentals, but the best way to learn and remember the fundamentals is to use them for design. Design provides the bridge between theory and application” (p. 657). Cardella, Atman, Turns, and Adams (2008) also acknowledged that “to succeed as a global engineer, students must learn how to integrate their mathematics and science content knowledge into their design processes, to show that they possess strong analytical skills” (p. 256).
Although promoting the integration of engineering science and engineering design may be the espoused values of many engineering educators, there are a number of challenges that must be overcome to achieve this integration. One approach to curriculum reform has been the addition of more design courses. Linder and Flowers (2001) acknowledged that while their engineering department has been adding design activities to the engineering science curriculum, it has resulted in the creation of “essentially two curricula occupying one educational program space” (p. 436). This dichotomy in curriculum presents challenges for students as they “are not developing knowledge and skills that synthesize the subjects covered in the two curricula” (p.436). Downey and Lucena (2003) expressed similar concerns and stated “the science-based engineering curriculum tells [students] that engineering design is simply an extension of the engineering method into a messier world…Students may come to know that the engineering sciences are fundamental and that design is both subordinate and dependent” (p. 171). Therefore, adding more design courses is necessary but not sufficient to ensure optimal learning. As Downey and Lucena suggested, “reform in engineering education may have to go beyond swinging a pendulum, expanding and enhancing design education, to altering the meaning of the distinction between ‘science’ and ‘design’ itself” (p. 168).

Linder and Flowers (2001) stated that: “Two activities are integrated for a learning objective when students produce behaviours and outcomes [emphasis added] in both activities that indicate progress towards that objective” (p. 437). These authors further identified three challenges to the integration of engineering science and engineering design activities: mismatched objectives, excessive focus on outcomes, and
inconsistent contexts. Mismatched objectives occur when “one activity supports a different learning objective that is required by the other activity” (p. 437). Therefore, the learning objectives for all activities must be aligned and contribute to the overall development. Furthermore, students must be aware of what this “overall development” or ‘big picture’ looks like, emphasizing the context of their learning. The second challenge, excessive focus on outcomes, poses problems because it does not consider the influence of student behaviours towards learning objectives (p. 438). Common learning activities may place an emphasis on outcomes for assessment by using tests and exams; however, when faculty members do not have an opportunity to observe and give feedback on students’ behaviours, another learning opportunity is lost (p. 438). The final challenge of integrating engineering science with engineering design is one of inconsistent contexts. The term ‘inconsistent contexts’ used here is referring to the difference in context between learning and applying what one has learned. When students “develop knowledge and skills that are dependent on the context in which they are learned,” it is difficult for students to transfer their learning to new contexts. Therefore, it is the difference between the learning and application contexts that poses challenges for curriculum integration. Transfer of learning or learning transfer is a term commonly used in the educational literature referring to one’s ability to apply concepts learned in one context to other contexts (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010, p. 108). The challenge of learning transfer is inherent in engineering design because the design process is open-ended, complex, and iterative—requiring students to apply their background knowledge in several different contexts.
Another challenge to integrating design education within engineering pertains to the nature of students’ prior knowledge. In their study, Downey and Lucena (2003) argued that engineering students do not bring an understanding of the distinction between ‘science’ and ‘design’ to their studies, but acquire this understanding through the engineering curriculum (p. 168). These authors raise concern over incoming engineering students’ misconceptions and how this prior knowledge influences their learning. The disconnect between design and engineering can be dated back to over thirty years ago when Lewin (1979) stated:

> Engineering is considered as an applied science and not as a respectable academic discipline in its own right…consequently, universities still consider that the best education for an engineer is to be taught the fundamental principles of science, coupled with some management and social studies and if possible industrial training. Design as such is thought of as an adjunct to the curriculum and constitutes training rather than education, thus the responsibility for training designers is laid firmly at the door of industry. (p. 113)

Lewin (1979) further argued that “it is essential to inculcate the correct attitude of mind… Universities unfortunately, tend in the main to educate their engineering undergraduates as applied scientists and then expect industry to retrain them as engineers.” (p. 113). Although this quotation was published over thirty years ago, it provides historical context so that the engineering community can learn from the past. While there has been curriculum reform over the years, as evidenced through multidisciplinary design courses working with industry clients (Strong, 2012), engineering educators should be critical of the current system for continuous improvement.

Although engineering educators recognize the value of learning engineering design, it is important to question whether engineering students share the same values.
Do engineering students simply see design as an intuitive act—just another tool, like calculus and statics, used to solve problems? Although students may be exposed to problem solving in their everyday lives, such experiences may rely on simple intuition. However, to solve more complex problems in the engineering context, a more systematic and robust way of thinking is required (Kimmel, Kimmel, & Deek, 2003, p. 810). It is understood that a student’s perception of the learning task will influence their approach to learning (Ramsden, 1988); so how might students’ prior experience of problem solving using intuition affect their learning of more sophisticated problem solving strategies like the design process?

Learning engineering design is not a linear, one-dimensional process. Like the practice of engineering design itself, learning engineering design is complex, iterative, and multidimensional. To meet these challenges, an integrated curriculum that balances the learning of engineering science and engineering design simultaneously has great potential to enhance learning.

In this section, I have outlined the issues facing the integration of learning design in the engineering curriculum. In the next section, I will discuss how design education is linked to students’ learning and development.
Designing Education – Background Theory from Educational Studies

Up to this point, I have discussed how design education relates to the engineering curriculum. However, designing curriculum to improve engineering education is a complex problem with several influencing factors. Much like the holistic approach to education itself, effective curriculum reform must be viewed from a holistic perspective, considering both curriculum theory and learning theory. Because the ‘curriculum’ consists of both plans and experiences of the student, understanding how students learn will significantly influence curriculum development. The following sections will discuss how an understanding of learning theory from educational psychology can inform instructional practice.

Educational Psychology: How Learning Works

This thesis is applied research that aims to apply the learning sciences to design educational systems to optimize learning. The field of cognitive science and educational psychology provides the background knowledge of how learning works (National Research Council, 2000; Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010). With this understanding, engineering educators can apply the science of learning to enhance the teaching of engineering students. Because this thesis is applied research, this section will outline the principles of learning that are applicable to this thesis.
Prior Knowledge

Students bring prior knowledge and conceptions to their learning tasks that help them connect their new learning. Students’ prior knowledge supports learning when it is activated, accurate, appropriate, and sufficient (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010). Students’ prior knowledge can hinder learning if these four elements are not considered.

Organization of Knowledge

Students organize knowledge into mental structures called schema that help them make sense of new information. As defined by Cross (1999) a schema is “a cognitive structure that consists of facts, ideas, and associations organized into a meaningful system of relationships” (p. 8). Based on the way students build their schema of new information, learning can be enhanced or hindered. It is helpful to introduce here the three different types of knowledge that will be referenced later on in this thesis: conceptual (declarative), procedural, and structural. Conceptual (declarative) knowledge is defined as “the facts and concepts that can be stated or declared” and procedural knowledge involves “knowing how and knowing when to apply various procedures, methods, theories, styles, or approaches” (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010, p. 18). Structural knowledge is the knowledge used in cognitive organization and facilitates the production of conceptual knowledge and procedural knowledge by helping learners draw relationships and make connections (Jonassen, Beissner, and Yacci, 1993, p. 4).
Metacognition

Metacognition is “the process of reflecting on and directing one’s own thinking” (National Research Council, 2000, p. 78). It is described as the awareness and control over one’s cognitive functions—that is, thinking about thinking. The cognitive processing of metacognition is important for learning so that students can identify their “present knowledge state, (i.e. what one knows, what one does not yet understand, what remains to be learned)” (Shapiro, Brown, & Astin, 2011, p. 512).

I have presented the science of learning as the theoretical tools for which engineering educators can apply to enhance student learning. The purpose of this thesis is to support how the science of learning can be applied in teaching practice. We may know how learning works, but our job as engineering educators is to apply what we know to create new learning experiences. The following section will look at how the science of learning is applied to the design of learning experiences.

An Educational Systems Approach to Improving Teaching and Learning of Engineering Design

First presented in the Introduction, engineering education can be understood in two ways: 1) as a noun/product or 2) as a verb/process. Up to this point, I have discussed the state of engineering design education as a product—that is, treating engineering design as the subject to be taught. The following section will look at how engineering education is a process—a process of designing learning environments (systems) to optimize student learning.
In Part 1 of the literature review, a curriculum studies approach was used as the framework to understand the state of engineering education. A learning theory approach will now be discussed as a framework to provide the scientific background applicable to this research.

Like the design of any product, process, or system, an engineering design approach can be taken to design engineering education that meets specific objectives.

Designing Learning Environments

Models of student learning are helpful to provide a framework when thinking about designing learning environments (see also Vanasupa, Stolk, & Herter, 2009). Figure 2 shows one model of student learning divided into three phases: presage, process, and product—representing three phases throughout learning and the elements of learning that are affected in each phase.

![Diagram of student learning model](image)

Figure 2: Model of student learning (Biggs, 2001, p. 87; Prosser & Trigwell, 1999, p. 12; Ramsden, 1988, p. 161).
As shown in Figure 2 above, Student Characteristics and Teaching Context are two of the major categories of inputs to the learning system. Within the Teaching Context category, educators can design for curriculum, teaching methods, assessment—each one of these becoming its own input to the system. Looking into these elements individually are various approaches to tackle the challenge of improving design education. But ultimately, all of the elements are integrated and interrelated—they work together and rely on each other—to achieve the desired outcome.

This thesis considers the Student Characteristics and Students Perceptions of Context, as the inputs to focus on in improving design education. The approach taken by this research is to gather a deeper understanding of these two areas so that the science of learning can be applied more effectively.

I have presented this model as a way of thinking about designing learning environments, grounded in educational psychology that considers the science of learning and characteristics of learners. In the same way, my approach to improving design education is to apply educational theory to deeply understand learners in the context of engineering education.

**Understanding the Stakeholders: A Look at Engineering Students’ Behaviour**

The previous sections have discussed the general insights for designing learning experiences from both approaches of curriculum and learning theory. As I continue to “tell the whole story,”—to build the context of the problem and offer my solutions—the following sections will delve into the specific area of literature that is the focus of my thesis: understanding students’ perspectives.
CHAPTER 2: LITERATURE REVIEW - PART 2

*Continuous Improvement in Engineering Education*

Three areas for continuous improvement in engineering education are identified as recruitment, retention, and performance (Tudor, Penlington, & McDowell, 2010). Focus on these areas is important for the engineering profession in Canada to meet societal demands, maintain its global competitiveness, and ensure high quality engineering graduates.

*Recruitment*

Engineering recruitment strategies are important to ensure an adequate supply of engineers entering the workforce. Tudor, Penlington, and McDowell (2010) recognized that “if we can understand how students perceive the teaching and learning environment and approach their studies then universities can consider making adjustments to encourage more students to enroll in engineering courses” (p. 70). How can educators inspire students to pursue engineering studies?

*Retention*

Once students are enrolled in an engineering program, it is important to offer the necessary support to retain them in their studies. How can educators retain and promote students’ motivation to learn engineering design?

*Performance*

Engineering education research ultimately serves to enhance engineering students’ performance as engineers. Several authors have investigated students’ retention
of design process knowledge in comparative studies using various design skill assessment
techniques (Bailey, 2008; Cardella, Atman, Turns, & Adams, 2008; Frank & Strong, 2010). These studies have shown that, despite efforts to teach design over the four year curriculum, changes in students’ design knowledge may be limited. As such, these studies have identified the need to deeply understand students’ design cognition and behaviour as a way to enhance learning. How can educators create environments that support students’ performance in learning and practicing engineering design? How can educators engage students in their learning to promote knowledge retention and transfer?

My research takes a holistic approach to address these issues. Students’ beliefs influence their attitude, and their attitude influences their motivation to behave in a certain way. Therefore, influencing students’ behaviour towards recruitment, retention, and performance in engineering studies, begins with an understanding of students’ beliefs.

**Engineering Students’ Perspectives towards Engineering Design**

I have set up the situation of my problem by discussing the state and future of engineering education. I have identified the problems and challenges facing engineering design education due to the “theory-to-practice” gap and its integration into the curriculum. I will now review the literature that looks at solutions to show what other researchers are doing to tackle the issues, and how their research presents new questions to explore. This section will discuss the need for qualitative inquiry of students’ perspectives towards learning engineering design.
CHAPTER 2: LITERATURE REVIEW - PART 2

To emphasize a holistic design of engineering education, consider how a curriculum studies orientation may suggest adding more design courses to the curriculum to enhance learning. Although this is important, simply adding more opportunities for design experiences does not necessarily mean that students will take away any meaningful learning. For example, Kurfess (2003) reported on his experience with teaching a second year design course and how students may use design tools:

If the students do not understand the need and capabilities of these tools they simply implement them in exercises or design projects, but do not truly understand them. This is quite similar to students taking a plug-and-chug approach to their analytic classes. They can plug all of the numbers into the equations and formulas; however, they do not have a feel for the expected results and, therefore, cannot interpret the answers that come from the analysis. (p. 118)

It is clear that educational reform cannot ignore the interplay between the three levels of curriculum: planned, enacted, and experienced (Marsh & Willis, 2007). Adding more design courses only serves the planned curriculum—that is, the curriculum that appears on paper. Whether or not the planned curriculum is taught effectively (the enacted curriculum) and how it is experienced by the students (the experienced curriculum) is another matter entirely. Qualitative research and analysis of students’ perspectives serves to enhance the enacted and experienced aspects of curriculum.

To investigate the experienced curriculum, Sheppard (2001), and Downey and Lucena (2003), questioned how a student’s learning of design is influenced by their learning of the engineering sciences, especially when the engineering sciences is a dominant part of the engineering curriculum. Drawing on personal experience, Sheppard stated that “many upper-division engineering students become frustrated when they attempt to apply the formal analytical methods they learned in their ‘fundamentals’
classes to verify or direct design decisions.” (p. 440). Linder and Flowers (2001) made similar observations of students who had “considerable difficulty applying their analysis skills in the design activities” (p. 436).

In the study by Dunsmore, Turns, and Yellin (2011), student portfolios were analyzed to gain insight into how students construct meaning of the engineering profession and connect this meaning with their educational experience. These researchers emphasize that this type of research “could generate leverage points to foster more effective student understandings of engineering practice” (p. 343). As the authors state, “additional study of student conceptions is needed to more completely characterize the nuances of their views of school, engineering practice, and the relation between them” (p. 343). This thesis serves to build onto the premise of understanding students’ conceptions by using different research methods and specifically looking at students’ conceptions of learning and practicing engineering design.

In the book Change by Design, Brown (2009) suggested that any design challenge begin with insight, observation, and empathy (p. 39). Designing educational systems is no different. As such, this thesis serves to develop a deeper understanding of engineering design education by qualitatively investigating the experiences of engineering students.

One example of qualitative research to understand students’ conceptions was the study by Stolk, Martello, Somerville, and Geddes (2010). These authors looked to understand engineering students’ definitions of and responses to self-directed learning. With the goal of gaining insights to be better designers of curricula that supports self-directed learning, these authors present “self-directed learning from the student perspective and in the words of student participants” (p. 906). Several qualitative studies
further point to the importance of understanding students’ conceptions of engineering (Atman, Kilgore, & McKenna, 2008; Meyers, Ohland, Pawley, & Christopherson, 2010; Matusovich, Streveler, & Miller, 2010; Stevens, O’Connor, Garrison, Jocuns, & Amos, 2008; see also Crawford, Gordon, Nicholas, & Prosser, 1994). It is difficult to identify the limitations of what is known about students’ conceptions because qualitative research findings are often of an interpretative nature and highly context dependent. The studies that I have consulted in my literature review include topics on student motivation, identity formation, and engineering knowledge. Although the topics may be different, the studies all utilize an approach grounded in understanding engineering students’ conceptions; therefore, it is important to consider the relationships and contributions from these studies in a holistic way.

Summary of Literature Review – Part 2

In the second part of the literature review, I have discussed the challenges of teaching and learning engineering design from a learning theory perspective. I have presented the background knowledge of the learning sciences that provide the foundation for my research, as well as the educational systems approach I utilized to frame my study.

The importance of understanding what meaning students’ hold of engineering design cannot be understated. I have presented the need for qualitative research to influence three areas of continual improvement in engineering education: recruitment, retention, and performance. I have positioned myself in the field of inquiry by reviewing similar research conducted to gain insight into students’ perspectives. With this
consideration, I have refined the methodology and methods that are appropriate for my study. These details will be discussed in the next chapter on research design.
CHAPTER 3
RESEARCH DESIGN

The following sections will outline how I have designed my study to explore my research questions. The research methodology section will discuss the theoretical underpinnings supporting my research. My research methods section will discuss the design of my measurement instruments and data collection procedures.

Objectives and Questions

This research is focused on exploring students’ understanding of engineering design. The overarching research question guiding this study is:

How do students understand and make meaning of engineering design?

This question was inspired by taking a design approach to influence students’ behaviour by first targeting their core beliefs (Fishbein & Ajzen, 1975; Marzano & Kendall, 2007). This behavioural change process is shown in the Figure 3:

![Figure 3](image)

**Figure 3:** Behavioural change process adapted from Fishbein & Ajzen (1975).

To influence students’ behaviour towards learning engineering design, it is important for engineering educators to target engineering students’ beliefs about engineering design.
CHAPTER 3: RESEARCH DESIGN

This process can be related to the model of student learning previously discussed in this thesis (Figure 2, p. 31).

To explore the research question further, the sub-question was asked:

*How do undergraduate engineering students’ think about learning and practicing design?*

Under this sub-question, three topics were identified as the areas of thinking to be explored:

1. What are students’ *conceptions* of design?
2. How do students describe the *meaning* of design?
3. How do students describe their *learning* of design?

With this framework, the purpose of this research was to explore the conceptions and relationships found in an engineering students’ understanding of design thinking. These research questions served as the foundation of my study—to ignite inquiry and drive exploration.

**The Stakeholders**

Like any complex system, the design of educational systems requires an understanding of the stakeholders involved and how these stakeholders will interact with the final product. Stakeholders in engineering education include, engineering faculty and administration, government, employers, industry, professional organizations, and students. While these stakeholders interact with each other and share common interests, this study specifically considers the engineering students as the participants for this research. Improving engineering education will require input from all stakeholders and
any understanding gained from a specific group may influence other stakeholders’ perspectives.

The stakeholders for this thesis are shown in Figure 4. Stakeholders include the primary users of this research as well as secondary individuals and organizations who may be interested in this work.

![Organizational map of research stakeholders.](image)

**Primary Stakeholders**

*Engineering educators, including administration and curriculum developers*

This group is directly charged with facilitating the learning of engineering design, so this research is the most applicable for these stakeholders.
CHAPTER 3: RESEARCH DESIGN

Engineering students

This research impacts engineering students because engineering students are the research participants. From a description of their peers’ experiences and perspectives, engineering students may be better positioned to draw meaning from and enhance their own learning experiences. By looking at the student experience, this research supports students’ development into self-directed, life-long learners.

Secondary Stakeholders

Primary and secondary school teachers, guidance counselors, and parents of prospective engineering students

This research is applicable for primary and secondary school teachers striving to promote engineering and design thinking in the classroom. It is illogical to expect school teachers to promote engineering in their classrooms when the teachers themselves may have limited exposure to engineering. Therefore, school teachers may gain a better understanding of what engineering is, from the students who are experiencing the engineering curriculum. Furthermore, guidance counselors and parents are often the source of encouragement for students to pursue engineering studies. This research serves to provide these stakeholders with a rich understanding of the elements of learning engineering design.

Educators from other disciplines

The full extent of engineering design requires an interdisciplinary perspective. As such, educators from all disciplines may benefit from an understanding of what
engineering design entails and how they can incorporate the same skills and attitudes in their own courses.

Engineering Organizations and Professional Bodies

This group of stakeholders includes organizations that represent the engineering profession to the public. Among this group include the Canadian Engineering Accreditation Board (CEAB), professional licensing bodies (such as Professional Engineers Ontario), engineering advocacy groups (Ontario Society of Professional Engineers), and non-governmental organizations (Engineers Without Borders). These organizations are involved with advancing the engineering profession through advocacy, awareness, and engineering recruitment activities.

Methodology

In this section, I will outline the research methodology for my study that is grounded in qualitative inquiry. Qualitative research methodology applied to engineering education is an emerging practice as shown with recent publications that provide an introduction to these techniques (Borrego, 2007; Borrego, Douglas, & Amelink, 2009; Case & Light, 2011). Qualitative research is “a means of exploring and understanding the meaning individuals or groups ascribe to a social or human problem” (Creswell, 2009, pg. 4). I use qualitative inquiry to deeply understand the ways engineering students’ think about learning and practicing engineering design. A qualitative research study is appropriate for this work because my research serves as an exploration of ways to connect with students in their learning.
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Constructivist Research Paradigm

I have adopted a constructivist research paradigm that holds the view “that reality is socially constructed” (Mertens, 2005, p. 12). My research does not seek to find “an objective reality that can be known” but seeks “to understand the multiple social constructions of meaning and knowledge” (Mertens, 2005, p. 14). It is appropriate that a constructivist view be applied to my research because the research specifically looks at how students construct meaning and knowledge of engineering design. In line with this research paradigm, I use an interpretivist approach to “understand and to portray the participants’ perceptions and understandings of the particular situation or event” (Bartlett & Burton, 2007, pg. 38). Because this thesis is my interpretation of the data, I have embraced this subjective nature by discussing my background and experiences that I bring to the research in Chapter 4 Research Analysis.

Methods

This section will outline the process for collecting my research data. I will discuss the targeted participant selection for my study and the design of my measurement instruments, and then discuss the procedures taken to collect the data.

Targeted Participant Selection

This study aims to understand undergraduate engineering students’ thinking about engineering design; therefore, the targeted participants for this study were undergraduate engineering students in first year, third year, and fourth year in all engineering programs. All possible engineering programs that were offered at the participating engineering
schools were targeted because it was assumed that an understanding of engineering design should be independent of a student’s engineering discipline. First year students were included to broaden the variability of participant experiences, as it was assumed that these students represented participants with no formal engineering education. Therefore, first year students would bring to the study the least amount of external influence from formal engineering education. It was also desirable to see how first year students would respond to the measurement instruments as a way to establish a baseline of students’ understanding. However, this intention was not pursued throughout the research study. Third year and fourth year students were chosen because this was the target population who would be closest to experiencing engineering design after the mid-way point in the engineering curriculum. Third year and fourth year students would have completed more coursework in their selected engineering discipline and would have more exposure to engineering design as part of their senior design projects.

Limitations of Targeted Participant Selection – Exclusion of second year students

With the exception of first year students, second year students were not targeted as it was desirable to have participants with at least two years of formal engineering education. Because all three of the schools offered a general first year engineering curriculum, where students do not have to choose their discipline until the end of first year, it was assumed that second year students would only be in the first year of their selected engineering discipline. As such, it was assumed that second year students would not have sufficient experience with the phenomenon under study to generate responses to
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the measurement instruments. In addition, given the time and resource constraints of the study, there was concern over the amount of data that would be collected by expanding the study to include second year students.

Institutional Context

Three engineering schools, located in Ontario, Canada, participated in this study: The University of Toronto, Queen’s University, and Western University. The three schools were selected to target students from a large, medium, and small engineering school, based on the enrollment size of the school’s engineering program. Schools of varying enrollment size were chosen to broaden the experiences of participating students who may bring wider description and variability in the data collection. Additionally, each school was required to offer the four major engineering disciplines of mechanical, electrical, chemical, and civil and offer a general first year engineering curriculum. For this study, a large school was categorized as having an undergraduate engineering enrollment of over 3000 students. A medium size school was categorized as having an undergraduate engineering population of approximately 1500 to 3000 students. A small school was categorized as having less than 1500 students. Table 2 shows the total enrollment of undergraduate engineering students for the participating schools (Engineers Canada, 2011b, p. 34, Table U.3.1).
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Table 2: Enrollment of undergraduate engineering students for large, medium, and small size engineering schools.

<table>
<thead>
<tr>
<th>School</th>
<th>School Size Classification</th>
<th>Total Enrollment of Undergraduate Engineering Students, 2010 (all four years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Toronto, Toronto, ON</td>
<td>Large</td>
<td>4294</td>
</tr>
<tr>
<td>Queen’s University, Kingston, ON</td>
<td>Medium</td>
<td>2575</td>
</tr>
<tr>
<td>Western University, London, ON</td>
<td>Small</td>
<td>1115</td>
</tr>
</tbody>
</table>

Limitations in Institutional Context

One limitation of the participating institutions is that they are all Canadian Universities from Ontario. This decision was due to the willingness of institutions to participate in the study and logistical access to engineering students at these institutions. Furthermore, budget and time constraints imposed on the research required that participating institutions be within a close distance to the researcher’s home institution. With all of the participating schools from Ontario, these schools may attract a higher percentage of students from Ontario who have followed the Ontario Provincial Secondary School Curriculum. However, this element of participant selection (i.e. students’ secondary school background) was not measured in this study because it was not an intended research question for this study.

There are many dimensions to participant selection, for example, year in program, engineering discipline, and type of school, that all can form different approaches for
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analysis and interpreting the results. However, although these dimensions are present, the purpose of this research was not to generalize the findings or draw specific conclusions based on relationships among the participant selection dimensions. The purpose of this research was to gain in-depth descriptions of participants’ experiences with engineering design. The dimensions for participant selection were used to extend the variability of participants’ experiences.

**Designing the Measurement Instruments**

The following section will discuss the design of the measurement instruments to collect data on students’ understanding of engineering design. The purpose of the measurement instruments was to elicit students’ descriptions about the research phenomenon. In my study, the research phenomenon was the learning and practicing of engineering design. Two measurement instruments for data collection were used: 1) a one-time online questionnaire and 2) personal interviews with interested participants.

**Theoretical Constructs**

Based on educational theory of student understanding, an inquiry model for my research questions was used to develop three constructs that would capture the three dimensions of understanding as outlined by the educational literature. This section will outline the theoretical constructs for this research and how these constructs were applied to design the measurement instruments.
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How do students understand design?

To develop the measurement instrument constructs, I considered my overarching research question: “How do undergraduate engineering students understand and make meaning of engineering design? But what does the word “meaning” actually mean, in this context? To understand the goals of this thesis, it is important to elaborate on the following three questions:

1. What is “understanding”?
2. What is “meaning”?
3. What is “learning”?

What is “understanding”?

Pask (1988) offered this explanation to answer the question ‘what is understanding?’: “An understanding involves not only the topics that are related and their relationship, but the ability to transfer and apply the relationship to new situations” (p. 84). In support of this claim, Anderson and Krathwohl (2001) stated: “students understand when they build connections between the ‘new’ knowledge to be gained and their prior knowledge” (p. 70). It is clear that students develop an understanding when the subject matter has meaning. Therefore, teaching for understanding can be seen as the process to facilitate the development of students’ cognitive frameworks (schema).
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What is “meaning”?

Dewey (1933) offered this explanation to answer the question of what is meaning?: “To grasp meaning of a thing, an event, or a situation is to see it in its relations to other things: to note how it operates or functions, what consequences follow from it, what causes it, what uses it can be put to” (p. 137). To gain understanding and meaning is to see something in context (Dewey, 1933).

What is “learning”?

The ultimate goal in engineering education and this thesis is to improve student learning. I use the definition of learning offered by Ambrose, Bridges, DiPietro, Lovett, and Norman (2010, adapted from Mayer, 2002) who define learning “as a process that leads to change, which occurs as a result of experience and increases the potential for improved performance and future learning” (p. 3, italics in original). This definition underscores retention and transfer as two important educational goals; where retention is “the ability to remember material at some later time” and transfer is “the ability to use what was learned to solve new problems” (Anderson & Krathwohl, 2001, p. 63).

These definitions have provided a framework to explore understanding, meaning, and learning. Bringing these three concepts together, my thesis is aimed at fostering meaningful learning: where students construct knowledge and ways of thinking to help them in successful problem solving (Anderson & Krathwohl, 2001; Ausubel, 1968; Novak, 2010).

This research serves to apply the learning sciences by understanding students’ prior knowledge and how they organize knowledge to support meaningful learning.
Understanding students’ constructions of knowledge can help identify areas where knowledge may be activated, sufficient, appropriate, and accurate (Ambrose, Bridges, DiPietro, Lovett, and Norman, 2010). As previously discussed, educational psychology explains how students’ minds organize knowledge in the form of schema or semantic networks (Jonassen, Beissner, & Yacci, 1993, p. 7). A visual representation of schema is shown in Figure 5, where the solid circles represent nodes of knowledge and the solid lines represent the connections between these nodes. A sophisticated schema, one that is dense and highly connected, promotes learning and transfer of knowledge by providing “a structure for making sense of new information” (Slavin, 2012, p. 167).

Fostaty Young and Wilson (2000) presented the ICE model as an acronym for Ideas, Connections, and Extensions, to simplify the stages of learning growth (p. 5). Although originally proposed as a model for student assessment, I also consider the ICE model as a representation of student understanding. Combining the ICE model and schema theory, it is clear that Ideas represent the individual packets of knowledge in one’s schema, Connections represent how these nodes are connected, and Extensions
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refers to one’s ability to transfer his or her schema to another domain. Figure 5B shows the extensions as dashed lines to represent the connections between two different domains of knowledge.

Using schema theory and the ICE model as a conceptual framework for knowledge organization, this research aims to investigate ways for educators to help build students’ schema. In other words, the research serves to understand the conceptions and relationships students have of engineering design.

The three aspects of understanding based on the ICE framework (Fostaty Young & Wilson, 2000) and the definition of understanding by Pask (1988) are listed in Table 3. These ways of thinking are appropriately matched to the sub-questions presented in my research purpose (Column C). The row numbers are provided to highlight how the individual aspects of understanding are associated across each construct.

Table 3: Ways of thinking about the representations of students’ understanding.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICE Framework (Fostaty Young &amp; Wilson, 2000)</td>
<td>Understanding (Pask, 1988)</td>
<td>Research sub-questions</td>
</tr>
<tr>
<td>1</td>
<td>Ideas</td>
<td>Topics</td>
<td>Conceptions</td>
</tr>
<tr>
<td>2</td>
<td>Connections</td>
<td>Relationships</td>
<td>Meaning</td>
</tr>
<tr>
<td>3</td>
<td>Extensions</td>
<td>Applications</td>
<td>Learning</td>
</tr>
</tbody>
</table>

To develop each sub-question construct and clarify the objective, inquiry-based questions were used. This relationship is presented in Table 4.
Table 4: Inquiry-based questions assigned to research constructs to conceptualize research objectives.

<table>
<thead>
<tr>
<th>My research sub-questions</th>
<th>Inquiry based construct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptions</td>
<td>What is it that students think engineers do?</td>
</tr>
<tr>
<td>Meaning</td>
<td>How do they describe the relationship between design and engineering?</td>
</tr>
<tr>
<td>Learning</td>
<td>Why do they describe it that way? Where does it come from? What influences their learning?</td>
</tr>
</tbody>
</table>

The theoretical constructs of understanding, meaning, knowledge organization, and learning, served as design considerations for the design of the measurement instruments.

**Design features of the measurement instruments**

The purpose of the measurement instruments was to elicit students’ descriptions of their experiences. All questions were designed to correspond to one of the three targeted research constructs presented in Table 4 above. With the emergent nature of qualitative research, these constructs and questions were used as a guideline for building the measurement instruments and for eliciting students’ descriptions for data collection purposes. Questions were generated from the literature review that looked at similar qualitative studies of applicable topics related to students’ learning and behaviour. For example, Stolk, Martello, Somervile, and Geddes (2010) investigated students’
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definitions of self-directed learning and what features make self-directed learning effective and challenging. Questions were also generated based on the researcher’s interest from personal experience as a teaching assistant in engineering design courses.

The following sections will present the questions on the questionnaire and interview instruments and the corresponding research constructs.

**Questionnaire**

The questionnaire and corresponding research constructs are provided in Table 5. It is important to note that Question 11 asks students if they wish to continue in the questionnaire. This question was added to respect participants’ time in completing the questionnaire, recognizing that participation required a reasonable amount of time because the questions were open-ended. Another feature on the questionnaire presented participants with the Canadian Engineering Accreditation Board’s definition of engineering design. This was done to challenge participants’ thinking about their responses after they were presented with a concrete and generally accepted definition. The final question on the questionnaire asked if participants would be willing to participate in a personal interview, and requested their name and email for contact purposes. The full questionnaire can be found in Appendix A: Research Instruments.
Table 5: Questions for questionnaire instrument and corresponding research objective construct.

<table>
<thead>
<tr>
<th>Question Number</th>
<th>Question</th>
<th>Research Objective Construct</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>How would you describe the profession of engineering to a senior high school student considering engineering undergraduate studies?</td>
<td>Conceptions (What)</td>
</tr>
<tr>
<td>2</td>
<td>In your opinion, describe the relationship between the fields of “math and science” and engineering.</td>
<td>Conceptions/ Meaning (What/How)</td>
</tr>
<tr>
<td>3</td>
<td>How do you see this relationship fitting in to your understanding of what it means to be an engineer?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>4</td>
<td>Describe what it means to you “to think like an engineer”?.</td>
<td>Conceptions (What)</td>
</tr>
<tr>
<td>5</td>
<td>What personal experiences have contributed to your thinking that you described above?</td>
<td>Meaning (How)</td>
</tr>
<tr>
<td>6</td>
<td>Has your coursework reinforced the thinking that you described above? If so, how?</td>
<td>Meaning (How)</td>
</tr>
<tr>
<td>7</td>
<td>In your own words, define engineering design?</td>
<td>Conceptions (What)</td>
</tr>
<tr>
<td>8</td>
<td>Has your understanding of design changed during your program? If so, how?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>9</td>
<td>In your opinion, how does learning engineering design relate to your undergraduate studies of engineering?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>10</td>
<td>Do you feel your engineering education supports your overall career and life goals? If so, how? If not, please explain?</td>
<td>Learning (Why)</td>
</tr>
<tr>
<td>11</td>
<td>NA – Question asks if participants wish to continue</td>
<td>NA</td>
</tr>
<tr>
<td>12</td>
<td>What do you think makes engineering design important to learn?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>13</td>
<td>What do you think makes engineering design challenging to learn?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>14</td>
<td>What would help you learn engineering design more effectively?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>15</td>
<td>The participant is presented with the definition of engineering design from CEAB and asked if he/she would answer the following questions differently.</td>
<td>NA</td>
</tr>
<tr>
<td>16</td>
<td>How does this definition vary from your previous understanding of engineering design?</td>
<td>Conceptions (What)</td>
</tr>
<tr>
<td>17</td>
<td>What do you think makes engineering design important to learn?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>18</td>
<td>What do you think makes engineering design challenging to learn?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td></td>
<td>What would help you learn engineering design more effectively?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
</tbody>
</table>
Interview Protocol

The interview questions and corresponding research constructs are presented in Table 6. The interview questions were designed to be open-ended and to focus on the meaning and learning constructs to gain rich descriptions. Questions 9 to 16 were repeated from the questionnaire in case participants opted to skip these questions in the questionnaire. The full interview protocol can be found in Appendix A: Research Instruments.

Table 6: Interview questions and corresponding research objective constructs.

<table>
<thead>
<tr>
<th>Question Number</th>
<th>Question</th>
<th>Research Objective Construct</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tell me a little bit about why you enrolled in an engineering program?</td>
<td>This question was not tied to a specific construct but used to open the interview.</td>
</tr>
<tr>
<td>2</td>
<td>What did you expect to learn in engineering?</td>
<td>This question was not tied to a specific construct.</td>
</tr>
<tr>
<td>3</td>
<td>Have these expectations been met in your program to date?</td>
<td>This question was not tied to a specific construct.</td>
</tr>
<tr>
<td>4</td>
<td>What are your future expectations for learning?</td>
<td>This question was not tied to a specific construct.</td>
</tr>
<tr>
<td>5</td>
<td>Tell me about one significant experience you’ve had with engineering design?</td>
<td>Open-ended question to elicit description. No construct attached.</td>
</tr>
<tr>
<td>6</td>
<td>In your opinion, what was it about this experience that made it engineering design?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>7</td>
<td>How did this experience shape your understanding of what it means to be an engineer?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>8</td>
<td>Has this experience made you more confident in your engineering abilities? How? Why?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>9</td>
<td>What do you think makes engineering design important to learn?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>10</td>
<td>What do you think makes engineering design challenging to learn?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>11</td>
<td>What would help you learn engineering design more effectively?</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>NA</td>
<td>The participant is presented with the definition of engineering design from CEAB and asked if</td>
<td>NA</td>
</tr>
</tbody>
</table>
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<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>he/she would answer the following questions differently.</td>
<td>Meaning/Learning (How/Why)</td>
</tr>
<tr>
<td>12</td>
<td>How does this definition vary from your previous understanding of engineering design?</td>
</tr>
<tr>
<td>13</td>
<td>Based on this definition from Engineers Canada, would you answer the following questions differently? If so, how?</td>
</tr>
<tr>
<td>14</td>
<td>What do you think makes engineering design important to learn?</td>
</tr>
<tr>
<td>15</td>
<td>What do you think makes engineering design challenging to learn?</td>
</tr>
<tr>
<td>16</td>
<td>What would help you learn engineering design more effectively?</td>
</tr>
<tr>
<td>17</td>
<td>How do you see the relationship between your engineering education and this definition of design?</td>
</tr>
<tr>
<td>18</td>
<td>Can you describe how you may have applied this definition in your design experience?</td>
</tr>
<tr>
<td>19</td>
<td>Do you feel your experiences and studies in engineering have prepared you to be successful at engineering design? If so, how? If not, why?</td>
</tr>
<tr>
<td>20</td>
<td>Do you feel your engineering education has prepared you for your future career? If so, how? If not, why?</td>
</tr>
<tr>
<td>21</td>
<td>Looking forward, what do you think you can do to enhance your learning in engineering?</td>
</tr>
</tbody>
</table>

Measurement Instrument Accessibility and Reliability – Thinking-Aloud Process

After the questionnaire and interview instruments were developed, it was important to verify the instruments’ accessibility and reliability. By accessibility, I am referring to the extent that students are capable of understanding the instrument questions. By reliability, I am referring to the extent that the instruments collect responses from participants that fit the research purpose. To accomplish these two objectives, a think-aloud process was conducted with three engineering students who fit the target participants for the study. Each participant met with the researcher for one hour during which time the questionnaire and interview protocol were administered.
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The purpose of the think-aloud process was to capture how students interpret and react to the questions by hearing participants internal thought processes as they respond to questions. Specifically, participants were instructed to talk out loud all of their thoughts as they were answering the questions (Ericsson & Simon, 1984, p. 78-81).

Before completing the think-aloud process, participants were told that their responses would not be included as research data for the study because the exercise was part of the development for the research instrument. The students were also instructed that they would not be eligible to participate in the official research study. Each interview was recorded on a digital voice recorder for the researcher’s records, but the interviews were not transcribed and the recorded data was not used for any research purpose.

The think-aloud process revealed that the phrasing of some questions were confusing for some participants. As a result, the wording of selected questions was changed on the final instruments to be more specific. No significant changes to the intent of the research instruments were made as a result of the think-aloud process. The think-aloud process also provided the researcher with practice at conducting research interviews before official data collection.
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Data Collection

This section will outline the procedures for data collection.

Questionnaires

A recruitment email was distributed to the target population at the three engineering schools via their respective Faculty of Engineering’s email distribution lists. Table B.1 in Appendix B shows the approximate number of students in each year at each participating school who were targeted for recruitment. In the recruitment email (Appendix B), a link to the online-questionnaire was provided. Campus Labs (formerly StudentVoice) is an online platform for research in higher education and was used for the online management and delivery of the questionnaire instrument to collect data. For data collection purposes, three separate projects on Campus Labs were created to keep data collection separate for each university. For the medium and large size university, the questionnaire email was distributed during Week 4 of the first academic term and participants were given two weeks to complete the questionnaire. For the small size school, the questionnaire was distributed during the first week of the second academic term. This difference in timing for delivery was due to unforeseen complications in achieving ethics approval from the small size school. This matter will be further discussed in the section on limitations in data collection.
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Interviews

Personal interviews were conducted with all respondents who were willing to participate in an interview. No participant was denied an interview if they expressed an interest to participate, with the exception of one participant where it was not feasible to conduct an interview due to location constraints. All interviews were conducted at the participating student’s home institution, in a private meeting room at each institution’s Faculty of Engineering offices, and at a convenient time for the student. Interviews at each participating university occurred within the first four weeks of the second academic term. All interviews were recorded using a digital voice recorder and transcribed verbatim by the researcher.

It was expected that students may not have experience in participating in a research interview. As such, the nature of the research and the purpose of the methods were explained to participants before proceeding with the interview. Also, the neutral position of the researcher was explained to interview participants at the beginning of the interview. Throughout the interview, there were opportunities for the researcher to probe deeper into explanations and descriptions that the researcher felt important to explore. The participant was also given the opportunity to clarify meanings and descriptions throughout the interview process.

Ethics Approval for Human Participants

Before the online questionnaire was distributed to participants, ethics approval for human participants was granted from each of the three participating institutions. The letter of information, recruitment email, and consent forms can be found in Appendix B.
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The researcher completed the online training course in research ethics titled “Course in Human Research Participant Protection (CHRPP),” mandated by the researcher’s home institution (Appendix C).

The approval letters from each institution can be found in Appendix C: Research Ethics Approval for Human Participants. Although all three universities required their own independent ethics approval, no recommendations from the respective ethics boards resulted in changing the nature of the data collection instruments or methods.

For confidentiality in data collection and reporting, all questionnaire responses were assigned a random alphanumeric identifier and all interview participants were assigned pseudonyms.

Limitations in Data Collection

The following sections will discuss the limitations in data collection for my study.

Distribution of Questionnaire - Limitations

It was intended that the questionnaire be distributed within the same time-frame at all participating universities. However, due to unforeseen complications with ethics approval, it was not possible to distribute the questionnaire until the second term at one of the universities. The specific requirements for ethics approval from each participating institution did not affect the nature or outcomes of the study. This research was not an evaluative study dependent on the timing of the questionnaire distribution. Although it was beneficial to maintain consistency for data collection, control for the timing of
delivery of the questionnaire was not critical because this study did not serve to compare or evaluate participant responses at a specific time.

Due to ethical constraints, the researcher did not have direct access to students’ emails; the recruitment email to students was distributed through each engineering Faculty’s email distribution lists. Although the recruitment email was only delivered to the target populations on the Faculty’s email lists, there was no way to monitor participant completion of the questionnaire or have control over participants. Any individual who obtained the link to the questionnaire would be able to complete the questionnaire. To detract students from completing the questionnaire multiple times, no incentive was offered for participation and completion of the questionnaire had no effect on a student’s standing in the university. The link to the questionnaire was de-activated on the deadline, preventing anyone from completing the questionnaire after the data collection period.

**Participant Selection - Limitations**

There existed an inherent self-selected bias in the students who participated because this study was completely voluntary. No incentive was offered for completion of the questionnaire or participation in an interview. This was done to attract participants who were genuinely interested in engineering education research and wished to offer meaningful and honest insight. As such, it could be assumed that participants of this study held a high level of engagement and interest in their engineering education.
Interviewing Participants - Limitations

Managing participants’ view of me as the researcher was a challenge in data collection. During my interviews, it became clear to me that some students may be unaware that my background was also in engineering. Managing this information posed a challenge in two ways.

In one way, I did not want the participants to see me as an engineer in case that would limit or bias their responses. I wanted to create a safe environment for the participants by reducing perceived power dynamics during the interview. To this end, I removed my engineering iron ring for all interviews so to distance myself as an engineering graduate. This way, students would not assume that I understood or could relate to what they were referring to—allowing me to probe further to gain deeper descriptions.

Despite my attempts to distance myself from the participants, I also sensed that students showed hesitation to share their story as they saw me as a complete outside researcher. For example, if they assumed that I would not understand a certain concept, then they would not explain it further. I realized that participants may have been making shortcuts in their descriptions because my background in engineering allowed me to quickly relate to the situation. However, to ensure that the description was true to the student, I had to suspend my past engineering experience, stay open-minded, and encourage the participant to fully describe their experience. At some points throughout the student interviews, I sensed some students were reluctant to explain their perspectives as they were experiencing difficulties articulating their responses. When this occurred, I encouraged the participants to be open and honest.
CHAPTER 3: RESEARCH DESIGN

Chapter Summary – Research Design and Data Collection

In this Chapter, I have presented the design of my research study that considers the methodology and methods to achieve my research objectives. I discussed the factors for participant recruitment and the theoretical underpinnings for the design of my measurement instruments. I also presented a detailed account of my data collection procedures. In the next Chapter, I will discuss how the analysis of my data was performed.
CHAPTER 4
RESEARCH ANALYSIS

This chapter will discuss the data analysis process, and the approaches taken to enhance the trustworthiness of the research. The purpose of qualitative analysis is to draw conceptual understandings, in the form of categories and themes, from the abstract ideas captured in participants’ responses. Research constructs were identified to guide the research and analysis process; however, the overarching objective of my research was to investigate ways to improve engineering education. With this broad approach, I was openly looking for categories to emerge from my data. The following sections will explain how the data analysis process was conducted.

Data Preparation

NVivo™ qualitative data analysis software was used to facilitate the organization and coding of the research data. For the purposes of organization, participants’ responses were organized under each question and remained separate for each school. All interviews were recorded using a digital voice recorder and transcribed verbatim by the researcher. Interviews were not organized by questions but remained as full interview transcripts for each participant.
Overview of Analytic Approach

To rigorously and systematically achieve the analysis objective, qualitative analysis procedures of coding and categorization of the data were conducted, followed by data interrogation to draw meaning and relationships from the categories. These procedures followed two phases of data analysis: 1) descriptive and 2) interpretative.

Phase 1: Descriptive analysis

This phase involved initial content analysis of the data: “identifying, coding, categorizing, classifying, and labeling the primary patterns in the data” (Patton, 2002, p. 463). The descriptive phase is outlined through the first and second stages of data analysis.

Phase 2: Interpretative analysis

This phase of analysis involved interrogation of the categories to make meaning and build conceptual understanding. As Patton (2002) explained, “the descriptive phase of analysis builds a foundation for the interpretative phase when meanings are extracted from the data, comparisons are made, creative frameworks for interpretation are constructed, conclusions are drawn, significance is determined, and, in some cases, theory is generated” (p. 465). The interpretative analysis is captured in the third and fourth stages of analysis. A discussion of the analytical tools used for the interpretative analysis is presented.
CHAPTER 4: RESEARCH ANALYSIS

Analytical Tools

A number of analytical tools were used to interrogate the data in the interpretative phase, once the basic codes were established. These analytical tools provided thinking strategies to draw meaning from the data and formulate the categories and themes presented in the research findings. To provide transparency and for future researcher reference, a list of these analytical tools from Corbin and Strauss (2008) is provided in Appendix D: Analytical Tools. Several resources were consulted for various analytical tools and strategies to apply to the research analysis process (Cresswell, 2012; Barbour, 2008; Dey, 1999; Charmaz, 2006). Analytical tools used in this research also included:

- memo writing to capture the researchers thoughts about the data and the analysis process
- direct data annotations
- applying metaphors and analogies
- comparison methods between categories
- creative brainstorming techniques (i.e. force fit, concept mapping) used in engineering design

One analytical tool involved the application of different ways of thinking to analyze random objects. Using analogies and random objects for creative brainstorming in this way sought to discover a better understanding of the nuances of the categories and concepts. Furthermore the goal was to draw out hidden and deeper meanings that may exist by stepping away from the data and applying the analytical thinking to different situations. As an example of this creative brainstorming technique, I used a cell phone as a random object. To investigate how I conceptually thought about understanding, questions were asked to understand “What is a cell phone?” My thought process is outlined:
CHAPTER 4: RESEARCH ANALYSIS

What is this? – “This is a cellphone, a black piece of plastic, you have this keypad, this screen”
What can it do? So what? What’s the impact? – “A cellphone is used to make phone calls”
Why? – “I need to arrange a meeting. A cellphone can be used to make phone calls from anywhere, anytime. I will use my cell phone to call my friend to arrange a meeting.” (I have used my knowledge and information to solve a problem)

The use of analytical tools in the interpretative phase of analysis was critical to draw meaning from the categories and formulate ways to present the research findings in a structured manner that would be useful to engineering educators.

Stages of Analysis

My research analysis process consisted of multiple iterations of analysis and synthesis—breaking down the data and then building it up. An overview of the stages of analysis is shown in Figure 6 and the methods for each stage are discussed.

![Figure 6: Overview of analysis process showing descriptive phase and interpretative phase.](image-url)
CHAPTER 4: RESEARCH ANALYSIS

Descriptive Analysis Phase

Stage 1: Indexing the data and initial coding

Open coding analysis was performed on the responses from the questionnaire using NVivo™ software to facilitate the coding process. Questionnaire responses were organized by school and question. The data was read and re-read, and initial codes were applied to familiarize myself with the data. Predetermined codes were not used. The open coding process served to capture the specifics and nuances of the student descriptions. It involved breaking down the descriptions into the smallest manageable unit of an idea and assigning words or phrases to capture these units of meaning. During this stage, I recorded memos in a separate notebook and I recorded annotations directly linked in the NVivo™ software. These memos and annotations captured my initial thoughts and surprises as I was reading the data for the first time.

Each interview was read completely and analyzed using open coding techniques to assign codes in the same way as the questionnaire responses. The interview data was not organized for each question, but was viewed holistically to gain a broad understanding of the data.

Stage 2: Focused coding and categorization

This stage of data analysis generated categories from the initial codes based on common elements and similarities of ideas. The initial codes were revisited to allow for grouping into categories that captured broader meanings and initial concepts for understanding. I refer to this stage of analysis as focused coding because I was making comparisons between the initial codes to refine and clarify the meaning of the categories.
I revisited my personal memos, notes, and annotations to explore and challenge my thinking. This process was conducted for the questionnaire and interview responses and organized using NVivo™ software. An example of the lists of codes and categories is provided in Appendix E as a printout from the NVivo™ software.

**Interpretative Analysis Phase**

**Stage 3: Building structure to the findings – generation of themes**

For each question and interview, all categories with sub-codes were listed alphabetically and printed on legal size paper. These sheets were spread out over a large area to display all of the categories and codes across questionnaire items and interviews. In this way, I was able to gain a physical sense of the data and see the origin of the categories and codes. Spreading out the lists of categories and codes supported the development of various concept maps to facilitate the visual thinking and analytic process.

In this stage, I was looking for interdependencies, interrelationships, and patterns between the categories. The questionnaires and interviews were analyzed holistically to supplement the data from each instrument. Common categories and themes across the data instruments and questions were compared to draw new meaning and insight. Concept mapping was used to organize the data and to further develop conceptual understandings of the meanings and significance behind students’ responses. The use of concept mapping for visual organization and documentation ensured that the analysis was systematic and rigorous. All categories and codes were systematically reviewed to ensure that no data was mistakenly omitted or overlooked. This process continued by
revisiting the initial codes and the original data to confirm the application of categories. To verify my logic in building the categories and to show the nature of my interpretation, I have extracted students’ responses and included their quotations in the presentation of my research findings.

Different ways of organizing the data into themes were tested for the most comprehensive way to present the research findings. For example, a structure that integrated two educational models was proposed and further analysis was conducted using this preliminary structure. The integrated structure generated themes from curriculum studies and learning theory to assign a single thematic concept to a given category. Analysis and comparison of the categories was conducted to ensure that the categories and themes were parsimonious, understandable, and clear. However, this preliminary structure was discarded as it was found that this application was not a strong representation of the data.

Another structural approach for my research considered the application of phenomenographic methods to create an “outcome space” that captured the various ways of students’ understanding (Zoltowski, Oakes, & Cardella, 2012). However, upon investigation and experimentation, this approach did not align with the purpose of my research.

The analysis of themes and categories continued with multiple iterations of experimentation, comparison, and refinement. The product of the final iteration of data analysis is a structure of themes and categories that uses two distinct educational orientations.
CHAPTER 4: RESEARCH ANALYSIS

**Stage 4:** Building the final concept maps

Concept maps were an analytical tool used continually throughout the analysis process. In this stage of analysis, concept mapping was used explicitly to draw relationships and connections between all of the categories and themes on a global, holistic scale. These concept maps serve as the final product of analysis to present the research findings into a comprehensive, visual map. These final concept maps conclude the analytical process of moving from abstract ideas found in students’ responses to concrete conceptualization for practical application.

**Data Analysis Considerations**

This study is not intended as evaluative research to evaluate the strength or quality of students’ thinking about engineering design. This research is an investigation to gain insight into students’ experiences—to fully understand the issues facing engineering design education from a student perspective. Therefore, comparative analysis of the data between universities, questions, and individual participants was not conducted for this study, although these strategies may be appropriate for future work using quantitative methods. Demographic information including age, gender, and engineering discipline was collected to provide context and background information, but this information was not used for analysis. Demographic information was not available for participants who only partially completed the study.

During the data analysis, other considerations emerged that affected the data analysis. To enhance trustworthiness of the collected data, the questionnaire and interview instruments were designed with multiple questions that targeted the same
CHAPTER 4: RESEARCH ANALYSIS

research constructs. As such, it was expected that there would be some overlap in each students’ responses between the questions. Because the data were separated by question—not participant, I was mindful of participants who responded in the same way on separate questions. This awareness was important to avoid duplicate coding and to resolve any nuances among the responses of participants on each question. If this situation ever occurred where double codes were noticed across questions, the original data was referenced to verify that the code originated from different participants.

Warrants of Quality – Approaches to Enhance Trustworthiness

As stated in my research methodology, my research does not seek to find “an objective reality that can be known” but seeks “to understand the multiple social constructions of meaning and knowledge” (Mertens, 2005, p. 14). This study is not evaluative or comparative—I am not looking at the strength of students’ responses in comparison to some “correct” answer. Therefore, the quality of this research cannot be judged using positivist traditions of validity and reliability (LeCompte & Goetz, 1982). In qualitative research, the quality of research is judged based on trustworthiness that considers the criteria of credibility, transferability, dependability, and confirmability (Lincoln, n.d.). I will discuss the approaches I have taken to enhance the trustworthiness of my study through research reflexivity and rigorous research methods.

Research reflexivity

With qualitative research, the researcher is the instrument for analysis: the data will be processed through the researcher and the outcomes will be the researcher’s interpretations presented as the research findings (Figure 7).
CHAPTER 4: RESEARCH ANALYSIS

Figure 7: Researcher as instrument for analysis.

With the researcher as the instrument for analysis, it is important to analyze and make explicit the researcher’s background to understand his or her perspectives that are brought to the research analysis. This self-analysis is accomplished through *reflexivity*, defined as:

> The process of acknowledging and critically examining one's own characteristics, biases, and insights, particularly as they influence participants and evaluation processes and findings. Reflexivity involves various efforts to identify the evaluators’ impact and either control it or document and account for it. (Williams, n.d.)

Within the constructivist research paradigm, “research is a product of the values of the researchers and cannot be independent of them” (Mertens, 2005, p. 13). I have been reflexive throughout my research in two ways. First, I have documented my background and experiences to account for the perspectives that may influence how I approach my research data. This statement on my background serves to enhance researcher credibility by explaining how my “beliefs have been socially constructed and how these values are impacting on interaction, data collection and data analysis” (Grbich, 2007, p.10). The statement of my background and experiences can be found in Appendix F: Statement of Researcher Background.

The second way that I have practiced reflexivity is through an autoethnographic study to understand how I have come to find meaning and identity in my research...
program. In my autoethnography, I discuss the critical perspectives in my research career that have challenged me to develop an interdisciplinary understanding and identity as an educational engineer. This meaning and identity is how I position myself as a graduate student in my research studies. My autoethnography can be found in Appendix G.

This research is about my interpretation; other researchers viewing the data may interpret the data differently depending on their own background and perspectives. Through my reflexivity, I have enhanced the trustworthiness of my research by making explicit my background and position as the researcher.

**Rigorous research methods and description**

I have employed rigorous research methods to enhance the overall trustworthiness of my study in all phases of research design, data collection, and data analysis:

*Research Design*

- To support the “philosophical belief in the value of qualitative inquiry” (Patton, 2002, p. 584), I have emphasized the need to deeply understand engineering students’ perspectives as a means to improve engineering education.

- I have aligned my research methods with the nature of my inquiry, holding trustworthiness as a primary design consideration for my measurement instruments. The questions were designed to target multiple and repeat theoretical constructs to enhance the quality of students’ responses. Before data collection, a think-aloud process (previously discussed on page 57) was
conducted with three targeted participants to validate the accessibility and reliability of the measurement instruments.

Data collection

- The conduct of my research interviews allowed participants to expand and clarify the meaning of ideas and provide rich description.
- I have shown the dependability of my research by outlining the systematic stages and phases of research analysis that I conducted to arrive at my research findings.
- Although the research constructs and objectives were used as guidelines for analysis, I did not approach my data with predetermined codes or categories—I allowed the categories to emerge from the research data.

Data Analysis

- Throughout the research process, I paid attention to my own researcher beliefs and biases by recording researcher memos and annotations linked to the data. To control researcher bias and preconceptions, I acknowledged and remained mindful throughout the analysis process that the purpose of this study was not a search for truth. This study was an explorative journey to map the field of students’ understanding of engineering design. The categories represent the findings that emerged from my study and are presented in a way that I have interpreted the findings to be relevant to my research purpose.
- To support the credibility and authenticity of my interpretation, I have included participant quotations embedded within my research findings. Block
CHAPTER 4: RESEARCH ANALYSIS

quotations are also provided to emphasize the nature of the particular category and provide complimentary evidence to the main text.

In this section, the approaches taken to enhance the trustworthiness of my study are outlined. Through my autoethnography and description of my experiences, I provided the background to understand my interpretation of my research. I have employed rigorous research methods throughout research design, data collection, and data analysis to enhance the overall trustworthiness of my study.

Chapter Summary – Data Analysis

The systematic process of data analysis that I conducted to make meaning out of my research data was presented. My data analysis consisted of four stages of analysis over two analytical phases: descriptive and interpretative. The approaches I have taken to enhance the trustworthiness of my study were outlined. In the next Chapter, I present my research findings.
CHAPTER 5

RESEARCH FINDINGS

The findings of my study are presented in three sections:

Section 1: The Participants – The number of participants who completed the questionnaire and the background information on the participants who participated in interviews.

Section 2: Word Frequency – The results from a word frequency query and text search of selected questions.

Section 3: Qualitative Research Findings – The main research findings of the qualitative analysis: the themes and categories that emerged to answer my research questions.
CHAPTER 5: RESEARCH FINDINGS

The Participants

The number of participants who completed each question on the questionnaire is listed in Table 7 because participants had the option to partially complete the questionnaire. The total number of responses includes participants from all years and all universities. Note: Question 11 asked participants if they wished to continue the questionnaire and therefore, the number of responses is not applicable (NA).

Table 7: Number of responses for each question on the online questionnaire instrument

<table>
<thead>
<tr>
<th>Question Number</th>
<th>Western</th>
<th>Queen’s</th>
<th>Toronto</th>
<th>Total Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>42</td>
<td>51</td>
<td>118</td>
</tr>
<tr>
<td>2</td>
<td>23</td>
<td>38</td>
<td>39</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>35</td>
<td>37</td>
<td>93</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>31</td>
<td>35</td>
<td>87</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>30</td>
<td>34</td>
<td>84</td>
</tr>
<tr>
<td>6</td>
<td>22</td>
<td>32</td>
<td>39</td>
<td>93</td>
</tr>
<tr>
<td>7</td>
<td>17</td>
<td>29</td>
<td>28</td>
<td>74</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>30</td>
<td>28</td>
<td>78</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>29</td>
<td>23</td>
<td>66</td>
</tr>
<tr>
<td>10</td>
<td>17</td>
<td>29</td>
<td>23</td>
<td>69</td>
</tr>
<tr>
<td>11</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>17</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>17</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>14</td>
<td>9</td>
<td>16</td>
<td>9</td>
<td>34</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>16</td>
<td>8</td>
<td>34</td>
</tr>
<tr>
<td>16</td>
<td>11</td>
<td>20</td>
<td>8</td>
<td>39</td>
</tr>
<tr>
<td>17</td>
<td>11</td>
<td>20</td>
<td>8</td>
<td>39</td>
</tr>
<tr>
<td>18</td>
<td>11</td>
<td>20</td>
<td>8</td>
<td>39</td>
</tr>
</tbody>
</table>
Although demographic data was collected in the questionnaire such as age, gender, and engineering discipline, this information was used to gain an awareness of interview participation and was not used for research purposes.

To maintain research participant confidentiality, pseudonyms were assigned to each interview participant and alphanumeric codes were assigned to questionnaire participants. Table 8 lists the participant pseudonyms and the engineering background of each student. In the presentation of the research findings, the use of a pseudonym to reference a participant’s response indicates that the participant’s response is from a personal interview. An alphanumeric code (ex. A-18) is used to reference participants’ responses from the online questionnaire. These alphanumeric identifiers were randomly assigned and are not related to participants’ university institutions.

### Table 8: Interview participant pseudonym and background information

<table>
<thead>
<tr>
<th>Participant (Pseudonym)</th>
<th>Engineering Discipline</th>
<th>Year of Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michael</td>
<td>Civil</td>
<td>4</td>
</tr>
<tr>
<td>Karen</td>
<td>Mechanical</td>
<td>4</td>
</tr>
<tr>
<td>Justin</td>
<td>Civil</td>
<td>4</td>
</tr>
<tr>
<td>Daniel</td>
<td>Engineering Science</td>
<td>4</td>
</tr>
<tr>
<td>Paul</td>
<td>Mechanical</td>
<td>4</td>
</tr>
<tr>
<td>David</td>
<td>Electrical</td>
<td>4</td>
</tr>
<tr>
<td>Tyson</td>
<td>Computer</td>
<td>3</td>
</tr>
<tr>
<td>Leah</td>
<td>Engineering Physics</td>
<td>3</td>
</tr>
<tr>
<td>Bryn</td>
<td>Civil</td>
<td>3</td>
</tr>
<tr>
<td>Robert</td>
<td>Civil</td>
<td>1</td>
</tr>
</tbody>
</table>
CHAPTER 5: RESEARCH FINDINGS

Word Frequency Analysis

A word frequency and text search query were conducted on specific questions using NVivo™ data analysis software. The results are presented below.

Word Frequency

A word frequency query searches the selected questionnaire responses and generates a list of the most frequently used words in the responses. A word frequency query that included data from all three Universities was conducted on Questions #1, #4, and #7 (Table 9). For each query, the top 150 words were listed with a minimum length of 3 characters. For presentation here, the lists have been truncated to the top twenty words (Tables 10, 11, & 12).

The “Count” column displays the frequency of the word, the ‘Weight Percentage’ column displays the frequency of the word relative to the total words counted, and the ‘Similar Words’ column displays similar words that were included in the frequency.
CHAPTER 5: RESEARCH FINDINGS

Table 9: Total number of responses for each question for word frequency analysis.

<table>
<thead>
<tr>
<th>Question Number</th>
<th>Question</th>
<th>Number of responses from each institution</th>
<th>Total number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Small</td>
<td>Medium</td>
</tr>
<tr>
<td>1</td>
<td>How would you describe the profession of engineering to a senior high school student considering engineering undergraduate studies?</td>
<td>25</td>
<td>42</td>
</tr>
<tr>
<td>4</td>
<td>Describe what it means to you to think like an engineer?</td>
<td>21</td>
<td>31</td>
</tr>
<tr>
<td>7</td>
<td>In your own words, define engineering design.</td>
<td>17</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 10: Word frequency results for Question #1: How would you describe the profession of engineering to a senior high school student considering engineering undergraduate studies?

<table>
<thead>
<tr>
<th>Number</th>
<th>Word</th>
<th>Count</th>
<th>Weighted Percentage (%)</th>
<th>Similar Words</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>engineers</td>
<td>136</td>
<td>5.79</td>
<td>engineer, engineered, engineering, engineers</td>
</tr>
<tr>
<td>2</td>
<td>problems</td>
<td>58</td>
<td>2.47</td>
<td>problem, problems</td>
</tr>
<tr>
<td>3</td>
<td>you</td>
<td>58</td>
<td>2.47</td>
<td>you</td>
</tr>
<tr>
<td>4</td>
<td>science</td>
<td>39</td>
<td>1.66</td>
<td>science, sciences</td>
</tr>
<tr>
<td>5</td>
<td>solving</td>
<td>39</td>
<td>1.66</td>
<td>solve, solving</td>
</tr>
<tr>
<td>6</td>
<td>using</td>
<td>38</td>
<td>1.62</td>
<td>use, useful, uses, using</td>
</tr>
<tr>
<td>7</td>
<td>profession</td>
<td>37</td>
<td>1.58</td>
<td>profession, professions</td>
</tr>
<tr>
<td>8</td>
<td>world</td>
<td>36</td>
<td>1.53</td>
<td>world, world’, worlds</td>
</tr>
<tr>
<td>9</td>
<td>works</td>
<td>35</td>
<td>1.49</td>
<td>work, working, works</td>
</tr>
<tr>
<td>10</td>
<td>design</td>
<td>32</td>
<td>1.36</td>
<td>design, designed, designing, designs</td>
</tr>
<tr>
<td>11</td>
<td>apply</td>
<td>21</td>
<td>0.89</td>
<td>applied, applies, apply, applying</td>
</tr>
<tr>
<td>12</td>
<td>things</td>
<td>20</td>
<td>0.85</td>
<td>thing, things</td>
</tr>
<tr>
<td>13</td>
<td>how</td>
<td>19</td>
<td>0.81</td>
<td>how</td>
</tr>
<tr>
<td>14</td>
<td>maths</td>
<td>19</td>
<td>0.81</td>
<td>math, maths</td>
</tr>
<tr>
<td>15</td>
<td>solutions</td>
<td>19</td>
<td>0.81</td>
<td>solution, solutions</td>
</tr>
<tr>
<td>16</td>
<td>have</td>
<td>18</td>
<td>0.77</td>
<td>have</td>
</tr>
<tr>
<td>17</td>
<td>knowledge</td>
<td>18</td>
<td>0.77</td>
<td>knowledge</td>
</tr>
<tr>
<td>18</td>
<td>way</td>
<td>18</td>
<td>0.77</td>
<td>way, ways</td>
</tr>
<tr>
<td>19</td>
<td>create</td>
<td>18</td>
<td>0.77</td>
<td>create, created, creating</td>
</tr>
<tr>
<td>20</td>
<td>make</td>
<td>16</td>
<td>0.68</td>
<td>make, makes, making</td>
</tr>
</tbody>
</table>
### Table 11: Word frequency results for Question #4: Describe what it means to you “to think like an engineer.”

<table>
<thead>
<tr>
<th>Number</th>
<th>Word</th>
<th>Count</th>
<th>Weighted Percentage (%)</th>
<th>Similar Words</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>thinking</td>
<td>80</td>
<td>5.23</td>
<td>think, 'think, thinking, 'thinking</td>
</tr>
<tr>
<td>2</td>
<td>problem</td>
<td>53</td>
<td>3.46</td>
<td>problem, problems</td>
</tr>
<tr>
<td>3</td>
<td>engineer</td>
<td>52</td>
<td>3.40</td>
<td>engineer, engineer', engineering, engineering', engineers</td>
</tr>
<tr>
<td>4</td>
<td>like</td>
<td>35</td>
<td>2.29</td>
<td>like</td>
</tr>
<tr>
<td>5</td>
<td>solution</td>
<td>32</td>
<td>2.09</td>
<td>solution, solutions</td>
</tr>
<tr>
<td>6</td>
<td>means</td>
<td>25</td>
<td>1.63</td>
<td>mean, means</td>
</tr>
<tr>
<td>7</td>
<td>you</td>
<td>21</td>
<td>1.37</td>
<td>you</td>
</tr>
<tr>
<td>8</td>
<td>solve</td>
<td>21</td>
<td>1.37</td>
<td>solve, solved, solving</td>
</tr>
<tr>
<td>9</td>
<td>creative</td>
<td>14</td>
<td>0.91</td>
<td>creative, creatively, creativity</td>
</tr>
<tr>
<td>10</td>
<td>how</td>
<td>14</td>
<td>0.91</td>
<td>how, 'how, 'how'</td>
</tr>
<tr>
<td>11</td>
<td>look</td>
<td>13</td>
<td>0.85</td>
<td>look, looking, looks</td>
</tr>
<tr>
<td>12</td>
<td>way</td>
<td>13</td>
<td>0.85</td>
<td>way, ways</td>
</tr>
<tr>
<td>13</td>
<td>work</td>
<td>13</td>
<td>0.85</td>
<td>work, working, works</td>
</tr>
<tr>
<td>14</td>
<td>all</td>
<td>13</td>
<td>0.85</td>
<td>all</td>
</tr>
<tr>
<td>15</td>
<td>can</td>
<td>12</td>
<td>0.78</td>
<td>can</td>
</tr>
<tr>
<td>16</td>
<td>from</td>
<td>12</td>
<td>0.78</td>
<td>from</td>
</tr>
<tr>
<td>17</td>
<td>have</td>
<td>11</td>
<td>0.72</td>
<td>have</td>
</tr>
<tr>
<td>18</td>
<td>best</td>
<td>10</td>
<td>0.65</td>
<td>best</td>
</tr>
<tr>
<td>19</td>
<td>box</td>
<td>10</td>
<td>0.65</td>
<td>box</td>
</tr>
<tr>
<td>20</td>
<td>ideas</td>
<td>10</td>
<td>0.65</td>
<td>idea, ideas</td>
</tr>
</tbody>
</table>

### Table 12: Word frequency results for Question #7: In your own words, define engineering design.

<table>
<thead>
<tr>
<th>Number</th>
<th>Word</th>
<th>Count</th>
<th>Weighted Percentage (%)</th>
<th>Similar Words</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>design</td>
<td>73</td>
<td>7.37</td>
<td>design, design', designed, designing</td>
</tr>
<tr>
<td>2</td>
<td>engineers</td>
<td>50</td>
<td>5.05</td>
<td>engineer, engineer', engineering, 'engineering, engineers</td>
</tr>
<tr>
<td>3</td>
<td>problem</td>
<td>26</td>
<td>2.62</td>
<td>problem, problems</td>
</tr>
<tr>
<td>4</td>
<td>solution</td>
<td>24</td>
<td>2.42</td>
<td>solution, solutions</td>
</tr>
<tr>
<td>5</td>
<td>process</td>
<td>16</td>
<td>1.61</td>
<td>process, processes</td>
</tr>
<tr>
<td>6</td>
<td>using</td>
<td>16</td>
<td>1.61</td>
<td>use, used, useful, using</td>
</tr>
<tr>
<td>7</td>
<td>creating</td>
<td>13</td>
<td>1.31</td>
<td>create, created, creating</td>
</tr>
<tr>
<td>8</td>
<td>solve</td>
<td>12</td>
<td>1.21</td>
<td>solve, solves, solving</td>
</tr>
<tr>
<td>9</td>
<td>product</td>
<td>9</td>
<td>0.91</td>
<td>product</td>
</tr>
<tr>
<td>10</td>
<td>something</td>
<td>9</td>
<td>0.91</td>
<td>something</td>
</tr>
<tr>
<td>11</td>
<td>like</td>
<td>8</td>
<td>0.81</td>
<td>like, likely</td>
</tr>
<tr>
<td>12</td>
<td>model</td>
<td>8</td>
<td>0.81</td>
<td>model, models</td>
</tr>
<tr>
<td>13</td>
<td>most</td>
<td>8</td>
<td>0.81</td>
<td>most</td>
</tr>
<tr>
<td>14</td>
<td>system</td>
<td>8</td>
<td>0.81</td>
<td>system, systems</td>
</tr>
<tr>
<td>15</td>
<td>technical</td>
<td>7</td>
<td>0.71</td>
<td>technical, technically</td>
</tr>
<tr>
<td>16</td>
<td>'thinking'</td>
<td>7</td>
<td>0.71</td>
<td>think, thinking, 'thinking</td>
</tr>
<tr>
<td>17</td>
<td>world</td>
<td>7</td>
<td>0.71</td>
<td>world</td>
</tr>
<tr>
<td>18</td>
<td>you</td>
<td>7</td>
<td>0.71</td>
<td>you</td>
</tr>
<tr>
<td>19</td>
<td>develop</td>
<td>7</td>
<td>0.71</td>
<td>develop, developed, developing</td>
</tr>
<tr>
<td>20</td>
<td>implementing</td>
<td>7</td>
<td>0.71</td>
<td>implement, implementation, implementing</td>
</tr>
</tbody>
</table>
These three questions (#1, #4, & #7) were chosen for a word frequency because they targeted the ‘Conceptions’ construct for this research, looking specifically at students’ descriptions of engineering and design. It is not surprising that specific words used in the questions appear in the top twenty lists. For example, the words ‘think’ and ‘engineer’ appear in the top twenty lists for Question #4 and these words were used in the question itself. The same reasoning applies for Question #7 and the words ‘engineer’ and ‘design’. A further look at the lists shows that there are non-trivial words that occur in multiple questions. The words ‘problem’ and ‘solving’ occur in the list for all three questions. The word ‘solution’ occurs in the lists for Question #4 (Table 11) and #7 (Table 12). It is surprising that the word ‘design’ does not appear in the list for Question #4 (Table 11) that asks students: Describe what it means to you “to think like an engineer”.

*Text Search*

A text search is a query that searches for the frequency and specific occurrences of a given word. A text search was conducted for Questions #1 and #4 for the word ‘design’. Question #7 was not included in this search because the word ‘design’ is used in the question itself. As shown in Table 10 for Question #1, ‘design’ had a frequency of 32 counts. For Question #4, ‘design’ had a frequency of 7 counts and did not make the top 20 words listed in Table 11.

The word frequency and text search were performed as a preliminary analysis to gain a broad picture of the type of language students were using in their responses. In the next sections, I present the main qualitative research findings.
CHAPTER 5: RESEARCH FINDINGS

Qualitative Research Findings

The main research findings have been structured into two parts. The first part is student-oriented and details the participants’ understanding of engineering design. This part is organized into three themes of understanding applicable to my research questions. The second part is curriculum-oriented and details participants’ responses that apply to the teaching and learning of engineering design. I have structured my findings into these two parts to capture the full extent of participants’ responses that serve to answer my research questions. Furthermore, these two orientations are used to provide a framework for thinking about the elements of education: the student and the curriculum.

Students’ responses from data collection are presented as embedded quotations in the text and independent text boxes. These quotations are provided to show the student descriptions that support my interpretations of the data and to enhance trustworthiness of the findings. At the end of each research findings section, a summary is presented in the form of a final concept map of the research findings. Figure 8 shows a visual representation of the structure of the research findings.

Figure 8: Structure of research findings
CHAPTER 5: RESEARCH FINDINGS

Understanding the presentation of my research findings

To understand the presentation of my research findings and apply the findings to teaching and learning practice, it is helpful to consider the research findings on two interpretative levels: conceptual and structural. On the conceptual level, the categories are viewed as mechanisms of learning engineering design: the description of the categories provide detail and insight into concepts that can be targeted as learning construction sites in students’ understanding and for curriculum development. On the structural level, the categories are viewed holistically as examples of elements that contribute to the respective overarching themes, building the framework to think about engineering design education.
Part 1

Engineering Students’ Understanding of Engineering Design

This section applies a learning-orientation to conceptualize students’ understanding of engineering design. Participants’ understanding of engineering design consists of their perceived awareness, relevance, and transfer. These concepts, presented as the themes of my research findings, serve to provide the platform and framework to think about engineering students’ design schema (Figure 9). I have used these terms to operationalize the meaning of understanding when thinking about the way students understand engineering design.

![Research Findings 1: Students’ Understanding of Engineering Design (LEARNING ORIENTATION)](image)

**Figure 9: Major themes of students’ understanding**
As previously discussed in Chapter 3 on research design, Table 13 shows the conceptual ways of thinking about understanding applied to this research. I have added Column D to include the themes of my research findings. The row numbers are included to emphasize the associations across the constructs of understanding.

**Table 13: Ways of thinking about the representations of students’ understanding**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE Framework (Fostaty Young &amp; Wilson, 2000)</td>
<td>Understanding (Pask, 1988)</td>
<td>Research Sub-questions</td>
<td>Themes of Research Findings</td>
</tr>
<tr>
<td>1</td>
<td>Ideas</td>
<td>Topics</td>
<td>Conceptions</td>
</tr>
<tr>
<td>2</td>
<td>Connections</td>
<td>Relationships</td>
<td>Meaning</td>
</tr>
<tr>
<td>3</td>
<td>Extensions</td>
<td>Applications</td>
<td>Learning</td>
</tr>
</tbody>
</table>

**Awareness**

Engineering students’ awareness of engineering design is characterized by their descriptions of what engineering design is about and the conditions in which engineering design takes place. These two traits can be categorized and thought of as the ‘what’ and ‘where’ of engineering design.

**Engineering as producing something**

This category captures how participants describe what engineering is about. Results for this category mainly come from Questions 1, 4, and 7 from the questionnaire instrument. Students were asked how they describe the profession of engineering to a high-school student interested in pursuing engineering studies (Question 1). Also, participants were asked what it means to them to think like an engineer (Question 4), and
to define engineering design (Question 7). Although these questions focus on engineering descriptions, it is important to note that the responses from all questionnaire items and interviews were interpreted holistically to formulate the results in this category.

Students’ descriptions about engineering revolved around two topics that make up this category: *application and applied science*, and *problem solving*. These topics capture students’ description of the action of engineering design.

*Application and applied science*

Students described an awareness of engineering as the application of math and science. In a general sense, their descriptions referred to the application of knowledge to do something.

As the following participant explained, “it is the application of science to define a problem, design a solution, and find ways to implement it in a way that makes sense scientifically (whether it's safe for public use, sustainable) and makes sense ethically” (A-51).

*Problem solving*

An awareness of problem solving as an independent construct was evident in the students’ descriptions—responses included simple statements like “engineers solve problems”.

89
Within problem solving, students also described aspects of problem solving in “the best way possible” as demonstrated through the two quotations below:

So what made this engineering design? We had a goal to complete, we had a bunch of tools and resources, and we just kind of went through some concepts and worked to make the best solution, so what makes it design is that I guess we had a goal and some resources and we tried to come up with the best way to use those resources to reach that goal in the best way possible. (Paul)

I guess it just means looking at the task at hand and given the resources that you have, you have to find the best solution to the problem that you’re dealing with, and doing it in the most efficient way and the best way is effective problem solving. (Bryn)

Problem solving as a construct was coupled with student’s descriptions of application and applied science in the sense that the application of this knowledge is used to solve problems. These descriptions present problem solving as one goal or outcome of engineering—that is, to generate solutions.

**Characteristics of the engineering design process**

This category comprises students’ descriptions of the elements of engineering design and the context in which engineering design takes place. Examples of how students described the characteristics of engineering design include: “being complex”, “open-ended”, “having multiple options”, and “iterative”. An awareness of engineering design as the *process* to solve problems was also evident. The nature of engineering design and elements of the process of doing engineering design were captured. For
example, this category is characterized by the question: In what context and setting does the action of engineering design take place? This category also captures adjectives to describe the process of engineering design, whereas the first category “Engineering design as producing something” captures what engineering design is about.

**Relevance**

This theme is characterized by how students describe the relevance and significance of engineering design. The categories depict how students make connections, relationships, and meaning between engineering design and their other learning.

**Skills involved in engineering design support learning**

This category captures students’ descriptions of the skills involved in, and learned through engineering design. It is organized under Relevance because the skills are not unique or specific to engineering design, but are applicable to all levels of higher education. Furthermore, the skills are independent of any subject matter domain. Students described the relationship of engineering design and their career in terms of the skills they develop. These skills are described as supporting the learning of other skills. Additionally, the development and importance of these skills were related to one’s effectiveness in their career: “It enhances my critical thinking skills which helps in every profession” (B-45).
Engineering design teaches many important life skills that can apply to a variety of different jobs: complex problem solving, how to work in a team, to balance complex and sometimes conflicting project priorities. (A-142)

Engineering design also teaches students how to work in a team, manage time, deal with frustration, and get a better sense of what industry will require of engineers. (A-92)

Codes that were applied in the skills category include: teamwork, communication, dealing with complexity, analysis and synthesis, ‘how to’ design, and hands-on skills.

Examples of engineering hands-on skills described by one participant included: “striping a wire or making an Ethernet cable, being competent in a lab, or as simple as digging a hole, or welding or properly using a mill” (David).

David, who had experience as a skilled tradesperson, described the importance of “hands-on practical skills” in his workplace where he was exposed to soldering: “we solder all the time there just to whip something up quick, or just to make a quick prototype to ship to the customer.” He also noticed where the hands-on skills may be lacking in his colleagues and how that limits them in their work: “they just don’t have those hard skills we’ll call them to really get into it, so there is a big delay with them being actually able to apply it.”
CHAPTER 5: RESEARCH FINDINGS – PART 1

Engineers making contributions to society

This category captures students’ relationships between their engineering studies and society. Students demonstrated the link to society by describing how the engineering profession aims to make contributions to society and serve the public.

When students’ say that engineers contribute “to the growth of society” (C-8), “making the world better” (C-1), and “to help others in life” (A-19), it demonstrates their understanding that the engineering profession is intimately related to society because of the work that engineers do. Other concepts in this category included engineering ethics and safety, as these two elements have major implications for society and the profession of engineering.

When asked “how does learning engineering design relate to your undergraduate studies”? students’ descriptions showed a future-oriented view, in that learning engineering design was preparing them for their work into the future.

Ideally, our programs will prepare us to go out into the working world and be able to design new and innovative solutions to problems that the world is currently facing. Learning about the design process itself will certainly aid us in this quest. (C-19)

This category captures the notion that engineering students make meaning out of engineering, through the connection that engineering has with society, and how their engineering studies prepares them for their careers.
CHAPTER 5: RESEARCH FINDINGS – PART 1

Math and science as tools - The role of math and science in engineering design

This category captures students’ description of the relationship between engineering and the fields of math and science. Exploring this area was a focus for this study because students are predominantly exposed to traditional math and science disciplines in high school and the early years of undergraduate study. Students’ descriptions centered on the view of math and science as “the tools” that enable an engineer to do his or her job effectively. If an engineer’s job is to problem solve, the tools of math and science allow engineers to “reduce the risk of failure” in their solutions. As one student describes, “by using theories learned to problems faced, mathematical models can be applied to determine if the solutions found are viable” (A-105). The two quotations in the boxes speak to the view of math and science as the tools of engineering to ensure designs are safe and reliable:

<table>
<thead>
<tr>
<th>Quotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineers must be good at math and science, so that they are able to come to the best conclusion that will be used for its proper purpose. Nothing can be done by chance. (C-21)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>The most complex problems that modern engineers tackle would be near impossible to solve without math and sciences. Solutions could be made, but there would be no way of knowing exactly how safe certain ideas would be for the public, which is a main concern of engineers. (A-8)</td>
</tr>
</tbody>
</table>
Another perspective regarding the role of math and science is that these disciplines form the theoretical basis of engineering, from which one can then apply to some use:

An engineer must first master the necessary scientific and mathematical concepts before they may do any field work. (A-142)

Math and sciences are very theoretical. Going into those fields would bring you to learn many interesting things, but not how to make use of them in everyday life. (B-36)

Math and science are the basis of engineering. Math and science study theoretical concepts; whereas engineering applies those concepts to real world situations. (A-137)

It is evident that students see the role of math and science as tools used to form the foundation of engineering.

The field of math and science was also described as a means to observe and explain phenomenon in the world:

Math and science explains why and how something works. (A-65)

Math and science explain and predict observable phenomena. (A-112)
The mathematics and science helps predict, model and create the required designs to engineer. (B-45)

These views support how math and science can be used as tools for engineering design through decision making.

I have presented the role of math and science as tools used for problem solving, and how these tools are conceived in students’ views as the basis for engineering and as decision making tools to model and predict phenomenon. Students will engage in math and science throughout the design process: in the early stages, as students conduct background research to see what concepts exist, and in later phases to develop, justify, and validate their designs. These actions of using math and science throughout the
design process are captured in students’ descriptions of the role of math and science. Although math and science are not the only tools for engineering design, I have interpreted these descriptions as one way students come to understand the relevance of engineering design.

**Transfer**

This section on students’ perspectives of transferring engineering design is characterized by how they describe their experiences of transferring their learning of engineering design to other contexts, and how they have used their understanding to solve problems. This section is also defined by elements that are not unique to engineering as a profession, but show students’ learning that serve their holistic development as individuals. Knowledge transfer in this thesis is characterized by knowledge that has no boundaries—the knowledge can be applied to many different contexts to solve problems. Two themes that emerged to capture students’ description of transfer are presented as an engineering design way of being and an engineering design way of thinking.

**An Engineering Design Way of Being**

This theme captures how students describe the embodiment of being an engineer. It is referring to how students feel, and is associated with the question “who am I as an engineering student?” I have differentiated between “a way of being” and “a way of thinking” (presented in the following category) by using the framework by Novak (2010), who categorized people’s behaviour into thinking, feeling, and acting. The three learning domains of cognitive, affective, and psychomotor correspond to this structure. An
engineering design “way of being” addresses the affective learning domain: how students feel. Specifically, this theme captures students’ responses that are related to the way they feel about being, and becoming, an engineer. I have structured this theme under “Transfer” because this level of understanding is applicable to many different contexts and is not explicit to any subject matter.

Higher Engineering Ideologies

This category captures students’ ways of internalizing higher engineering ideologies related to engineering and society. I have interpreted this understanding to be a personal philosophy for students—a higher purpose for what it means to be an engineer.

The societal relationships section categorized under “Relevance” captures how students see a relationship between engineering and society. In contrast, the category presented here under “Transfer” captures the embodiment of being an engineer as someone who helps society. The category captures the affective way of being an engineer and shows how students make personal connections to the profession to give their lives meaning.

Students show an emotional connection between being an engineer and contributing to society: “[engineering education] gives me the ability to make good on
CHAPTER 5: RESEARCH FINDINGS – PART 1

this planet before leaving it’’ (C-2). Another student said: “to be an engineer is to commit oneself to the protection and development of mankind. (C-29)

In describing the importance of learning engineering design, Tyson said, “it's important to learn because these are real world things, that people need—that society needs…it's important to know so that we can benefit society and benefit the world as a whole—that’s why we do these things, it shouldn't be a selfish thing, to do these works, it benefits everybody.”

The above description captures a feeling of selfless work to make the world better. The descriptions show students’ recognition that their engineering education enables them with the power to influence change. To help citizens make a positive impact on society is a noble mission for all disciplines of higher education.

As engineers, we have not only the duty, but also the power, to affect change that affects our society, our natural environment, and people. These changes can be negative or positive, but it is the role of good engineering to determine the full socio-environmental effect of all decisions made in our profession. This is especially important as it concerns ethical decisions that affect other cultures and societies, or may harm the environment. (C-24)

Engineers are an integral portion of society; without engineers society would not progress forward. Engineers, thus, have the power to invoke change, the nature of which is governed by an unwritten set of ethics. With power comes great responsibility; an engineer has an inherent responsibility to society. (A-59)
CHAPTER 5: RESEARCH FINDINGS – PART 1

Positioning the engineering profession with a higher sense of purpose is the way of being that encompasses the category of higher engineering ideologies.

*Optimization as a way of being*

Students described their intrinsic motivation to solve problems and do things better. Where engineering design thinking may enable students to accomplish tasks and behave in a certain manner, an engineering design way of *being* is characterized by a way of feeling about engineering. The desire for optimization is one way of feeling that emerged from students’ descriptions.

If you approach every problem like there's no other solution, then you're never going to find one. But if you **approach problems like ‘maybe we can do it a bit better’** which is how I approach most problems now—thinking about ‘how can I improve this?’, ‘how can I do better?’, ‘how can I make it…often it's how can I make it easier for myself. (Tyson)

My engineering education is helping me look at things differently. **It motivates me to take what's not working and think of ways to fix it.** My way of thinking is now more analytical, detailed-oriented and user-oriented. (B-47)

When asked about their personal experiences that contributed to their thinking about engineering design, students described their everyday experiences and seeing problems in their everyday lives. For example, as one student describes “If I run into little problems through everyday life, such as stuck in traffic, this is how I approach the problem: Evaluating my alternatives and choosing the best option” (C-10). Students also
described how they solved everyday common problems at home: “living with engineers, it's obvious whenever a household problem arises (uneven table, leaky sink, etc.)” (A-72).

David talked about “the engineering sixth sense,” a feeling when one “can look at something and figure out if it’s going to fail intuitively.” He described his experience of seeing the “engineering sixth sense” in the context of tradespersons doing electrical and plumbing work, where these individuals have a natural “ability to look at something and instantly tell if it’s going to fail [and] what’s wrong with it.” In this situation, optimization as a way of being captures the aspects of problem solving and identifying failures. David described how he developed a design way of being through course projects and personal experiences:

that was the best way [to learn], through projects, and not necessarily through projects from the university, but simple things at home, you know what I mean, messing around with electronics or mechanical systems, modifying your car, all these things are what teach you the deeper understanding of engineering design and give you the sixth sense. (David)

Tyson also expressed how he has personally embodied a sense of “being an engineer”:

I've been told multiple times ‘you really are an engineer at heart’ and I'm like ‘it's just the way I do things now’, I think of everything analytically, I think of everything as an algorithm essentially, of how can I do this better, how can I improve the way things are going and make them faster and make them more efficient, to get more done. (Tyson)

This theme has presented examples of student’s perspectives that I have called an engineering design way of being.
An Engineering Design Way of Thinking

An engineering design way of thinking is described as the cognitive approach to solve problems—the means to achieve one’s objective. Within this approach, students described two thinking processes: analytical and creative.

An engineering undergrad [degree] teaches you how to think, how to approach problems and I think that can be applied to a lot of different fields regardless of whether they are technical or non-technical in nature. (Karen)

Analytical Thinking

Analytical thinking is characterized by the ability to break down problems into smaller units, to be able to solve them. As one student explains, “a methodical way of doing things will allow me to better visualize and answer problems” (A-24). An example of analytical thinking is captured in two students’ description below:

To me 'thinking like an engineer' means looking at complex problems, breaking that down into smaller parts or applying a framework and then systematically addressing each element of the framework or part of the problem. (A-146)

… breaking down a problem into functions, objectives and constraints. Or at least considering that any problem could be broken down into such categories and the best solution could be found from alternative solutions. (B-26)
CHAPTER 5: RESEARCH FINDINGS – PART 1

Based on students’ descriptions, I have included within this category the thought processes and actions that encompass analytical thinking prevalent in engineering design. For example, students described systems thinking (“to see problems in the context of systems” [A-72]) and critical thinking (to evaluate designs based on effectiveness and utility [A-59, C-32]) as ways of thinking that one utilizes when engaged in analysis. Examples of codes used to itemize actions of analytical thinking include: “consider multiple perspectives”, “dealing with complexity”, “justify ideas,” and “decision making”.

*Creative Thinking*

Creative thinking emerged in students’ descriptions as the ability to create something—to turn ideas into reality.

Engineers are practical people who are concerned with applications of science. Engineers constantly invent and innovate, and the practice of engineering is a delicate mixture of theoretical sciences, intuition, and creative thinking … engineers constantly try to find a way to use theoretical sciences in a new way—in a way that enhances our technology. (B-53)

The two quotations below capture students’ descriptions of creative thinking, and show how they have combined elements from the previous themes of Awareness and Relevance.
In one of the quotations, the student mentions “new solutions” which I have interpreted to be linked to “problem solving” (found in Awareness). In the other quotation, the student mentions “application of science,” (linked to Awareness) and “for the purpose of bettering our world/lifestyle” (linked to Relevance). It is evident that these responses contain elements consistent with the Awareness and Relevance themes of students’ understanding. Therefore, it is appropriate to categorize these quotations within the theme of Transfer, recognizing that students are demonstrating a complete understanding.

The two categories, analytical thinking and creative thinking, capture two major components of an engineer’s “design way of thinking”: analysis and synthesis—breaking problems down and building anew. This theme captures students’ ability to transfer their learning because the descriptions are not limited to any subject matter. The way of thinking described is applicable to any form of higher education.
Summary of Research Findings Part 1 – Learning Orientation

I have presented a conceptual understanding of students’ perspectives from a learning orientation that considers students’ holistic understanding of engineering design. I have presented themes and categories of students’ awareness of design, how they describe the relevance and relationships of engineering design, and how they describe the ability to transfer their knowledge to new learning. The findings here are not presented as a complete and comprehensive students’ understanding of engineering design; rather, the findings are presented as the categories that emerged from my interpretations of the data that was collected for this study. As educators strive to develop students’ schema of engineering design, the research findings present opportunities and insight for enrichment of the learning process. The framework for conceptualizing students’ understanding of engineering design is summarized in the concept map (Figure 10).
Figure 10: Concept map summary of Research Findings Part 1
Part 2

The Teaching and Learning of Engineering Design

This section adopts a curriculum orientation to present the results of students’ description that are directly applicable to the teaching and learning of engineering design. With this curriculum orientation, the results have been organized within the three elements of curriculum: subject matter, society, and the individual (Marsh & Willis, 2007) as a framework for thinking about designing holistic engineering education (Figure 11). The categories presented in this section can be considered as either 1) influences on teaching and learning or 2) outcomes of teaching and learning. Some categories can be considered as both an influence and an outcome. It is appropriate to consider these categories as influences and outcomes of teaching and learning to help the reader make meaning and apply the research findings. Evidence from students’ responses will be provided to enhance the trustworthiness of my interpretation.

Figure 11: Major themes of teaching and learning of engineering design.
Teaching the Subject Matter of Engineering Design

This theme captures elements related to teaching the subject matter of engineering design, for engineering educators to be mindful of when creating their engineering design curriculums.

Challenges with the design setting

The educational context in which the learning of engineering design takes place can be a challenge for students. This category identifies two sub-categories that capture students’ descriptions about these challenges.

Conditions of engineering design make it challenging to learn

The nature of engineering design makes it challenging to learn. Students described engineering as challenging to learn because of its inherent complexity, open-endedness, multiple options and solutions, iterations, working in teams, and overall process. It is apparent that all of these conditions of engineering design will place heavy cognitive demands on students. As one student responded:

I suppose part of the challenge is also in the breadth of engineering design. The different technical aspects, all the types of constraints (those given by client or governing body, technological limitations), the many areas your design will effect and consequences you must be aware of. (A-72)

In a personal interview, Bryn explained his views on the open-ended nature of engineering design:

Because it’s open-ended there’s not a fixed route to learn engineering design, so I’d say that’s the challenging part to it, where you could go down many paths, which also makes it interesting to learn, it’s not a bad thing, it just makes it a little bit harder. (Bryn)
Comparing the design process to learning calculus or structural design, Bryn further explained:

> It’s not like calculus or structural design, where you have a problem and these are the methods you use to solve that problem, it’s more of you have a problem and you’re making up your own methods and using other methods, and changing those methods to work for you. (Bryn)

Bryn summarized his thoughts and pointed to experiential learning as influencing his learning of engineering design: “the open-ended nature of it makes it difficult to really get a good grasp of it, unless you’re doing it, then you sort of understand it.”

As presented in this category, the various conditions of engineering design place heavy cognitive demands on students, thereby adding to the challenges of learning. I have interpreted this category to be an influence on the teaching and learning of engineering education.

“Playing designer” - Learning engineering design through design projects

Students described their learning of engineering design at university, engineering jobs, and in their personal lives. Design projects in university are where students most commonly drew their experiences of learning engineering design. The concept of “playing designer” is a direct code from one student’s response and captures students’ feelings that their design experiences only imitated the problems they expect to face in industry. This category captures the challenges and learning opportunities in design projects from the students’ descriptions.
One challenge that Bryn experienced was feeling that his coursework only allowed him to “play designer for half the semester.” Bryn described how he felt when he was not experiencing the whole design process, but just focusing on the beginning and end. He said that design experiences were “sort of like an add on to the course, as opposed to being the course’s focus, there’s not a lot of attention put into the actual design process—a lot of attention is ‘we want this, and you have to get that’ and we give you the problem description and we want to see that the result works” (Bryn). This challenge is an aspect of design projects that educators must be mindful of—that learning engineering design is a process that takes time and students must see the full process to really appreciate what they are learning.

Another aspect to the concept of “playing designer” is found in Leah’s feelings that the design projects in university were very specific. Leah explained, “with each engineering design project, it's never ‘go design this whole entire thing’, it's like: ‘here's this one problem, fix it’—it’s not ‘here's a whole slew of problems.’” When describing her other engineering experiences from her summer work, she said, “it's never just one problem, it is ‘we have this enormous problem, we have these constraints and we have these means to fix it,’ so it’s challenging because it's hard to put students in that scenario” (Leah). In this sense, Leah described the challenge of learning in a simulated university
environment, where her design experiences in university have applied to a specific problem.

There are several issues to explore with the concept of “playing designer”. Although design projects may be specific to a special problem, the design process itself is applicable to many problems. This perspective points to the need to understand student’s beliefs about doing a design project, where the learning opportunity lies in learning about the design process and strategies of going through the exercise. Learning about the specific problem that students are faced with in their design project is only one aspect of doing a design project. Furthermore, there is a need to understand Faculty’s perspective about design to see how they position design within the engineering science courses.

Engineering epistemology – Ways of understanding engineering knowledge

Epistemology is defined as “our theories of knowledge, how we come to know the world and our ideas about the nature of evidence and knowledge” (Barbour, 2008, p. 294). This category captures students’ descriptions related to the nature of engineering knowledge and consists of three sub-categories: 1) engineering design as procedural knowledge 2) engineering design as structural knowledge and 3) engineering design as lifelong learning.

Engineering design as procedural knowledge

Procedural knowledge is characterized by “knowing how and knowing when to apply various procedures, methods, theories, styles, or approaches” to solve problems (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010, p. 18). This category captures
the nature of engineering as procedural knowledge based on the way one student describes how he learned engineering strategies to solve problems.

In his interview, Justin described how he managed one challenge stemming from a perceived misalignment between teaching and assessment. He explained his frustration with what was taught in the lectures and tutorial, being different to what was asked on the quizzes or final exam. To make sense of this perceived misalignment, Justin explained his Professor’s approach to teaching, in the words of his Professor:

I basically teach you the reason why you're learning this in class—I give you stories, I give you the theory behind the equations we’re doing; and then the assignments, I give you a problem that I haven't given you an example of because I don't want you to just follow my steps. (Justin)

Justin recognized that “for the final exam or the quiz, now you have the strategy for the problem and not the solution for it—but you now know how to go and find a solution for it”. Justin acknowledged that this process was a significant learning experience:

If you have a similar problem or a new problem that you’ve never seen before, using the techniques and the stuff that you have learned, then you are definitely going to be able to go through it, and I find this is the major component of study… (Justin)

It is evident that Justin views his engineering abilities as procedural knowledge based on the strategies he has learned to solve problems.
CHAPTER 5: RESEARCH FINDINGS - PART 2

*Engineering design as structural knowledge*

Structural knowledge is defined as knowledge that “mediates the translation of declarative into procedural knowledge and facilitates the application of procedural knowledge” (Jonassen, Beissner, & Yacci, 1993, p. 4). Structural knowledge is concerned with the knowledge that learners use for cognitive organization and how learners make connections of their conceptual (declarative) and procedural knowledge.

There is evidence that shows how students describe their thinking of engineering design as structural knowledge. Robert offered his views on the structure of technical skills and design skills:

> It runs parallel, so you have your technical skills and your design skills, you technical skills allow you to do better design and your design skills allow you utilize your technical skills much more efficiently, create a framework of how to implement them, … so they run side by side supporting each other. (Robert)

When Paul was asked to think about his past design experiences, he said that “in subsequent years my design projects have always been better—not necessarily because of the engineering knowledge I have, but because I understand the design process better, as every time I do it I learn a little bit more about it.” Paul offered further explanation of his thinking, that I have interpreted as the application of structural knowledge—the ability to connect conceptual and procedural knowledge:

> As I’m designing it I always think about—I’ve learned to think more about—the goal we’re meeting and the requirements, or the constraints, to always keep those in mind and to try to redefine what the goal is. Like sometimes the goal is to make this part, when really someone defines your goal like that, but that’s not the real goal—the real goal is make something that can do this function, not necessarily this object or product. So that kind of opens up other avenues for design to go in, other concepts you can have, and often times those concepts can be better. (Paul)
Students described design thinking as a way to structure their thinking because of its methodical and logical approach to problem solving. Students also offered their own ways of conceptualizing engineering knowledge. David described engineering knowledge as a three-dimensional spiral that you climb upwards. Robert described engineering knowledge as concentric rings of information that expand from the centre, like a dart board target.

_Engineering design as lifelong learning_

I have interpreted engineering epistemology to include a sense of engineering design as lifelong learning, where students recognize the need for continuous learning. This idea is demonstrated through Paul’s response, “I’d say it made me realize that there’s always more to learn, there’s always more you can know, no matter how many times you design the same thing there’s always going to be room for improvement.”

When asked what he thinks he can do to enhance his learning of engineering design, Paul described his attitude to learn from others: “always being open to learning new ways of doing engineering design or approaching problems.” He further elaborated on his response:

If I see someone else doing it another way I would probably want to learn it. I’ve always asked other people how they are doing things, … I’m just interested in how people would think about it, … I think I’ll continue to try to learn the way, try to think of new ways to approach problems and also to learn other people’s way of doing it—because having all these approaches, I feel would really help being able to solve a lot of different problems—having all this knowledge and problem solving approaches, I feel I would be a lot more versatile, than someone who just has a lot of knowledge or knows how to solve a problem one way. (Paul)
Paul’s descriptions capture a sense of lifelong learning fitting into students’ engineering epistemology.

**Supportive Learning Experiences**

This category captures two sub-categories where students described supportive learning experiences related to their learning of engineering design.

*Translating theory to practice in support of learning*

Engineering design is inherently tied to the translation of theory to practice through the application of math and science to design artifacts. It is not surprising that this concept appears in students’ understanding of engineering design as discussed in the first part of the research findings (Awareness and Relevance). In students’ understanding, translating theory to practice was described as something engineers do. The category presented here captures how students describe the translation of theory to practice to support their learning. For example, translating theory to practice is linked to students’ confidence about their performance. As Tyson described, the ability to apply his knowledge helped increase his confidence:

all that stuff that I thought was too hard and I didn't do very well in—‘oh I can actually apply it now’—I'm confident enough in the amount that I’ve done now, I'm confident in what I know and I can go back and reference what I felt like I didn't know for exams, but I actually know it better now that I'm actually applying it into scenarios. (Tyson)

Students’ descriptions of theory to practice in support of learning are captured below:
Bryn discussed his experience working in a research lab for one summer term where he saw theory to practice in action:

that [experience] was really huge to open my eyes to what we’re learning about, sometimes we learn more about the theoretical side to everything and we lose sort of the practical sense, to where the theory to implementation goes, and when I was working with my professor I really saw like the calculations I was doing were leading to this (Bryn)

Bryn further described the importance of theory to practice: “you have to see what you’re making and how it’s going to work, and just the design on paper isn’t always good enough, you have to have a tangible sense.”

Bryn also talked about the importance of having a physical sense of what you are doing. Not only is this level of understanding important for practice, but having a physical sense of what you are doing also supports the actual learning process. Bryn offered a basic example of the challenges to grasp a physical sense when solving structural engineering problems:

… not only did we learn engineering—we went through the design process again—but we got a better understanding of what we were learning because we actually had to put it into practice. (Bryn)

It was really good to actually complete problems and fix problems based on what I was learning in class, that was a huge part of why I enjoy engineering as a whole—the practical part of it. (Tyson)
you don’t really have any idea of, like how long a 15m beam is and you have so many kilonewtons on one end, and let’s make it a reaction somewhere else—it’s difficult to get a physical sense of that. (Bryn)

He also pointed out that it may be difficult to grasp this practical understanding “unless you experienced it”, emphasizing the need for applying theory to practice to support learning.

This category can be considered to be both an influence to students’ learning and an outcome of their learning. As one student described, “learning engineering design teaches me some aspects of real life work outside school. Without which, I would be an expert at solving math problems, not how to apply the knowledge” (B-26). I have interpreted the first sentence in this quotation to be the influence aspect, where ‘theory to practice’ has influenced what the student learns (“some aspects of real life work”). I have interpreted the second sentence in this quotation to be the outcome aspect, where ‘theory to practice’ (“how to apply the knowledge”) is the outcome of this student’s learning.

Students showed that while translating theory to practice is a part of practicing engineering design, it also supports their learning of engineering design by enhancing confidence and providing a physical sense of the subject matter.

*Realizing the significance of learning*

This category captures students’ realizations of where their learning fits into their development as engineers. Students recognize the significance of their learning by transferring elements of design practice and bringing their experiences together.
Tyson explained how he was able to apply his teamwork skills in other project courses outside of engineering and in his work as a residence life coordinator. He showed critical reflection on his experiences by acknowledging that “it helped a lot more than I was really aware of at the time” (Tyson). Tyson showed his capability for metacognition where he was not “aware at the time” but he realizes the significance of the learning experience now. Recognizing that the practice of metacognition enhances learning, educators can foster the realization of this “learning significance” early on in the learning process.

Justin talked about his experiences in bringing his learning together in the fourth year design project. His design courses allowed him to see the application of science to create something that is safe and functional. He describes his level of understanding progressing from first year and second year through to his experience in upper years:

[In first year] I didn't really know what was going on, second year, a little bit, third-year, ‘oh I see what’s happening’ … when you're doing it you thought [sic] ‘why am I doing this,’ ‘it’s not going to click,’ or ‘I’m not going to use this in real life,’ but in fourth year or third year when doing steel design, at those points, ‘oh, now I understand,’ (Justin)

Both participants’ descriptions here show how students realized the significance of their learning and that this realization can be nurtured to promote further learning.
Societal Connections

A societal curriculum orientation considers how the school is preparing students to operate in the current society and in an uncertain future. The future is uncertain because we do not know what the future will look like because of the ever-changing social factors that shape our world—technology, politics, and culture. I have organized students’ responses that capture societal connections related to the teaching and learning of engineering design.

Preparing students for society

Students’ described a feeling that school was preparation for ‘the real world’ of work—providing the knowledge and skills to secure a job after graduation. As one student said, “I have wanted to become an engineer since I was four. With an undergraduate degree (and a masters too) I will feel confident in finding a successful job” (C-8). In contrast to the engineering job-specific descriptions, another student said, “I don't plan on pursuing a career as a professional engineer, however I'm confident that the knowledge and skills I'm developing through my education are highly relevant to other callings and life applications.” (A-112) These two instances of students’ descriptions highlight the importance of holistic curriculum design. Where the societal orientation may only consider preparing students for engineering work, the engineering curriculum must balance the demands from students for a holistic undergraduate education.
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Societal learning outcomes

This category captures students’ connection between society and their learning. Students described the need for societal design exposure to enhance their learning: “I think if holistic design projects (which examined more significantly the social and economic impacts) were a greater part of my education, I would be even better prepared” (A-72).

One student’s response captures the need to connect learning to the real world: “The use of real-life examples when illustrating a concept can be very helpful. For instance, modeling a shock-absorption system in a car to teach the fundamentals of differential calculus or control systems” (A-71).

In connection with society and learning, Bryn felt that societal and other interdisciplinary factors may not be communicated clearly in engineering education. Bryn said that in his experience, “we know engineering, but we don’t know a whole lot else, about maybe why we’re doing it, we don’t have a good grasp of the people side of what we’re building.” He elaborated further with the following example:

when we’re looking at a contaminate spill, and we know that we have to meet certain requirements further downstream, so you have to model a system [to see] if that is going to exceed the threshold, we don’t really understand where that threshold comes from, or the implications of exceeding that threshold of contaminant in the stream … I don’t really know what’s going to happen if let’s say I design a drinking water plant and there is a certain level of like E.Coli that go out, I know that children and senior citizens will be affected and there may be a few deaths like in the Walkerton incident, but I don’t know what else is going to happen except for a few deaths, and I know that’s awful and I know that I have to make sure that that doesn’t happen, but I don’t really have a good sense of that sort of impact (Bryn)

The level of understanding described above identifies a need to “see the big picture”, the broader context, and the full extent of societal implications for the work that engineers
do. As Bryn said, “I think it would be important to get a full circle understanding of why you’re doing what you’re doing, and just really hit it home so that you know the objective that you’re meeting and why you are meeting it.”

As shown in the above student descriptions, students see a connection between society and their learning based on the nature of the engineering profession. It is important for engineering educators to consider how their curriculum balances the societal orientation and the needs of student learners. The individual curriculum as it relates to the needs of student learners is capture in the following theme.

**Individual Experiences**

This theme is characterized by the individual element of curriculum that considers how the curriculum serves an individual student’s learning needs and interests. The categories that make up this theme consist of elements that are related to the individual experiences of students.

**Learning spillover effects**

This category captures descriptions where students apply their education outside of their formal engineering training and typical environment. Spillover, in the innovation management literature, is a term used to describe how firms can benefit from the research and development findings of another firm (Afuah, 2003, p. 71). The word spillover is used here to describe how students’ development of knowledge and skills in a formal setting has unintentionally spilled over into other aspects of their lives.
When asked to describe his ability to problem solve, Bryn described his experience with playing a puzzle-based, cooperative, multiplayer video game. In the video game, two players are required to work together through a series of puzzles that will lead them to the end of the level. Bryn described his success in the video game: “I could see the key points, not because I’m smarter [than my partner], not because I’m necessarily more observant, but I think because I have this problem solving skill that helps out a lot, and it showed [in the video game] actually.” Bryn further describes his success in the video game due to his ability to make connections: “I was able to pinch together what was going on and see how it would flow through, I think engineering kind of taught me that.”

The second example of positive learning spillover is from Tyson’s description of how he applied engineering design in his job as a residence life coordinator. Tyson described how he was able to improve the process of scheduling staff by making a simple Excel spreadsheet with formulas that verify staff member’s availability with input dates entered by the user. Tyson said that the current spreadsheet is being implemented in other residence buildings on campus and a more sophisticated spreadsheet for a larger scale is in development. In Tyson’s words: “that spreadsheet which is very simple in nature but makes a huge difference in time, it's being used now just because people see it's more efficient and it's a lot easier.”

Tyson attributes his desire to improve the current system to his analytical frame of mind: “if I didn't think the analytical side to it and say “can I do this better?” I probably would not have … I probably would've just done it the old way and taken the time, plug and chug and got it done.” He further describes that “because I didn't like the way it was
being done, and I have the background knowledge to do that thanks to what I'm doing in school—because if I wasn’t in engineering I probably wouldn't have known how to do all the formulas and all that fun stuff with Excel and I probably wouldn't have even thought about doing it that way—so that's coming back to where my knowledge from engineering even the design process has become tangible again and benefiting me professionally.”

Tyson’s story is an example of how students can create artifacts that serve to improve lives. As engineering education strives to develop students into global, holistic citizens, this is an example of the kind of experiences that have an impact on students’ learning transfer.

Although the participants did not feel that the examples were directly related to their formal engineering education, both participants talked about their experiences as significant examples of applying their engineering knowledge and skills. The spillover effect is a positive outcome of learning and can be thought of as a type of learning transfer. Where traditional learning transfer in formal education refers to the ability to apply learning to new contexts, I distinguish the spillover effect as a hidden, unexpected, unintentional type of learning transfer. The students showed how they transferred their learning in new contexts and novel ways, but the examples did not seem to be intentional. That is, the students’ reason for learning the engineering knowledge and skills was not to solve the specific problem they described.

By recognizing that these spillover effects occur and seeing them as positive learning outcomes, educators can approach their teaching in new ways. The opportunity to intentionally teach to experiences that promote learning spillover is one way to enhance the learning experience.
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The personal pursuit of an engineering education

Part of teaching to the individual is recognizing that students enter into an engineering program for various reasons and all have various aspirations upon graduation. Of the participants who participated in an interview, one participant (Tyson) transferred into engineering after his first year of study in an arts and science program. Another participant, (David) transferred into engineering after completing a technology diploma in college. Some students may enter engineering with the intention to pursue engineering as a career, while other students may wish to pursue other professional programs. Karen plans to work in engineering industry for a while and then to pursue law school. Justin said that he was reluctant to pursue engineering but has grown to love it.

Whatever students’ reasons for pursuing engineering studies or for their future plans, engineering educators must acknowledge and appreciate this aspect of student diversity as it directly influences the teaching of the individual curriculum. Engineering educators cannot assume that all engineering students have a desire to be engineers. As demonstrated through this student’s quotation, even for students who are in an engineering program, the idea of what engineering is may still be unclear: “Honestly, I'm not extremely confident on what engineering truly is” (B-2).

The engineering curriculum is challenging because it is a professional program; therefore, the program must meet educational standards and requirements set forth by the
engineering profession to achieve accreditation. At the same time, engineering is an undergraduate degree program, where many students start their formal engineering education directly after high school. Balancing these needs and constraints is an engineering design challenge in itself, but one requirement should serve as principle to guide decision making: engineering education should strive for high-quality, personalized learning—learning that is aligned with each individuals’ needs.

**The learning continuum**

This category emerged from students’ descriptions on confidence and learning. I have defined the learning continuum to capture students’ realization of a perpetual cycle of learning based in humility and lifelong learning. The learning continuum describes the phenomenon where the more one learns and expands his or her knowledge base, the more one becomes exposed to the full extent of the field, thereby realizing that there is much more to learn. The following student descriptions show examples of how the development of the learning continuum emerged from the data.

In describing his participation with one of the University’s design teams, Paul showed metacognitive awareness when he said:

> I wouldn’t say it made me more confident, it made me, I guess, always think about that as an engineer, never think that I’m infallible, don’t assume what I’ve done is perfect or is right, it made me a little bit more confident in the fact that I’m not as afraid that I’m going to be too confident I guess. (Paul)
David also expressed similar sentiments when asked if his engineering experience has increased his confidence in his engineering abilities:

the more that you learn the more you know you don’t know… so I know that the more I’ve delve into the profession the more I know that I have a long way to go to actually become competent and you know, really proficient at it. (David)

In these two instances, the learning continuum is related to students’ confidence in their engineering abilities. The learning continuum captures the affective relationship between confidence and learning and how this attitude may impact students’ performance in their careers. Furthermore, the learning continuum is one demonstration of how students construct personal understandings of lifelong learning and metacognition. As educators strive to develop students into lifelong learners, recognizing and fostering attitudes of the learning continuum plays an important role on the teaching and learning of design.

**Summary of Research Findings Part 2 - Curriculum Studies Orientation**

In the second part of the research findings, I have presented a conceptual understanding of students’ perspectives using a curriculum studies orientation. In this way, the research findings provide insight into the design of holistic engineering education to target the teaching and learning of subject matter, societal connections, and individual experiences. This framework is summarized in the concept map (Figure 12).
Figure 12: Concept map summary of Research Findings Part 2
CHAPTER 5: RESEARCH FINDINGS - PART 2

Limitations of Research Findings

The following sections will discuss the limitations of the researching findings.

Teacher’s perspectives

The research findings are structured into two parts that adopt a learner orientation and a curriculum orientation to enhance engineering education. Both of these orientations are grounded in engineering students’ perspectives. One limitation to this study is that engineering educator’s perspectives were not investigated using my methodology and approach. Examining teachers’ perspectives of engineering design was beyond the scope of this thesis but allows for a promising avenue for further research. Understanding teachers’ perspective will provide insight into the planned and enacted curriculum. Additionally, engineering educators’ perspective will provide insight into alignment issues between students and teachers. Several authors have investigated engineering Faculty and practitioners’ perspectives on engineering using qualitative methodology (Daly, Adams, & Bodner, 2012; Pawley, 2009; Waks, Trotskovsky, Sabag, & Hazzan, 2011). Another study by Zoltowski, Oakes, and Cardella (2012) applies a phenomenographic approach to describe the different ways students’ experience human-centered design. These studies have revealed insights that complement my research findings. With these recent studies, the body of literature is growing that acknowledges the value of qualitative research directed at understanding student and faculty perspectives.

Consistent with qualitative methodology, this literature was consulted after my analysis to avoid influencing the way that I approached my data analysis. I did not set
out to find specific constructs or meanings or to emulate previous research studies—I allowed my themes and categories to emerge from my data. However, the subjective nature of my research limits the extent to which I can bracket my experience and control for external influences that may shape my own perspective. For example, my design philosophy and background will influence how I interpret my data. At the same time, I must have an awareness of current research to ensure that my research is contributing to the field.

**Difference between thinking and acting**

My questionnaire instrument for data collection was limited by the way students’ interpret the questions. So although students can describe what they think, their descriptions may not necessarily match their behaviour. For example, although engineering students can describe what they think it means to “think like an engineer,” this does not mean that they actively practice this way of thinking in their studies or daily behaviour. Furthermore, students can describe what it is, but may or may not aspire to what they are describing.

It is important to recognize that the research findings are based on my interpretation of students’ descriptions that were collected in this research. Despite differences that may exist between the way students think and act, the research findings are not intended to validate a specific reality. For example, the research findings within the theme of Transfer only considered the affective (way of being) and cognitive (way of thinking) learning domains. Where the psychomotor learning domain may exist in
realism, this domain was not considered as the data collection methods did not capture students’ actions or behaviour.

To account for these limitations, future studies involving student participants should incorporate research method triangulation. By utilizing a mix of research techniques such as focus groups and task-oriented observations, data can be collected to confirm if students act in the same way as they describe.

**Dynamic nature of students’ perspectives**

As researchers try to understand students’ perspectives, students’ perspectives may change. Karen acknowledged in her interview: “I'm actually learning as we go through this discussion”. This quotation highlights one of the challenges in qualitative research where research participants may change their behaviour based on their awareness of participation in the research study. Recognizing the difference between what students think and how they may act is important and this clarification was achieved in the personal interviews. This quotation also supports the potential for learning through metacognition and reflection.

To account for the dynamic nature of students’ perspectives, I am interpreting a snapshot of students’ understanding, where their understanding is constrained by time and place (Godfrey & Parker, 2010). I refer to the constraints of time because as students move through their education, they will have gained more experience through their coursework and extra-curricular activities. I refer to the constraints of space because each participating institution holds contextual differences. Although the purpose of this study was not to draw relationships between institutions, I included three institutions to
broaden the experiences of participating students. With this understanding, my research findings are grounded in my interpretation of the underlying concepts found within students’ perspectives given the specific time and place.

Summary of Research Findings

I have presented the research findings in a structure that offers a way of thinking about engineering design education from two orientations: 1) students’ understanding and 2) curriculum design. It is important to realize that these two orientations are not mutually exclusive as any effort to improve the design of education must utilize a holistic approach.

In the first part of the research findings, I presented insight into students’ understanding of engineering design as a way of thinking for educators to enrich learning experiences. In the second part of the research findings, I presented conceptual elements for consideration in the design of holistic engineering curriculum. In the next Chapter, I will discuss my research findings in the context of applied research to inform teaching and learning practice. I will offer new insight to make meaning out of the research findings.
CHAPTER 6

DISCUSSION

In this discussion, I will offer my interpretation as a way for engineering educators to make meaning out of the research findings. Indeed, there are very important implications and insights to be realized.

The discussion section is guided by the following questions:

1) How can engineering educators use and apply these findings in their teaching and research practice? That is, how can we make meaning out of the research findings?

2) How can students utilize my research to enhance their learning of engineering and engineering design?

To address these questions, I have interpreted the findings to make meaning for myself in three ways:

1) for my teaching practice as an educator

2) for my future work as an educational designer and engineer

3) for my personal growth as a lifelong learner

In my discussion, I will revisit each of the themes presented in my research findings to make connections between the categories and extend the findings to teaching practice. I will revisit the engineering education literature to support my findings and interpretation.
Part 1

Discussion of Students’ Understanding

A Critical View of Students’ Awareness

The aim of my research was to investigate the descriptions of meaning students have of engineering design. To this end, I presented an understanding of engineering design from the student perspective, captured in the category of Awareness. But where do these understandings come from? To take a critical view of students’ awareness, I will discuss how my research has provided insight into two elements of teaching engineering: 1) the received view of engineering design and 2) engineering design discourse.

Insight into the received view of engineering design

Slack and Wise (2007) defined the received view as “the beliefs, practices, and experiences that constitute the dominant cultural sense” (p. 67). The received view of engineering design can be applied to understand the origins of engineering students’ knowledge and challenge educators to consider what this view means for their teaching practice. The received view consists of articulations that are common and popular in the engineering culture—it is the view that students receive from the external environment. I have defined the received view as the information and perspectives that students gather from their lived experiences and external sources such as the media and schooling. These backgrounds contribute to what and how students think about engineering and engineering design. To understand the relationship between my research and the received view of engineering it is important to recognize that the received view is not positive nor negative—correct nor incorrect. The received view can be considered
information that exists in the minds of students as prior knowledge or as information that is yet to be discovered. This research has provided a basis in understanding elements that constitute to the received view of engineering and engineering design.

From the prospective student literature published by each Faculty of Engineering that participated in my study, it is evident that the projected view of engineering shares elements with students’ descriptions from my study. I have extracted quotations from the prospective student literature that speak to what engineering is about. My research findings show that student descriptions of engineering mirror the language used in these documents:

… to apply your creativity and see it in action … to learn to work together in effective groups … and to tell the world about what you have done. It’s what Engineers do in the real world. (Queen’s University, 2012a)

An engineering degree from Western will provide you with the skills and knowledge to be a successful problem solver, preparing you to address and find solutions to the needs of society. (Western University, 2012)

Our economic prosperity, health, safety and overall quality of life depend on innovations that engineers create every day. (University of Toronto, 2012, p. 4)

As my research has shown, while students’ descriptions are aligned with the projected view of engineering from the prospective student literature, it is important to challenge students to consider what these elements really mean. Slack and Wise (2007) revealed limitations in thinking when the received view of culture and technology is challenged. These limitations can raise new problems in thinking and affect our approach to solving problems. When students are challenged to think about the received view of engineering, it creates opportunities for deeper learning, enriched constructions of understanding, and
new insight. I will discuss what this practice of challenging the received view may look like, using three examples from my research findings.

*Example 1*

From the results section on student’s awareness, it is clear that there are two elements to students’ awareness of engineering design. The first element, “Engineering as producing something,” refers to what engineering design is about, what it is used for, and why. The second element “Characteristics of the engineering design process,” refers to how engineering design takes place: In what way is engineering design performed? What are the operating conditions and settings of engineering design? Examples of these two elements are presented in the following statements:

1) Engineering design is the application of math and science to solve problems—this is the “what” and “why”.
2) Engineering design is a complex, and open-ended process—this is the “where” and “how”.

In this way, I have presented students’ understanding of engineering design at the awareness level in two distinguishable elements. Each statement taken independently is insufficient to holistically describe engineering design and capture the full extent of the activity. Furthermore, these statements of common understanding may pose limitations on students’ views of engineering and subsequent openness to integrate new ideas. For example, what else is involved in applied science? What does problem-solving *really* mean?
CHAPTER 6: DISCUSSION – PART 1

Example 2

One example of how students may view engineering design is shown in the following student’s response, where this student sees a design engineer as a type of engineer:

Because if you don't understand [design], you can't work as a design engineer. And although not everyone chooses design, someone has to do it. (A-36)

Whether or not engineers actually practice design as ‘design engineers’ is not the point—all practicing engineers are engaged in the process of design. Another example of a student’s view of engineering design is provided below:

Engineering design is engineering without producing anything physical besides files or papers. For example, engineering design of a building is producing a 3D model of that building. After the model is the implementation which can involve engineering judgment which is not necessarily design. (A-137)

The nature of my study may have limited these students’ responses and there is nothing inherently false about these students’ statements; however, these quotations highlight how holistic thinking about engineering design may be challenging. Furthermore, these responses emphasize the limitations and problems that may arise from the received view, if students are not exposed to broader ways of thinking about engineering design.

Example 3

Within the theme of Relevance, students discussed the relationship of engineering education and society in terms of their preparation for a job after graduation. Because engineering is a professional program, the connection between students’ engineering studies and preparation for the job-market was not surprising. The Queen’s Faculty of
Engineering and Applied Science also promotes a similar job-related message on their prospective student website:

One of the most important differences between a pure science versus an engineering degree is that there is a career path from an undergraduate degree in engineering. Engineering graduates are qualified to pursue their professional license. Not so in science, where one typically requires graduate work to be employable in that field. (Queen’s University, 2012b)

It is important to be critical of hidden messages that may be projected. Is the professional career path afforded with an engineering undergraduate degree really “one of the most important differences” between science and engineering? Are other hidden messages about the value of other disciplines being projected or received by students through this description of the engineering profession?

It is important to challenge students’ constructions of the meaning of engineering. These constructions include what engineers do (conceptual knowledge), how engineers think (procedural knowledge), and why engineers do the work that they do (structural knowledge). These constructions must also consider the cognitive, affective, and psychomotor domains of learning. My research has provided examples of students’ constructions for engineering educators to explore in their teaching practice. It is also important for educators to realize how the received view of engineering design may impact students’ understanding. By challenging the received view of engineering, educators can make deeper connections to students’ learning.
Insight into engineering design discourse

Along with insight to the received view of engineering design, this research offers insight into design discourse—the language of design used by students in their learning experiences. Analyzing engineering discourse is important to recognize and understand hidden, “taken-for-granted” meanings of words used in engineering (see also Atman, Kilgore, & McKenna, 2008).

For example, the word design and creativity may be understood in an artistic context compared to its use in an engineering context. There is evidence of this understanding when Tyson said, “that's where I consider it to be engineering design versus just design, because if I call something design it's like ‘oh I can paint a pretty picture on the computer’, but I'm not actually building anything, I’m not actually doing anything with it.”

Another instance of engineering discourse is when David identified the difference between “problem solving” and “problem solving to create an engineered solution.” As David described below, an engineered solution is a design that does what it is intended to do, is economically viable and considers all aspects of the problem:

See that’s the thing, any problem is solvable if you throw money at it basically. I mean there aren’t many problems that can’t be solved without spending a ton of money: you can build a bridge or you can dump a ton of dirt in the ground and make a causeway. Is it necessarily the best way to do it? Probably not—it’s going to cost you a bunch of money in the long run, you got to worry about erosion, all these other factors. All these things is what the engineer takes into account. Long term and cost, I guess would also be part of it—it has to last, or else it’s not an engineered solution, it’s just a solution. (David)

While problem solving—in the most general sense—involves moving from some undesired state to a desired state, David recognized that an engineered solution is
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constrained by cost and other factors. This example exemplifies how engineering design involves problem solving, but problem solving is not necessarily engineering design.

The above instances from students’ descriptions identify areas where engineering educators can consider exploring the meaning of commonly used terms in engineering discourse. Research to deeply understand and characterize the nuances and meanings of hidden, taken-for-granted engineering language is valuable to explore further opportunities for meaningful learning.

**Applying Students’ Conceptualization of Relevance**

In this study, students described the relationship between engineering design and their learning in terms of the skills they develop throughout the learning process. This concept is categorized under Relevance because I have interpreted the skills students learn as a way students make meaning of engineering design. The skills described by students are similar in nature to the Canadian Engineering Accreditation Board (CEAB) twelve graduate attributes (Engineers Canada, 2011a, pp. 12-13).

For the purpose of this discussion, I will refer to these skills as the same as the CEAB attributes. Because these skills contribute to the way students see relationships, I challenge educators to consider the CEAB twelve attributes as more than learning outcomes to be developed throughout the teaching of some subject matter. What would a learning culture look like where the direct teaching and development of the CEAB attributes is the emphasis? These attributes are not only applicable to engineering design but are applicable to the purpose of higher education. For example, a commitment to
lifelong learning should help students continue learning beyond the classroom and in any life situation (Riley & Claris, 2008).

Can students’ understanding of engineering design be strengthened if the relationships through which they learn engineering design are also strengthened? This means developing students’ conceptual, procedural, and structural knowledge of engineering design simultaneously. Specifically, if the skills of engineering design are taught explicitly, will this help students draw deeper connections and meaning of engineering design? To address this question I will consider what past research has considered in the teaching and learning of transferable skills.

In the study by Chadha and Nicholls (2006), three approaches are applied to develop transferable skills in students: embedding, integrating, and bolting-on. Embedding is an approach where “no direct reference is made to skills development” whereas with bolting on, the “skills are developed independently of the core discipline” (p. 117). Unlike the embedded approach, an integrated approach develops skills and core competency in unison, with the intent of developing both simultaneously. Even though integrating skills development is a more common approach, the results show that students are receptive to embedding and bolting-on approaches. With these methods, the students did show the ability for metacognition – to reflect upon and be aware of their learning and personal development (Chadha & Nicholls, 2006). The study does not conclusively identify whether any one approach is better, but suggests that, as with all learning and teaching tools, various approaches should be utilized as some students may be more receptive to different styles and different situations call for different teaching methods. Teaching approaches becomes a concern for learning if there is poor implementation or
misalignment between the intended objectives and final outcomes. With an understanding of these three approaches, engineering educators must consider the extent to which they are utilizing a variety of teaching approaches and how these approaches affect learning.

Implications of Students’ Learning Transfer

Within the theme of Transfer, I presented an engineering design way of being and way of thinking. These two categories consisted of intrinsic, heavily nuanced, ways of being, seeing, and thinking. The knowledge, skills, and attitudes described in this section are applicable to any discipline. These qualities are developed throughout one’s study, but not directly as a result of one’s formal study—you will not find these elements of a students’ learning as part of any course syllabus. A design way of being and a design way of thinking extend an understanding of engineering design beyond an awareness of the work that engineers do. These affective and cognitive qualities are applicable to a broad range of industries and serve to develop holistic citizens. In line with the theme of Transfer, I will discuss two points of insight to conceptualize the transfer of my research findings to enhance teaching practice.

Engineering design as the language of innovation

To facilitate the transfer of engineering knowledge, one view is to see engineering design as the language of innovation. This idea is suggested by one participant’s response: “If Engineers know about the engineering design process, this makes collaboration easier and streamlined” (C-8). Furthermore, Karen described engineering
design as a communication tool: “you have to keep thinking that engineering is not a career, it’s a way of thinking—in that way, when I’m talking to—it doesn't matter who I'm talking to or what their background is, I can still find a way to talk about engineering things with non-engineering people.” From this perspective, engineering design enables communication across disciplines. These students have shown thinking of engineering design in terms of a language that facilitates their ability to work with others to solve problems. The research findings position educators and students to conceptualize other elements that exist in the language of learning and practicing engineering design.

The interrelationship between learning, culture, and identity – Connections of my research findings to contemporary literature

Recent publications in engineering education have utilized qualitative methodology to deeply understand students and faculties perspectives about engineering; these studies complement the findings presented in my thesis and support the usefulness of my work (Daly, Adams, & Bodner, 2012; Dunsmore, Turns, & Yellin, 2011; Pawley, 2009; Waks, Trotskovsky, Sabag, & Hazzan, 2011; Zoltowski, Oakes, & Cardella, 2012). One study conducted by Godfrey and Parker (2010) applied ethnographic methodology to study the culture of engineering. It is interesting to see that the study by Godfrey and Parker produced similar research findings to my study, although each study used two different approaches to the research. Where my research was focused on investigating students’ learning and engineering curriculum through a learning oriented lens, Godfrey and Parker used a cultural studies lens to map six cultural dimensions of engineering. Despite the different application of these two approaches to view educational research,
the six cultural dimensions show similar elements to my research findings. This unexpected outcome directs attention to understand the interplay between learning and culture when designing learning experiences. My research findings can be transferred to an understanding of engineering culture and identity formation by considering how an engineering design way of being and way of thinking, as themes presented in my research, influence culture and identity. It is clear that the design of engineering education must consider culture and identity as elements to the social construction of engineering knowledge. In this way, my research contributes to the body of literature and supports further work to understand engineering culture and identity, and its impact on learning.

In this section, I have highlighted how my research can be transferred to enhance engineering education. By considering engineering design as the language of innovation, educators can conceptualize how an engineering design way of being and way of thinking fit into this language. My research findings also contribute to the body of literature in engineering education aimed at deeply understanding engineering students to enhance learning experiences.
Part 2

Challenges to Teaching and Learning Engineering Design

In the first part of the discussion chapter, I addressed the implications of my research findings in terms of students’ understanding and learning. I will now discuss my research findings in relation to teaching practice and curriculum development, revisiting the question: how can engineering educators enhance the learning experience of engineering design? This discussion follows a similar pattern of addressing issues related to the curriculum elements of subject matter, society, and the individual.

Teaching the Subject Matter

In the following sections, I will discuss elements to conceptualize and challenge the way engineering design is taught.

Engineering design as learning transfer

To emphasize the importance of design in engineering education, I will discuss my view of engineering design as learning transfer. In this way, I offer ways to conceptualize the teaching of engineering design.

To position design activities in an educational context, I view the activity of design as synonymous with the learning objective “to create,” found at the highest level of the revised Bloom’s taxonomy of learning objectives by Anderson and Krathwhol (2001). The elements of design activities can also be found in the New Taxonomy by Marzano and Kendall (2007) within the fourth level called knowledge utilization. This
level consists of four knowledge utilization tasks all required for engineering design: 
*decision making, problem solving, experimenting, and investigating* (p. 51). It is clear 
that design is a cognitive activity that requires higher ordering thinking and learning.

As previously discussed, learning transfer is the ability to apply knowledge 
learned in one context to a different context. The significance of learning transfer in 
engineering is twofold. Learning transfer is the process of how students learn and come 
to understand subject matter; learning transfer is also what engineers do in the 
engineering profession. Connecting theory to practice—the application of math and 
science—is how we learn as engineering students and it is also our job as engineers.

Thinking about engineering design as learning transfer offers educators a way to 
conceptualize the importance of design in engineering education. From my study, 
students described their learning in terms of their ability to apply their learning. From 
this description, I realized that the way students learn is also the way engineers design.

To support my interpretation, Tyson described how he learned engineering design 
through application:

I learned more from that [experience] than anything I learned in lecture 
because I actually had to take my knowledge and apply it, and I remember it now, because I had to do it. In my mind, I’m triggered by real world applications, so that would help for learning design, having more real world applications and less theory helps. Don’t get me wrong, theory is essential and I’m well aware of that, but if you want to learn design, then you need to have problems to solve—in my opinion at least—so as I said multiple times, working on design projects helped me, I learned more from those [design projects] almost more than I do from lectures, just because I am applying the knowledge I have learned from lectures and I remember it then. (Tyson)

As shown above, the process of applying learning also enhances learning. When students 
practice design, they are required to transfer their learning. Therefore, transfer of
learning serves as the process of learning and the outcome of engineering education. This dual nature is an added benefit of training engineers because engineering educators can utilize the congruency between design and learning transfer, to enhance engineering experiences that are in line with the way students learn. While Faculty from other academic disciplines may align their teaching methods with how students learn, the engineering discipline has the opportunity to align the very work that engineers do with how students learn. In this way, active learning through design experiences—seeing theory to practice in action—is not just good pedagogy for engineering education, but it is the very nature of an engineer’s job. This concept of congruency can be applied to all disciplines and fields of study, as all higher education should foster in students the ability for problem solving; however, I emphasize that it is especially important for engineering education, because engineering is the profession characterized by the creation of products, processes, and systems.

I have discussed how engineering design, as a product and a process of engineering education, is intimately aligned with the process of learning itself. I have presented my view of engineering design as learning transfer and how this congruency opens up new opportunities to enhance learning.

**Learning to design, learning through design**

While students participate in engineering design activities, a simultaneous process of ‘learning to design’ and ‘learning through design’ is occurring. Engineering students indeed learn how to design, in that they learn the process and tools of design. Students also experience ‘learning through design,’ characterized by the learning of other
knowledge and skills, that may or may not be directly related to technical engineering itself. ‘Learning through design’ uses the process of designing as the medium for other learning. For example, because students are designing in a multidisciplinary team, they are learning and practicing teamwork skills, although teamwork skills may not be the direct objective for doing the design project. As Tyson described:

The biggest thing I learned in that class was not so much engineering process, but how to work with a team. That was probably the most tangible thing I could think of that we learned—yea we learned how to do the diagrams and the processes and that kind of stuff, but it was actually figuring out how to work together to meet deadlines, to meet criteria, to do all these things together and not have one person do everything. (Tyson)

In as much as design experiences can be used to teach and reinforce technical engineering science, it is clear that students also learn a great deal of other skills and knowledge. Design projects offer rich learning experiences for students through various pedagogical characteristics as shown in Figure 13.

**Figure 13: Pedagogical characteristics of design projects.**

Design projects provide multiple streams of learning with the advantage of learning in multiple learning domains. I refer to streams of learning as the ways students *can* learn.

Design projects provide opportunities to learn individually or in a team, to conduct
research through reading or through experiments, to work at a desk or in the field. I refer to the different learning domains as cognitive, affective, and psychomotor, to describe the extent of knowledge, attitudes, and skills that are developed through design projects. As one student says, “design projects are the time when I can bring together knowledge from other areas” (A-146). Finally, design projects are multidimensional in relation to the three elements of curriculum and the three types of knowledge. Design projects allow for the integration of learning across subject matter, society, and the individual; design projects afford students the opportunity to develop and enhance their conceptual, procedural, and structural knowledge of engineering.

I have presented the pedagogical characteristics of design projects that afford the opportunity for students to learn to design and through design. With a conceptual framework for thinking about the design project experience, engineering educators can engage students in meaningful learning.

**Prototyping learning through reflection**

One critical element in any engineering design process involves building a prototype or model of the product, process, or system. In product development, prototypes are used to “validate form, fit, and/or function” (Eggert, 2005, p. 208). Brown (2009) offered another way of thinking about prototypes as “anything tangible that lets us explore an idea, evaluate it, and push it forward” (p. 92). As Brown said, the goal of prototyping is to “give form to an idea to learn about its strengths and weaknesses and to identify new directions for the next generation of more detailed, more refined prototypes” (p. 91). Adopting an engineering design approach to the design of educational systems,
what would an educational prototype look like? How can engineering educators build prototypes of their teaching methods? How can students build prototypes of their learning? That is, how can students “explore an idea, evaluate it, and push it forward” (Brown, 2009, p. 92)? I propose that one way for students to prototype their learning is to engage in reflection. Schön (1983) identified ways professionals develop their thinking through reflective practice (see also Adams, Turns, & Atman, 2003; Currano & Steinert, 2012). To explore the idea of prototyping learning through reflection, I will consider the similarities between the process of design and the process of experiential learning.

Each year of schooling provides more opportunities for students to learn and grow. From first year to fourth year, students take more engineering courses and gain more life experience. However, as Kolb (1984) and Schön (1987) identified, experience alone is not enough to ensure learning. Reflection on the experience is also necessary to translate experience into learning and complete the learning cycle from abstract concepts to concrete examples (Kolb, 1984).

To bring together ideas of learning and design, Figure 14 shows how the learning process can be mapped onto the design process. Using an extended experiential learning cycle that includes two additional times for reflection (Leberman & Martin, 2004), I have matched the elements of the learning process with the general engineering design process (Massachusetts Department of Education, 2006, p. 84). By showing the relationships between each phase of each process, this figure supports the idea of engineering design as learning transfer previously presented in this thesis. Furthermore, this figure provides a way of thinking about how students experience design and learning simultaneously.
Figure 14: Extended experiential learning process (outer cycle) matched with the engineering design process (inner cycle) to show design as learning.

Although each year of schooling provides new opportunities for learning, reflection is required to translate the experience into meaningful learning. Therefore, prototyping learning through reflection offers one way to help students realize their learning for themselves. I present the diagram above (Figure 14) as a way of thinking about design education that meets the need for students to experience design combined with reflection, to translate their experience into meaningful learning. With this diagram, students and Faculty can conceptualize what it means to prototype their learning through reflection.
Enhancing student engagement

Student engagement involves the interaction of two elements: student motivation and active learning (Barkley, 2010). In the quotation below, Barkley (2010) captured several of the aims of my thesis, one of them being to support engineering educators in their teaching role:

As college teachers, we can strive to increase experiences of deep engagement, reduce the incidence of indifference and apathy that characterize lack of engagement, and attend to the many ways we can adapt our teaching methods to enhance engaged learning. (p. 8)

In the following section, I will discuss how this research has provided insight to advance both elements of student engagement: student motivation and active learning.

Student motivation

A high level of student engagement, leading to high quality learning, requires the participation of two partners: the teacher and the student. Teachers can create the opportunities and environment for active learning. Through our teaching practice, we can also stimulate learners towards given tasks. But motivation towards learning is an intrinsic quality that must come from the student. As Slavin (2012) explained:

All students are motivated. The question is: Motivated to do what? …Your job is not to increase motivation per se but to discover, prompt, and sustain students’ motivation to learn the knowledge and skills needed for success in school and in life, and to engage in activities that lead to this learning. (p. 286)

Can educators support students’ motivation by helping students make connections to see the reason behind their learning—that is, to gain a better understanding of “why?”
Justin described his struggle in first year when he did not understand why he was taking certain courses. He realized that first year was a general first year so it was a necessary program requirement:

[in first year] a lot of courses were very general, like I have to take chemistry when I knew that I'm not going to ever use chemistry … I didn't really feel much [sic] that I'm studying civil engineering, but it is called general engineering year. (Justin)

Justin described how he made the connection in his final year of studies: “the most beautiful thing is … how you put everything together and that happens only in fourth year.”

Students who are motivated to pursue engineering may have an easier time adopting an engineering education. Students who are highly motivated know what they want, know why they are doing the work, and know where they want to go. But for students who may be unsure about what they are doing—students who are still exploring their career options and discovering themselves—what can an engineering education offer them? As I have presented in this thesis, an engineering education grounded in learning engineering design offers a wide range of experiences and opportunities for students. It is up to engineering educators to take advantage of these multiple understandings and opportunities to help students realize their full potential as engineers and as citizens. In the next section, I will present one theory from educational psychology to help educators engage students’ motivation towards engineering design.
Engaging students’ self-system thinking about engineering design

Marzano and Kendall (2007), in their new taxonomy of educational objectives, identified self-system thinking as an “interrelated arrangement of attitudes, beliefs, and emotions … that determines both motivation and attention” of student learning (p. 55). The four types of self-system thinking are presented below (Marzano & Kendall, 2007):

1) examining importance
2) examining efficacy
3) examining emotional response
4) examining overall motivation

With this understanding, engineering educators can apply my research findings to engage students’ self-system thinking. For example, the findings suggested that the way students understand engineering design is through the relationships they make between engineering and society. Therefore, this relationship serves as an opportunity for students to examine the importance of what they are doing.

Another opportunity for engaging students’ self-system thinking is to identify and probe views of students’ future career paths. For example, this student describes the utility of engineering in response to the question about how engineering supports one’s career:

Engineering education fashions skills so essential and applicable to a diverse number of fields, it becomes irrelevant whether or not one’s particular ambitions fall inside or outside the realm of engineering. (A-74)

This example demonstrates one student’s perception of engineering which may influence all types of his or her self-system thinking. I present this example to challenge
engineering educators to consider how their teaching practice influences and accounts for students’ perceptions in their self-system thinking.

Engineering curriculum must aim to provide students with as much exposure and opportunities to experience engineering design—to see it in action and apply what they are learning. On top of this, it is important that students understand the purpose of these goals, opportunities, and objectives to engage in metacognition and their self-system thinking. My research findings provide a conceptual framework for engineering educators to target students’ self-system thinking in their teaching practice.

*Experiences that stick – Active learning to engage all three levels of understanding*

Active learning occurs when a student “actively examines, questions, and relates new ideas to old, thereby achieving the kind of deep learning that lasts” (Barkley, 2010, p. 17). As Barkley (2010) described, active learning is about students being part of the learning process through their involvement in processing knowledge—“where students make information or a concept their own by connecting it to their existing knowledge and experience” (p. 17). As described here, the essence of active learning involves students engaging in metacognition and reflective practice. Active learning calls for students to prototype their learning.

Another process for active learning is found in the visual thinking process presented by Dan Roam (2009) in his book, *The Back of the Napkin*. Roam (2009) presented four phases of visual thinking: *look, see, imagine, show*. Visual thinkers look at the situation, see what is really there (critical thinking), imagine what could be
(creative thinking), and show it to others (communication). By connecting the visual thinking process and the definitions of active learning, the visual thinking process can be applied to better understand what active learning means and how engineering educators can achieve active learning in the classroom.

As shown below, Justin showed elements of active learning by recognizing the moments of “deep learning that lasts” (Barkley, 2010):

if something happens that I find ‘oh, that makes a lot of sense to me,’ it would stick to my head forever, and when I started to work on the design project, a lot of moments that I had before really came back to me at that point. (Justin)

What makes certain learning experiences stick with students? I define experiences that stick as those that students remember; and they remember those experiences because they had an impact—the experience had meaning. So what are the elements of meaningful learning? As I have presented in this thesis as the themes of understanding, for meaningful learning to occur, engineering educators must engage students in all three areas of Awareness, Relevance, and Transfer.

**Engineering Curriculum and Society**

Engineering as a profession is intimately linked to society because everything that engineers design is used by humans and is intended for the benefit of society. Students in this study identified this relationship. Beyond the relationships between engineering and society through the work that engineers do, there was also sentiment of a higher engineering ideology as part of an engineering design way of being, where it is an engineer’s calling to “help the world.”
Because engineering is a professional degree program, it is not surprising for engineering students to value societal implications in their work, as this aspect is promoted in the engineering curriculum. One student’s description captures the importance of understanding people and culture in engineering:

I would put more emphasis on the fact that background knowledge is key and knowing something about a lot of different topics, especially humanities, is a huge advantage. Engineers are not taught nearly enough about the social effects of the technology they develop … if the design is for the benefit of people, then we should really understand the needs of the people it is meant to benefit. (A-7)

Recognizing that engineers serve people, this quotation supports the use of service-based learning to engage students to connect with society as a part of what it means to be an engineer. In this way, identifying engineering and society as an element in how students’ draw relationships, opens up many opportunities for program and learning enrichment.

Designing for the Individual

The three elements of education that make up an educational experience are students, teachers, and curriculum. To create high quality learning experiences, educators can control for their own behaviour: they have a direct influence over the planned and enacted curriculum. However, controlling for the student becomes complicated because there are many external factors that affect how students learn. As teachers, we can only create an environment that fosters learning. We cannot impose learning onto others, but we can facilitate and direct students through their own journey of learning. Therefore, can we provide the resources for students to become better engineering learners? That is, through our teaching and curriculum, can we prepare students to be learners of the engineering discipline? In this thesis, I have focused on
how engineering educators can design curriculum and learning experiences; but what would a design of our students look like, to prepare them to learn engineering?

In his interview, David identified a need to teach students to be self-directed learners:

David is referring to the need for students to be lifelong learners: learners with the ability to “set goals, apply appropriate knowledge and skills, engage in self-direction and self-evaluation, locate required information, and adapt their learning strategies to different conditions” (Kirby, Knapper, Lamon, and Egnatoff, 2010, p. 292; see also Knapper & Cropley, p. 47, 2000).

Engineering educators can create opportunities for learning, but for these opportunities to be effective in producing high quality learning, the learner must also be receptive and take responsibility as an active participant in the learning process.

Therefore, can engineering educators do a better job on both educational fronts: creating the environment for learning and creating better learners?

To create better learners, engineering educators can teach students a framework for learning grounded in self-directed learning theory. Loacker & Dohery (1984) presented a transitional model, shown in Figure 15, which identifies three phases of self-directed learning development.
Phase 1: Internalizing Learning

Phase 2: Transfering Learning

Phase 3: Directing Learning

Figure 15: Self-directed learning process (Loacker & Dohery, 1984).

A description of each phase is provided (Loacker & Dohery, 1984):

**Phase 1:** Learners relate learning to themselves in two ways:

1) Realization of the self as the agent of learning and that one must engage in learning within, as a change in perception and abilities
2) Realization of the importance of learning

**Phase 2:** Realization that learning can be applied in different situations and can be adapted for new settings

**Phase 3:** Learning in informal and non-formal settings

- Learner can integrate and use abilities independently
- Learner takes the initiative for planning and evaluating development

Candy (1991) also provided three dimensions educators can foster in their classrooms to promote self-directed learning: *competence, resources, and rights* (pp. 417-424):

- *Competence* – develop the appropriate skills and attitudes of self-directed learning in students
- *Resources* – providing learners with the appropriate resources
- *Rights* – enabling the learner’s personal belief and perceptions about their own learning and how societal factors contribute to these perceived rights

I have presented the above resources as examples of how educators can promote self-directed learning in their teaching practice. Thinking about self-directed learning in terms of these frameworks and dimensions provides educators with the conceptual knowledge of education. The research findings from my thesis provide the context and further understanding for engineering educators to apply their knowledge to design effective learning experiences.
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Although the goals of self-directed learning may be hidden and implicit in current engineering education, I present the idea that designing for the individual student—beyond designing curriculum to meet individual needs—is an opportunity for engineering educators to enrich learning experiences. Teaching the learning process explicitly—the knowledge, skills, and attitudes for learning—has the potential for enhancing students’ abilities for metacognition and self-directedness, therefore leading to more meaningful learning experiences.

Other Emerging Opportunities

The following sections present opportunities for research that emerged from my research findings. Although these sections were not major themes or categories for my study, the insights presented offer opportunities for further research and alternative ways of thinking about teaching and learning in engineering education.

Holistic engineering design outreach

Students pursue engineering studies for various reasons—their careers after graduation are varied and broad. Engineering education has the challenge of preparing students for the engineering profession, while recognizing that the practice of engineering is only one potential career path. This is one constraint on the education of engineers: to balance professional accreditation requirements while providing students with a holistic education. While the professional status of engineering may be a marketable feature to prospective students and highlights what engineers do, can engineering be marketed as a career because of the way of being and way of thinking one learns from studying
engineering? As I have presented in the theme of Transfer, are the ways of being and thinking being promoted to provide students with a holistic view of engineering education? Above all, enhancing engineering recruitment strategies requires prospective students to take an active role in choosing their career paths. Through engineering design outreach, educators can stimulate students’ motivation to pursue engineering.

Outreach activities are not only concerned with student recruitment. The goals of outreach can simply be to increase awareness for the engineering profession. In any case, I propose that engineering outreach emphasize the many facets of engineering that make up a holistic understanding of awareness, relevance, and transfer—including what we do, how we think, and why we do it.

**Hidden learning and experiences**

Students are having experiences and learning from these experiences, but it is not necessarily the intended learning outcomes—although the learning is still beneficial and important. Sometimes, the learning may be exactly what we want them to take away from the experience, but comes as a by-product of going through the experience, not necessarily as an explicit objective. This emphasizes the importance of instructional design: Are we actually designing experiences for learning?

Throughout an engineering education, there may be many instances of hidden learning—learning that is not explicitly part of any subject matter, but highly applicable to the development of an engineer. Are there hidden learning experiences that are critical to an engineer’s development that can be designed into the formal engineering
curriculum? For example, Paul described his learning on the school’s extra-curricular aero design team, where he had the opportunity to travel to the design competition:

… you talk to the other teams, you always learn a lot from the other teams, even though you do your own research and you build your own plane … some teams really try some interesting things and it’s always cool to learn how those things work too (Paul)

In addition to Paul’s experience, another student also shared similar sentiments on learning from others: “seeing everyone else's solutions was very effective in becoming open to engineering design (A-137). These descriptions support the need for students to learn from their peers and connect their learning in new contexts. Justin provided another example of hidden learning through his interactions with his Professors, teaching assistants, and peers. These interactions acted as experiences of positive reinforcement, helping to increase his confidence in engineering. Although educators cannot account for every aspect of learning, recognizing and fostering these opportunities for hidden learning will serve to enrich students’ overall educational experiences.

**Students’ engineering voice - Constructivism in learning engineering design**

Recognizing that students construct their own meanings of engineering design is important for engineering pedagogy. Based on a constructivist view, learning is a social activity where students construct meanings based on their social interactions. Therefore, engineering educators can create learning opportunities where students practice constructivism to generate their own knowledge. I refer to this concept as developing students’ engineering voice.
voice. As one student points out, “the fundamental mindsets and approaches to engineering design are difficult to impart because they are different for so many people because it comes from personal experience” (C-13). Students draw meaning from their design projects, summer work experiences, and personal initiatives related to engineering. These experiences can act as prior knowledge sites, allowing learners to fit new information from their classes into their prior experience. Exposure to engineering environments and problems can provide students with a context for their learning.

Not only can student constructions of engineering design help engineering educators teach more effectively, but the exploration of students’ constructions can be a learning activity in itself for students to generate their own understandings. As one student said, “I think developing your own idea of engineering design is important” (B-33). In a personal interview, Karen described her personal constructions of engineering design:

I think it's a very versatile skill, I think the word engineering doesn't necessarily mean that you are an engineer. When you engineer something you don't have to have an engineering background, it just helps to learn that way, but I mean engineering in my opinion is a way of thinking … if you are going through this design process that we kind of learn in engineering—this way to approach problems and critical thinking and kind of the iterative approach—I guess then I think that is engineering, and it's important because that is how society progresses. (Karen)

As I have presented in this section, engineering educators can support students to find their own engineering voice and develop their own engineering identity through a constructivist approach to learning. In this way, students can develop their critical thinking skills and independent thought that is the hallmark of higher education.
CHAPTER 6: DISCUSSION – PART 2

Engineering students’ epistemic beliefs on learning engineering design

It is important for educators to have an awareness of engineering students’ epistemic beliefs about learning engineering design. We know that students’ conceptions of their learning task will influence how they approach the task.

Some participants in my study expressed concerns that “engineering design cannot be taught.” I will not argue over the validity or applicability of this statement, but being critical about this statement reveals aspects of the received view that provide a platform for discussion from an educational perspective. I challenge engineering educators to reflect in their teaching philosophy: what does it mean to teach? Through this reflection, the statement “engineering design cannot be taught” can be challenged to reveal insight into how educators can teach engineering design. Pratt (1998) offers five perspectives of teaching in higher education that considers how educators’ attitude towards teaching influences their teaching strategies. If teachers and students are viewed as partners in the learning process, engineering educators must make their teaching approach explicit, to support students’ metacognition and self-directedness.

The attitude that “engineering design cannot be taught” is coupled with the sense that to learn engineering design, one must experience it. As one student said:

I think engineering design is challenging to learn because it is challenging to teach. It is difficult to impart knowledge gained from personal and work experiences, which is where engineering design is really learned. (C-13)

Another student expressed similar sentiments:

Engineering design is a mix between pure creativity, and expertise in your discipline. It's not possible to teach creativity, only to practice it. Expertise only comes with time and most undergrads have not spent enough time in their fields. (B-22)
As discussed in the section on prototyping learning through reflection, although students may be exposed to engineering design through experience, to capture tacit knowledge and translate experience into learning, engineering educators and students must engage in reflective practice. The implementation of reflective practice is growing, with current literature being published on teaching techniques using reflection (Currano & Steinert, 2012; Schaefer, Panchal, Thames, Haroon, & Mistree, 2012). The call for reflective practice in design is not new; my research, grounded in students’ epistemic beliefs about learning engineering, has provided further insight into the context for engaging students and engineering educators in critical reflection.

In this section, I have focused on two aspects of engineering students’ epistemic beliefs about learning engineering design: 1) engineering design cannot be taught and 2) learning engineering design comes from experience. Being critical of these elements directs engineering educators to consider the meaning of teaching and the role of reflection on learning.

Summary of Discussion

This research has addressed several challenges to the teaching and learning of engineering design: How can engineering educators create meaningful learning experiences? How can we promote deep learning? How can we promote learning transfer? The discussion section has served to provide insight into these questions, offering engineering educators with ways to apply educational research to inform teaching practice. By presenting a conceptual understanding of students’ perspectives, engineering educators are challenged with ways of thinking about teaching and learning,
and how design education can be integrated into the engineering curriculum—educators may be better positioned to teach to the holistic student. I have also offered critical perspectives for students to consider as active participants in the learning process, to support their development into self-directed lifelong learners. The concept map presented in Figure 16 displays a summary of the concepts found in the research discussion.
Figure 16: Concept map summary of research discussion.
CHAPTER 7

CONCLUSION

The design of engineering education is a complex, open-ended challenge with many social and technological constraints—it is a dynamic and humanistic process. This research aimed to explore how educators can create meaningful learning experiences in engineering design education. A qualitative investigation was conducted to understand engineering students’ perspectives of their experience with learning and practicing engineering design. Data collection methods consisted of an online questionnaire targeting undergraduate engineering students in first year, third year, and fourth year at three Canadian engineering schools. Follow-up personal interviews with willing participants were also conducted to gain in-depth information. Rigorous qualitative analysis was performed to conceptualize students’ descriptions and provide practical ways for engineering educators to create meaningful learning experiences.

My thesis has taken two orientations to structure students’ perspectives about teaching and learning in engineering education: 1) a learning theory (cognitive studies) orientation and 2) a curriculum studies orientation. From a learning theory orientation, the themes of awareness, relevance, and transfer are offered as a way to conceptualize students’ understanding of engineering design. Within these themes, I have outlined opportunities where engineering educators can target students’ constructions of engineering design to enhance learning. From the curriculum studies orientation, my research has identified ways to enact the curriculum elements of subject matter, society, and the individual that are directly linked to students’ experiences. Through these two orientations, I have provided conceptual, procedural, and structural knowledge about
students’ perspectives, as a way to apply educational theory to enhance engineering education. The structure from the concept maps offer engineering educators with a framework of conceptual ways to promote holistic engineering design education—an engineering education that considers the three elements of students’ understanding and the three elements of curriculum.

Engineering education is one of the greatest design challenges facing engineers in the 21st century. The performance of engineering education as a product, process, and system will undoubtedly play a significant role in shaping society. In the final chapter, I provide recommendations to advance the teaching and learning of engineering.
CHAPTER 8
RECOMMENDATIONS

The recommendations that have emerged from this research are applicable to a wide audience in the engineering education community. I have organized my recommendations for the following stakeholders:

- Students
- Engineering Educators
- Curriculum Developers
- Further Researchers

Although specific stakeholders are targeted, it is important to interpret these recommendations holistically to appreciate the perspectives and implications for all stakeholders. For each recommendation, the corresponding thesis section is included in parentheses.

**Recommendations for Students**

**Recommendation #1**: *To promote self-directed learning, it is important for students to practice metacognition and think critically about their own learning process.*

*(Research Findings and Discussion)*

Higher education strives to develop students into self-directed, lifelong learners: Learners who can activate their own intrinsic motivation, create their own personalized learning curriculum, and engage in their own assessment. To accomplish this goal, students must take an active role in their education by critically engaging in their learning
CHAPTER 8: RECOMMENDATIONS

process. This research challenges students to understand their learning process of engineering design and how it relates to their experiences. The research offers a platform for students to practice metacognition in their learning of design, by reflecting on how their own design experiences may fit into the learning and curriculum frameworks presented in the research concept maps.

Recommendations for Engineering Educators

Recommendation #2: There are opportunities to create meaningful learning experiences when students engage in all three levels of understanding: awareness, relevance, and transfer. (Research Findings Part 1, Students’ Understanding of Engineering Design)

Insight into these levels of understanding from students’ perspectives is offered to help educators apply the science of learning in their teaching practice. Beyond characterizing engineering by the activities of what engineers do, the themes of relevance and transfer support the ways students think about design, learn design, and formulate an engineering design identity. In an effort to build engineering educators’ pedagogical content knowledge, the research findings provide ways engineering educators can think about student engagement and designing instruction to target students’ holistic understanding of engineering design.
CHAPTER 8: RECOMMENDATIONS

**Recommendation #3:** Reflective practice allows engineering educators to capture their tacit knowledge of teaching and learning and make meaning out of their experiences.

*(Discussion Part 2, Challenges to Teaching and Learning Design)*

My research has offered perspectives and insight to challenge engineering educators to be critical of their own teaching practice. My research findings provide points of entry for engineering educators to help build students’ metacognitive ability. In the same way, engineering educators can benefit from engaging in metacognition to learn about their own teaching as a way to connect with students.

**Recommendations for Curriculum Developers**

**Recommendation #4:** To foster holistic engineers, holistic engineering education considers all three elements of curriculum: subject matter, society, and the individual.

*(Research Findings Part 2, The Teaching and Learning of Engineering Design)*

My research offers conceptual ways of thinking about engineering education as a means for educators to apply research to teaching practice. In this way, this research strives to increase the innovative capacity of engineering educators and curriculum developers to create new learning experiences that are intentional and authentic. The research provides insight for educators to think critically about improving design education—positioning educators to challenge their assumptions, appreciate the influences of varying educational contexts, gain awareness for diversity, support decision making and evaluation, and search for new possibilities in pedagogy. For example, based on the constructivist view of knowledge generation, there are opportunities for learning
through communities of practice and student portfolios. These activities promote social interaction, creative knowledge generation, identity formation, and critical reflection.

Balancing the elements of curriculum, and utilizing holistic pedagogies, will support the development of holistic engineers who are prepared for the complex societal and technological challenges of the future.

This research can be applied to develop teaching and learning workshops to target the training of engineering educators. Based on the connections between design and learning, my research has also provided in-roads for thinking about integrating engineering design across all programs in higher education.

**Recommendations for Further Researchers**

**Recommendation #5:** *Further research into students’ perspectives can be done using mixed method research designs including various qualitative measurement techniques and quantitative research approaches.*

Recognizing that knowledge and understanding is socially constructed, future avenues for this research include focus groups and observations to see how engineering students negotiate meaning with their peers. Also, future studies should include observational activities that provide the opportunity for the application of knowledge in action, to see if the way students think and feel is actually how they act in reality. Further research should also include engineering educators’ perspectives on engineering design, including faculty, administration, and curriculum developers.
CHAPTER 8: RECOMMENDATIONS

Quantitative inquiry can be pursued to determine the strength of my research constructs in students’ understanding. Quantitative methods are also appropriate to quantify the extent of curriculum elements in engineering education.

As partners in the educational process, educators and students both play an important role to optimize engineering education. The recommendations offer a conceptual basis to enhance the teaching and learning of engineering design.
EPILOGUE

I began my Master’s Program with a passion to improve the education of engineers. What this final product would look like, or how this process would unfold, was unclear to me—but my passion has always remained true.

This thesis is how I have come to understand engineering education. As students and educators navigate the field of engineering education for themselves, they will formulate unique identities and stories. This thesis is my story: capturing my growth as an engineer, a researcher, an educator, and an educational designer. My journey has taken many different paths and seen many challenges—but it has been a truly enriching, rewarding, and invaluable experience.

Creating meaningful learning experiences for engineering students is a highly complex and open-ended task. If this thesis has inspired, challenged, or enlightened you with a creative way of thinking, a new way of feeling, or a different way of doing—as it has for me—then I am happy to have made my contribution to engineering education.
REFERENCES


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REFERENCES


Queen’s University. (2012a). *Engineering and Applied Science at Queen’s - Prospective student brochure*. Kingston, ON: Faculty of Engineering and Applied Science


REFERENCES


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REFERENCES


REFERENCES

APPENDIX A

RESEARCH INSTRUMENTS

A.1 Questionnaire
A.2 Interview Protocol
APPENDIX A: RESEARCH INSTRUMENTS

A.1 Questionnaire

Questionnaire

Student Perspectives of Engineering Design Education

It is important that you try your best to answer the questions honestly and in your own words. You will not be able to go back to questions once you have clicked to the next question. If you are ready to begin, click next.

1. How would you describe the profession of engineering to a senior high school student considering engineering undergraduate studies?

2. In your opinion, describe the relationship between the fields of “math and science” and engineering.
   a. How do you see this relationship fitting in to your understanding of what it means to be an engineer?

3. Describe what it means to you “to think like an engineer”?
   b. What personal experiences have contributed to your thinking that you described above?
   c. Has your coursework reinforced the thinking that you described above? If so, how?

4. In your own words, define engineering design?
   d. Has your understanding of design changed during your program? If so, how?

5. In your opinion, how does learning engineering design relate to your undergraduate studies of engineering?

6. Do you feel your engineering education supports your overall career and life goals? If so, how? If not, please explain?

The next section is an optional part of the questionnaire and will take approximately 15 minutes. If you would like to continue, click next. If you would like to complete the demographic section and end the questionnaire, click Demographic Questions. Thank you for your time.

1. What do you think makes engineering design important to learn?

2. What do you think makes engineering design challenging to learn?
3. What would help you learn engineering design more effectively?

According to the Engineers Canada, engineering design is defined as:

[the integration] of mathematics, natural sciences, engineering sciences, and complementary studies in order to develop elements, systems, and processes to meet specific needs. It is a creative, iterative, and open-ended process, subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may also relate to economic, health, safety, environmental, societal or other interdisciplinary factors. (Engineers Canada, 2010, p. 18)

4. How does this definition vary from your previous understanding of engineering design?

5. Based on this definition from Engineers Canada, would you answer the following questions differently? If so, how?

a. What do you think makes engineering design important to learn?

b. What do you think makes engineering design challenging to learn?

c. What would help you learn engineering design more effectively?

Demographic Information

Current Year of Study: 1 3 4 Other (Please explain)

Age:

Gender: Male, Female, Prefer not to reply
APPENDIX A: RESEARCH INSTRUMENTS

Please select your engineering discipline: Year One Common Year, Chemical, Civil, Computer, Electrical, Engineering Chemistry, Engineering Physics, Engineering Science, Geological, Industrial or Manufacturing, Mathematics and Engineering, Materials or Metallurgical, Mechanical, Mechatronics, Mining or Mineral, Software, Other (Please specify)

Did you start your engineering undergraduate program directly after high school? YES NO

If no, please describe what you did before enrolling in engineering undergraduate studies (ie. college program, transferred from another degree program into engineering, extra year of high school, work).

Did you participate in any of the following activities (check all that apply)?

- Extracurricular design team (ex. Baja SAE, Concrete Canoe, Solar Design Team)
- Professional internship (12- or 16-months)
- Summer work term in engineering related field (4 months) (Please explain)

Request for participation in a personal interview

For the second part of data collection, personal interviews will be conducted to follow-up with students’ questionnaire responses. Please provide your name and email if you would like to participate in a personal interview. Participation in an interview is completely voluntary and your contact information will be confidential.

Name:
Email:

If at any time you wish to remove your responses from the study, the researcher requires an anonymous reference code to identify your responses in the database. Please enter a unique 6 figure reference code (any combination of letters, numbers, and/or symbols) that will be your unique identification for this study. Retain this code for your records. If you wish to remove your data, you may email the researcher (Richard Aleong, aleongr@appsci.queensu.ca) with this reference code.

Thank you for participating in this study.
A.2 Interview Protocol

Interview Protocol

Student Perspectives of Engineering Design Education

Interviewee: ____________________
Date: ___________________________
Location: _______________________

Hello,
My name is Richard and I am the graduate student from Queen’s University conducting this study. Thank you for volunteering to participate in this interview. The purpose of this research is to understand how undergraduate engineering students describe their experiences and thinking about engineering education. You will be asked to reflect on your experiences and describe what engineering means to you. You are not obliged to answer any question if you do not wish to do so.

This interview will be tape recorded for research purposes but the interview will be confidential. Before we begin, please review this consent form and sign at the bottom if you wish to proceed.

Do you have any questions before we begin?

2. Tell me a little bit about why you enrolled in an engineering program?

3. What did you expect to learn in engineering?
   b. Have these expectations been met in your program to date?
   c. What are your future expectations for learning?

4. Tell me about one significant experience you’ve had with engineering design?
   b. In your opinion, what was it about this experience that made it engineering design?
   c. How did this experience shape your understanding of what it means to be an engineer?
   d. Has this experience made you more confident in your engineering abilities? How? Why?

7. What do you think makes engineering design important to learn?
8. What do you think makes engineering design challenging to learn?

9. What would help you learn engineering design more effectively?

According to the Engineers Canada, engineering design is defined as:

[the integration] of mathematics, natural sciences, engineering sciences, and complementary studies in order to develop elements, systems, and processes to meet specific needs. It is a creative, iterative, and open-ended process, subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may also relate to economic, health, safety, environmental, societal or other interdisciplinary factors. (Engineers Canada, 2010, p. 18)

10. How does this definition vary from your previous understanding of engineering design?

11. Based on this definition from Engineers Canada, would you answer the following questions differently? If so, how?
   a. What do you think makes engineering design important to learn?
   b. What do you think makes engineering design challenging to learn?
   c. What would help you learn engineering design more effectively?

12. How do you see the relationship between your engineering education and this definition of design?
   e. Can you describe how you may have applied this definition in your design experience?

13. Do you feel your experiences and studies in engineering have prepared you to be successful at engineering design? If so, how? If not, why?
   a. Probing: Have your studies reinforced this definition of design?

14. Do you feel your engineering education has prepared you for your future career? If so, how? If not, why?

15. Looking forward, what do you think you can do to enhance your learning in engineering?

That’s all of my questions. Is there anything you would like to add? Do you have any questions for me?

Thank you for your time and best of luck with your studies.
APPENDIX B

PARTICIPANT RECRUITMENT DOCUMENTS

B.1 Enrollment numbers of targeted students for recruitment

B.2 Letter of Information

B.3 Recruitment Email

B.4 Consent Form
APPENDIX B: PARTICIPANT RECRUITMENT DOCUMENTS

B.1 Enrollment numbers of targeted students for recruitment

Table B.1: Approximate enrollment numbers of targeted students for recruitment.

<table>
<thead>
<tr>
<th></th>
<th>Western</th>
<th>Queen’s</th>
<th>Toronto</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Year</td>
<td>-</td>
<td>633</td>
<td>1248</td>
</tr>
<tr>
<td>3rd Year</td>
<td>-</td>
<td>660</td>
<td>1048</td>
</tr>
<tr>
<td>4th Year</td>
<td>-</td>
<td>852&lt;sup&gt;a&lt;/sup&gt;</td>
<td>974&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>2145</td>
<td>3270</td>
</tr>
</tbody>
</table>

Notes:
Enrollment numbers obtained from respective Faculty of Engineering and Applied Science Offices.

Western – Enrollment numbers not available.

Queen’s
Enrollment as of January 31, 2012
<sup>a</sup>This includes all years after 4<sup>th</sup> year.

Toronto
Enrollment as of November 1, 2011
<sup>b</sup>This number does not include 574 students enrolled in the Internship year.
B.2 Letter of Information

Letter of Information

Student Perspectives of Engineering Design Education

This research is being conducted by Richard Aleong, a graduate student in the Department of Mechanical and Materials Engineering at Queen’s University in Kingston, Ontario, Canada, under the supervision of Professor David Strong.

The purpose of this research is to understand how undergraduate engineering students describe their experiences and thinking about engineering education. You will be asked to reflect on your experiences and describe what engineering means to you. The questionnaire will take approximately 30 minutes of your time. At the end of the questionnaire, you will be asked if you would like to participate in a personal interview to describe your experiences further. If you wish to participate in an interview, you will be asked to provide your name and email for contact purposes. If you choose to participate, you will be making a contribution to enhance the quality of engineering education.

There are no anticipated risks for this study and participation is completely voluntary. You may decline to answer any or all questions that you do not wish to answer. You are free to withdraw at any time with no effect on your standing in school. If you wish to withdraw from the study during the questionnaire, simply close the questionnaire window at any time. If you wish to withdraw your responses from the questionnaire after submission, email Richard Aleong at the contact information provided at the end of this letter. All responses will be confidential and no identifying information will be linked to your responses. Access to data will be limited to the primary researcher and supervisor. Results of the study may be disseminated at conference presentations and papers, and the researcher’s Master’s thesis.

In accordance with Queen’s policy, data will be retained for a minimum of five years, after which it will be destroyed or retained indefinitely. If the data is used for secondary analysis, it will contain no identifying information.

Your decision to continue with this questionnaire will be interpreted as an indication of your consent to participate. By choosing to continue with the study, you indicate that you have read this Letter of Information, understand the nature of the study, and give consent to participate voluntarily.

Any questions about study participation may be directed to Richard Aleong at aleongr@appsci.queensu.ca or the supervisor of this study Professor David Strong at (613) 533-2606, strongd@appsci.queensu.ca. Any ethical concerns about the study may be directed to the Chair of the General Research Ethics Board at 613-533-6081 or chair.GREB@queensu.ca.
APPENDIX B: PARTICIPANT RECRUITMENT DOCUMENTS

This study has been granted clearance according to the recommended principles of Canadian ethics guidelines and Queen’s policies.

Thank you for your consideration to participate in this study.

Richard Aleong – M.A.Sc. Candidate, Mechanical and Materials Engineering, Queen’s University
David S. Strong, P.Eng. – (Research Supervisor), Professor and NSERC Chair in Design Engineering, Faculty of Engineering and Applied Science, Queen’s University

If you wish to participate in this study, click “Continue.” Otherwise, you may exit the study. Thank you for your time.
Hello,

My name is Richard Aleong and I am a graduate student in the Department of Mechanical and Materials Engineering at Queen’s University in Kingston, Ontario, Canada. I am conducting a study as part of my graduate research to understand how undergraduate engineering students describe their experiences and thinking about engineering education. In this study, we are asking students in first year, third year, and fourth year to complete an online questionnaire that will take approximately 30 minutes of your time. Participants must be 18 years of age or older at the time of completing the questionnaire. If you choose to participate, you will be making a contribution to enhance the quality of engineering education. At the end of the questionnaire, you will be asked if you would like to participate in a personal interview to describe your experiences further. If you wish to participate in an interview, you will be asked to provide your name and email for contact purposes.

If you would like to participate in this study, please follow the link below and you will find more information in the Letter of Information. Please complete the questionnaire by October 21, 2011.

Thank you for your time and interest in participation.

Link to questionnaire: http://ca.studentvoice.com/queens/studentperspectives2

Richard Aleong
M.A.Sc. Candidate
Mechanical and Materials Engineering
Queen’s University, Kingston, Ontario

David S. Strong, P.Eng., (Research Supervisor)
Professor and NSERC Chair in Design Engineering
Faculty of Engineering and Applied Science
Queen’s University, Kingston, Ontario
APPENDIX B: PARTICIPANT RECRUITMENT DOCUMENTS

B.4 Consent Form

Consent Form

Title of the Research: Student Perspectives of Engineering Design Education

Principal Investigator: Richard Aleong

1. I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

2. I am 18 years of age or older.

3. I grant permission for the researcher to use a digital voice recorder.

4. I grant permission for the researcher to use quotations from my interview but these quotations will remain anonymous.

5. I understand that my participation in this study is voluntary and I may withdraw at any time. I understand that every effort will be made to maintain the confidentiality of the data now and in the future. The data may also be published in professional journals or presented at scientific conferences, but any such presentations will be of general findings and will never breach individual confidentiality. Should you be interested, you are entitled to a copy of the findings.

6. I am aware that if I have any questions, concerns, or complaints, I may contact the graduate student conducting this research, Richard Aleong, aleongr@appsci.queensu.ca; or the project supervisor, Professor David Strong (613-533-2606), strongd@appsci.queensu.ca. If I have any ethical concerns about the study, I may contact the Chair of the General Research Ethics Board (613-533-6081) at Queen’s University: chair.GREB@queensu.ca.

I have read the above statements and freely consent to participate in this research:

Name of Participant (print): __________________________
Signature of Participant: ____________________________ Date: __________________

Name of Researcher Obtaining Consent: Richard Aleong
Signature of Researcher Obtaining Consent: ____________________________
Date: __________________

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APPENDIX C

RESEARCH ETHICS APPROVAL FOR HUMAN PARTICIPANTS

C.1 Certificate of Completion of Research Ethics Course

C.2 Ethics Approval Letter from Queen’s University

C.3 Ethics Approval Letter from University of Toronto

C.4 Ethics Approval Letter from Western University
C.1 Certificate of Completion of Research Ethics Course

Certificate of Completion

This document certifies that

ALEONG, RICHARD J C M

has completed the Queen’s University online Course in Human Research Participant Protection (CHRPP).

Date of Issue: January 4, 2011
C.2 Ethics Approval Letter from Queen’s University

September 06, 2011

Mr. Richard Aleong, Master’s Student
Department of Mechanical & Materials Engineering
Queen’s University
Beamish Munro Hall, Room 301
45 Union Street
Kingston, ON K7L 3N6

GREB Ref #: GMECH-013-11; Romeo # 6006114
Title: “GMECH-013-11 Student Perspectives of Engineering Design Education”

Dear Mr. Aleong,

The General Research Ethics Board (GREB), by means of a delegated board review, has cleared your proposal entitled "GMECH-013-11 Student Perspectives of Engineering Design Education" for ethical compliance with the Tri-Council Guidelines (TCPS) and Queen’s ethics policies. In accordance with the Tri-Council Guidelines (article D.1.6) and Senate Terms of Reference (article G), your project has been cleared for one year. At the end of each year, the GREB will ask if your project has been completed and if not, what changes have occurred or will occur in the next year.

You are reminded of your obligation to advise the GREB, with a copy to your unit REB, of any adverse event(s) that occur during this one year period (access this form at https://eservices.queensu.ca/romeo_researcher/ and click Events - GREB Adverse Event Report). An adverse event includes, but is not limited to, a complaint, a change or unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that all adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be cleared by the GREB. For example you must report changes to the level of risk, applicant characteristics, and implementations of new procedures. To make an amendment, access the application at https://eservices.queensu.ca/romeo_researcher/ and click Events - GREB Amendment to Approved Study Form. These changes will automatically be sent to the Ethics Coordinator, Gail Irving, at the Office of Research Services or irvingg@queensu.ca for further review and clearance by the GREB or GREB Chair.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Yours sincerely,

Joan Stevenson, PhD
Professor and Chair
General Research Ethics Board

cc: Dr. David Strong, Faculty Supervisor
C.3 Ethics Approval Letter from University of Toronto

PROTOCOL REFERENCE #20884

September 16, 2011

Dr. Susan McCahan  Mr. Richard J. Aleong
Mechanical and Industrial Engineering  Mechanical and Industrial Engineering
University of Toronto  University of Toronto
2 King’s College Road  2 King’s College Road
Toronto, ON M5S 3G8  Toronto, ON M5S 3G8

Dear Dr. McCahan and Mr. Aleong:

Re: Your research protocol entitled, “Student Perspectives of Engineering Design Education”

ETHICS APPROVAL

Original Approval Date: September 16, 2011
Expiry Date: September 15, 2012
Continuing Review Level: 1

We are writing to advise you that the Social Sciences, Humanities and Education Research Ethics Board has granted approval to the above-named research study under the REB’s delegated review process. Your study has been approved for a period of one year and ongoing projects must be renewed prior to the expiry date.

All your most recently submitted documents have been approved for use in this study.

Any changes to the approved protocol or consent materials must be reviewed and approved through the amendment process prior to its implementation. Any adverse or unanticipated events should be reported to the Office of Research Ethics as soon as possible.

Please ensure that you submit an Annual Renewal Form or a Study Completion Report 15 to 30 days prior to the expiry date of your study. Note that annual renewals for studies cannot be accepted more than 30 days prior to the date of expiry, as per federal and international policies.

If your research has funding attached, please contact the relevant Research Funding Officer in Research Services to ensure that your funds are released.

Best wishes for the successful completion of your project.

Yours sincerely,

Dean Sharpe, Ph.D.
Research Ethics Board Manager–Social Sciences and Humanities
C.4 Ethics Approval Letter from Western University

Use of Human Participants - Ethics Approval Notice

Principal Investigator: Dr. Ralph C. Echols
Review Number: 19-4126
Review Level: Full Board
Approved Local Adult Participants: 0
Approved Local Minor Participants: 0
Protocol Title: Student Perspectives of Engineering Design Education
Department & Institution: Mechanical & Materials Engineering, University of Western Ontario
Sponsor: Nature, Sciences and Engineering Research Council

Ethics Approval Date: December 08, 2011

Documents Reviewed & Approved & Documents Received for Information:

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This is to notify you that The University of Western Ontario Research Ethics Board for Non-Medical Research involving Human Subjects (NMREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the applicable laws and regulations of Ontario has granted approval to the above named research study on the approval date noted above.

This approval shall remain valid until the expiry date noted above, subject to: (a) receipt of timely and acceptable responses to the NMREB's periodic requests for assurance and monitoring information;

Members of the NMREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussions related to, nor vote on, such studies when they are presented to the NMREB.

The Chair of the NMREB is Dr. Riley Hinson. The UWO NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number: IRB 00006941.

Signature

The University of Western Ontario
Office of Research Ethics
Support Services Building Room 2154 • London, Ontario • CANADA • N6G 1G3
PH: 519-661-3000 • F: 519-661-2400 • ethics@uwo.ca • www.uwo.ca/ore/ethics

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APPENDIX D

ANALYTICAL TOOLS

The following list of analytical tools were used during the qualitative analysis process. A full description of these analytical tools can be found in Corbin and Strauss (2008, p. 69).

- The use of questioning – “so what?” and “what if?”
- Making comparisons
- Thinking about the various meanings of a word
- Using the flip-flop technique – turning a concept “inside out” or upside down” to obtain a different perspective, looking at opposite or extreme range to bring out significant properties
- Drawing upon personal experience
- Waving the red flag – being aware of analysts and participants biases, beliefs, and assumptions
- Looking at the language
- Looking at emotions that are expressed and the situations that aroused them
- Looking for words that indicate time
- Thinking in terms of metaphors and similes
- Looking for negative cases
- Looking at structure of the narrative and how it is organized in terms of time or some other variable
APPENDIX E

EXAMPLE OF RESEARCH DATA CODES AND CATEGORIES

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APPENDIX F

STATEMENT OF RESEARCHER BACKGROUND

This statement of my background and experiences is provided to position myself as the researcher in this work. I outline my perspectives as a way for other researchers to understand how I approach the research. This statement is organized into three sections that capture the facets of my background as a researcher and educator: 1) My experience in education and teaching 2) Other influential experiences and 3) My personal perspectives.

My experiences in education and teaching

My graduate level courses were taken in the Faculty of Education and include courses in curriculum design, qualitative research methods, adult education, and technology and culture. Also, I have taken a full term course on teaching and learning in higher education. I am an active participant in extra-curricular programs and events as part of my University’s Centre for Teaching and Learning. I have completed the full series of four certificates of the Program for University Teaching and Learning that recognized teaching foundations, leadership, experience, and scholarship. I was a teaching assistant for a third year and fourth year multidisciplinary design course. I was also a teaching assistant for a fourth year elective course in ergonomics and design. I have also served as a project manager for a first year design course, supervising project teams of first year students, and as a problem-analysis mentor for a first year course using model-eliciting activities.
In my role as a teaching assistant for the third and fourth year multidisciplinary design course, I was responsible for the evaluation of course deliverables including weekly team progress reports and memos, as well as evaluating interim and final presentations and reports. Being involved with student assessment of these deliverables made me realize where students were having difficulty understanding the design process. Two areas I observed as lacking in students’ understanding was communication and project management. At some points throughout the course, it was not clear to me if the students were engaging effectively with progress reports and memos as communication and project management tools. Because I was a teaching assistant as I was conducting my research, I bring this bias towards the interpretation of my research results. I am driven to help students see the deeper meaning behind what they are learning; therefore, I approach this research in a way that looks for tools to help me facilitate learning in my students.

My graduate courses and teaching activities have largely shaped my views of education, the way I approach my teaching and learning, and how I draw meaning from my research. I am mindful of how my perspectives, my own design knowledge, and my pragmatic approach, may influence my interpretations of the research data.

Other Influential Experiences - Other roles in engineering outreach and an educational capacity

I completed a 16-month Professional Internship after my third year of engineering studies (2008-2009). I worked in the Quality Assurance and Research & Development Department of a large general contracting construction firm. Although I was not directly
applying the technical coursework I had studied in school, this internship helped me build confidence in my personal abilities. Upon returning to school, I was able to see the direct benefit of my internship as I could relate my coursework to my work experience.

Throughout my undergraduate engineering program and my graduate studies, I have volunteered with engineering outreach and recruitment events, including university fairs and engineering faculty open house events. In this capacity, I talked to prospective high school students who were considering engineering studies. These interactions influenced my attitudes towards engineering education as I wanted to provide as much information to prospective students to help them make their career path decisions.

I have worked for three summer terms (2005-2007) in an educational capacity at the Ontario Science Centre, an interactive science museum. I have also worked at Shad Valley (2009-2010), an engineering enrichment summer program as a Program Assistant, Program Manager, and guest facilitator where I delivered workshops and lectures about engineering design. I also volunteered as a Scout Leader (2008-2009) planning educational and recreational activities for youth ages 11 to 14. Because these experiences in teaching and learning have shaped who I am as an educator, it is important to recognize these experiences as influential to my pragmatic approach to engineering education research.

My personal development and perspectives

To capture my perspectives that have influenced my development as a researcher, designer, and educator, I have conducted an autoethnographic study of my experiences in navigating the field of engineering education (Appendix G). My autoethnography is the
APPENDIX F: STATEMENT OF RESEARCHER BACKGROUND

process of how I have come to find meaning and identity in my graduate program. It is important to recognize that my autoethnography occurred alongside my own thesis research and as such, may have influenced my thesis work. I challenged myself in my master’s program to develop a personal curriculum, through which I formulated an identity as an educational engineer with an interdisciplinary understanding. I realize that this identity formation is one of the driving factors behind my attitude to teach to the holistic learner.

In this statement of my experiences and perspectives, I have presented my researcher background to enhance researcher credibility and transparency. My background serves to position myself as the qualitative researcher and to enhance the trustworthiness of my research interpretations.
APPENDIX G

RESEARCHER AUTOETHNOGRAPHY

This autoethnography was published in the 2012 conference proceedings of the American Society of Engineering Education, San Antonio, Texas.

In Search of Meaning and Identity: An Autoethnography of a Graduate Student Navigating the Field of Engineering Education

Introduction

Institutions of higher education strive to develop students into self-directed, lifelong learners. To support this mission and create high quality learning experiences, it is important to consider how students’ learning experiences influence their development. As a graduate student navigating the field of engineering education, what experience can I offer to support fellow students in their personal development as self-directed, lifelong learners? This paper is about my formative experiences as a second year Master’s Candidate conducting research in engineering design education.

For me, navigating the field of engineering education has been a challenge in navigating the unknown. I use the term ‘unknown’ to describe my situation at the start of my graduate studies. I was driven to make the most of my experience, but I did not know what I was looking for or what my path would look like. I present this autoethnography as an account of my experience in the cultural phenomenon of navigating the unknown:
searching to make the most out of my graduate experience in a field that was unfamiliar to me.

I define this work as autoethnography because I use myself as the primary data source, recalling my memories and using my documented personal reflections, to explore how the cultural phenomenon of navigating the unknown has shaped who I am. As Chang (2008) stated, “autoethnography is not about focusing on self alone, but about searching for understanding of others (culture/society) through self” (p. 48-49). Chang further explains that “the writing process evokes self-reflection and self-analysis through which self-discovery becomes a possibility. The study of other self-narratives helps readers compare and contrast their lives with those of self-narrators” (p. 41). I inquire into my journey as a graduate student in engineering education so that other students and educators may find meaning from my experience.

My Critical Perspectives

My story begins in my undergraduate years of study where I started to form critical perspectives towards my education. I started my undergraduate studies in engineering directly after high school because it was the next thing to do. My attitude at the time was simply to go to University and get a degree, which would then serve as the springboard for my career. Despite seemingly limited options, I was not challenged after graduating from high school to be critical of my career path. Upon graduating from University, I became aware of the choice of options before me: I could work in engineering industry, I could pursue my entrepreneurial dreams, I could pursue graduate research in engineering, I could pursue graduate work in another area of interest. Faced
APPENDIX G: RESEARCHER AUTOETHNOGRAPHY

with these decisions, I started to be critical of my career and my goals for further education. I started to question how graduate studies would benefit me in the future. My critical perspectives started in undergraduate studies and have been strengthened and developed throughout my graduate program. These critical perspectives challenged my assumptions and caused me to question the purpose of my actions. Through analysis of my personal memories and reflection entries, I have organized my critical perspectives into four categories:

1. Challenges in Undergraduate Engineering
2. Other Opportunities
3. My Graduate Degree Program
4. Benefit for Employers, Benefit for Myself

Challenges in Undergraduate Engineering

I realize that during my undergraduate years, I was a passive stakeholder in my education—I allowed the curriculum of the school to act on me. A personal reflection made during my graduate studies captures my frustration in my learning during my undergraduate years:

I didn’t really take responsibility for my learning because I never really figured out what my learning should look like, I didn’t know what I really wanted out of my education…so four years came and went…I had closed my eyes and did whatever I had to do just to finish undergrad. (Aleong, Personal reflection, May 2011)

Perhaps my passive attitude towards my education was not challenged during my undergraduate years because I was overwhelmed with trying to survive in engineering—I did not have the time or energy to step back and consider what I was doing.

Undergraduate engineering was an academically challenging program for me. I was highly driven by my academic performance and the workload of engineering kept me very busy. My personal reflection above points to this survival mode: “I had closed my
eyes and did whatever I had to do …”. Although my undergraduate experience was rich with learning, and prepared me well to advance my career, I did not embrace self-directed learning to the fullest extent. I never challenged myself to identify the need for what I was learning. I passively accepted a third party—the engineering school—to set my educational curriculum, and so I did not have time to explore my other interests. Although I was able to choose course electives to customize my program, I did not establish the underlying need for my studies that would make my coursework meaningful for me.

Other Opportunities

At the start of my program, I was very aware that pursuing graduate work would require me to stay in school for another two years, when my friends would be moving on to other opportunities and life experiences. I was aware that graduate work would be a significant financial commitment. Because I also had many opportunities presented to me after graduation, I questioned how my career may have unfolded, had I gone down a different path. However, because the path to pursue graduate work was one that I actively chose, I was determined and inspired to make my experience meaningful. How could I validate my graduate work to myself, to prove that my time and energy was worthwhile? At the end of my program, I wanted to be able to identify my personal growth for myself.
APPENDIX G: RESEARCHER AUTOETHNOGRAPHY

My Graduate Degree Program

I started my graduate degree program directly after my undergraduate engineering studies, and I am now in my second year as a Master of Applied Science Candidate registered in the Department of Mechanical and Materials Engineering. Although my institution does not currently have a formal engineering education research program, my master’s thesis research is in engineering design education. My research is not technical engineering work in traditional engineering science areas. I do not model fluid dynamics in wind tunnels. I do not measure the tensile strength on metal alloys used in nuclear reactors. I am conducting qualitative research to understand undergraduate engineering students’ perspectives of their engineering design education. Because my degree program is a Master’s of Applied Science but my research is in engineering education, I struggled with an internal conflict over the nature of my degree. Do my colleagues in engineering value my program differently because I am not conducting traditional engineering science research? Do my colleagues in education judge the legitimacy of my program because it is different and unique? With this struggle over the nature of my degree, I challenged myself with self-reflective questions to make sense of my career path: Who am I as an engineer? Who am I as an educator? Where do I fit in engineering education? How is this shaping me into the person I wish to become?

Benefit for Employers, Benefit for Myself

Pursuing graduate studies provides the opportunity to enhance one’s credentials to be more competitive in the job market. Although an advanced degree may be attractive to potential employers, this was not a heavily weighted factor in my decision to pursue
graduate work. Nonetheless, the economic pressure to secure a job had an impact on my attitude to make my graduate education meaningful. How can I best position myself to be marketable to potential employers? How can I market myself as an engineer when my Master’s degree is not in a technical engineering field? If I continued to pursue education, what will I teach? If I pursued engineering work after graduate studies, what artifact will I design in industry? Am I pursuing an advanced degree by building off of my undergraduate studies, or am I starting all over again in a new field completely?

More importantly, beyond thinking about potential employers, I started to think critically about my education to find the real benefit for myself. Beyond the knowledge and skills employers may find attractive, what knowledge and skills do I want to develop for myself as an individual?

The stories and questions captured in these four categories formulate my critical perspectives towards my education. These critical perspectives motivated me to make the most out of my graduate experience and reveal my personal questions as I attempt to make sense of my decisions and behaviour.

My Search for Meaning and Identity

My critical perspectives reveal an overarching theme that I identify as “my search for meaning and identity”. I was driven to make my graduate experiences meaningful and my critical perspectives show why finding meaning in my graduate work was important to me. My search for identity is captured through my struggle to situate myself as an engineering student studying education at the graduate level, while conducting applied educational research.
By being critical about my education and challenging my assumptions about my career path, I have repositioned myself as an engineer, researcher, and educator. I have found meaning in my work through an interdisciplinary understanding that serves to integrate my various positions. Mansilla, Miller, and Gardner (2000) state that individuals show an interdisciplinary understanding when “they integrate knowledge and modes of thinking from two or more disciplines in order to create products, solve problems, and offer explanations of the world around them” (p. 18). These authors explained that “with an interdisciplinary understanding disciplines are not simply juxtaposed. Rather, they are purposefully intertwined. Concepts and modes of thinking in one discipline enrich students’ understanding in another discipline” (p. 29). I have embraced an interdisciplinary understanding to balance the triadic tension I felt between my identities as an engineer, researcher, and educator.

Stevens, O’Connor, Garrison, Jocuns, and Amos (2010) described identity as “a double-sided process of positioning ourselves and being positioned by others” (p. 357). My sense of identity refers to the way I see myself and the way others see me, in the engineering education context. Applying an interdisciplinary understanding to position myself both within engineering and education, I identify myself as an educational engineer (see also Charters, 1945; Charters, 1951; Anderson, 1961): designing products, processes and systems to optimize student learning. Finding my sense of identity as an educational engineer has led me to new growth and understanding in my engineering education research and practice. I am able to situate myself in my work as an engineer, researcher and educator.
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Discussion - New Questions, New Insights

At the start of my graduate program, I did not set out to find personal meaning and identity. I was driven to make the most of my experience, but I did not know what I was looking for or what my path would look like. In navigating the field of engineering education, my search for meaning and identity emerged as the process and the product of my growth. As a process, my search for meaning and identity provides two insights: 1) it is how I have come to understand my growth in the field of engineering education and 2) it is how I have come to make meaning out of my critical perspectives that challenged me at the beginning of my graduate work. As a product, I now identify myself as an educational engineer with an interdisciplinary understanding. The following two sections will discuss how I have applied this understanding to make sense of my experiences.

Integrated Thinking

I remember one Professor encouraging me that if I was serious about engineering education, I should first work towards my Ph.D. in a technical engineering field. After this achievement, he said, I would then be able to pursue my interests in engineering education. I am reminded of this conversation as I question my own engineering education values to make sense of my experiences.

Do I hold technical engineering as my primary strength and education as secondary? Am I a mechanical engineer first and interested in education second? Are my interests in education independent to my knowledge, skills, and attitude as an engineer? How do engineering educators view the research field of engineering
education in relationship to their own discipline specific technical research? How do engineering educators position themselves in an interdisciplinary framework?

With my sense of identity as an educational engineer, I am better prepared to tackle and unpack these challenging questions. I have broadened my scope of what engineering means to me to encompass a holistic definition. With an interdisciplinary understanding, my engineering and education experience both support and elevate one another to higher levels of thinking. I no longer have to choose between engineering or education. Instead, I can pursue both my passions under one framework of integrated thinking—that of an interdisciplinary educational engineer.

**Designing My Path**

The technical knowledge of math and science that are engrained in undergraduate engineering studies are only a few of an engineer’s tools for design. As an educational engineer, the technical tools that I apply for design are different to the analytical tools of math and science common to traditional engineering fields. Although I have not studied technical engineering science at the graduate level, I have been able to build and strengthen my technical skills in engineering design. For me, my degree is an advanced degree because—compared to my thinking after undergraduate studies—I have developed a higher, more sophisticated, holistic, level of thinking and attitude towards learning.

From the beginning of undergraduate studies until now, I have realized that my education has followed an iterative process of divergence-convergence-divergence-convergence—an outward-inward movement to find my true passion and calling. The
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first stage of divergence occurred during the early years of undergraduate studies where I was exploring all the fields of engineering and had not chosen my engineering discipline. My junior and senior years mark the first phase of convergence: within the broad field of mechanical engineering, my interests converged on materials engineering. The first year of my master’s program marks the second phase of divergence, where I branched out to explore the field of engineering education. Now, in my final year of my Master’s program, I am converging onto the area of engineering education that interests me.

Adopting the same time scale and applying the divergence-convergence model, my engineering colleague’s paths may look more like divergence-convergence-convergence. After the first phases of divergence and convergence similar to my experience, they continued to converge further into an area of specialty within their chosen engineering discipline. This area has now become their specific research topic and area of expertise.

My graduate program afforded me the time to develop my knowledge and skills as a self-directed, lifelong learner. As I sought to extend my learning beyond the institution’s curriculum, I embraced the opportunity to take ownership for my education. Each student’s story is unique and meaningful, and the struggle to find my identity has helped me make sense of my story. With my sense of identity as an educational engineer, I know that the path I am on is the path that I have designed for myself—and I am prepared to create meaningful experiences as I traverse new pathways.
Conclusion and Recommendations

I have presented my experiences and perspectives in finding meaning and identity as a graduate student in the field of engineering education. I have discussed how these experiences have shaped me into a self-directed, lifelong learner. Although my autoethnography offers an account of my experiences and perspectives that are unique to me, the overarching theme for this work has been about a search for meaning and identity. I offer the following recommendations to students and educators in their search for meaning and identity.

For Students

Being critical about my education led me to find meaning in my graduate program and has strengthened my experience as a graduate student. Are students critical of their school experience? Do students question how their educational curriculum, encompassing activities guided by the school and themselves, influences their learning and growth? My autoethnography strives to challenge students to think critically about their education and find their own sense of meaning and identity in their school experience.

For Educators

There is a resounding call in academia for interdisciplinary research and practice to drive innovation. My autoethnography presents my enculturation of an interdisciplinary understanding within engineering education. For educators who may be interested in growing graduate programs in engineering education, it is recommended that
the development of new program structures, resources, and strategies consider the role of meaning and identity on students’ learning and growth.

As students and educators navigate the field of engineering education for themselves, they will formulate unique identities and stories. Capturing and making meaning out of these stories will continue to provide insight into the culture of engineering education, to ultimately create high quality learning experiences.

**References**


