EXPLORING STUDENTS' MOTIVATION TO ENGAGE IN SUSTAINABLE ENGINEERING PRACTICE

by

Natasha K. Lanziner

A thesis submitted to the Department of Mechanical & Materials Engineering

In conformity with the requirements for

the degree of Master of Applied Science

Queen's University

Kingston, Ontario, Canada

(June, 2017)

ABSTRACT

This study used a quantitative approach to explore Canadian undergraduate students' motivation to engage in sustainable engineering practice. Engineering is considered to be a key profession for sustainable development, which requires engineers and engineering students to be motivated. An ex-post facto design was used to measure students' stereotypes of and previous experiences with, self-concept of abilities of, and relative value of sustainable engineering practice. These elements were used to investigate and compare students' motivation levels across gender, year of study, and engineering discipline. A survey instrument was developed specifically for this study and was tested in a mixed method pilot study with a sample of graduate engineering students. After the pilot study, the improved survey instrument was distributed to undergraduate students at eight engineering institutions across Canada.

The results from the survey instrument suggested that students' have high value for but limited experiences with sustainable engineering practice. As a result, the the results suggested that students are not necessarily motivated to engage in sustainable engineering practice. Male students were found to have slightly higher self-concepts of some of their abilities and no differences were found among year of study. Most differences occurred among the engineering disciplines in the Stereotypes and Previous Experiences factors. Students in the ECE and Science, and Mechanical- Based disciplines had less positive and more limited experiences than students in the Chemical- and Environmental-Based disciplines. There were some differences between the ECE and Science and the Environmental-Based disciplines in students' relative value. Generally, students valued sustainable engineering practice more for utility than intrinsic

reasons. In all disciplines, students were biased towards the environmental element of sustainable engineering practice and incorporated only simplistic considerations.

A universal definition and understanding of sustainable engineering practice should be adopted to provide a foundation for practice. Generally, students require more experiences with sustainable engineering practice in their engineering programs. To address the differences among the disciplines, discipline-specific interventions should be developed to address the application and integration of the social, economic, environmental, and multidimensional elements of sustainable engineering practice.

ACKNOWLEDGEMENTS

I would first like to thank the research participants who gave their time and energy to make this study possible. The participants would have been far fewer without the assistance of the indispensable individuals who volunteered their time at the participating institutions. I would also like to thank the participating institutions generally, and more specifically, the assistants, instructors, and students that aided in the distribution process.

The Faculty of Education at Queen's University welcomed me warmly and supported me as if I were a student in their faculty. I would like to personally thank Dr. Lynda Colgan, Dr. Don Klinger, and Dr. Jamie Pyper for their patience, guidance, and support as I stepped into the world of educational research.

To my fellow Master student colleagues and friends, David Waller, Ajay Sivanand, and Hannah Smith, thank you for your time, understanding, and support. Your enthusiasm for engineering education was inspiring and made my graduate experience that much more enjoyable.

I would like to thank Myriam Beaulne for her multifaceted support. First and foremost, thank you for your assistance with translation, I would have been lost without you. But more so, thank you for listening and providing a different perspective on my research topic.

I would especially like to acknowledge and thank my supervisor, Professor David Strong, for providing me with this exceptional opportunity to conduct engineering education research. Thank you for your interest, openness, and support for my research topic of interest. Your encouragement, guidance, feedback, and support were critical throughout the entire process. I would also like to acknowledge and thank the NSERC Chairs in Design Engineering program for funding.

As a final note, I would like to thank my family and friends for their support. In particular, I would like to thank Thomas Watson for his continuous encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

EE	Engineering Education
EESD	Engineering Education for Sustainable Development
ESD	Education for Sustainable Development
KMO	Kaiser-Meyer-Olkin measure of sampling adequacy
SDG	Sustainable Development Goal
SEP	Sustainable Engineering Practice
TBL	Triple Bottom Line elements including people, planet, and profit

CHAPTER 1

INTRODUCTION

In 2015, the United Nations outlined 17 Sustainable Development Goals (SDGs), of which at least 11 relate directly to the engineering profession (UN, 2015). In accordance with the SDGs, the UNESCO Engineering Initiative emphasized the need to "apply engineering and technology to global issues and challenges such as poverty reduction, sustainable development and climate change" (UNESCO, 2010, p. 6). However, sustainable development was first established in traditional western culture through the Bruntland report in 1987 where it was defined as "Development that meets the needs of the current generation without compromising the ability of future generations to meet their own needs," (World Commission on Environment and Development, 1987, p. 43). In addition to this definition, sustainable development is considered to have three central pillars: social, environmental, and economic. Sustainable development is interdisciplinary in nature, but political and professional organizations worldwide consider engineering to be a key profession in the achievement of sustainable development (Byrne, Desha, Fitzpatrick, & Hargroves, 2010; WFEO, 2013). However, to fulfill this role, changes to the traditional roles of engineering professionals are needed (Fuchs, 2012).

In response to the changes in the roles of engineering professionals with regard to sustainable development, Engineering Education for Sustainable Development (EESD) has emerged with an aim to teach engineering students to think critically and to act for sustainable development. Some EESD literature explores students' approaches towards sustainable engineering as opposed to sustainable development (Haase, 2014; McCormick, Bielefeldt, Swan, & Paterson, 2015a). However, there is no accepted definition of sustainable engineering. In the literature, sustainable engineering is associated with the Triple Bottom Line (TBL) elements, people, planet, and profit, which align with the central pillars of sustainable development. Sustainable engineering is also associated with environmental stewardship, which aligns with the environmental pillar (WFEO, 2013). Although not clearly defined, sustainable engineering is often associated with the development of new technologies with low environmental impacts, or environmental benefits when compared to current alternatives. Technologies that offer low economic or social impacts, or economic or social benefits, are rarely discussed in reference to the term sustainable engineering.

This study aimed to broaden the range and depth of consideration of sustainable development within the context of engineering by using the term sustainable engineering practice. Sustainable engineering practice was considered to be within the context of professional engineering practice, and was defined as the practice of engineering in a manner that contributes towards sustainable development. Such practice was considered to incorporate the TBL elements in accordance with sustainable engineering principles. Gagnon, Leduc, and Savard (2008) outlined a framework of sustainable engineering principles organized by the TBL elements and central pillars of sustainable development as shown in Figure 1. Sustainable engineering principles are also supported by portions of the WFEO Model Code of Practice for Sustainable Development and Environmental Stewardship (WFEO, 2013).

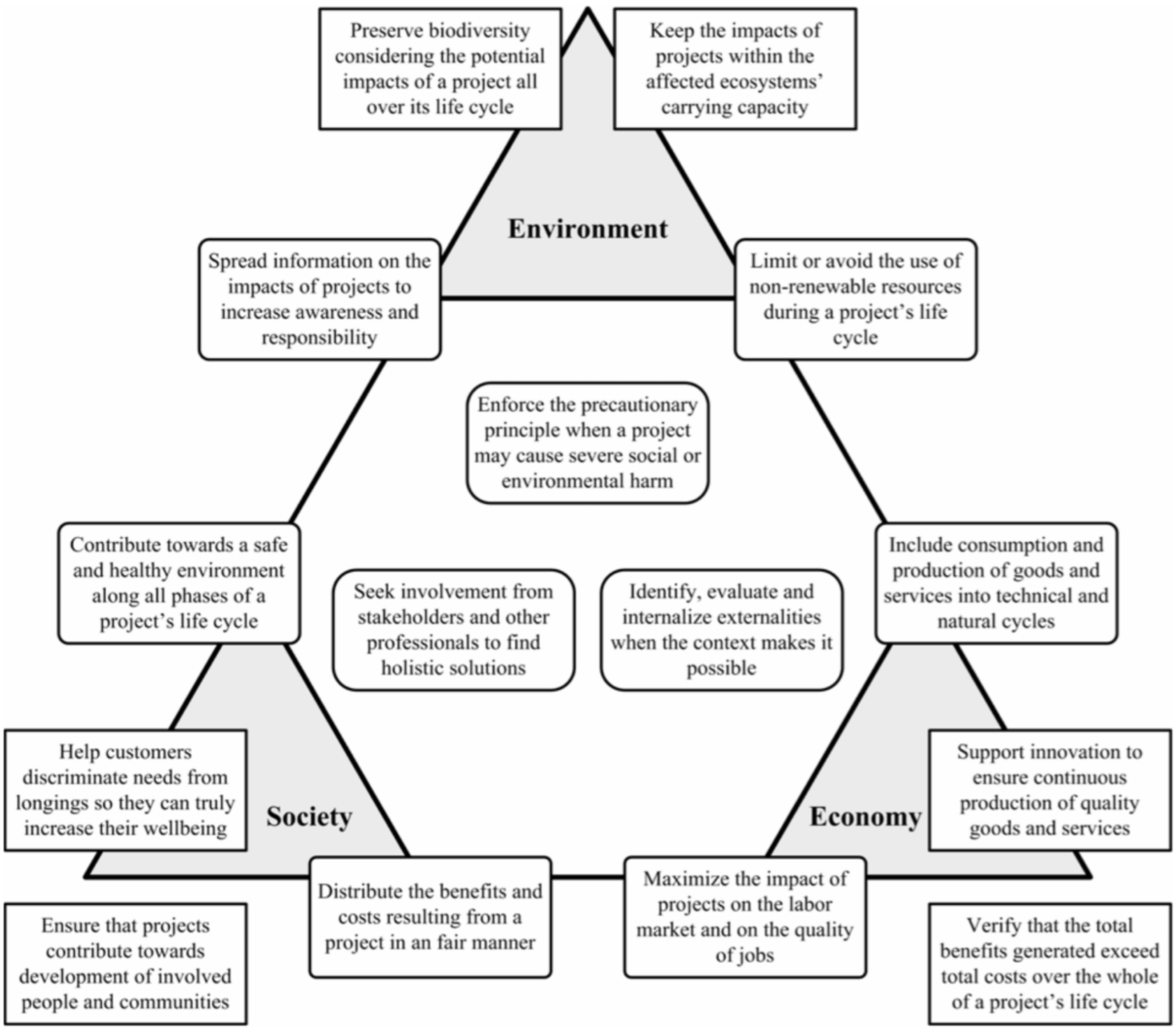

Figure 1. Sustainable engineering principles (Gagnon et al., 2008).

Sustainable engineering practice was also considered to require the implementation of a sustainable engineering design process and corresponding design tools. In a different working paper, Gagnon, Leduc, and Savard (2010) outlined an integrated sustainable engineering design process and identified design tools to be used in the integrated process. The design process and design tools are shown in Table 1 and Table 2, respectively.

Table 1

Sustainable engineering design process with critical tasks in italics (Gagnon et al., 2010).

Design Phase	**Tasks**
I – Planning and problem definition	*1 – Form a multidisciplinary team* *2 – Define sustainability principles* 3 – Define a sustainability conceptual framework *4 – Identify sustainability issues associated with the defined problem* 5 – Identify the relationships between the project and the elements in the conceptual framework 6 – Analyze stakeholders and plan stakeholder involvement
II – Conceptual analysis	*7 – Define sustainability criteria in line with the sustainability issues previously identified, in parallel with technical functions* 8 – Confirm the comprehensiveness of the sustainability criteria with the conceptual framework 9 – Develop a vision for the future in which functions are fulfilled respecting the sustainability principles *10 – Generate at least one alternative concept radically different from conventional ones using sustainability creativity tools* 11 – Define broad scenarios in which the alternative concepts are likely to evolve *12 – Define sustainability indicators derived from the issues or criteria, in parallel with technical specifications derived from functions* *13 – Identify the analysis tools with which data will be generated for each of indicators* *14 – Chose a multi-criteria decision aid method*
III – Preliminary design	*15 – Assess the performance of alternative concepts according to the sustainability criteria or indicators, including one “benchmark alternative” representative of current practice* *16 – Validate the multi-criteria decision aid method chosen and use it to recommend a preferred concept* 17 – Validate the performance of the alternative concepts under the scenarios identified

Design Phase	**Tasks**
IV – Detailed design	18 – Refine the assessment of the preferred concept and optimize its performance along sustainability criteria or indicators 19 – Maximize the adaptability of the preferred concept under scenarios identified 20 – Communicate recommendations for the manufacturing, construction, use and end of life phases *21 – Generate the set of sustainability indicators for monitoring*

Table 2

Design tools for sustainable engineering design process (Gagnon et al., 2010).

Creativity	**Analysis**	**Synthesis**
- Backcasting - Biomimicry - Eco-design strategies - Ecological engineering - Factor X engineering - Industrial ecology	*Environmental* - Ecological footprinting - Emergya or exergyb analysis - Environmental impact assessment - Environmental life cycle assessment - Strategic environmental assessment	*Elementary* - Disjunctive and conjunctive methods - Lexicographic method - Maximin method
	Economic - Cost-benefit analysis - Economic impact analysis - Environmental valuation - Inequality and equity analysis - Life cycle costing	*Value and utility based* - Weighted sum - AHP (Analytic hierarchy procedure) - SMART (Simple multi-attribute rating technique) - TOPSIS (Technique for order by similarity to ideal situation)
	Social - Social impact assessment - Social life cycle assessment	*Outranking* - ELECTRE - PROMETHEE

Creativity	Analysis	Synthesis
	Multidimensional - Generic criteria or indicators lists - Integrated impact assessment - Question grids	

This study hinges on the notion that in order for practicing professional engineers to contribute significantly to the achievement of sustainable development, they must be engaged in sustainable engineering practice. Although the education of an engineer begins before the undergraduate level, undergraduate engineering programs are of importance in defining the early roles and expectations of engineers. Thus, this study is focused on undergraduate engineering students and their motivation to engage with sustainable engineering practice.

Rationale for the Study

The rationale for conducting this study is presented through the consideration of knowledge of students' engagement with sustainable engineering practice, engineering curriculum, and the context of Canadian engineering programs.

Students' Engagement with Sustainable Engineering Practice

As a relatively new field between Engineering Education (EE) and Education for Sustainable Development (ESD), there is limited EESD research. Research in the field is dominated by topics regarding inhibitors to change in engineering institutions and single case initiatives to embed SD topics in engineering courses (Byrne et al., 2010). Byrne et al. also established a need for more rigorous research into EESD. As a result, there is limited academic knowledge on students' engagement with sustainable engineering practice within the current engineering curriculum. Students' engagement incorporates elements of their value of sustainable engineering practice and whether or not they expect to be successful when engaging in sustainable engineering practice. Although some studies have considered students' value, studies have not considered whether students expect they can successfully follow sustainable engineering principles and use a sustainable engineering design process. Current knowledge on the topic often relates to specific contexts and engineering disciplines, which limits generalizability (Azapagic, Perdan, & Shallcross, 2005; Hanning, Abelsson, Lundqvist, & Svanström, 2012; Segalàs, Ferrer-Balas & Mulder, 2008). As well, only one study has been conducted specifically on students' motivation for sustainable engineering (McCormick et al., 2015a). Researchers have suggested that independent factors such as gender, year of study, and engineering discipline may play a role in students' engagement, but these results are not generalizable. Thus, there is a gap in the field for research on the different elements of students' engagement with sustainable engineering practice and the factors that may influence their engagement.

Engineering Curriculum

Some studies in EESD have assessed the quantity of sustainable development content within the current engineering curriculum (Allen at al., 2008; Hanning et al., 2012; Palmer, Terenzini, Harper, & Merson, 2011). Generally, these studies indicated that sustainable engineering content is starting to be incorporated into some engineering programs. However, such content predominantly corresponded to the environmental pillar of sustainable development. The research also suggests that there are differences in inclusion according to the institution and engineering discipline. More research is needed to inform changes to the engineering curriculum to include sustainable engineering practice content on all and central pillars. Such research should also suggest which topics and disciplines of engineering require changes to the curriculum.

Canadian Context

As outlined by Engineers Canada (2016), students graduating from accredited engineering programs must possess 12 graduate attributes. Of the graduate attributes, 4 apply to sustainable engineering practice, which makes Canadian engineering programs unique. The description of the graduate attribute Design includes the ability to give appropriate attention to "economic, environmental, cultural and societal considerations," (Engineers Canada, 2016, p. 14). When referring to the responsibilities of an engineer, the graduate attribute Professionalism emphasizes the "primary role of protection of the public and the public interest" (Engineers Canada, 2016, p. 14). The Economics and Project Management graduate attribute emphasizes the need for "an ability to appropriately incorporate economics and business practices," (Engineers Canada, 2016, p. 14). The graduate attribute, Impact of Engineering, directly refers to the central pillars of sustainable development in its description:

> "An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society … and the concepts of sustainable design and development and environmental stewardship" (Engineers Canada, 2016, p. 14).

The context of sustainable development within Canadian society is also unique. Canada is considered to have three founding peoples, the Aboriginal, the French, and the British

(Citizenship and Immigration Canada, 2012). The majority of people are part of a traditional western culture with similarities to the U.S. and parts of Europe. For the western majority, sustainable development was established in the Bruntland report in 1987. However, the idea of sustainable development was not new to Aboriginal peoples in 1987. According to the Assembly of First Nations (2017):

> "Everything is taken and used with the understanding that we take only what we need, and we must use great care and be aware of how we take and how much of it so that future generations will not be put in peril."

Today, Canadian society includes people from diverse cultures, which contributes to unique consideration of the social pillar of sustainable development (Citizenship and Immigration Canada, 2012). In addition to the broadness of Canadian culture, the physical and human geography of Canada creates unique sustainable development challenges. Canada's geography contributes to consideration of all the central pillars of sustainable development. Thus, sustainable engineering practice in Canada differs from other contexts.

Purpose and Research Questions

The purpose of this study was to contribute to our knowledge of students within EESD by exploring Canadian undergraduate engineering students' motivation to engage in sustainable engineering practice using an expectancy-value theory of motivation. The specific research questions were as follows:

1. What are students' expectancies of success as defined by their previous experiences and concept of their abilities when engaging in sustainable engineering practice?
2. What are students' values of sustainable engineering practice?

3. What are the effects of gender, year of study, and engineering discipline on students' motivation to engage in sustainable engineering practice?

Theoretical Framework

To answer the research questions, a theoretical framework for students' motivation to engage in sustainable engineering practice was developed. The framework was based on the Eccles et al. expectancy-value theory, of which a simplified version was used by McCormick et al. (2015a) in a study on students' motivation for sustainable engineering. The Eccles et al. theory, as shown in *Figure 2*, is a modern expectancy-value theory that was developed from Atkinson's 1964 model. Their theory is for academic, achievement-related choices (Eccles et al., 1983). Modern expectancy-value theories link the expectancy and value components to broad psychological determinants and assume that expectancies and values are related to one another positively (Eccles & Wigfield, 2002).

In the model, choices are assumed to be influenced by negative and positive task characteristics. For this study, the task considered was engagement in sustainable engineering practice. Students' options with regard to this task were conceptualized as follows: (a) active engagement; (b) inactive engagement; and (c) no engagement. Active engagement was considered to be engagement in accordance with the sustainable engineering principles, design process, and corresponding design tools. The key determinants of choice are relative value and expectancy of the various options. Relative value and expectancy are influenced by social cognitive variables, which in turn are influenced by the individual's perceptions of other people's attitudes and expectations of the individual, and by the individual's perception of previous achievement outcomes (Eccles & Wigfield, 2002).

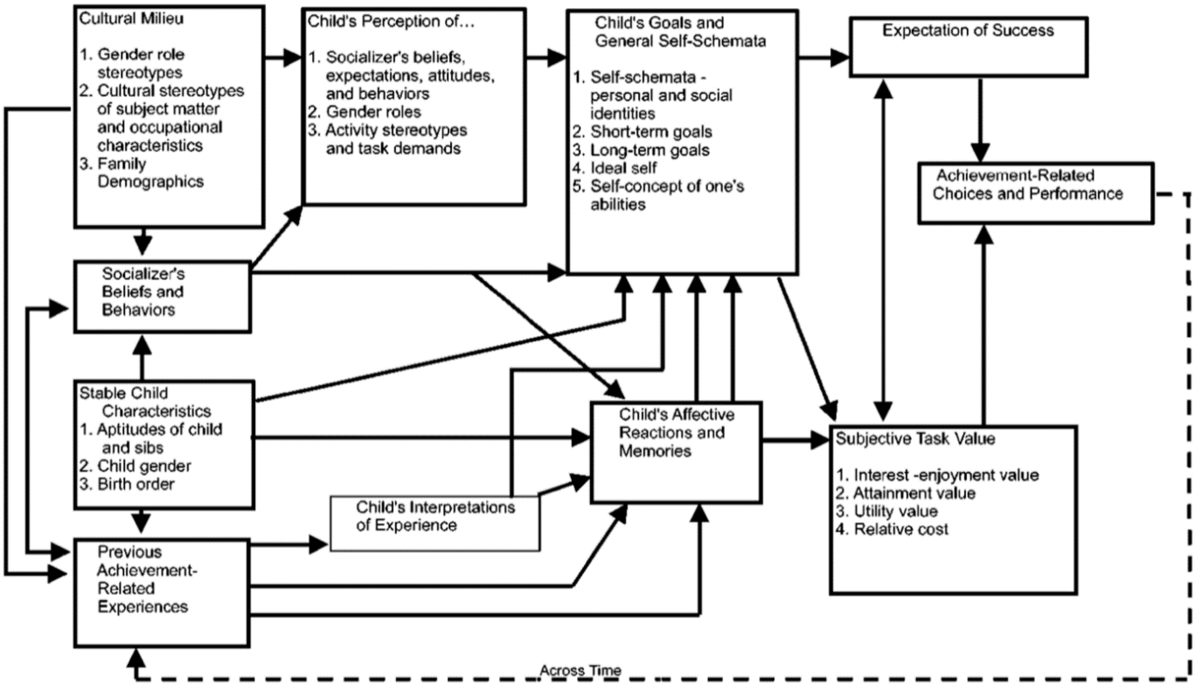

Figure 2

Visualization of the Eccles et al. expectancy-value model (Eccles & Wigfield, 2002).

The concept of expectancy or probability for success is defined as an individual's belief "about how well they will do on upcoming tasks, either in the immediate or long-term future" (Eccles & Wigfield, 2002, p. 119). Expectancies are increasingly important with age for achievement choices, which include academic performance, task persistence, and task choice (Eccles et al., 1983). The expectancies are influenced most directly by self-concept of ability and the students' estimate of the task difficulty. Because the field of EESD is not fully established, it was expected that students would struggle with estimating the task difficulty. In attempting to develop an estimate, it was expected that students would refer to their previous experiences with sustainable engineering practice as well as their knowledge and stereotypes of the topic. For this study, expectancies were simplified to include two elements: (a) Stereotypes and

Previous Experiences, and (b) Self-Concept of Abilities. Students' Stereotypes and Previous Experiences with respect to sustainable engineering practice were considered to have developed primarily in an academic context, potentially with some development in an extracurricular, or professional engineering or industry context. Stereotypes of sustainable development were considered to influence stereotypes of sustainable engineering practice. Self-Concept of Abilities applied to both the academic and professional engineering and industry contexts.

Initially, Eccles et al. (1983) defined relative value using three components. However, in 2002, Eccles & Wigfield incorporated the component relative cost to establish the four components shown in Table 3. The inclusion of the relative cost component is important because the Eccles et al. model relates to choices (Flake, Barron, Hulleman, McCoach, & Welsh, 2015). For this study, the components of relative value were considered to be manifested in academic, disciplinary, and professional engineering or industry contexts.

Table 3

Components of relative value (Eccles & Wigfield, 2002).

Component	**Description**
Attainment Value	The personal importance of doing well on the task, and the relevance of engaging in the task for confirming or disconfirming aspects of one's self-schema.
Intrinsic Value	The enjoyment the individual gets from engaging in a task and/or the subjective interest the individual has for the task.
Utility Value	Determined by how well a task relates to the individual's future goals, e.g. career goals.
Relative Cost	The negative aspects of engaging in the task, for instance the fear of failure or success, the amount of effort needed to engage in the task, and the lost opportunities that result from making one choice rather than another.

For this study, the Eccles et al. theory was simplified and represented aby the following three elements: (a) Stereotypes and Previous and Experiences, (b) Self-Concept of Abilities, and (c) Relative Value.

CHAPTER 2

LITERATURE REVIEW

According to Byrne et al. (2010), there has been substantial progress in the implementation of sustainable development in engineering education on an international scale. Despite this progress, Byrne et al. (2010) suggested that the approach to curriculum renewal is highly variable and that “there has not been a large-scale transition to producing engineering graduates with the knowledge and skills to meet the changings needs of the profession” (p. 5). Furthermore, there is little agreement on which sustainable engineering practice topics should be considered necessary in engineering education. When conducting a content analysis of 15 sets of sustainable engineering principles, Hoffman, Pawley, Rao, Condella, and Ohland (2011) found the following six themes of principles: (a) traditional environmental engineering, (b) specific items to protect or improve, (c) ethics and guiding beliefs, (d) business perspectives and values, (e) social and societal aspects, and (f) engineering design criteria. The most important finding was the significant variation in the sets of principles: no single set encompassed all 6 themes. Hoffman et al. suggested that the variation contributes to the overall uncertainty in the term sustainable engineering as well as the topics the term encompasses. The variation and uncertainty in the term was a prominent theme throughout this literature review.

Research on EESD, specifically sustainable engineering practice, is limited. Therefore, in this review, literature is also included on select Education for Sustainable Development (ESD) topics in higher education. The literature was reviewed on the following topics for this study: (a) sustainable engineering practice in courses and programs; (b) the role of instructors in teaching sustainable development and sustainable engineering topics; (c) students’ competency in sustainable engineering practice; (d) students' knowledge, attitudes, and perceptions of sustainable engineering practice; and (e) students' motivation for sustainable engineering practice.

Courses and Programs

Students' expectancies depend on their stereotypes of and previous experience with sustainable engineering practice. Students may have experiences with sustainable development topics prior to their undergraduate education, but sustainable engineering practice is specific to the engineering profession. Thus, undergraduate courses and programs were important to consider when addressing Stereotypes and Previous Experiences.

Allen et al. (2008) reported findings of a project commissioned by the U.S. Environmental Protection Agency that examined sustainable engineering at accredited engineering institutions across the United States. As part of the study, data was gathered through a questionnaire on sustainable engineering courses and research programs. The questionnaire was sent to 327 individuals that were identified as sustainable engineering champions and yielded a 43% response rate (Allen et al., 2008). Analysis of the responses identified 155 individual courses related to sustainable development. From the courses, four means of incorporating sustainable engineering content into the curriculum were identified as: (a) dedicated sustainable engineering courses; (b) integration of sustainable engineering concepts into traditional engineering courses; (c) courses that focus on the technologies predicted to be important in developing sustainable engineering solutions; and (d) courses offered in conjunction with non-engineering departments to create an interdisciplinary offering. The courses were also organized according to grouped disciplines of engineering. Not surprisingly, a higher prevalence of courses was found in civil and environmental engineering disciplines; these disciplines interact more directly with the environment and society than other disciplines.

The high response rates indicated nationwide interest in the United States and served to enhance the credibility of the study. However, Allen et al. (2008) indicated one concern for reliability: the questionnaires "did not provide a comprehensive definition of either 'sustainability' or 'sustainable engineering,' which reflected the state of the art, but necessarily increases the subjectivity inherent in these results" (p. 13). The most important finding from the study was that there is are differences in the inclusion of sustainable engineering topics among engineering disciplines.

A large portion of EESD literature originates from European countries. Hanning et al. (2012) compared engineering students' competence in the environment and sustainable development with the needs of Swedish industries. To do this, the authors reviewed the content in 70 courses on the environment and sustainable development offered at Chalmers University of Technology and sent a questionnaire to third year engineering students. The questionnaire yielded a response rate of 26.6% with 650 responses. The amount of environmental and sustainable development content in the courses was assessed using a simple five level scale on the frequency of inclusion of the content. However, the quality of the content was not assessed. The results of the study were analyzed for four of the offered engineering programs, namely chemical engineering, mechanical engineering, engineering physics, and computer science and engineering. Chemical and mechanical engineering had five courses that integrated the environment and SD, whereas engineering physics and computer science and engineering only had one course. The analysis of the course content indicated that the environmental aspects of sustainable development were highlighted most in the courses, with very little or no inclusion of the economic and social pillars of sustainable development. Despite this, 75% of students felt that they had good insight into the concept (Hanning et al., 2012). These findings indicated a bias towards the environmental pillar in engineering programs of which students are unaware.

To improve similar studies in the future, Hanning et al. suggested that validated assessment tools are needed to evaluate the quality and level of competence in sustainable development among students. Similar to Allen et al.'s study, this study provided an overview of the disciplinary dependence of sustainable development teaching and knowledge in engineering programs. Only one institution was included in the sample so the generalizability was limited. Swedish institutions in particular have integrated significant ESD content at all academic levels (Olsson, Gericke, and Rundgren, 2016). As such, this study may provide an example of the highest level of integration of sustainable engineering practice in courses and programs.

Excluding the consideration of the graduate attribute Impact of Engineering in accreditation, national studies of the integration of sustainable engineering practice in courses and programs have not been conducted in Canada. National studies have been conducted in the implementation of ESD in Canadian faculties of education (Sims & Falkenberg, 2013, Swayze, Creech, Buckler, and Alfaro, 2012). Generally, these studies found that faculty research on ESD is not advanced and that the main challenges of reorienting teacher education towards sustainability are programmatic and logistical. EESD research represents a smaller volume of

Canadian literature than ESD research. Thus, if faculty research on ESD in Canada is limited, it is likely that faculty research on EESD in Canada is also limited. A study of all 220 accredited Canadian post-secondary institutions suggested that institutions in larger communities, and in Québec and British Columbia have more sustainability initiatives. (Beveridge, McKenzie, Vaughter, & Wright, 2015). Although the study considered institutional level characteristics and not courses and programs, it is possible that there is also variation in the incorporation of ESD in courses and programs according to community size and province.

Roles of Instructors

The various roles of instructors are significant factors in developing higher education students' motivation (Sogunro, 2015). Canadian ESD researchers have suggested that instructors' value of sustainable development influences the quantity and quality of their inclusion of sustainable development topics (Jaspar, 2008).

In 2004, Summers, Corney and Childs reported findings of a survey of 61 geography and science postgraduate student teachers on their knowledge and perception of sustainable development. Summers et al. indicated that most knowledge was directed towards the environmental pillar of sustainable development and that the geographers were more aware than the scientists of the full scope of sustainable development. The generalizability of the results was limited by the small sample size, but the study provided motivation to investigate the role of academic discipline in teachers' sustainable development knowledge and perception.

Borg, Gericke, Höglund, and Bergman (2012) examined the influence of Swedish upper-secondary teachers' subject area on their abilities to implement an ESD approach when teaching sustainable development. At the time of the study, "all teachers in all subjects [had] a responsibility to integrate a holistic perspective of [sustainable development] including economic, ecological and social aspects" (Borg et al., 2012, p. 186). Data was collected from 3,229 teachers at 224 schools using a questionnaire. The sampling design used to obtain a high response rate and sample size was well detailed, which increased the trustworthiness of the results. Teachers' subject areas were organized into the following groups for analysis: (a) science; (b) social science; (c) language; (d) vocational and esthetical-practical; and (e) other, which included teachers with two or more subject areas across the previous groups. Prior to distribution, the questionnaire was validated in a pilot study (n = 138). The published paper detailed results from 36 items on topics relating to background details, sustainable development attitudes, themes in their subject(s), and teaching methods, teaching traditions, and difficulties in including sustainable development topics in their teaching. The study found that subject-based teaching traditions from higher education and teacher education influenced the inclusion of sustainable development topics. Specifically, the social science teaching traditions were most in line with the ESD approach. Because of the dependence on subject, Borg et al. suggested that specific training in ESD is needed for teachers in some subjects. The training would also have to address the largest obstacles to inclusion of sustainable development topics, which were found to be a lack of inspiring examples and lack of expertise (Borg et al., 2012). Although engineering relates primarily to the science subject, some of the findings reported by Borg et al. may be applicable to engineering education specifically.

Lattuca, Knight, and Brown (2014) conducted a study on the factors that influence engineering instructors' emphasis of interdisciplinary topics, which included the topic sustainability. A survey was sent to faculty members at 31 American institutions, which yielded 987 responses from tenure-track or tenured faculty. A multiple linear regression for course emphasis on interdisciplinarity was conducted using the instructor gender, discipline affiliation, faculty rank, course type, and faculty and industry experience as control variables, and the remaining survey questions on the value of interdisciplinary topics in engineering education and the responsibility as an instructor as independent variables. Some of the independent variables were found to be significant but the reliability of these variables was low because independent questions, not factors, were used. There also was limited information on the survey reliability and validity. The control variables discipline affiliation and industry experience were significant in the model, which agreed with previous studies (Lattuca, Knight, & Brown, 2014). Affiliations with electrical engineering were associated with lower emphasis on interdisciplinarity while higher amounts of industry experience were associated with a higher emphasis. Although Lattuca, Knight, and Brown did not directly address emphasis on sustainable engineering practice the findings may be extrapolated with caution.

Overall, the literature on the roles of instructors suggested that disciplinary affiliation and industry and sustainable development experience influence instructors' value and inclusion of sustainable engineering practice topics. Because of instructors' influence in students' motivation, it is possible that instructors' disciplines and experience influence students' motivation to engage in sustainable engineering practice.

Students' Competency

The element of the expectancy-value theory, Self-Concept of Abilities, was considered to be related to students' competency in sustainable engineering practice. The literature reviewed on this topic included research on students' conceptualizations of their competency as well as assessments of students' competency.

Palmer et al. (2011) conducted a study the purpose of which was exploring how engineering programs can best develop their students' ability to integrate context and design. Palmer et al. defined contextual competence as "an engineer's ability to anticipate and understand the constraints and impacts of social, cultural, environmental, political, and other contexts on engineering solutions," (p. 2). Students at 31 American institutions were invited to participate in an online survey, which yielded a response rate of 16% (n = 5,249). The survey questions were on the following topics: (a) demographic, (b) self-assessments of selected learning outcomes, (c) future career plans, (d) perceptions of classroom practices, (e) out-of-class interactions with faculty, and (f) extracurricular experiences. A blocked linear regression model was found to account for 26% of the variance in students' contextual competence skills. The regression model indicated that higher levels of contextual competence were related to curricular emphases, active membership in particular clubs and activities, participation in service work, and the existence of an entrepreneurship minor or certificate. While establishing the importance of the educational context for students' contextual competence, Palmer et al. provided practical suggestions to engineering administrators and faculty to improve students' contextual competence. Suggestions included modifications to curriculum design, support of co-curricular activities, facilities improvement, and connections to authentic, real-world experiences. Although the definition of contextual competence incorporated the central pillars of sustainable development, the suggestions were of particular relevance to the social pillar.

The sample size and similarities between American and Canadian contexts allowed for some generalizability of the results to Canadian engineering programs.

Ro, Lattuca, Merson, and Terenzini (2012) developed a 4-item scale to measure engineering students' contextual competency. Ro et al. defined contextual competence as the competence in understanding "the complex interdependence between the profession and society," (p. 2). As such, an engineering professional must be prepared to "make judgements in light of historical, social, economic, scientific, and political realities," (Ro et al., 2012, p. 2). This definition differed from most definitions of the social pillar as it included historical, scientific, and political elements. The scale included the following self-report items on contextual competency: (a) knowledge of contexts that might affect the solution to an engineering problem; (b) knowledge of the connections between technological solutions and their implications for the society or groups they are intended to benefit; (c) ability to use what you know about different cultures, social values, or political systems in developing engineering solutions; and (d) ability to recognize how different contexts can change a solution (Ro et al., 2012). A thorough assessment of content, construct, discriminant, and concurrent validity for the 4-item scale was conducted.

The scale was distributed to 32,737 engineering students in the United States, which yielded a response rate of 16% (5,249 responses). The sample included students in biomedical, chemical, civil, electrical, industrial, mechanical, and general engineering. However, the sample was not stratified for engineering discipline. A regression analysis was conducted to explore the relationship between contextual competence and gender, citizenship, SAT composite score, class year, and discipline. Students in higher years had higher scores than those in lower years, and males reported higher competence than females. As well, students in general and industrial engineering reported higher competence than students in mechanical and electrical engineering. Ro et al. provided initial details on content, structural, discriminant, and concurrent validity. The rigorous approach and large sample size allowed for the findings to be generalized to the population of American engineering students and some generalizations can be made to the Canadian context.

The previous studies on contextual competence relied on self-report data (Palmer et al., 2011; Ro et al., 2012). Other researchers have conducted assessments of engineering students' abilities to solve sustainability problems and apply sustainability principles. Adams, Beltz, Mann, and Wilson (2010) developed and tested an approach to assess students' abilities to formulate complex, contextualized, and cross- disciplinary problems involving sustainability issues. Participants were asked to identify "the issues they would consider important and the expertise they would need" (Adams et al., 2010, p. 326) to solve a disaster relief problem. The sample included primarily engineering students, with 24 participants from the United States and 25 from China. Data was collected over a two-year period, but the form of the data was unclear. The data was coded using two coding schemes: (a) sustainability intentions, and (b) cross-disciplinary functions. Adams et al. suggested that when combined, the disaster scenario task and coding framework could be used as a research, assessment, or instructional tool, but the ways this could be accomplished were unclear.

McCormick et al. (2015b) conducted a similar study in which they developed and tested a rubric to directly assess students' ability to apply sustainability principles in engineering design and problem solving challenge questions. The rubric incorporated analytic and holistic elements to assess elements of students' abilities on a 6-point scale. The analytic portion included three elements with respect to central pillars of sustainable development, while the holistic portion of the rubric included the following elements: (a) interpret problems or issues; (b) analyze/evaluate ideas or solutions; and (c) structure and explain problem solutions, self-regulate ability to solve problem (McCormick et al., 2015b). The rubric was tested by asking students to answer one of two challenge questions set in different contexts. The first question was in the context of a college campus and the second question was in the context of a low income community in Tanzania. Sampling was conducted at three American universities of different sizes. The majority of the 277 respondents were male seniors and majored in civil or environmental engineering. The second challenge question was the most popular (76% of responses) and there was significant variation in the quality and length of responses (McCormick et al., 2015b).

Interestingly, the results indicated that male students scored significantly higher than female students, which McCormick et al. indicated contradicted findings of similar studies. Students also scored lower on the environmental element than the other two elements, which was unexpected (McCormick et al., 2015b). However, the majority of the students answered the challenge question in the context of the low income Tanzanian community. Because the study was conducted at American universities and the context of the question was in a developing country it is possible that the question was biased towards the social and economic pillars of sustainable development. The study did not provide information on the development of the challenge questions, which limited the reliability of the results. However, inter-rater, intra-rater, and parallel reliability of the rubrics were assessed and the construct validity was discussed.

The approaches to measuring students' competency in sustainable development and sustainable engineering practice were found to be varied. Bias was introduced in the questions on surveys that relied on self-report data and in the challenge scenarios in the assessment-based studies. Additional development and testing is required to develop valid and reliable measures of students' competency.

Students' Knowledge, Attitudes, and Perceptions

The UN's Decade for Sustainable Development occurred from 2005 to 2014. During the decade, there was an increase in the quantity of published ESD studies in higher education (Wu, Shen, 2016). A large number of EESD studies published during and after the decade related to students' knowledge, attitudes, and perceptions of sustainable development and sustainable engineering. In the context of this study, knowledge, attitudes, and perceptions relate to students' stereotypes of, previous experiences with, and value of sustainable engineering practice.

Azapagic, Perdan, and Shallcross (2005) presented findings on what they believed to be the first international survey of engineering students' knowledge of sustainable development. A questionnaire was distributed at 40 universities in Europe, North and South America, the Far East, and Australia. A total of 3,134 questionnaires were completed at 21 of the contacted universities. The survey results suggested that engineering students have an unsatisfactory level of knowledge on sustainable development topics, but are most knowledgeable on environmental issues. The questionnaire relied on students' self-reported knowledge and limited discussion was provided on the validity and reliability of the questionnaire. The sample included students in varied years of study, but was dominated by European institutions (62%) and chemical engineering students (71%). Despite these limitations, the study provided an important starting point for international investigation of engineering students' sustainable development knowledge. Azapagic, Perdan, and Shallcross suggested further investigation into the influence of engineering discipline on students' knowledge of sustainable development.

Nicolaou and Conlon (2012) used a modified version of the survey instrument designed by Azapagic, Perdan, and Shallcross to investigate Irish final year engineering students' knowledge and understanding of sustainable development. The 143 surveyed students were found to have inadequate knowledge of sustainable development with extreme knowledge gaps in topics related to social issues, legislation, policies, and standards. These results agreed with the results presented by Azapagic, Perdan, and Shallcross. New results included a discipline dependence of engineering students' knowledge of sustainable development and the student perspective that sustainable development is a professional requirement rather than a personal commitment issue. Generalizability of the study was limited by the selection of participants primarily from one Irish higher education institution.

Kagawa (2007) used an online questionnaire to explore the knowledge and attitudes of University of Plymouth engineering students towards SD. Definitions of SD were not included in the questionnaire to avoid biasing the participants. The questionnaire was unbiased, and used open-ended and Likert scale questions to elicit a range of responses. A response rate of 8% was achieved resulting in a collection of 1,889 responses. One of the most significant findings of the study was that greater than 90% of the participants had a positive attitude towards sustainable development. Despite this, the concept was associated predominantly with the environmental pillar and the economic and social pillars were less well represented. The results were supported by the unbiased inferential statistical analysis, but the results of the study could not be generalized to other institutions.

Lourdel, Grondran, Laforest, Debray, and Brodhag (2007) used a different approach to assess engineering students' knowledge and perceptions of sustainable development. Based on previous work in environmental education, Lourdel et al. used concept maps to identify engineering students' knowledge in sustainable development and compared their findings to concept maps developed by sustainable development researchers. The following six categories were used for coding of the concept maps: (a) social and cultural aspects; (b) environmental aspects; (c) economic, scientific, and technical aspects; (d) multidimensional approaches including complexity, temporal relations, and spatial directions; (e) procedural and political approaches; and (f) actors and stakeholders (Lourdel et al., 2007). The small sample included 10 students and 17 researchers, which reduced the generalizability of the results of the coding analysis but successfully illustrated the use of concept maps to capture the complexity of knowledge and perceptions of sustainable development.

Following Lourdel et al.'s work, Segalàs, Ferrer-Balas and Mulder (2008) used concept maps to study improvements in students' knowledge of sustainable development as a result of enrollment in six different sustainable development courses offered at three European engineering institutions. The courses were on topics including sustainable technology, technology and the environment, and energy. Segalàs, Ferrer-Balas and Mulder used a different coding approach than Lourdel et al. that had a higher level of granularity: (a) environmental, (b) resource scarcity, (c) social impact, (d) values, (e) future generations (temporal), (f) unbalances (spatial), (g) technology, (h) economy, (i) education, and (j) actors and stakeholders. Results of the coding analysis suggested that prior to taking a sustainable development course, students' conception of sustainable development was linked primarily to the environmental and technological categories. After completing the courses, the complexity indicator of the concept maps increased (Segalàs et al., 2008). The researchers suggested that, "the main learning outcomes of the current SD courses is the capacity to connect concepts in a systems' perspective" and "the courses seemed not to succeed in highlighting the importance of the social side" (p. 305) of SD. Although this study was conducted in Europe, it is possible that the social elements of sustainable development also are not adequately highlighted in Canadian engineering courses.

Haase (2014) attempted to inform improvements to sustainability teaching practices by providing Danish engineering institutions with information about incoming first year engineering students' attitudes towards sustainability. Data was collected using a survey instrument comprised of 69 items on "students' conceptions of important engineering attitudes, their own competencies and interests in relation to sustainable engineering, and their engagement," (Haase, 2014, p. 251). The survey was optimized prior to deployment using the think-aloud method. The extensive statistical analyses included a factor analysis to reduce the 69 items to 16 dimensions and a cluster analysis that used the resulting factor scores. The results identified three distinct clusters of first year engineering students: (a) the math/science focused; (b) the all-around focused and confident; and (c) the professionally focused. The all-around cluster had the highest factor scores for all dimensions. There were some correlations between clusters and engineering discipline (Haase, 2014). Because the study relied on self-reported knowledge, there may be additional error in the findings.

Sheikh, Aziz, and Yusof (2012) also considered first year engineering students and investigated their perception of sustainable development. In a qualitative design, Sheikh, Aziz, and Yusof conducted 10 in-depth interviews with students from one institution in Malaysia. The interviews included protocols for background information, perception and definition of sustainable development, and daily activities towards sustainable development. The examples listed for daily activities were biased towards the environmental pillar, which suggested that the study may have been biased. The trustworthiness of the study was limited by the shallow depth in the detailing of the findings. Generally, the participants were uninformed on sustainable development topics, so their perceptions were minimal. The qualitative approach and differences between Malaysian and Canadian cultures did not permit the findings to be generalized. This study was important because it used a qualitative methodology, whereas most of the studies reviewed used quantitative methodologies.

Similar to Haase (2014) and Shekh, Aziz, and Yusof (2012), Beiler (2017) studied incoming engineering students' knowledge and perception of sustainability. Beiler developed and implemented a sustainability module at an American engineering summer camp. Pre- and post-assessments on students' sustainability knowledge of the learning objectives were conducted during three sessions of the summer camp between 2014 and 2016. The learning objectives of the module included definitions of sustainability, explanations of how to integrate sustainability into engineering design, application of the ecological footprint concept, and illustration of green building designs (Beiler, 2017). The learning objectives suggested a bias towards the environmental pillar of sustainable development. Reliability and validity of the pre- and post-assessments were not discussed. Generally, the findings suggested that secondary school students have limited knowledge of sustainability, especially within the context of engineering.

Micangeli, Naso, Matrisciano, Fairoli, and Belfiore (2013) explored the relationship between engineering students' sustainability attitudes and their learning characteristics. An electronic survey was used to collect responses from 101 participants. The survey measured two dimensions related to sustainability, six dimensions related to learning characteristics that were developed from the multiple intelligence model, and one dimension related to self-efficacy (Micangeli et al., 2013). The consideration of student learning characteristics was important to the field of EESD, but the study lacked rigor in the detailing of the research design and statistical analysis.

One of the more rigorous studies of students' knowledge, attitudes, and perceptions of sustainability was published by Goodwin, Klotz, Hazari, and Potvin in 2016. The purpose of the study was to investigate the perceptions and career goals related to sustainability of underrepresented groups in engineering. In the context of the study presented in this thesis, career goals were related to intrinsic and utility value. Electronic distribution of a survey yielded 6,772 responses from students at 50 different American institutions (Goodwin et al., 2016). The survey included 47 Likert-type questions and evidence of validity was provided. The results suggested that there were many intersectional differences in students' sustainability-related career goals when considering race, ethnicity, and gender. Overall, the results suggested that gender was more influential than ethnicity and race for career goals. Goodwin et al. suggested that the findings may be beneficial for developing interesting and versatile sustainability course content and for improving recruitment strategies for increasing the diversity of students in engineering programs.

The literature reviewed on students' knowledge, attitudes, and perceptions of sustainable engineering practice suggested that researchers are biased towards the environmental pillar. The generalizability of the results of each study was limited, but engineering discipline, year of study, and gender seem to influence knowledge, attitudes, and perceptions. There were no validated and reliable measures of knowledge, attitudes, and perceptions of sustainable development in an engineering context or of sustainable engineering practice.

Motivation

The purpose of this study was to explore students' motivation to engage in sustainable engineering practice. Searches produced very few studies with similar purposes, which indicated a gap in the research.

Mulder et al. (2015) conducted a case study of five optional sustainable development courses offered at five different European institutions to analyze how motivators were used to improve the learning process. The four motivators analyzed were autonomy, reflection, connection, and self-fulfillment. Because of the success of the courses, Mulder et al. suggested that these motivators may be beneficial to incorporate into course designs. The courses considered were optional, which suggested that students in the courses already had higher levels of motivation for sustainable development. Consideration of students' motivation was outside the scope of the study.

McCormick et al. (2015a) developed a survey consisting of 32 statement-based questions to assess students' motivation to engage in SE. Items were adopted from existing surveys to represent three motivational constructs: (a) self-efficacy: students' beliefs about their own abilities; (b) value: students' beliefs about task importance, intrinsic motivation and extrinsic motivation; and (c) affect: students' internal reaction to the task. These motivational constructs were developed from Eccles et al.'s expectancy-value theory of motivation.

The survey was pilot tested at three American universities differing in size. The sample quality was impacted by the different distribution methods used at each university. A total of 515 responses were received, with 61% female and 39% male. The majority of the responses were from civil (51%) or environmental engineering (36%). Results were analyzed to determine the influence of learning experiences, gender, and academic rank. The findings suggested that there were correlations between (a) participation in enriching educational experiences and sustainable engineering affect and value, and (b) internship experience and sustainable engineering self-efficacy. Female students had significantly higher sustainable engineering affect and value scores than male students. Male students were found to be significantly more confident in economic knowledge and female students were found to be slightly more confident in societal knowledge. Self-efficacy was found to increase with academic rank (McCormick et al., 2015a).

Using the pilot study data, the researchers assessed internal reliability of the survey by conducting a factor analysis with an oblique rotation. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was found to be 0.913 and Bartlett's Test of Sphericity was statistically significant. The Cronbach's alpha coefficients indicated good internal consistency with values of

0.96, 0.79, and 0.87 for the self-efficacy, value, and affect factors respectively (McCormick et al., 2015a). Despite having good internal consistency, the survey items could be improved to remove bias and a 7-point Likert-type scale could be implemented to increase variance in responses. Many of the SE value items were highly saturated (McCormick et al., 2015a). Limited information was provided on content validity of the items. This study was of significant importance to the current research study on students' motivation to engage in sustainable engineering practice.

The literature reviewed in this chapter illustrated a range of approaches to and conceptualizations of sustainable development in the context of engineering education. Generally, the literature suggested that gender, year of study, engineering discipline, academic experiences, and extracurricular experiences may influence students' conceptualizations. The lack of research in this field, particularly in the Canadian context, illustrates the need for this study.

CHAPTER 3

METHODOLOGY

This chapter outlines the rationale for the research design, ethical clearance, the sampling design and sample, and the methods used to develop and pilot the survey instrument. The methods used for data collection and analysis are also outlined.

Rationale for Quantitative Research

A quantitative research design was selected as it best suited the type of research questions. The first two research questions are descriptive types, while the third is a difference type (McMillan & Schumacher, 2010). The main purpose of quantitative research is to "emphasize objectivity in measuring and describing phenomena," (McMillan & Schumacher, 2010, p. 21). In this study, objectivity in measuring and describing students' motivation to engage in sustainable engineering practice is necessary to provide generalizable results that can inform actions by EE and EESD researchers and instructors.

Population

The population for this study was the current undergraduate engineering student body in Canada, which includes students enrolled in engineering programs accredited by Engineers Canada. There are 43 institutions across the provinces of Canada that offer numerous different engineering programs (Engineers Canada, 2016). Thus, participants in the study were undergraduate engineering students enrolled in Canadian accredited programs. The population aligns with the rationale for the study, part of which was collecting information within the Canadian context.

Rationale for Ex-Post Facto Research Design

Ex-post facto research designs allow for the exploration of a potentially causal relationship among variables where the independent variable cannot be controlled by the researcher (McMillan & Schumacher, 2010). The ex-post facto design was primarily dictated by the third research question on the effect of the independent variables of gender, engineering discipline, and year of study. However, the design was also applicable to the first and second descriptive research questions. At the time of study, the independent variables were previously determined by the participants, and thus could not be controlled.

Ethical Clearance

Ethical clearance was obtained from the Queen's University General Research Ethics Board (GREB) prior to data collection at Queen's University, and prior to contacting other institutions. Ethical clearance was also obtained from the respective Research Ethics Board at each of the participating institutions prior to data collection. When necessary, permission was also obtained from other representatives at the participating institutions prior to data collection. Documentation regarding the Queen's University GREB clearance is included in Appendix A.

Methods

This section details methods applied to conduct the study. First, the sample and sampling design are outlined. Next, the development of the survey instrument is discussed, including the design of the questions and pilot study of the survey instrument. Finally, the survey instrument used in the study is outlined.

Sample

Sampling was conducted in two stages, with the first stage to sample Canadian engineering institutions and the second to sample students within the selected institutions.

Sampling of institutions. A combination of stratified and convenience sampling was applied to select 8 (18.6%) of all Canadian engineering institutions in Canada and maintained a manageable number of institutions for the timeline of this study.

Proportional stratified sampling was used for the institution geographic location and size. Canada is commonly divided into the following five regions: (a) The Atlantic Provinces, (b) Central Canada, (c) The Prairie Provinces, (d) The West Coast, and (e) The Northern Territories (Citizenship and Immigration Canada, 2012). There are no engineering institutions in The Northern Territories so the region was removed for this study. The region Central Canada, which includes Ontario and Québec, is the most populated at an estimated 22,451,018 people in Quarter 1 of 2017 (Statistics Canada, 2017). For this study, Ontario and Québec were considered as two separate regions because of their differences in official languages and approaches to sustainable development and climate change (David Suzuki Foundation, 2012). Thus, the provinces of Canada were organized into five geographic regions as shown in Table 4. Of the regions considered, Regions 2, 3, and 4 are the most populated, while Regions 1 and 5 are the least populated.

Table 4

Regions of Canada and respective populations for proportional stratified sampling by geographic location

Region	Province(s)	Population Estimate (Statistics Canada, 2017)	Percentage of Population Estimate for Provinces
1	Newfoundland and Labrador	2,388,874	6.6
	Prince Edward Island		
	Nova Scotia		
	New Brunswick		
2	Québec	8,356,851	23.00
3	Ontario	14,094,167	38.7
4	Manitoba	6,766,812	18.6
	Saskatchewan		
	Alberta		
5	British Columbia	4,777,157	13.1

According to Universities Canada (2016), undergraduate student populations in universities range from approximately 70 to 70,000. For proportional stratified sampling according to institution size, undergraduate student populations of universities were split into 4 ranges as follows: (a) large, greater than 25,000; (b) high-medium, greater than 10,000 and less than 25,000; (c) low-medium, greater than 4,000 and less than 10,000; and (d) small, less than 4,000. The majority of institutions that offer engineering programs are in the high-medium and large ranges (Engineers Canada, 2016). To stratify the sample according to the size of institution, the sample included 2 large institutions, 4 high-medium institutions, 1 low-medium institution, and 1 small institution, considering only institutions with engineering programs.

Convenience sampling was also used to select the institutions. Previously established contacts that expressed interest in assisting with the study had been established at accessible institutions. Because of the convenience sampling the sample was not stratified perfectly in accordance with geographical location. The sample included 2 institutions from each of Regions 2, 3, and 5, and 1 institution from each of Regions 1 and 4 for a total of 8 institutions. The institutions were included to be representative of Canada and not the five regions. Thus, geographic location and institutional size were not considered as independent variables.

Sampling of participants at selected institutions. Stratified sampling was used to sample students at each of the selected institutions. Proportional stratified sampling was used for gender and year of study. To simplify the sampling process, engineering disciplines at the participating institutions were categorized into five groups as follows: (a) Mechanical-Based, including mechanical, industrial, and aerospace; (b) ECE and Science, including electrical, computer, software, and biomedical engineering, mathematics and engineering, and engineering physics; (c) Chemical-based, including chemical, and materials engineering, and engineering chemistry; (d) Environmental-Based, including civil, mining, geological, environmental, and sustainable design engineering; and (e) Other, including general first year programs, and those not specified. Non-proportional stratified sampling was used for the discipline groupings.

Demographics of the sample. A response rate of approximately 1% was achieved, which yielded a sample size of 243. The distribution of the sample among the independent variables is shown in Table 5. According to Engineering Canada, as of 2015, 20% of engineering students in

Canada were female. The sample included significantly more females than the Canadian engineering student population ($t = 5.61$, $p < .001$).

Table 5

Sample as characterized by the independent variables

Independent Variable	**Group**	***n***	***%***
Gender	Male	152	62.6
	Female	91	37.4
	Other	0	0
Year of Study	1	42	17.3
	2	65	26.7
	3	62	25.5
	4+	74	30.5
Engineering Discipline	Mechanical-Based	62	25.5
	ECE and Science	73	30.0
	Chemical-Based	33	13.6
	Environmental-Based	55	22.6
	Other	20	8.2

Instrument Design

The initial survey instrument was developed with consideration of McCormick et al.'s survey, which used a substantially simplified version of the Eccles et al. expectancy-value theory of motivation. There were limited questions on stereotypes and previous experiences and only one component of value was included. The initial instrument for this study was designed to incorporate additional perspectives on stereotypes and previous experiences and the four components of value. The studies reviewed in Chapter 2 were referenced to reduce bias in the survey questions and to consider a comprehensive range of contexts. The initial survey instrument was comprised of demographic questions, 3 open-ended questions and 62 closed-ended questions to measure the expectancy-value theory elements as follows: (a) Stereotypes and Previous Experiences (20 questions), (b) Self-Concept of Abilities (14 questions), and (c) Relative Value (28 questions).

A 7-point Likert-type scale was used for the Stereotypes and Previous Experiences, and Relative Value questions. Likert scales (5-point scale) and Likert-type scales are commonly used as validated scales for survey research (Krosnick & Presser, 2010). Following McCormick et al.'s approach, a 7-point confidence interval scale was used for the Self-Concept of Abilities items. Labels were included for both scales on points 1, 4, and 7 to reduce confusion for participants. On the Likert-type scale, the labels were Strongly Disagree, Neutral, and Strongly Agree, while they were Not Confident, Neutral, and Very Confident on the confidence interval scale. Sustainable development and sustainable engineering practice are generally viewed positively, which could have resulted in social desirability bias (UN, 2015). The 7-point scales were used to increase variance in responses by providing participants with additional points to indicate small deviations from neutral. Reliability and validity of 7-point scales are also greater than those of scales with fewer points (Krosnick & Presser, 2010).

The questions for the Stereotypes and Previous Experiences element included the 3 open-ended questions and closed-ended for the importance of the TBL elements, sustainable development components, disciplinary stereotypes, academic experiences, and professional engineering and industry stereotypes. The open-ended questions included were as follows: (a) What is sustainable development? (b) What is sustainable engineering practice? and (c) What are the most common sustainability considerations in your discipline? The closed-ended questions are shown in Table 6. The TBL elements questions were adopted and modified from questions in McCormick et al.'s survey. Questions on disciplinary, and professional engineering and industry stereotypes were informed by the literature on courses and programs.

Table 6

Stereotypes and Previous Experiences closed-ended questions.

Question	**Type**
The social elements of sustainable engineering practice are the most important elements.	TBL elements
The environmental elements of sustainable engineering practice are the most important elements.	TBL elements
The economic elements of sustainable engineering practice are the most important elements.	TBL elements
The social, environmental, and economic elements of sustainable engineering practice are equally important.	TBL elements
Sustainable engineering practice is most useful to current generations.	TBL elements
Sustainable engineering practice is most useful to future generations.	Sustainable development components
Projects in my discipline have limited sustainability considerations.	Disciplinary stereotypes
Sustainable engineering practice is applicable to every project in my discipline.	Disciplinary stereotypes
Other engineering disciplines have more sustainability considerations than my discipline.	Disciplinary stereotypes
Sustainable engineering practice is integrated into how we solve problems in my discipline.	Disciplinary stereotypes
My course instructors are knowledgeable about sustainable engineering practice.	Academic experiences
Sustainable engineering practice is valued by my course instructors.	Academic experiences
I have many opportunities to apply sustainable engineering practice in my design projects.	Academic experiences
I receive recognition in my courses for creating sustainable engineering solutions.	Academic experiences
I have many opportunities to apply sustainable engineering practice in my technical courses.	Academic experiences

Question	Type
Engineers-In-Training in the workforce are encouraged to incorporate sustainable engineering practice in their projects.	Professional engineering and industry stereotypes
It is not practical to apply sustainable engineering practice to real-world engineering projects.	Professional engineering and industry stereotypes
Sustainability is just a word used in industry for promotion and public image.	Professional engineering and industry stereotypes
Sustainability is a shared vision among all engineers working in a single company.	Professional engineering and industry stereotypes
Sustainability is just a word used in industry for promotion and public image.	Professional engineering and industry stereotypes

The Self-Concept of Abilities questions pertained to the TBL elements and the sustainable engineering design process, as shown in Table 7. The TBL understanding questions were adopted and modified from the self-efficacy questions in McCormick et al.'s survey. The sustainable engineering design process questions were developed from Gagnon et al.'s 2010 working paper.

Table 7

Self-Concept of Abilities closed-ended questions.

Question	Type
Understand the short-term social costs and benefits associated with engineering projects.	TBL understanding
Understand the long-term social costs and benefits associated with engineering projects.	TBL understanding
Understand the short-term environmental costs and benefits associated with engineering projects.	TBL understanding
Understand the long-term environmental costs and benefits associated with engineering projects.	TBL understanding
Understand the short-term economic costs and benefits associated with engineering projects.	TBL understanding
Understand the long-term economic costs and benefits associated with engineering projects.	TBL understanding

Question	Type
Understand the interdependency among the social, environmental, and economic elements of engineering projects.	TBL understanding
Apply sustainable engineering practice throughout the engineering design process.	Sustainable engineering design process
Seek expertise of others in areas where your own knowledge is not adequate to address sustainability issues.	Sustainable engineering design process
Define sustainability indicators in parallel with technical specifications.	Sustainable engineering design process
Identify analysis tools to generate data for sustainability indicators.	Sustainable engineering design process
Incorporate environmental costs and benefits in economic analyses.	Sustainable engineering design process
Incorporate social costs and benefits in economic analyses.	Sustainable engineering design process
Develop appropriate engagement processes for all stakeholders involved with a project.	Sustainable engineering design process

The Relative Value questions included questions on attainment, intrinsic, and utility value, and relative cost, as shown in Table 8. The intrinsic and utility value, and relative cost questions were developed with consideration of the value and effect questions in McCormick et al.'s survey as well as the literature review on students' knowledge, attitudes, and perceptions of sustainable engineering practice. Many of the value questions on McCormick et al.'s survey had ceiling effects, so the value questions developed for the survey instrument for this study used stronger phrasing. The attainment value questions were developed directly from the sustainable engineering principles outlined by Gagnon et al. (2008). The attainment value questions were prefaced by the phrase: it is important for me personally to.

Table 8

Relative Value closed-ended questions.

Question	**Type**
I am or would like to be enrolled in a sustainable engineering practice course.	Intrinsic
I enjoy solving problems that incorporate complex social, environmental, and economic elements.	Intrinsic
I would like to become a leader in sustainable engineering practice.	Intrinsic
I often discuss sustainable engineering topics with my peers.	Intrinsic
My peers are more interested in sustainable engineering practice than I am.	Intrinsic
Apply sustainable engineering practice to every project I work on.	Attainment
Contribute to global sustainable development through my professional work.	Attainment
Help others to learn to apply sustainable engineering practice in their projects.	Attainment
Preserve the natural environment by considering the potential impacts of a project over its life cycle.	Attainment
Spread information to the general public on the impacts of projects to increase awareness and responsibility.	Attainment
Limit or avoid the use of non-renewable resources during a project's life cycle.	Attainment
Contribute towards a safe and healthy environment along all phases of a project's life cycle.	Attainment
Help customers discriminate needs from wants so they can truly increase their wellbeing.	Attainment
Ensure that projects contribute towards the wellbeing of the people and the development of the communities impacted by the project.	Attainment
Distribute the benefits and costs from a project in a fair manner globally.	Attainment
Maximize the positive impact of projects on the labour market and on the quality of jobs.	Attainment
Verify that the total benefits generated equal or exceed the total costs over the whole of a project's life cycle.	Attainment
Reinvest in innovation to ensure continuous development of quality goods and services.	Attainment
Learning about sustainable engineering practice now will be useful for me in my career.	Utility
The ability to assess the social, environmental, and economic elements of projects is a useful skill that will make me stand out to potential employers.	Utility

Question	Type
Learning about sustainable engineering practice will help me to become a more responsible engineer.	Utility
Applying sustainable engineering practice will help me to develop better engineering solutions.	Utility
Incorporating sustainable engineering practice has a higher economic cost than not incorporating it.	Relative Cost
I do not have enough time to engage in sustainable engineering practice.	Relative Cost
It is too difficult to understand the complex elements of sustainability.	Relative Cost
Learning about sustainable engineering practice will take too much of my attention away from learning about technical engineering topics.	Relative Cost
Learning about sustainable engineering practice will take too much of my attention away from learning about important professional skills for engineering.	Relative Cost
Understanding sustainable engineering practice will limit the industries I can work in.	Relative Cost

Pilot study. The purpose of the pilot study was two-fold: to reduce measurement error and to provide evidence to evaluate the performance of the initial survey questions. The pilot study served to pre-test the survey instrument, which provided three types of evidence to evaluate the performance of the initial survey questions: (a) statistical; (b) direct study of the question-and-answer process; and (c) experimental (Collins, 2001). Statistical evidence was used for preliminary evaluation of the reliability of the survey instrument. The task-focused model of measurement error includes four components: (a) comprehension problems, (b) validity problems, (c) processing difficulties, and (d) pronunciation or communication difficulties (Collins, 2001). Direct study of the question-and-answer process assisted in reducing the four components of measurement error and provided evidence for the survey validity.

A mixed method design was used to provide a more comprehensive pretest of the survey instrument "by collecting both quantitative and qualitative data, because each provides a partial view," (Creswell & Plano Clark, 2007, p. 151). The quantitative stage provided statistical evidence, while the qualitative stage provided direct study of the question-and-answer process. Experimental evidence was not collected. Specifically, a convergent parallel design was used to obtain "different but complementary data on the same topic," (Morse, 1991, p. 122). In the convergent parallel design, the qualitative and quantitative stages are given equal priority with an independent level of interaction. Concurrent timing is used for data collection and analysis, and mixing occurs during interpretation of the results. A strength of the convergent parallel design is its intuitive and efficient nature, which is advantageous for a pilot study (Creswell & Plano Clark, 2007).

Sample. Graduate engineering students at Queen's University were selected as participants by convenience sampling. As a graduate engineering student at Queen's University myself, other graduate engineering students were easily accessible. Typically, graduate engineering students have completed an undergraduate engineering degree, but not necessarily in an accredited Canadian engineering program. Queen's University offers two Master graduate engineering degree programs, one course-based and one thesis-based, as well as a Doctorate degree program. The 10 departments of engineering in which Queen's University offers graduate degree programs are representative of the undergraduate engineering discipline-based programs across Canada. Emails were sent to all graduate engineering students from departmental assistants to recruit participants for the quantitative stage of the study. At the end of the quantitative stage, participants were asked if they were interested in participating in the qualitative stage and were informed that if they did so, they would receive a $15 gift card. Participants were selected for the qualitative stage with the purpose of maximizing variation in the undergraduate engineering disciplines represented in the qualitative sample. The quantitative sample included 15 participants with demographics shown in Table 9. The qualitative sample included 4 participants, all of whom participated in the quantitative stage of the study. There were 2 females and 2 males in the qualitative sample and 2 of the 4 participants completed their undergraduate engineering education outside of Canada.

Table 9

Pilot study sample demographics for the quantitative stage.

Demographic Variable	**Group**	***n***	***%***
Gender	Male	12	80
	Female	3	20
	Other	0	0
Graduate Program	MEng	3	20
	MASC	8	53.3
	PhD	4	26.7
Engineering Discipline	Mechanical-Based	5	33.3
	ECE and Science	5	33.3
	Chemical-Based	2	13.4
	Environmental-Based	3	20
	Other	0	0

Instruments. The pilot study used the initial survey instrument to collect quantitative data and think-aloud interviews to collect qualitative data. Cognitive interviews allow for the direct study of the question-and-answer process for survey questions (Collins, 2001). The two techniques in cognitive interviewing are the think-aloud protocol and probing. In think-aloud interviews, the participant is asked “to ’think-aloud’ as he or she answers the questions or completes the questionnaire,” (Collins, 2001, p. 235). In 2011, Trenor, Miller, and Gipson used the think-aloud protocol to validate a survey instrument in engineering education research. The think-aloud interview is driven by the participant whereas probing is driven by the interviewer; however, the two methods can be combined in a single interview. Cognitive probes can be characterized into five categories: (a) think-aloud or general, (b) comprehension, (c) retrieval, (d) confidence judgement, and (e) response (Collins, 2001). For the pilot study, a semi-structured format was used to incorporate the think-aloud protocol, and comprehension and confidence judgement probing questions. The interview protocol included an introduction to the study, an explanation of the think-aloud method, and an example of the think-aloud process for a survey question. The example of the think-aloud process is included in Appendix B. Participants were provided with a copy of the survey questions and were asked to explain his or her thought process for answering each survey question. Depending on the response, comprehension probing questions were used to gain further understanding of the participants' thought process. If the participant appeared hesitant with his or her response, confidence judgement questions were used.

Data collection methods. Data was collected separately for the quantitative and qualitative stages of the pilot study. FluidSurveys, an online survey tool, was used to collect data using the initial survey instrument electronically. A standardized recruitment email was sent to participants that included a link to the online pilot study survey. The first page of the survey included an electronic Letter of Information and a click button for consent. Participants were able to withdraw from the survey portion of the study by exiting the survey prior to submission. A link was provided at the end of the online survey to a second FluidSurveys survey to collect initial contact information from participants interested in completing a think-aloud interview. The second survey informed participants that a $15 gift card would be provided to recognize their time in participating in the think-aloud interview. Prior to the interview, participants were provided with a Letter of Information and Consent Form specific to the think-aloud portion of the study. The think-aloud interviews occurred in-person and were a maximum of 75 minutes in length. The interviews were recorded electronically with permission of the participants and then transcribed. The transcriptions were used for all analyses. Pseudonyms are used in this thesis to protect the identity of the pilot study participants. The Letters of Information and Consent Forms for the pilot study are included in Appendix A.

Data analysis. The quantitative and qualitative data were analyzed separately. Because of the low response rate (n<30), only descriptive statistics were calculated for the quantitative data. The shape of the distribution (skewness and kurtosis) was examined for each question to assess normality of the data (Field, 2013). The transcriptions of the think-aloud interviews were analyzed on a question-by-question basis to assess content validity. The transcriptions were also analyzed by deductive coding using the task-focused model of measurement error outlined by Collins.

Pilot study results. The descriptive statistics for the quantitative data and the question-by-question analysis of the interviews are shown in Appendix B. For all initial survey questions, the standard errors were 0.58 and 1.12 for the skewness and kurtosis, respectively. According to Field (2013), acceptable values for skewness and kurtosis are within twice the respective standard error. Thus, the acceptable ranges were within ±1.16 and ±2.24 for the skewness and kurtosis, respectively. The majority of the attainment and utility value questions had skewness or kurtosis values outside of the acceptable ranges, which suggested departures from normality. The deductive coding analysis resulted in the following three main themes: (a) importance of context, (b) simplicity in terminology, and (c) simplicity in phrasing. The themes provided areas for improvement to the instrument fairness.

Importance of context. Explicit statement of the context of a question was needed to reduce comprehension problems and processing difficulties. Some questions did not explicitly state the context, which resulted in variations in interpretations by the think-aloud participants. Depending on the question, the participants debated between academic and professional engineering or industry contexts, personal or general contexts, or current and future contexts. In some cases, the variations in interpretations impacted participants' responses.

Simplicity in terminology. There were some comprehension problems with terminology related to sustainable development and the sustainable engineering design process. Most comprehension problems occurred with the following terms: engineering design process, sustainability indicators, technical specifications, and engagement process. Participants that completed their undergraduate engineering program outside of Canada had more instances of comprehension problems with the sustainable engineering design process terminology.

Simplicity in phrasing. Some comprehension and validity problems occurred as a result of the phrasing of questions. For some questions, individual participants had more than one interpretation, and interpretations among the participants varied. Problems with interpretation were most common with the attainment value and sustainable engineering design process questions.

Modifications to the survey instrument from the pilot study. The results of the quantitative and qualitative analyses were interpreted together to inform modifications to the survey instrument. The most major modification was the removal of the attainment value questions, which were removed because of the kurtosis and skewness, comprehension, and validity and fairness problems. Additional intrinsic value questions were created from some of the initial attainment value questions because there was conceptual overlap. The terminology in the sustainable engineering design process questions was simplified to reduce comprehension and fairness problems. For consistency, the Self-Concept of Abilities questions were rephrased and a Likert-type scale was used. Definitions for short-term and long-term were also added prior to the TBL understanding questions. The number of questions in the survey instrument was reduced by 18. Detailed modifications are included in Appendix B on a question-by-question basis.

Instrument. The survey instrument used for the study included 3 open-ended questions and 44 closed-ended questions distributed among the expectancy-value theory elements as follows: (a) 3 open-ended and 13 closed-ended for Stereotypes and Previous Experiences; (b) 14 closed-ended for Self-Concept of Abilities; and (c) 17 closed-ended for Relative Value. The Relative Value questions were distributed among the components as follows: (a) 8 closed-ended for intrinsic value; (b) 4 closed-ended for utility value; and (c) 5 closed-ended for relative cost. The questions on the survey instrument are shown in Appendix C. The survey questions were ordered to minimize survey bias wherever possible. The open-ended questions on the definitions of sustainable development and sustainable engineering practice were asked first. After these questions, definitions were provided for sustainable development and sustainable engineering practice. The closed-ended questions appeared in the order shown in Appendix C and the third open-ended question on common sustainability considerations was asked after the question “I am expected to apply sustainable engineering practice in my design projects.”

Instrument validity. Translation validity was established from the development process and the pilot study. Face validity is an informal measure of validity, which was established by the question-by-question development process of the instrument and the question-by-question analysis of the think-aloud interviews. Content validity is a “subjective measure of how appropriate the items seem to a set of reviewers who have some knowledge of the subject matter” (Litwin, 1995, p. 3). For this study, initial evidence for content validity included the connections between the survey questions and the foundations of sustainable engineering practice, and the expectancy-value theory of motivation. Other forms of validity include criterion and construct validity. Criterion validity, which is comprised of concurrent and predictive validity, measures “how well one instrument stacks up against another instrument or predictor” (Litwin, 1995, p. 3). The main purpose of this study was not to develop a new instrument, thus data was not collected using other instruments. As well, there are no validated measures to assess students’ motivation to engage in sustainable engineering practice, or sustainable development in general. Construct validity requires years of implementation of a survey instrument, and thus was not considered for this study (Litwin, 1995).

Instrument reliability. According to Litwin, reliability is “a statistical measure of how reproducible the survey instrument’s data are.” Commonly, the three forms of reliability are test-retest, alternate form, and internal consistency. The purpose of this study was not to develop and validate the instrument, test-retest reliability was not assessed because it would have required the same participants to complete the survey multiple times (Litwin, 1995).

Similarly, alternate form reliability was not assessed in this study. Internal consistency reliability was assessed using the data collected nationally from undergraduate students. Survey questions were examined for comprehension in the pilot study, which may have improved the internal consistency of the measured factors.

Instrument fairness. Instrument fairness can be broken into the elements individual fairness and group fairness. Individual fairness refers to equity while group fairness refers to the fairness for groups by race, ethnicity, social class, language, and urbanicity (Camilli, 2013). Individual fairness was primarily addressed by the use of the FluidSurveys platform, which ensured consistent presentation of the survey to all participants. However, there was no control of the setting in which participants completed the survey. In the development of the initial survey instrument, group fairness was addressed when establishing the context of the questions. The think-aloud interviews in the pilot study included two graduate students that completed their undergraduate education outside of Canada. Some of the modifications to the survey instrument for comprehension and clarity addressed group fairness. These modifications included the removal of the attainment value questions and simplifications to the terminology used in the SE design process questions. As well, the survey instrument was translated into French for participants at Québec institutions.

Data Collection

As in the pilot study, data was collected electronically using FluidSurveys. Ethical clearance was obtained at all participating institutions prior to distribution. A variety of recruitment methods were used at the participating institutions to accommodate varying privacy rules. In all but one institution, standardized emails were sent to faculty and departmental assistants, course instructors, and registered student clubs asking them to voluntarily distribute a standardized recruitment email to undergraduate students in their faculty, department, course, or club, as applicable. At the remaining institution, standardized recruitment notices were posted on institutional websites. Recruitment notices on institutional websites were also used at other institutions. As with the pilot study, the first page of the survey included an electronic Letter of Information and a click button for consent. Participants were able to withdraw from the survey portion of the study by exiting the survey prior to submission. The survey was translated into French for distribution at one of the institutions in Québec, and responses were collected in French. The French responses to the open-ended questions were translated to English by the same translator for data analysis. The Letters of Information and Consent Forms are included in Appendix A.

Data Analysis

To answer the research questions, three phases of data analyses were completed. First, exploratory factor analyses were conducted using the closed-ended questions. Next, the effects of gender, year of study, and engineering discipline were examined through independent sample t-tests, ANOVAs, and Pearson's chi-square test. Finally, the open-ended questions were analyzed using deductive coding. For instances of missing data, cases were excluded analysis by analysis.

Exploratory factor analysis. Exploratory factor analyses were completed for the closed-ended questions, excluding the ranking of the social, environmental, and economic elements. Factor analysis is based on the "notion that measurable and observable variables can be reduced to fewer latent variables [factors] that share common variance and are unobservable"

(Yong & Pearce, 2013, p. 80). One exploratory factor analysis was completed for each of the three simplified Eccles et al. expectancy-value elements: (a) Stereotypes and Previous Experiences, (b) Self-Concept of Abilities, and (c) Relative Value. Exploratory factor analysis was appropriate for this study as its purposes are as follows: (a) to understand the structure of a set of variables; (b) to develop a questionnaire to measure an underlying variable; and (c) to reduce the number of variables of a dataset while retaining as much of the original information as possible (Field, 2013).

The required sample sizes for factor analyses are somewhat imprecise, however a larger sample is better. Comrey and Lee (1992) suggest a minimum sample size of 300. If there are higher loadings on a number of factors, sample sizes smaller than 300 are acceptable. Rules of thumb suggest ratios of participants to variables ranging from 10:1 or 30:1 (Yong & Pearce, 2013). For this study, the ratios of participants to variables were within the suggested ranges at 20.25:1 for the stereotypes and previous experience and the Self-Concept of Abilities analyses, and 15.20:1 for the Relative Value analysis. To assess sample size, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was calculated for each analyses (Field, 2013). The KMO statistic varies between 0 and 1, where 0 indicates a diffusion in the pattern of correlations and 1 indicates relatively compact patterns of correlations. Thus, a KMO statistic that is close to 1 indicates that “factor analysis should yield distinct and reliable factors” (Field, 2013, p. 684). Factor loadings are also important in assessing the reliability of factors. Though definitions vary, factors with five or more strongly loading questions (0.50 or greater) are considered strong, reliable factors (Costello & Osborne, 2005). The main components for consideration in factor analysis are the factor extraction and rotation method, factor loadings and number of factors, and factor scores (Yong & Pearce, 2013).

Factor extraction and rotation. The maximum likelihood method of extraction and direct oblimin method of rotation were used for all analyses. The maximum likelihood method has been shown to be superior to other extraction methods when factors are underextracted or factors are correlated with unequal loadings (Winter & Dodou, 2012). The direct oblimin method is an oblique method of rotation, which assumes that factors are correlated (Yong & Pearce, 2013). Oblique rotation methods produce a pattern and structure matrix. Field (2013) recommends basing interpretations of the analysis on the pattern matrix.

Factor loadings and number of factors. Factor loadings less than 0.31 were suppressed and factors with fewer than three contributing questions were removed from the analyses (Costello & Osborne, 2005). Kaiser's criterion, which suggests that only factors with eigenvalues greater than 1 be retained, is commonly used. Alternatively, the elbow of the curve on Cattell's Scree plot can be determined graphically to define a cutoff point (Cudeck & MacCullum, 2007). According to Yong and Pearce (2013), the number of factors to retain for extraction may rely on a researcher's best judgment. For this study, Kaiser's criterion, the Scree plot, and loadings in the pattern matrix were considered to determine the number of factors to retain.

Factor scales. Factor scores were constructed by calculating an equally-weighted average of scores for questions with substantial loadings and ignoring the questions with minor loadings according to the pattern matrix. This method of construction created factor scores on a 7-point scale, the same scale as the survey questions. Kim and Mueller (2011) reference the following two reasons for this type of construction: (a) factor loadings that are zero in the population are nonzero in the sample, and (b) factor loadings that are uniform in the population are non-uniform in the sample. Cronbach's alpha was calculated for each factor to provide an estimate of the scale reliability. Generally, Cronbach's alpha values greater than 0.70 are acceptable (Field, 2013). Descriptive statistics were calculated for the factors for the sample and the independent variables, gender, year of study, and engineering discipline.

Independent sample t-tests, ANOVAs, and Pearson's chi-square tests. A 95% confidence interval was used for all inferential statistics. Independent sample t-tests were calculated for each obtained factor for the independent variable gender. One-way independent ANOVAs were conducted for the independent variables year of study, and engineering discipline, for each factor. Levene's test was conducted for each ANOVA to determine the validity of the assumption of homogeneity of variance (Field, 2013). If ANOVAs were found to be statistically significant ($p < 0.05$), post-hoc testing was conducted using Hochberg's GT2 because of unequal sample sizes (Field, 2013). Pearson's chi-square test, which is used to see if there is a relationship between two categorical variables, was calculated for each independent variable for the ranking of the social, environmental, and economic elements (Field, 2013). If a difference was found, Cohen's *d* was calculated to determine the effect size of the difference. Cohen's *d* values less than 0.2 are negligible, between 0.2 and 0.5 are a small effect, between 0.5 and 0.8 are a medium effect, and greater than 0.8 are a large effect (Cohen, 1988).

Open-ended questions. The open-ended questions were analyzed on a question-by-question basis using deductive coding. Deductive coding, where the codes are created prior to data collection, is commonly used in quantitative research (Benaquisto, 2008). The deductive codes used by Lourdel et al. (2007) to code sustainable development concept maps were used with some modifications in this study. For the first open-ended question on the definition of sustainable development, the Lourdel et al.'s six codes were used as follows: (a) social or cultural; (b) environmental; (c) economic, scientific, or technical; (d) multidimensional, including complexity, spatial, and temporal; (e) procedural and political; and (f) actors and stakeholders. For two of the remaining open-ended questions on the definition of sustainable engineering practice, and common sustainability considerations, 2 additional codes were added: (a) engineering design process, and (b) not applicable. The code not applicable was used for responses where the other 7 codes did not apply.

CHAPTER 4

RESULTS

This chapter outlines the results from the analysis of the survey data. The results of the exploratory factor analyses are presented, followed by descriptive and inferential statistics. The results of the deductive coding analysis for the open-ended questions are also presented. Descriptive statistics for each survey question for the sample are shown in Appendix C.

Exploratory Factor Analyses

Exploratory factor analyses were conducted for the three elements of the simplified Eccles et al. expectancy-value theory elements. Multiple attempts were made for each analysis to improve the reliability of the obtained factors. The KMO measure of sampling adequacy was calculated for each attempt. The following guidelines were developed by Hutcheson and Sofroniou (1999) to interpret KMO values: (a) marvellous for values in the 0.90s, (b) meritorious for values in the 0.80s, (c) middling for values in the 0.70s, (d) mediocre for values in the 0.60s, (e) miserable for values 0.50s, and (f) unacceptable for values below 0.50.

Stereotypes and Previous Experiences

Two attempts were completed for the stereotypes and previous experience factor analysis. The 13 closed-ended stereotypes and previous experiences questions were included in the first attempt and the KMO statistic verified the sampling adequacy for the analysis, KMO = 0.82 (meritorious). Three factors had eigenvalues greater than 1 and in combination explained 39.89% of the variance. However, the question “Sustainability is currently a shared vision among all engineers working in a single company” did not load onto any of the factors in the pattern or structure matrix.

A second attempt was completed with the 12 loading questions. The KMO statistic verified the sampling adequacy for the analyses, KMO = 0.83 (meritorious). Three factors were retained by examination of the point of inflection on the Scree plot as shown in *Figure 3*. The retained factors explained 42.9% of the variance.

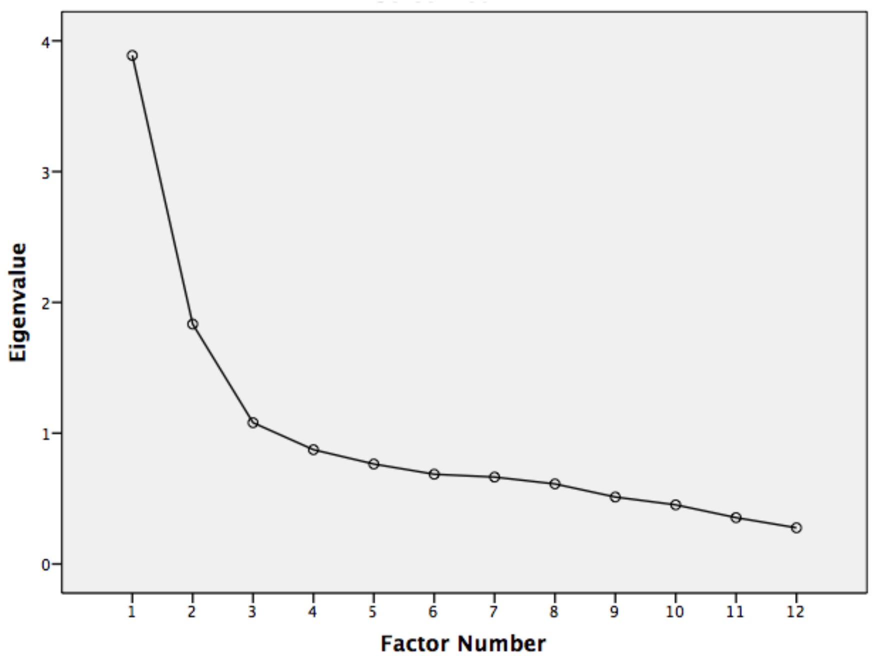

Figure 3

Scree plot for the second attempt of the stereotypes and previous experiences factor analyses.

The loading of questions onto the factors in the pattern matrix shown in Table 10 suggested that Factor 1 represented Academic Experiences, Factor 2 represented Application of Sustainable Engineering Practice (SEP) Experiences, and Factor 3 represented Applicability to Engineering Discipline. In the pattern matrix, each factor had four loading questions. The Academic Experiences factor had three strongly loading questions, while the other two factors only had two strongly loading questions. The Cronbach's alpha values were 0.81, 0.55, and 0.60 for the Academic Experiences, Application of SEP Experiences, and Applicability to Engineering

Discipline factors, respectively. Only the Academic Experiences factor had an acceptable value for Cronbach's alpha (> 0.70 according to Field, 2013). Given the loadings and Cronbach's alpha values, only the Academic Experiences factor was considered to be reliable. However, inferential statistics were still completed using the Application of SEP Experiences and Applicability to Engineering Discipline factors. The structure matrix for the stereotypes and previous experiences factor analysis is included in Appendix D.

Table 10

Pattern matrix for the stereotypes and previous experiences factor analysis.

Survey Question	**Academic Experiences**	**Application of SEP Experiences**	**Applicability to Engineering Discipline**
Number of Courses with SEP	0.44		
Sustainable engineering practice is valued by my course instructors.	0.63		
I am expected to apply sustainable engineering practice in my design projects.	0.93		
I receive marks in my courses for creating sustainable engineering solutions.	0.82		
I could have applied sustainable engineering practice more in my design projects.		0.45	
Practicing engineers should apply sustainable engineering practice to more elements of their projects.		0.60	
Course projects in my discipline have limited sustainability considerations.		0.35	

Survey Question	**Academic Experiences**	**Application of SEP Experiences**	**Applicability to Engineering Discipline**
I have to create opportunities myself to apply sustainable engineering practice in my design projects.		0.62	
Sustainability is just a word used in industry for promotion and public image.			0.34
Sustainable engineering practice is easily applied to real-world projects in my discipline.			-0.52
Other engineering disciplines have more sustainability considerations than my discipline.			0.39
Sustainable engineering practice is deeply integrated into my discipline.			-0.69

The assumption of correlated factors in using the direct oblimin rotation method was confirmed by the factor correlation matrix shown in Table 11. The largest correlation was between the Academic Experiences and Applicability to Engineering Discipline factors, while the other correlations were small (Field, 2013). The maximum likelihood method was also appropriate because the factors were correlated with unequal loadings.

Table 11

Factor correlation matrix for the stereotypes and previous experiences factor analysis.

Factor	**Academic Experiences**	**Application of SEP Experiences**	**Applicability to Engineering Discipline**
Academic Experiences	1.00		
Application of SEP Experiences	-0.19	1.00	
Applicability to Engineering Discipline	-0.54	-0.04	1.00

The descriptive statistics for the stereotypes and previous experiences factors are shown in Table 12. The factor scores were calculated on a 7-point Likert-type scale. At twice the respective standard deviations, the acceptable ranges were within ±0.32 and ±0.64 for the skewness and kurtosis, respectively (Field, 2013). The statistics suggested that participants had relatively neutral academic experiences in sustainable engineering practice with high variability. The Application of SEP Experiences factor was negatively skewed and leptokurtic. The statistics suggested that the participants had slightly negative experiences with the application of sustainable engineering practice and slightly positive stereotypes of sustainable engineering practice in their discipline.

Table 12

Descriptive statistics for the stereotypes and previous experiences factors.

Factor	***n***	$\bar{x}$	***s***	**Skewness**	**Kurtosis**
Academic Experiences	225	4.10	1.41	0.13	-0.52
Application of SEP Experiences	240	5.00	0.99	-0.72*	1.23*
Applicability to Engineering Discipline	241	3.55 (4.45)	1.20	0.15	-0.38

Self-Concept of Abilities

Two attempts were also completed for the self-concept of abilities factor analysis. The 14 closed-ended questions were included in the first attempt. The KMO statistic verified the sampling adequacy for the analyses, KMO = 0.84 (meritorious). Three factors had eigenvalues greater than 1 and in combination explained 56.43% of the variance. However, only two questions loaded onto the second factor in the pattern and structure matrix. These questions were “I can incorporate environmental costs and benefits in economic analyses” and “I can incorporate social costs and benefits in economic analyses.”

The questions that loaded to the second factor in the first attempt were removed from the second attempt. The KMO statistic verified the sampling adequacy for the analyses, KMO = 0.86 (meritorious). Two factors had eigenvalues over Kaiser’s criterion of 1, as shown in the Scree plot in *Figure 4*. In combination, the two factors explained 51.68% of the variance. The loading of questions onto the factors in the pattern matrix shown in Figure 4 suggested that Factor 1 represented TBL Understanding and Factor 2 represented SE Design Process Abilities. The TBL Understanding and SE Design Process Abilities factors had seven and five loadings questions in the pattern matrix, respectively. All questions loaded strongly, which suggests that the factors were strong (Costello & Osborne, 2005). The Cronbach’s alpha values were acceptable (> 0.70 according to Field, 2013) at 0.88 and 0.81 for the TBL Understanding and SE Design Process Abilities factors, respectively. Based on the strong loadings and high Cronbach’s alpha values, both factors were considered to be reliable. The structure matrix for the self-concept of abilities factor analysis is included in Appendix D.

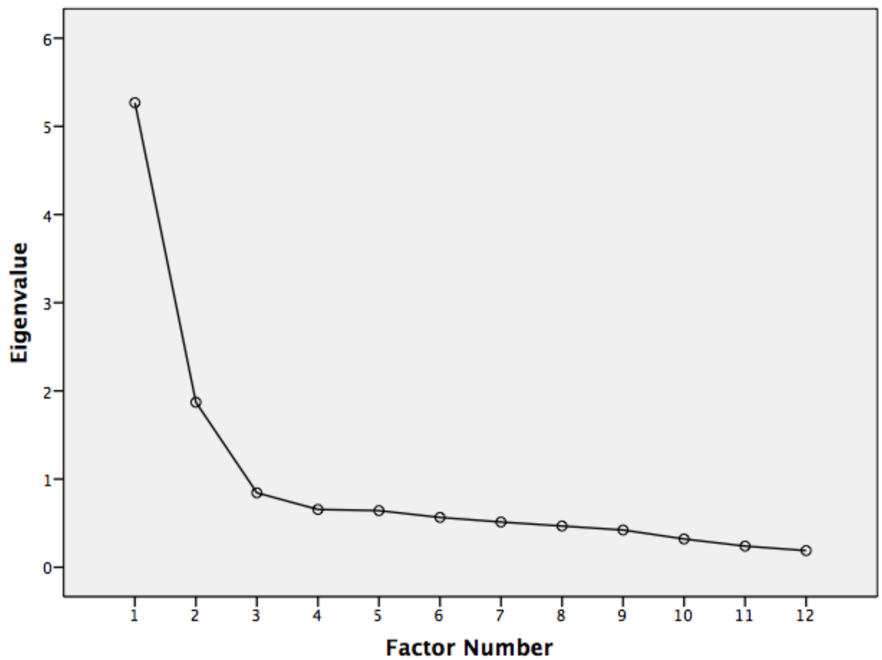

Figure 4

Scree plot for the second attempt of the self-concept of abilities factor analysis.

Table 13

Pattern matrix for the self-concept of abilities factor analysis.

Survey Question	**TBL Understanding**	**SE Design Process Abilities**
I understand the short-term social costs and benefits associated with engineering projects.	0.79	
I understand the long-term social costs and benefits associated with engineering projects.	0.78	
I understand the short-term environmental costs and benefits associated with engineering projects.	0.66	
I understand the long-term environmental costs and benefits associated with engineering projects.	0.59	
I understand the short-term economic costs and benefits associated with engineering projects.	0.69	
I understand the long-term economic costs and benefits associated with engineering projects.	0.81	

Survey Question	TBL Understanding	SE Design Process Abilities
I understand the interdependency among the social, environmental, and economic elements of engineering projects.	0.55	
I can apply sustainable engineering practice throughout the engineering design process.		0.76
I can identify experts in areas where my own knowledge is not adequate to address sustainable engineering issues.		0.68
I can define sustainability specifications for projects.		0.82
I can find information to assess a project to see if it meets sustainability specifications.		0.53
I can appropriately engage all types of stakeholders involved in a project.		0.52

The assumption of correlated factors in using the direct oblimin rotation method was confirmed (r = 0.46). The maximum likelihood method was also appropriate because the factors were correlated with unequal loadings. The descriptive statistics for the sample are shown in Table 14. Both factors were negatively skewed, and the SE Design Process Abilities factor was leptokurtic. The results suggested that participants have some confidence in their TBL Understanding and SE Design Process Abilities, both with high variability. The TBL Understanding scores were significantly higher than the SE Design Process Abilities scores (t (230) = 6.41, p < 0.01). The difference was a medium effect (d = 0.45).

Table 14

Descriptive statistics for the self-concept of abilities factors.

Factor	n	$\bar{x}$	s	Skewness	Kurtosis
TBL Understanding	234	5.07	1.10	-0.41*	0.06
SE Design Process Abilities	236	4.57	1.14	-0.72*	1.23*

Relative Value

Two attempts were also completed for the relative value factor analysis. The 17 closed-ended questions were included in the first attempt. The KMO statistic verified the sampling adequacy for the analyses, KMO = 0.89 (meritorious). Four factors had eigenvalues greater than 1 and in combination explained 60.00% of the variance. The location of the elbow of the curve on the Scree plot in *Figure 5* at the third factor suggested that the factors were overextracted. The questions “My classmates are more interested in sustainable engineering practice than I am” and “I will not work for companies that do not value sustainable engineering practice” did not load to any factors in the pattern matrix. However, the question “I will not work for companies that do not value sustainable engineering practice” loaded to all four factors in the structure matrix included in Appendix D.

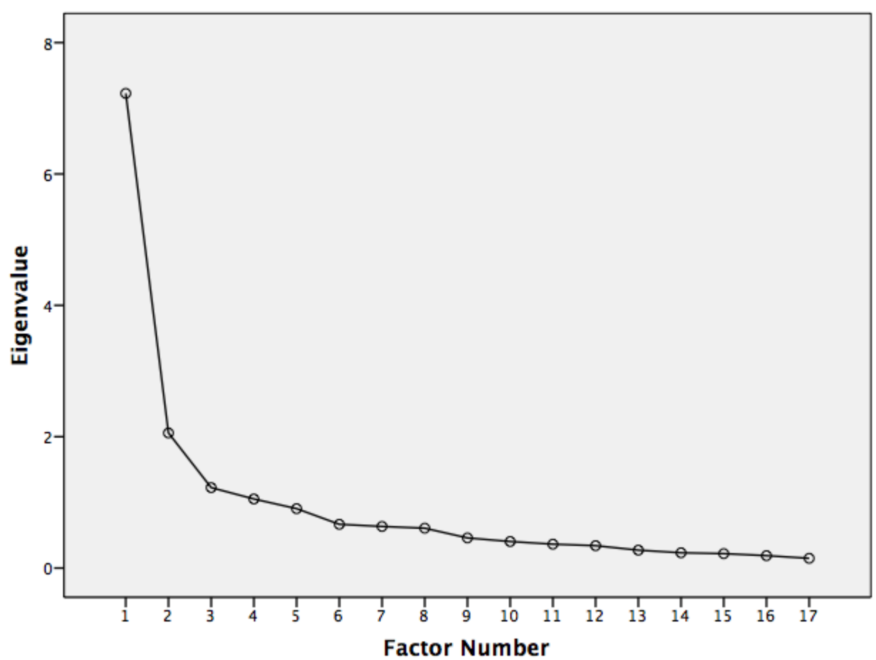

Figure 5

Scree plot for the first attempt of the relative value factor analysis.

The second attempt excluded the question “My classmates are more interested in sustainable engineering practice than I am.” The KMO statistic verified the sampling adequacy for the analyses, KMO = 0.89 (meritorious). Three factors had eigenvalues over Kaiser’s criterion of 1 as shown in the Scree plot in *Figure 6*. In combination, the factors explained 57.50% of the variance.

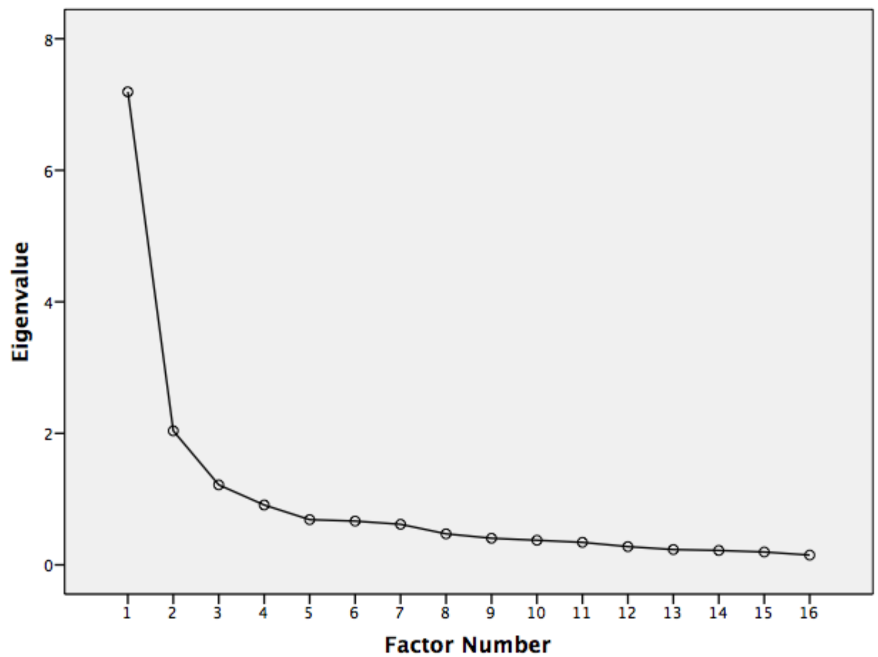

Figure 6

Scree plot for the second attempt for relative value factor analysis.

The loading of questions onto the factors in the pattern matrix shown in Table 15 suggested that Factor 1 represented Intrinsic Value, factor 2 represented Utility Value, and Factor 3 represented Relative Cost. The Intrinsic Value, Utility Value, and Relative Cost factors had eight, six, and four loading questions in the pattern matrix, respectively. Double loading occurred between the Intrinsic Value and Utility Value factors for the questions “I want to apply sustainable engineering practice to every project I work on” and “I want to ensure that projects contribute towards the development of communities that are impacted by projects." The Intrinsic Value factor had six strongly loading questions, while the Utility Value and Relative Cost factors only had three and two strongly loading questions, respectively (Costello & Osborne, 2005). The Cronbach's alpha values were acceptable (> 0.70 according to Field, 2013) at 0.89, 0.85, and 0.80 for the Intrinsic Value, Utility Value, and Relative Cost factors, respectively. Based on the loadings and Cronbach's alpha values, the Intrinsic Value and Utility Value factors were considered to be reliable, while the Relative Cost factor was considered to be somewhat reliable. The structure matrix for the Relative Value factor analysis is included in Appendix D.

Table 15

Pattern matrix for the relative value factor analysis.

Survey Question	**Intrinsic Value**	**Utility Value**	**Relative Cost**
I want to be enrolled in a sustainable engineering practice course.	0.70		
I would prefer to learn about sustainable engineering more than any other engineering concept.	0.79		
I enjoy solving problems that incorporate complex social, environmental, and economic elements.	0.62		
My goal is to become a leader in sustainable engineering practice.	0.86		
I often discuss sustainable engineering topics with my classmates.	0.64		
I will not work for companies that do not value sustainable engineering practice.	0.36		
I want to apply sustainable engineering practice to every project I work on.	0.53	0.40[a]	
I want to ensure that projects contribute towards the development of communities that are impacted by projects.	0.38[a]	0.48	

Survey Question	Intrinsic Value	Utility Value	Relative Cost
I need to learn about sustainable engineering now to be successful in my career.		0.47	
Learning about sustainable engineering practice is necessary to be a responsible engineer.		0.93	
The application of sustainable engineering practice creates better engineering solutions.		0.77	
The ability to assess the social, environmental, and economic elements of projects is a useful skill that will make me stand out to potential employers.		0.61	
Fully incorporating sustainable engineering practice into a real-world project is too expensive to be practical.			0.89
Fully incorporating sustainable engineering practice into a real-world project requires too much time to be practical.			0.87
Technical engineering topics are more important to learn about than sustainable engineering practice.			0.39
Engineering professional skills are more important to learn about than sustainable engineering practice.			0.49

a: question was not used for applicable factor when factor scores were computed

The assumption of correlated factors in using the direct oblimin rotation method was confirmed by the factor correlation matrix shown in Table 16. The highest correlation was between the Intrinsic Value and Relative Cost factors. The other correlations were medium in size (Field, 2013). The maximum likelihood method was also appropriate because the factors were correlated with unequal loadings.

Table 16

Factor correlations for the relative value factor analysis.

Factor	Intrinsic Value	Utility Value	Relative Cost
Intrinsic Value	1.000		
Utility Value	-0.36	1.000	
Relative Cost	0.62	-0.21	1.000

The descriptive statistics for the sample are shown in Table 17. The Intrinsic and Utility Value factors were negatively skewed, and the Utility Value factor was leptokurtic. The statistics suggested that participants have intrinsic and utility value for sustainable engineering practice. The statistics also suggested that the relative cost of engaging in sustainable engineering practice is minimal. The Utility Value scores were significantly higher than the Intrinsic Value scores (t (235) = -10.55, p < 0.01). The difference between the two factors was a medium effect (d = 0.52).

Table 17

Descriptive statistics for the relative value factors.

Factor	***n***	$\bar{x}$	***s***	**Skewness**	**Kurtosis**
Intrinsic Value	238	5.14	1.33	-0.81*	0.22
Utility Value	237	5.78	1.10	-1.57*	3.34*
Relative Cost	238	3.39	1.23	0.33	-0.04

Descriptive and Inferential Statistical Analyses

Descriptive statistics were calculated for the ranking of the central pillars, and for each of the factors for the independent variables, gender, year of study, and engineering discipline. A 95% confidence interval was used for the inferential statistics. For all factors and all levels of the independent variables, the standard errors were 0.16 and 0.32 for the skewness and kurtosis, respectively. Thus, the acceptable ranges were within ±0.32 and ±0.64 for the skewness and kurtosis, respectively (Field, 2013). One-way ANOVAs were conducted for each factor for the Year of Study variable and the Engineering Discipline variable. For all ANOVAs, Levene's test was not significant, which confirmed the assumption of homogeneity of variance.

The engineering discipline grouping, Other, was not included in the ANOVA for the variable Engineering Discipline.

Stereotypes and Previous Experiences

The descriptive statistics for the importance ranking of the central pillars and TBL elements are shown in Table 18. Only 2.9% of participants ranked the elements as equally important. The environmental element was considered most important as 54.6% of participants ranked it highest, and only 7.8% ranked it lowest. The economic element was considered the least important, as 62.1% of participants ranked it lowest and only 14.8% of participants ranked it highest. Only 7.7% of participants ranked two or more of the elements as being equally important. The most common ranking of importance order was environmental, social, and then economic.

Table 18

Descriptive statistics for the importance ranking of the social, environmental, and economic elements, organized by frequency.

Ranking Order			**Frequency**	**Percentage**
1	**2**	**3**		
Environmental	Social	Economic	86	35.4
Social	Environmental	Economic	58	23.9
Environmental	Economic	Social	39	16.0
Economic	Environmental	Social	22	9.1
Economic	Social	Environmental	10	4.1
Social	Economic	Environmental	8	3.3
Social, Environmental, Economic			7	2.9
Social, Environmental	Economic		4	1.6
Economic	Environmental	Social	2	0.8
Environmental	Social, Economic		2	0.8

Ranking Order			Frequency	Percentage
1	**2**	**3**		
Environmental and Economic	Social		1	0.4
Environmental	Social, Economic		1	0.4
Social and Economic	Environmental		1	0.4
Blank			2	0.8
Total			243	100.0

The results for the Pearson's chi-square tests are shown in Table 19. There were no significant differences in the ranking of the elements according to the independent variables.

Table 19

Pearson's chi-square results for the ranking of the social, environmental, and economic elements.

Test Group	*df*	χ^2	*p*
Gender	12	8.38	0.76
Year of Study	36	44.60	0.15
Engineering Discipline	48	47.60	0.49

The descriptive statistics for Academic Experiences factor based on the independent variables are shown in Table 20. The distributions for the female, Years 4+ of study, and ECE and Science and Other engineering discipline variable levels were platykurtic. The distribution for the Environmental-Based discipline variable level was positively skewed. There was no statistical difference in responses between genders ($t(223) = -0.49$, $p = 0.63$).

Table 20

Descriptive statistics for the Academic Experiences factor.

Variable	**Variable Level**	***n***	$\overline{x}$	***s***	**Skewness**	**Kurtosis**
Gender	Male	140	4.06	1.46	0.22	-0.43
	Female	85	4.16	1.34	-0.04	-0.71*
Year of Study	1	39	3.85	1.28	-0.26	-0.51
	2	60	4.08	1.14	0.07	0.25
	3	58	4.08	1.33	0.24	-0.60
	4+	68	4.28	1.73	0.04	-1.09*
Engineering Discipline	Mechanical-Based	57	3.71	1.44	0.22	-0.40
	ECE and Science	68	3.64	1.27	0.10	-0.96*
	Chemical-Based	30	4.68	1.29	-0.04	-0.31
	Environmental-Based	52	4.66	1.36	0.35*	-0.63
	Other	18	4.49	1.26	-0.17	-1.20*

The results of the ANOVAs for the Academic Experiences factor are shown in Table 21. The statistically significant differences among the engineering discipline groupings were determined through review of the Hochberg's GT2 post-hoc testing. The Mechanical-Based disciplines had less positive academic experiences than the Chemical-Based and Environmental disciplines, with Cohen's *d* values of 0.71 and 0.68, respectively. In both cases, the effect sizes were medium. The ECE and Science grouping also had less positive academic experiences than the Chemical-Based and Environmental-Based disciplines. The Cohen's *d* values were 0.81 for the ECE and Science and Chemical-Based disciplines and 0.68 for the ECE and Science and Environmental-Based disciplines, which indicated a large and medium effect, respectively. There were no statistically significant differences for Year of Study.

Table 21

One-way ANOVA results for the Academic Experiences factor.

Test Group	**Source**	***df***	***F***	***p***
Year of Study	Between Groups	3	0.76	0.52
	Within Groups	221		
Engineering Discipline	Between Groups	3	9.09	<.01*
	Within Groups	203		

The descriptive statistics for Application of SEP Experiences factor based on the independent variables are shown in Table 22. Most of the distributions for the variable levels were negatively skewed or leptokurtic. There was no statistical difference in responses between genders ($t(238) = -0.73$, $p = 0.47$).

Table 22

Descriptive statistics for the Application of SEP Experiences factor.

Variable	**Variable Level**	***n***	$\bar{x}$	***s***	**Skewness**	**Kurtosis**
Gender	Male	151	4.97	0.96	-0.55*	1.10*
	Female	89	5.06	1.04	-0.99*	1.63*
Year of Study	1	42	5.04	0.91	-0.11	-0.24
	2	64	4.91	0.94	-0.55*	0.77*
	3	61	5.07	1.01	-1.05*	2.40*
	4+	73	5.00	1.07	-0.85*	1.42*
Engineering Discipline	Mechanical-Based	61	5.20	1.11	-1.20*	2.33*
	ECE and Science	73	5.12	0.80	-0.02	-0.34
	Chemical-Based	33	5.00	1.11	-0.70*	0.49
	Environmental-Based	54	4.73	0.83	-0.26	-0.15
	Other	19	4.70	1.27	-1.10*	1.70*

The results of the ANOVAs for the Application of SEP Experiences factor are shown in Table 23. The statistically significant differences among the engineering discipline groupings were determined through review of the Hochberg's GT2 post-hoc testing. The Mechanical-Based disciplines had more negative experiences with for the Application of Sustainable Engineering Practice factor than the Environmental-Based disciplines. The difference was a small effect (*d* = 0.48). There were no statistically significant differences for Year of Study.

Table 23

One-way ANOVA results for the independent variables for the Application of SEP Experiences factor.

Test Group	**Source**	***df***	***F***	***p***
Year of Study	Between Groups	3	0.27	0.85
	Within Groups	236		
Engineering Discipline	Between Groups	3	2.67	0.05*
	Within Groups	217		

The descriptive statistics for the Applicability to Engineering Discipline factor based on the independent variables are shown in Table 24. The distributions for the Environmental-Based and Other discipline variable levels were negatively skewed. Platykurtic distributions were found for the female, Years 4+ of study, and the Chemical-Based discipline variable levels. There was no statistical difference in responses between genders ($t(239) = -0.58$, $p = 0.56$).

Table 24

Descriptive statistics for the Applicability to Engineering Discipline factor.

Variable	**Variable Level**	***n***	$\bar{x}$	***s***	**Skewness**	**Kurtosis**
Gender	Male	151	3.58	1.18	0.25	-0.09
	Female	90	3.49	1.24	0.02	-0.80*
Year of Study	1	42	3.48	1.25	0.29	0.14
	2	65	3.43	1.12	0.20	-0.40
	3	61	3.67	1.18	0.20	0.04
	4+	73	3.60	1.27	-0.01	-0.78*
Engineering Discipline	Mechanical-Based	62	3.77	1.13	0.28	0.54
	ECE and Science	73	4.00	1.15	-0.24	-0.14
	Chemical-Based	33	3.33	1.08	-0.06	-1.08*
	Environmental-Based	54	2.87	1.05	0.61*	0.16
	Other	19	3.49	1.39	0.37*	-0.31

The results of the ANOVAs for the Applicability to Engineering Discipline factor are shown in Table 25. The statistically significant differences among the engineering discipline groupings were determined through review of the Hochberg's GT2 post-hoc testing. The Mechanical-Based disciplines had more negative stereotypes of sustainable engineering practice within their discipline than the Environmental-Based disciplines. The difference was a large effect (d = 0.83). The ECE and Science disciplines had more negative stereotypes of sustainable engineering practice within their discipline than both the Chemical-Based and Environmental-Based disciplines. The Cohen's d values were 0.60 for the ECE and Science and Chemical-Based disciplines and 1.03 for the ECE and Science and Environmental-Based disciplines, which indicated a medium and large effect, respectively. There were no statistically significant differences for Year of Study.

Table 25

One-way ANOVA results for the independent variables for the Applicability to Engineering Discipline factor.

Test Group	**Source**	***df***	***F***	***p***
Year of Study	Between Groups	3	0.53	0.66
	Within Groups	237		
Engineering Discipline	Between Groups	3	11.75	<0.01*
	Within Groups	218		

Self-Concept of Abilities

The descriptive statistics for the TBL Understanding factor based on the independent variables are shown in Table 26. Many of the distributions were negatively skewed, which suggested that the participants had high self-reported levels of TBL Understanding. Leptokurtic distributions were found for the male, Year 3 of Study, and Mechanical-Based discipline variable levels. Male participants self-reported significantly higher understanding of the TBL elements than female students ($t(232) = 2.22$, $p = 0.03$*). The effect size of the difference was small at 0.30.

Table 26

Descriptive statistics for the TBL Understanding factor.

Variable	**Variable Level**	***n***	$\bar{x}$	***s***	**Skewness**	**Kurtosis**
Gender	Male	147	5.19	1.04	-0.57*	0.65*
	Female	87	4.86	1.16	-0.37*	0.12
Year of Study	1	40	5.09	1.34	-0.74*	0.10
	2	64	5.09	0.95	-0.33*	0.56
	3	58	4.83	1.06	-0.31	0.72*
	4+	72	5.22	1.08	-0.62*	0.39
Engineering Discipline	Mechanical-Based	59	5.12	1.06	-0.86*	0.87*
	ECE and Science	71	5.05	1.00	-0.17	-0.03
	Chemical-Based	33	5.10	1.20	-0.10	-0.61
	Environmental-Based	53	5.05	0.95	-0.42*	0.37
	Other	18	4.94	1.74	-0.74*	-0.42

The results of the ANOVAs for the TBL Understanding factor are shown in Table 27. There were no statistically significant differences among the variable levels.

Table 27

One-way ANOVA results for the independent variables for the TBL Understanding factor.

Test Group	**Source**	***df***	***F***	***p***
Year of Study	Between Groups	3	1.39	0.25
	Within Groups	230		
Engineering Discipline	Between Groups	3	0.72	0.98
	Within Groups	212		

The descriptive statistics for the SE Design Process Abilities factor based on the independent variables are shown in Table 28. As with the TBL Understanding factor, many of the distributions were negatively skewed. Platykurtic distributions were found for the Year 1 of

Study and the Other engineering discipline variable levels. There was no statistical difference in responses between genders ($t(234) = -0.83$, $p = 0.41$).

Table 28

Descriptive statistics for the SE Design Process Abilities factor.

Variable	**Variable Level**	***n***	$\overline{x}$	***s***	**Skewness**	**Kurtosis**
Gender	Male	147	4.62	1.12	.-0.38*	0.05
	Female	89	4.49	1.17	-0.37*	0.12
Year of Study	1	40	4.53	0.85	0.12	-0.83*
	2	64	4.45	1.15	-0.57*	-0.17
	3	60	4.44	1.22	-0.41*	0.57
	4+	72	4.82	1.18	-0.44*	-0.30
Engineering Discipline	Mechanical-Based	61	4.54	1.16	-0.52*	0.46
	ECE and Science	73	4.43	1.14	-0.23	-0.05
	Chemical-Based	43	4.67	1.03	-0.52*	-0.21
	Environmental-Based	53	4.69	1.19	-0.20	-0.34
	Other	16	4.76	1.17	-1.62*	3.90*

The results of the ANOVAs for the SE Design Process Abilities factor are shown in Table 29. There were no statistically significant differences among the variable levels.

Table 29

One-way ANOVA results for the independent variables for the SE Design Process Abilities factor.

Test Group	**Source**	***df***	***F***	***p***
Year of Study	Between Groups	3	1.68	0.17
	Within Groups	232		
Engineering Discipline	Between Groups	3	0.81	0.60
	Within Groups	216		

Relative Value

The descriptive statistics for the Intrinsic Value factor based on the independent variables are shown in Table 30. The distributions for all variable levels were negatively skewed, which suggests that the participants value sustainable engineering practice intrinsically. Leptokurtic distributions were found for the Year 3 of Study and the Other engineering discipline variable levels. There was no statistical difference in responses between genders ($t(236) = -1.49$, $p = 0.14$).

Table 30

Descriptive statistics for the Intrinsic Value factor.

Variable	**Variable Level**	***n***	$\bar{x}$	***s***	**Skewness**	**Kurtosis**
Gender	Male	149	5.05	1.38	-0.80*	0.12
	Female	89	5.31	1.24	-0.78*	0.32
Year of Study	1	41	5.35	1.22	-0.90*	0.43
	2	63	5.08	1.33	-0.62*	-0.64
	3	61	5.18	1.31	-0.92*	1.17*
	4+	73	5.06	1.41	-0.84*	0.28
Engineering Discipline	Mechanical-Based	62	5.29	1.36	-0.84*	0.25
	ECE and Science	73	4.81	1.34	-0.69*	-0.28
	Chemical-Based	33	5.19	1.23	-0.63*	-0.14
	Environmental-Based	52	5.39	1.17	-0.59*	-0.24
	Other	18	5.21	1.68	-1.56*	2.21*

The results of the ANOVAs for the Intrinsic Value factor are shown in Table 31. The statistically significant differences among the engineering discipline groupings were determined through review of the Hochberg’s GT2 post-hoc testing. The ECE and Science disciplines had lower intrinsic value for sustainable engineering practice than the Environmental-Based disciplines. The difference was a small effect (*d* = 0.46). There were no statistically significant differences for Year of Study.

Table 31

One-way ANOVA results for the independent variables for the Intrinsic Value factor.

Test Group	**Source**	***df***	***F***	***p***
Year of Study	Between Groups	3	.47	.70
	Within Groups	234		
Engineering Discipline	Between Groups	3	2.49	.05
	Within Groups	215		

The descriptive statistics for the Utility Value factor based on the independent variables are shown in Table 32. The distributions for all variable levels were negatively skewed, excluding the distribution for the female participants, which was positively skewed. Excluding the distribution for the Environmental-Based disciplines, the distributions for the variable levels were leptokurtic. There was no statistical difference in responses between genders ($t(235) = -1.44$, $p = 0.15$).

Table 32

Descriptive statistics for the Utility Value factor.

Variable	**Variable Level**	***n***	$\bar{x}$	***s***	**Skewness**	**Kurtosis**
Gender	Male	147	5.70	1.09	-1.55*	3.32*
	Female	90	5.91	1.09	0.66*	0.80*
Year of Study	1	41	6.00	0.88	-0.92*	1.10*
	2	64	5.77	1.16	-1.04*	0.74*
	3	60	5.85	1.06	-2.08*	6.91*
	4+	72	5.61	1.19	-1.77*	3.60*
Engineering Discipline	Mechanical-Based	61	5.79	1.22	-1.80*	4.01*
	ECE and Science	72	5.55	1.08	-1.08*	1.16*
	Chemical-Based	33	5.82	1.06	-1.09*	1.81*
	Environmental-Based	53	6.10	0.72	-0.45*	-0.57
	Other	18	5.69	1.58	-2.05*	3.95*

The results of the ANOVAs for the Utility Value factor are shown in Table 33. The statistically significant differences among the engineering discipline groupings were determined through review of the Hochberg's GT2 post-hoc testing. The ECE and Science disciplines had lower Utility Value for sustainable engineering practice than the Environmental-Based disciplines. The difference was a medium effect (d = 0.60). There were no statistically significant differences for Year of Study.

Table 33

One-way ANOVA results for the independent variables for the Utility Value factor.

Test Group	**Source**	***df***	***F***	***p***
Year of Study	Between Groups	3	1.19	.31
	Within Groups	233		
Engineering Discipline	Between Groups	3	2.81	.04
	Within Groups	215		

The descriptive statistics for the Relative Cost factor based on the independent variables are shown in Table 34. The distributions for the female, Years 2 and 4+, and Mechanical-Based and Environmental-Based disciplines variable levels were positively skewed. Platykurtic distributions were found for the female, Year 3, and Chemical-Based variable levels. There was no statistical difference in responses between genders ($t(236) = -1.42$, $p = 0.16$).

Table 34

Descriptive statistics for the Relative Cost factor.

Variable	**Variable Level**	***n***	$\bar{x}$	***s***	**Skewness**	**Kurtosis**
Gender	Male	149	3.48	1.31	0.16	-0.29
	Female	89	3.24	1.09	0.66*	0.80*
Year of Study	1	42	3.39	1.16	0.10	-0.33
	2	63	3.59	1.38	0.41*	-0.08
	3	61	3.26	1.15	-0.16	-0.68*
	4+	72	3.33	1.21	0.56*	0.29
Engineering Discipline	Mechanical-Based	62	3.38	1.23	0.53*	0.23
	ECE and Science	72	3.65	1.22	0.21	0.08
	Chemical-Based	32	3.28	1.09	0.29	-0.88*
	Environmental-Based	53	3.22	1.26	0.41*	0.19
	Other	19	3.13	1.40	0.31	0.11

The results of the ANOVAs for the Relative Cost factor are shown in Table 35. There were no statistically significant differences among any of the variable levels.

Table 35

One-way ANOVA results for the independent variables for the Relative Cost factor.

Test Group	**Source**	***df***	***F***	***p***
Year of Study	Between Groups	3	.81	.49
	Within Groups	234		
Engineering Discipline	Between Groups	3	1.49	.22
	Within Groups	215		

Open-Ended Questions Deductive Coding

Multiple codes were assigned to the responses as applicable. The results from the deductive coding of the first open-ended question on sustainable development are shown in Table 36. A total of 509 instances of the codes were deduced from 243 responses. The most common codes were environmental and multidimensional. Of the three central pillars, the environmental pillar occurred most frequently. The political and procedural code occurred least frequently.

Table 36

Deductive coding results for the question, what is sustainable development? (n = 243).

Deductive Code	**Frequency**	**Percentage of Responses**
Social and cultural	73	30.04
Environmental	174	71.60
Economic	70	28.81
Multidimensional (complexity, spatial, temporal)	128	52.67
Political and procedural	9	3.70
Actors and stakeholders	55	22.63

The results from the deductive coding of the second open-ended question on sustainable engineering practice are shown in Table 37. A total of 429 instances of the codes were deduced from the 239 responses. The deductive codes did not apply to 11.72% of the responses. Generally, such responses were vague in details such as “engineering things that are sustainable” or “the practice of designing things with sustainability in mind.” The environmental code occurred most frequently. The percentages of responses that included the social and cultural, economic, and multidimensional codes were reduced compared to the first open-ended question. As with the first open-ended question, the political and procedural code occurred least frequently.

Table 37

Deductive coding results for the question, what is sustainable engineering practice? (n = 239).

Deductive Code	**Frequency**	**Percentage of Responses**
Social and cultural	44	18.41
Environmental	168	70.29
Economic	35	14.64
Multidimensional (complexity, spatial, temporal)	70	29.29
Political and procedural	6	2.51
Actors and stakeholders	48	20.08
Design process	30	12.55
Not Applicable	28	11.72

The results from the deductive coding of the third open-ended question on common sustainability considerations are shown in Table 38. A total of 314 instances of the codes were deduced from the 224 responses, which was a decrease from the first and second open-ended questions. The deductive codes did not apply to 12.50% of the 224 valid responses. The environmental code occurred most frequently. Excluding the three central pillars, the frequency of each code decreased compared to the previous open-ended questions. Again, the political and procedural code occurred least frequently.

Table 38

Deductive coding results for the question, what are the most common sustainability considerations in your discipline? (n = 224).

Deductive Code	**Frequency**	**Percentage of Responses**
Social and cultural	35	15.63
Environmental	174	77.68
Economic	47	20.98
Multidimensional (complexity, spatial, temporal)	11	4.91
Political and procedural	1	0.45
Actors and stakeholders	4	1.79
Design process	14	6.30
Not Applicable	28	12.50

CHAPTER 5

DISCUSSION

The details presented in this chapter were used to answer the research questions that were outlined in Chapter 1. The research questions were as follows:

1. What are students' expectancies of success when engaging in sustainable engineering practice?
2. What are students' relative values of sustainable engineering practice?
3. What are the effects of gender, year of study, and engineering discipline on students' motivation to engage in sustainable engineering practice?

Interpretations of the results from all closed- and open-ended questions in the survey are presented for each research question. An analysis of the limitations of the study is also presented.

Research Question 1 on Students' Expectancy of Success

Students' expectancy of success when engaging in the task sustainable engineering practice was simplified and represented by the two elements Stereotypes and Previous Experiences, and Self-Concept of Abilities.

Stereotypes and Previous Experiences

The three open-ended questions, ranking of the social, environmental, and economic elements, and the three factors Academic Experiences, Application of SEP Experiences, and Engineering Discipline Stereotypes contributed to the Stereotypes and Previous Experiences element. The results of the open-ended questions and the ranking of the central pillars suggested that students' have a stereotype of sustainable engineering practice that primarily incorporates the environmental element. There were increasingly fewer codes for the social and economic elements than the environmental element as the open-ended questions became more specific for the context of sustainable development in engineering education. The social and economic elements were also ranked as having lower importance than the environmental element. The bias towards the environmental element agreed with the findings of previous studies (Azapagic, Perdan, & Shallcross, 2005; Beiler, 2017; Hanning et al., 2012; Hoffman et al., 2011; Kagawa, 2007; Segalàs et al., 2008; Sheikh, Aziz, & Yusof, 2012).

For the definitions of sustainable development and sustainable engineering practice, the Multidimensional code occurred more often than the other codes, with the exception of the Environmental code. This suggested that students consider the complexity, spatial relations, and temporal directions of sustainable development and sustainable engineering practice. Common considerations that contributed to the Multidimensional code were the number of and interconnectedness of sustainability topics, local and global settings, and current and future generations. There were substantially fewer Multidimensional codes for the question on common sustainability considerations in their discipline. This suggested that although students recognize multidimensionality within sustainable development and sustainable engineering practice, they do not consider it commonly in their respective disciplines. Commonly, students only consider simplistic environmental topics.

According to the descriptive statistics, students reported relatively neutral Academic Experiences with sustainable engineering practice. This suggested that students may not have had substantial previous experiences with sustainable engineering practice in an academic setting. Although studies have not been conducted in Canada on the prevalence of sustainable engineering practice in courses and programs, American and European studies have found that academic experiences of sustainable engineering practice are limited (Allen et al., 2010; Byrne et al., 2010; Hanning et al., 2012). It is possible that students have had previous experiences in an academic setting, but did not recognize them as being related to sustainable engineering practice. Although definitions for sustainable development and sustainable engineering practice were provided prior to the closed-ended questions, it is possible that students' bias toward the environmental element influenced what they considered to be sustainable engineering practice in the academic setting.

The descriptive statistics suggested that students reported slightly negative Application of SEP Experiences. Similar to the Academic Experiences factor, this suggested that students may not have had substantial previous experiences in applying sustainable engineering practice. The two strongest loading questions on the Application of SEP Experiences factor were "Practicing engineers should apply sustainable engineering practice to more elements of their projects" and "I have to create opportunities myself to apply sustainable engineering practice in my design projects." Considering the descriptive statistics for the Application of SEP Experiences factor, the responses suggested that students slightly agree with these statements. Thus, it is possible that students' interpretation of their previous experiences were that sustainable engineering practice is not applied enough in engineering.

The strongest loading questions for the Engineering Discipline Stereotypes factor were "Sustainable engineering practice is easily applied to real-world projects in my discipline" and "Sustainable engineering practice is deeply integrated into my discipline." The descriptive statistics for the factor suggested that students slightly agreed with these statements. This suggested that students have a slightly positive stereotype of sustainable engineering practice in the context of their discipline. However, social desirability bias and students' bias for the environmental element of sustainable engineering practice may have influenced their responses.

Overall, the results suggested that students' experience with sustainable engineering practice is limited and suggests an environmental bias and minimal consideration of multidimensionality. The results also suggested that they view sustainable engineering practice as being slightly applicable to their discipline.

Self-Concept of Abilities

The TBL Understanding and SE Design Process Abilities factors contributed to the Self-Concept of Abilities element. The descriptive statistics suggested that students have slightly positive self-concepts of their abilities for both factors. Students reported more positive self-concepts for the TBL Understanding factor than the SE Design Process Abilities factor to a medium effect size. Although the cause of this difference was unclear, there are some possible explanations. In the open-ended question on common sustainability considerations, the multidimensionality code was not prevalent. It was possible that students had simple, single dimensional perspectives of the costs and benefits associated with the social, environmental, and economic elements in the short- and long-term ranges. The terminology in the TBL Understanding loading questions was simpler than in the SE Design Process questions. As well, the SE Design Process Abilities factor would have required students to have positive self-concepts of their abilities in sustainable engineering practice and in engineering design. If students have overly high self-concepts of their abilities, their abilities to engage well in sustainable engineering practice ay be compromised. The think-aloud interviews in the pilot study suggested that some students may have limited knowledge in engineering design generally and in the sustainable engineering design process. Because of the sample size and demographics of the pilot study, these results cannot be generalized to the national study.

There also was a disconnect between students' self-concept of abilities and their responses to the open-ended questions. The social and economic elements were not highly addressed in the open-ended questions, but students reported overall high self-concepts of their abilities to understand all of the TBL elements. As well, a small amount of the codes for the sustainable engineering practice and common sustainability consideration open-ended questions were for the design process code. However, the purpose of the Self-Concept of Abilities element was to assess students' confidence, and not their competence (Eccles & Wigfield, 2002).

Overall Expectancy for Success

The simplified model in Table 39 was used to assess students' expectancy for success from the results for the two elements. Overall, students had slightly positive stereotypes but minimal previous experiences, and slightly above neutral self-concept of their abilities. From the results of the study, it is reasonable to suggest that students do not fully expect success when engaging in the task sustainable engineering practice. Using Table 39, students' expectancy for success is in the lower range between maybe and no.

Table 39

The simplified model used to assess expectancy of success from the stereotypes and previous experiences and self-concept of abilities elements. The first two columns are inputs and the Expect Success column is an output.

Positive Stereotypes and Substantial Previous Experiences	High Self-Concept of Abilities	Expect Success
Yes	Yes	Yes
Yes	Maybe or No	Maybe
Maybe or No	Yes	Maybe
Maybe or No	Maybe or No	No

Research Question 2 on Students' Relative Value

The factors Intrinsic Value, Utility Value, and Relative Cost contributed to the relative value element. Overall, students reported Intrinsic and Utility Value for sustainable engineering practice and minimal relative cost when engaging in the task. The highest loading questions for the Intrinsic Value factor were "My goal is to become a leader in sustainable engineering practice" and "I would prefer to learn more about sustainable engineering more than any other concept." The highest loading questions for the Utility Value factor were "Learning about sustainable engineering practice is necessary to be a responsible engineer" and "The application of sustainable engineering practice creates better engineering solutions." Students reported higher Utility Value than Intrinsic Value for sustainable engineering practice with a medium effect size. The context of the loading questions for each factor suggested Utility Value factor was more subject to extrinsic sources than the Intrinsic Value factor. Overall, the results suggested that students do value sustainable engineering practice.

Research Question 3 on Effects on Students' Motivation

According to the Eccles et al. expectancy-value theory, students must expect success when engaging in the task, and value the task to be motivated to engage in the task (Eccles & Wigfield, 2002). For this study, the simplified model in Table 40 was used to assess students' motivation to engage in sustainable engineering practice. Based on the propositions that students have a limited expectancy of success when engaging in the task sustainable engineering practice but that they do value sustainable engineering practice, students' motivation to engage in it is limited. Using the results in the model in Table 40, students motivation level is "Maybe." To meet the expectations of political and professional organizations for contributions to sustainable development, students should be definitively motivated to engage in sustainable engineering practice. However, the results suggest that this is not the case.

Table 40

The simplified model used to assess motivation from the expectancy and value elements. The first two columns are inputs and the Motivated column is an output.

Expect Success	**Value**	**Motivated**
Yes	Yes	Yes
Yes	Maybe or No	Maybe
Maybe or No	Yes	Maybe
Maybe or No	Maybe or No	No

Differences were found in students' expectancy of success, value, and motivation according to the independent variables gender, year of study, and engineering discipline.

Gender

For most factors and for the ranking of the social, environmental, and economic elements, there were no differences between genders. Male students reported higher levels of understanding for the TBL Understanding factor than female students with a small effect size. Other studies have found that male engineering students self-report higher levels of knowledge and competence than female engineering students for sustainable development topics (McCormick et al., 2015a; Ro et al., 2012).

Year of Study

There were no differences for the factors or for the ranking of the social, environmental, and economic elements according to year of study. The consistency among years of study contradicted previous studies in the United States (McCormick et al., 2015a; Ro et al., 2012). Students' motivation to engage in sustainable engineering practice does not seem to decrease or increase in Canadian engineering programs as they progress through the programs. This suggested that engineering programs are neither dissuading nor motivating students to engage in sustainable engineering practice. Graduating engineering students from accredited programs are expected to demonstrate competency in the graduate attribute Impact of Engineering (Engineers Canada, 2016). Although the graduate attribute does not require students to be motivated for sustainable engineering practice, it does require students to have an understanding of elements of sustainable engineering practice and an ability to apply them. There were no differences in the TBL Understanding factor or the SE Design Process factor, which suggested that students' self-concept of abilities in sustainable engineering practice do not improve as they progress. However, the study did not, and was not intended to, directly address students' knowledge and understanding of the SE Design Process.

Engineering Discipline

As outlined in Chapter 3, the 5 engineering discipline groupings were as follows: (a) Mechanical-Based, including mechanical, industrial, and aerospace; (b) ECE and Science, including electrical, computer, software, and biomedical engineering, mathematics and engineering, and engineering physics; (c) Chemical-based, including chemical, and materials engineering, and engineering chemistry; (d) Environmental-Based, including civil, mining, geological, environmental, and sustainable design engineering; and (e) Other, including general first year programs, and those not specified. The grouping Other was not considering when conducting the ANOVAs.

There were differences among the engineering discipline groupings for 5 of the 8 factors, as summarized in Table 41. There were differences for all factors that contributed to the Stereotypes and Previous Experiences element but no differences for the Self-Concept of Abilities factors. This suggested that there are differences among students' Expectancy for Success according to engineering discipline. There were no differences between the Mechanical-Based and ECE and Science disciplines or the Chemical-Based and Environmental-Based disciplines. Many of the differences had medium to large effect sizes that when considered with the sample size indicated that that differences were dependable.

Table 41

Summary of the effect sizes from Chapter 4 for the significant differences among the engineering discipline groupings for all factors. The Mechanical-Based or the ECE and Science discipline groupings scored lower than the comparison discipline.

Factor	**Base Discipline Grouping**	**Comparison Discipline Grouping**	**Effect Size**
Academic Experiences	Mechanical-Based	Chemical-Based	Medium
		Environmental-Based	Medium
	ECE and Science	Chemical-Based	Large
		Environmental-Based	Medium
Application of SEP Experiences	Mechanical-Based	Environmental-Based	Small
Applicability to Engineering Discipline	Mechanical-Based	Environmental-Based	Large
	ECE and Science	Chemical-Based	Medium
		Environmental-Based	Large
Intrinsic Value	ECE and Science	Environmental-Based	Small
Utility Value	ECE and Science	Environmental-Based	Medium

Mechanical-Based disciplines. The Mechanical-Based disciplines had lower scores than the Chemical-Based and Environmental disciplines for factors contributing to the Stereotypes and Previous Experiences element of the expectancy-value theory. The average for the Mechanical-Based discipline grouping was slightly below neutral for the Academic Experiences factor. This suggested that the Mechanical-based discipline students had slightly negative or limited Academic Experiences with sustainable engineering practice. The large effect size for the difference between the Mechanical-Based and Environmental-Based disciplines on the Applicability to Engineering Discipline factor was notable. The descriptive statistics suggested that students in the Mechanical-Based disciplines reported only slight applicability of sustainable engineering practice to their discipline with high variability. The average and variability suggested that some students did not view sustainable engineering practice as applicable to the Mechanical-Based disciplines.

Overall, the differences suggested that when compared to the students in the Chemical- and Environmental disciplines, students in the Mechanical-Based disciplines had neutral stereotypes and very limited previous experiences. Based on the effect sizes, the results suggested that students in the Mechanical-Based disciplines have a lower expectancy for success for engaging in the task sustainable engineering practice, particularly when compared to the Environmental-Based disciplines. Using the model in Table 40, this suggested that students in the Mechanical-Based disciplines have lower motivation to engage in sustainable engineering practice than those in the Chemical- and Environmental-Based disciplines.

ECE and Science disciplines. The ECE and Science disciplines had lower scores than the Chemical- and Environmental- Based disciplines for factors contributing to the Stereotypes and Previous Experiences and the Relative Value elements of the expectancy-value theory. The large effect size for the difference between the ECE and Science and Chemical-Based disciplines on the Academic Experiences factor was notable. The large effect size for the difference between the ECE and Science and Environmental-Based disciplines on the Applicability to Engineering Discipline factor was also notable. As with the Mechanical-Based disciplines, the average for the ECE and Science disciplines was slightly below neutral for the Academic Experiences factor. This suggested that the students had slightly negative or limited Academic Experiences with sustainable engineering practice. The descriptive statistics suggested that students in the ECE and Science disciplines reported the applicability of sustainable engineering practice to their discipline as neutral with high variability. This suggested that although some students think it is slightly applicable to the ECE and Science disciplines, others think it is slightly not applicable. The ECE and Science disciplines also had lower scores than the Environmental-Based disciplines for the Intrinsic and Utility Value factors. The descriptive statistics suggested that students had only slight Intrinsic Value for sustainable engineering practice. Although the students reported Utility Value for sustainable engineering practice, the average was lower than that of the Environmental-Based disciplines to a medium effect.

Overall, the differences suggested that when compared to the students in the Chemical- and Environmental disciplines, students in the ECE and Science disciplines had neutral stereotypes and very limited previous experiences. Based on the effect sizes, the results suggested that students in the ECE and Science disciplines have a lower expectancy for success for engaging in the task sustainable engineering practice. The results also suggested that students in the ECE and Science disciplines may have lower value for sustainable engineering practice than the Environmental-Based discipline. Using the model in Table 40, this suggested that students in the ECE and Science disciplines have lower motivation to engage in sustainable engineering practice than students in the Chemical-Based disciplines, and particularly lower than students in the Environmental-Based disciplines.

Chemical-Based disciplines. The Chemical-Based disciplines scored higher than the Mechanical-Based and ECE and Science disciplines for the Stereotypes and Previous Experiences factors with medium or large effect sizes. According to the descriptive statistics, students in the Chemical-Based disciplines reported slightly positive Academic and Application of SEP Experiences, and slight applicability of sustainable engineering practice to their discipline.

Overall, the differences suggested that when compared to the students in the Mechanical-Based and ECE and Science disciplines, students in the Chemical-Based disciplines had slightly positive stereotypes and some previous relevant experiences. This suggested that their Expectancy for Success, and thus their motivation for engaging in the task sustainable engineering practice, was somewhat higher.

Environmental-based disciplines. The Environmental-Based disciplines scored higher than the Mechanical-Based and ECE and Science disciplines for the Stereotypes and Previous Experiences factors and higher than the Mechanical-Based disciplines for two of the Relative Value factors. According to the descriptive statistics, students in the Environmental-Based disciplines reported slightly positive Academic and Application of SEP Experiences and relatively high applicability of sustainable engineering practice to their discipline. For the Relative Value factors, the Environmental-Based disciplines reported relatively high Intrinsic Value and very high Utility Value for sustainable engineering practice. For all disciplines, students' stereotypes of sustainable engineering practice included an environmental bias. This may be why the effect sizes incorporating the Environmental-Based disciplines were larger.

Overall, the differences suggested that when compared to the students in the Mechanical-Based and ECE and Science disciplines, students in the Environmental-Based disciplines had slightly positive stereotypes and some previous experiences. This suggested that their Expectancy for Success for engaging in the task sustainable engineering practice was higher. Using the model in Table 40, this suggested that students in the Environmental-Based disciplines have higher motivation to engage in sustainable engineering practice than students in the Mechanical-Based disciplines and particularly higher than students in the ECE and Science disciplines. Previous studies have suggested that engineering discipline influences the inclusion of sustainable engineering topics in programs as well as students' knowledge, attitudes, and perceptions of sustainable engineering practice (Allen at al., 2008; Haase, 2014; Lattuca, Knight, & Brown, 2014; Nicolaou & Conlon, 2012).

Overall Influences on Motivation

The results suggested that there is a relationship between engineering discipline and students' motivation to engage in sustainable engineering practice. Differences were most prevalent in the Stereotypes and Previous Experiences element. Students develop perceptions of sustainable engineering practice in part through their academic experiences, which suggests that there may be differences in the quality and quantity of sustainable engineering practice content among discipline-based engineering programs. Overall, the results suggested that students in the Chemical- and Environmental-Based disciplines had higher levels of motivation to engage in sustainable engineering practice than those in the Mechanical-Based and ECE and Science disciplines. Gender and Year of Study does not influence motivation to engage in the task sustainable engineering practice.

Limitations

The limitations of the study were influenced by the the sample and the survey instrument. The sample limitations impacted the generalizability while the survey instrument limitations impacted the reliability and validity.

Sample

Non-random sampling methods were used for the study. Only 243 responses to the survey were received, which resulted in a very low response rate of approximately 1%. The response rate was lower than typical response rates for online surveys using email distribution at Canadian institutions (National Survey of Student Engagement, 2015). The sample also was not proportional to the population according to gender. Despite these limitations, the sample included 8 institutions that were representative of Canadian engineering institutions.

The survey was distributed electronically with the assistance of faculty and departmental assistants, course instructors, and representatives from registered clubs. It was possible that those who chose to assist with distribution had a higher value for sustainable engineering practice. The participants were also self-selected, which when considered with the low response rate, suggested a degree of sample bias. No information was collected to address nonresponse bias. However, it was possible that those who responded had stronger and possibly more positive opinions regarding sustainable engineering practice. Because of the topic of the survey, social desirability bias may also have influenced participants' responses to the survey questions. Thus, it was reasonable to generalize the results to the population, Canadian undergraduate engineering students, with reservations for the sample limitations.

Survey Instrument

The factor analyses resulted in seven factors, of which some had limited strength and reliability. Within the stereotypes and previous experience element, the Application of SEP Experiences factor and the Engineering Discipline Stereotypes factor had Cronbach's alpha values less than the recommended value 0.70 (0.55 and 0.60, respectively). As well, each of these factors only had four loading questions, of which only two were strongly loaded. Differences were identified through the ANOVAs for these factors for the independent variable engineering discipline, with one and three differences for the Application of SEP Experiences and Engineering Discipline Stereotypes factors, respectively. The effect sizes were small for the difference in the Application of SEP Experiences factor and medium to large for the differences in the Engineering Discipline Stereotypes factor. Caution should be applied when interpreting the differences, particularly for the Application of SEP Experiences factor.

The remaining 5 factors had Cronbach's alpha values above the recommended value 0.70. However, the Academic Experiences factor within stereotypes and previous experience element only had 4 loading questions of which only three were strongly loaded. Within the relative value element, the Utility factor had 6 loading questions of which only three were strongly loaded, and the Relative Cost factor only had 4 loading questions of which only two were strongly loaded. These factors are more reliable than the Application of SEP Experiences factor and the Engineering Discipline Stereotypes factor, but caution should still be applied when interpreting the descriptive and inferential statistics to the broader population.

CHAPTER 6

CONCLUSION

This study explored Canadian undergraduate engineering students' motivation to engage in sustainable engineering practice. A quantitative ex-post facto research design was used to investigate the research questions. A survey instrument was developed based on the Eccles et al. expectancy-value theory and was improved through a mixed method pilot study. The pilot study used think-aloud interviews and quantitative survey responses to reduce measurement error and to provide evidence to evaluate the initial survey questions. The improved survey was distributed at 8 institutions across Canada and provided evidence for the survey reliability.

Evaluations of the generalizability of the results should consider the limitations of the sample and the reliability and validity of the survey instrument. The study was only conducted at 8 institutions across Canada and the response rate was very low. However, the number of responses and the effect sizes were sufficient to yield trustworthy results in most areas. These areas included students' expectancy for success and value of sustainable engineering practice and the differences found among the engineering disciplines for some of the factors. Although the Application of SEP Experiences and Engineering Discipline Stereotypes factors had lower estimates of internal consistency, the size of the differences among the engineering disciplines were medium to large. Based on the initial estimates of reliability and validity, and the sample size and demographics, the results are likely applicable to most Canadian engineering programs accredited by Engineers Canada.

Overall, students' expectancy of success when engaging in the task sustainable engineering practice is limited. Through their undergraduate programs, students have had very few experiences with sustainable engineering practice. The ranking of the social, environmental, and economic elements, and the open-ended questions confirmed that students have an environmentally biased view of sustainable development and sustainable engineering practice, which agreed with previous studies from other countries. Students associated sustainability considerations predominantly with environmental considerations. In doing so, they largely neglected social, environmental, complexity, temporal, and spatial considerations, which are integral to sustainable engineering practice. Their biases and associations were likely a result of their interpreted experiences with sustainable engineering practice in their engineering program. Despite this, students have relatively high self-concepts of their abilities in sustainable engineering practice. Based on their biases and associations as well as the phrasing of the Self-Concept of Abilities questions, this suggested that students have simplifications in their views of sustainable engineering practice. At this stage, the effect of their simplifications on their expectancy for success is unclear. It is possible that if provided with an authentic opportunity to apply sustainable engineering practice, they may realize the incompleteness of their sustainable engineering practice views and abilities. However, the conclusion from this study was that students do not wholly expect success when engaging in the task of sustainable engineering practice.

Despite their limited experiences, engineering students have high Relative Value for sustainable engineering practice. They value sustainable engineering practice more for utility purposes than intrinsically. This suggested that if the utility of sustainable engineering practice is not clear, students may not value sustainable engineering practice as highly. A definition was provided for sustainable engineering practice in the survey and the Relative Value questions were developed from the conceptualizations and theoretical framework in Chapter 1. It was still possible that the responses were influenced by students' biases (environmental and simplification) in sustainable engineering practice and by social desirability bias. Students may value the environmental element, but may not value the environmental and economic elements, which was suggested by the ranking results for the importance of the central pillars. Social desirability bias may have influenced the Intrinsic Value factor. The conclusion from this study was that students have high value for what they perceive to be sustainable engineering practice.

Overall, the results of the study suggested that students are not necessarily motivated to engage in sustainable engineering practice. In contrast to previous studies in other contexts, gender and year of study did not seem to influence students' motivation. The consistency among the years of study suggested that students' expectancy of success for and value of sustainable engineering practice do not improve as they progress through their engineering programs. Unlike gender and year of study, there were significant differences among the engineering disciplines in students' expectancies for success for and therefore their overall motivation to engage in sustainable engineering practice. The Chemical- and Environmental-Based disciplines had higher levels of motivation while the ECE and Science, and Mechanical-Based disciplines had lower levels. The largest differences occurred in students' Stereotypes and Previous Experiences, many of which were developed in an academic context. However, the ECE and Science disciplines had slightly lower Relative Value than the Environmental-Based disciplines. Wholly, the results suggested that there may be differences among engineering discipline programs in the coverage of sustainable engineering practice topics.

CHAPTER 7

RECOMMENDATIONS FOR PRACTICE

Practical recommendations for engineering education have been developed from the results of this study. Generally, students had relatively high value for sustainable engineering practice but relatively low expectancies for success. Thus, the recommendations focus on methods to improve students' expectancies for success. The recommendations pertain to the definition and assessment of, and interventions for sustainable engineering practice in Canadian engineering programs, and the establishment of connections with industry leaders. Implementation of the recommendations may help to improve students' academic experiences with and in return their motivation to engage in sustainable engineering practice.

Definition of Sustainable Engineering Practice

Students' biases and associations with regard to sustainable engineering practice highlighted the need to establish a universal definition and understanding of sustainable development in the context of engineering education. This study intentionally used the term sustainable engineering practice instead of the general term sustainable engineering, in an attempt to position the term in the context of professional engineering practice. In the literature there are a number of different sustainable engineering definitions, principles, and design processes that all incorporate concepts related to the social, environmental, and economic elements, and multidimensionality. However, there is no universally accepted definition in the literature as specific details vary with geographic location and engineering discipline. The results of this study suggest that in practice, definitions are simplistic and narrow, often only considering the environmental element. Canadian engineering education programs should consistently teach sustainable engineering practice using a universal definition and understanding that centrally incorporates all elements and multidimensionality. Most importantly, sustainable engineering practice should not be considered as an afterthought. Instead, it should be understood as an integral component of professional engineering practice, like public safety. From the deductive codes for the definition of sustainable development question, students have an acceptable understanding of the term. However, sustainable development predates sustainable engineering and sustainability, so more time may be required to establish sustainable engineering practice in engineering education.

Assessment of Sustainable Engineering Practice

The results of this study suggest that students' previous experiences with sustainable engineering practice were limited, but the students had high self-concepts of their abilities in sustainable engineering practice. The disconnect between students' actual competence and their perceived competence may be influenced by students' experiences with the assessment of sustainable engineering practice topics in their courses. The question "I receive marks in my courses for creating sustainable engineering solutions" contributed to the Academic Experiences factor, which had relatively low scores. Students should be specifically assessed and awarded marks in their courses for creating sustainable engineering solutions as part of the overall teaching and learning of professional practice. Furthermore, students should be expected to integrate sustainable engineering practice topics in their work. When awarding marks and defining expectations, care must be taken to ensure that students integrate all elements, and not just the environmental element.

Impact of Engineering Graduate Attribute

The graduate attribute, Impact of Engineering, requires students to demonstrate abilities in topics related directly to sustainable engineering practice. The results of this study suggest that students are not well equipped for sustainable engineering practice upon graduation. Moreover, the results suggest that students' experiences do not improve or increase as they progress through engineering programs. However, the engineering programs in which the participants of this study were enrolled are accredited. This suggests that modifications are needed in the accreditation process to ensure that students are proficient in sustainable engineering practice topics. The expectations of engineering students' abilities should be raised so they align with the high leadership expectations of practicing engineers for sustainable development. The requirements for demonstrating graduating students' proficiency in the Impact of Engineering attribute should be higher. This could be accomplished in part by creating minimum curriculum components for Impact of Engineering specifically, and not just complimentary studies (Engineers Canada, 2016). The graduate attribute Impact of Engineering also requires modifications to require higher levels of competency in sustainable engineering practice. Because of the dependency of sustainable engineering practice on engineering design, the Design graduate attribute should also be modified to incorporate the major elements of sustainable engineering practice. This would also require a clear definition of sustainable engineering practice to be provided within the Engineers Canada accreditation guidelines. Strengthening the requirements for and assessment of the Impact of Engineering graduate attribute will encourage positive changes to the inclusion of sustainable engineering practice topics in Canadian engineering programs.

Development of Curriculum and Interventions

Modifications to the engineering curriculum and the development of interventions are needed to increase students' motivation to engage in sustainable engineering practice. The engineering curriculum should be modified to coherently incorporate sustainable engineering practice to more areas, including engineering design. Interventions should be developed for specific engineering disciplines to illustrate the value and importance of sustainable engineering practice and to provide students the fundamental knowledge and skills to be successful when engaging in sustainable engineering practice.

Responses to the open-ended questions and literature in the area both highlighted the association of sustainable engineering practice with engineering design. The description of the graduate attribute, Design, includes considerations that relate to sustainable engineering practice. To normalize sustainable engineering practice, engineering design curricula should, at a minimum, incorporate elements of sustainable engineering design processes and design tools outlined in Chapter 1. In particular, engineering economic analyses should be taught such that social and environmental costs and benefits are incorporated. Curriculum changes or interventions for engineering design should consider all three elements of sustainable engineering practice as well as multidimensionality.

The purpose of this study was not to address the causes of differences, nor was it to suggest the role of sustainable engineering practice in the various disciplines. However, the results suggest that students from different disciplines have different interpretations of the applicability of sustainable engineering practice to their discipline. All disciplines of engineering contribute to development in society, so to meet the expectations of political and professional organizations, all disciplines of engineering should and can contribute to sustainable development. As well, most industry projects are multidisciplinary in nature, so students from different disciplines of engineering should have a similar base level understanding of sustainable engineering practice, which is interdisciplinary in nature. Discipline-specific interventions should be developed to integrate all elements of sustainable engineering practice. The ranking of the elements, responses to the open-ended questions, and scores for the Stereotypes and Previous Experiences factors suggest that all discipline programs require interventions to incorporate the social and economic elements, and multidimensionality of sustainable engineering practice. Such interventions should address knowledge, attitudes, and perceptions of sustainable engineering practice and sustainability at least in general terms. By using discipline-specific interventions, authentic and relatable learning experiences could be created that emphasize the value and importance of sustainable engineering practice in the context of each discipline.

Current interventions often relate to immediate and visible environmental impacts of engineering projects in the Chemical- and Environmental-Based disciplines. Approaches occasionally taught in the Mechanical-Based and ECE and Science disciplines, such as traditional Life Cycle Analysis, do not typically address all aspects of sustainable engineering practice and are not applicable in some contexts. This may partially explain the lower scores for the ECE and Science as well as the Mechanical-Based disciplines. However, when examining the products, services, and processes developed predominantly by these disciplines in the Industrial and Digital Revolutions, the social, economic, and environmental costs and benefits are undeniable. So too with the aspects of multidimensionality including complexity, time, and place.

Interventions should highlight and teach the application of sustainable engineering practice for a range of modern projects in all disciplines, but particularly to the ECE and Science, and Mechanical-Based disciplines that seem to be missing academic opportunities for experiences. Social, environmental, and economic costs and benefits that are not immediate and visible should be incorporated in all disciplines. Current interventions that are applicable to most Chemical- and Environmental-Based disciplines should be enhanced to incorporate long-term and indirect environmental benefits and social and economic costs and benefits.

Connections with Industry Leaders

Establishing connections between undergraduate students and industry leaders in sustainable engineering practice may improve students' motivation. Engineering students in all disciplines had high Utility Value for sustainable engineering practice. Thus, students may value the perspective of practicing engineers that routinely apply sustainable engineering practice in their career. Connections with industry leaders may also prove to illustrate that success is possible when engaging in sustainable engineering practice. To be effective in engaging students with low motivation levels, connections should be established with industries that match well with the different disciplines of engineering. The introduction of multidisciplinary applications of sustainable engineering practice may serve to broaden students' knowledge and understanding.

CHAPTER 8

FUTURE RESEARCH WORK

Topics for future research work have been identified from the results of this study. The future work topics pertain to the validity and reliability of the instrument, further exploration of students' motivation, and expansion of the study to additional contexts.

Validity and Reliability of the Instrument

The survey instrument was developed and validated for use in this study. The development process and pilot study provided evidence for translation validity, specifically face and content. However, further research would be required to fully establish criterion validity (Field, 2013). The responses from the national study were used to provide an estimate of the internal consistency of the factors. To improve the internal consistency, the survey questions may require modifications and additions, particularly those contributing to the Application of SEP Experiences and Engineering Discipline Stereotypes factors. Additional research would be required to provide other types of evidence for reliability of the survey instrument including stability, equivalence, and agreement reliability (McMillan & Schumacher, 2010).

Further Exploration of Students' Motivation

Most of the differences in students' motivation occurred for factors contributing to the Stereotypes and Previous Experiences portion of the expectancy-value theory. This study used an ex-post facto design, so there was no evidence to confirm or deny causation in the influence of engineering programs on students' perspective of sustainable engineering practice. Further research should be conducted to examine these differences from program evaluation and qualitative perspectives. A study should be conducted to investigate the inclusion of sustainable engineering practice topics in Canadian engineering programs at the program and course levels. Ideally, all accredited engineering programs would be included in the sample, and course-specific documents (e.g. syllabi and assignments) would be used as data sources. Similar studies conducted in the United States and Sweden are not entirely generalizable to the Canadian context (Allen et al., 2008; Hanning et al., 2012). Such a study may provide evidence for causation of some of the differences among the engineering disciplines, and the lack of differences for year of study. Qualitative studies on students' motivation to engage in sustainable engineering practice would provide further insight into the complexities of the topic. A qualitative study may provide reasoning to explore other, individualistic influences on students' motivation using quantitative approaches.

Students reported high self-concept of abilities in sustainable engineering practice. However, data was not collected to assess students' competency. Students' actual competencies are not influential in the expectancy-value theory of motivation. Despite this, information on their competencies may be beneficial in designing measures and future studies. Information is also needed on Canadian students' competencies to inform the Canadian engineering education curriculum.

Expansion of the Study

Further investigation of students' motivation to engage in sustainable engineering practice should be conducted. Within Canada, the study should be expanded to include more engineering institutions, and recruitment methods should be modified to increase the response rate. The influence of other independent variables should also be explored. These variables include but are not limited to extracurricular activities, socioeconomic status, academic achievement, and work experience as well as contextual influences, such as geographic location and urbanicity. Although the sample size was small, the think-aloud interviews suggested that participants that completed their undergraduate degree outside of Canada had different academic experiences with sustainable engineering practice than those that completed their degree in Canada. To resolve this observation, the study should be expanded internationally to explore contextual influences.

This study explored undergraduate students' motivation to engage in sustainable engineering practice, but the exploration of other units of analysis would be beneficial. In an academic setting, undergraduate students are influenced by course instructors and teaching assistants. A study should be conducted to explore graduate students' motivation to engage in sustainable engineering practice. Canadian engineering instructors' motivation to engage in and to teach sustainable engineering practice should also be investigated. To play an effective role for sustainable development and meeting the UN Sustainable Development Goals, practicing professional engineers need to be motivated to engage in sustainable engineering practice. Studies should be conducted to determine the motivation levels of professional engineers in industry in addition to those involved with educational institutions. A longitudinal study to track individual students' motivation levels as they begin their careers may provide essential information for informing transformations in engineering education and the engineering profession.

REFERENCES

Adams, R. S., Beltz, N., Mann, L., & Wilson, D. (2010). Exploring student differences in formulating cross-disciplinary sustainability problems. *International Journal of Engineering Education, 26,* 324-338.

Allen, D., Allenby, B., Bridges, M., Crittenden, J., Davidson, C., Hendrickson, C., Matthews, S., Murphy, C., & Pijawka, D. (2008). *Benchmarking Sustainable Engineering Education: Final Report.* Retrieved from Center for Sustainable Engineering website: http://csengin.syr.edu/wp-content/uploads/2015/08/Final-Report.pdf

Atkinson, J. W. (1964). *An Introduction to Motivation.* Princeton, NJ: Van Nostrand.

Azapagic, A., Perdan, S., & Shallcross, D. (2005). How much do engineering students know about sustainable development? The findings of an international survey and possible implications for the engineering curriculum. *European Journal of Engineering Education, 30,* 1-19.

Beiler, M. R. O. (2017). Sustainability interest and knowledge of future engineers: identifying trends in secondary school students. *International Journal of Engineering Education, 33,* 489-503.

Benaquisto, L. (2008). Codes and coding. In L. M. Given (Eds.), *The SAGE Encyclopedia of Qualitative Research Methods* (86-89). Thousand Oaks: SAGE Publications.

Beveridge, D., McKenzie, M., Vaughter, P., & Wright, T. (2015). Sustainability in Canadian post-secondary institutions: the relationship among sustainability initiatives and geographic and institutional characteristics. *International Journal of Sustainability in Higher Education, 16,* 611-638.

Borg, C., Gericke, N., Höglund, H., & Bergman, E. (2012). The barriers encountered by teachers implementing education for sustainable development: discipline bound differences and teaching traditions. *Research in Science and Technological Education, 30,* 185-207.

Byrne, E., Desha, C., Fitzpatrick, J., & Hargroves, K. (2010). Engineering education for sustainable development: a review of international progress. *3rd International Symposium for Engineering Education.* Symposium conducted at the meeting of Educating Engineers for 2020, Cork, Ireland.

Camilli, G. (2013). Ongoing issues in test fairness. *Educational Research and Evaluation, 19,* 104-120.

Citizenship and Immigration Canada. (2012). *Discover Canada: The Rights and Responsibilities of Citizenship*. Ottawa, ON: Canada.

Collins, D. (2001). Pretesting survey instruments: An overview of cognitive methods. *Quality of Life Research, 12,* 229-238.

Comrey, L. A., & Lee, H. B. (1992). *A first course in factor analysis.* Hillside, New Jersey: Lawrence Erlbaum Associates, Publishers.

Costello, A. B., and Osborne, J. W. (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. *Practical Assessment, Research & Evaluation, 10,* 1-9.

Creswell, J.W., & Plano Clark, V.L. (2007). *Designing and Conducting Mixed Method Research*. Thousand Oaks: SAGE Publications.

Cudeck, R., & MacCallum, R. C. (2007). *Factor Analysis at 100 Historical Developments and Future Directions.* Mahwah, New Jersey: Lawrence Erlbaum Associates, Publishers.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* Hillsdale, NJ: Erlbaum.

David Suzuki Foundation. (2012). *All Over the Map 2012: A Comparison of Provincial Climate Change Plans*. Vancouver, BC: Miranda Holmes with contributions from Paul Lingl, Dale Marshall, Ian Bruce, Morag Carter and Faisal Moola.

Eccles, J.(Parsons), Adler, T. F., Futterman, R., Goff, S. B., Kaczala, C. M. (1983). Expectancies, values, and acedmic behaviors. In J. T. Spence (Eds.), *Achievement and Achievement Motivation* (75-146), San Francisco, CA: Freeman.

Eccles, J. S., & Wigfield, A. (2002). Motivational Beliefs, Values, and Goals. *Annual Review of Psychology, 53,* 109-132.

Engineers Canada. (2016). *Accreditation Criteria and Procedures 2016.* Retrieved from http://www.engineerscanada.ca/sites/default/files/accreditation_criteria_procedures_2016.pdf

Field, A. (2013). Exploratory Factor Analysis. In M. Carmichael, R. Lupton, I. Antcliff, & R. Leigh (Eds.), *Discovering Statistics Using IBM SPSS Statistics* (pp. 665-719). Thousand Oaks, California: Sage.

Flake, J. K., Barron, K. E., Hulleman, C., McCoach, B. D., & Walsh, M. E. (2015). Measuring cost: the forgotten component of expectancy-value theory. *Contemporary Educational Psychology, 41,* 232-244.

Fuchs, W. (2012). The new global responsibilities of engineers create challenges for engineering education. *Journal of Education for Sustainable Development, 6,* 111-113.

Gagnon, L., Leduc, R., & Savard, L. (2008). *Sustainable development in engineering: a review of principles and definition of a conceptual framework.* Groupe de Recherche en Économie et Développement International Working Paper 08-18.

Gagnon, L., Leduc, R., & Savard, L. (2010). *From a conventional to a sustainable engineering design process: different shades of sustainability.* Groupe de Recherche en Économie et Développement International Working Paper 10-09.

Goodwin, A., Klotz, L., Hazari, Z., & Potvin, G. (2016). Sustainability goals of student underrepresented in engineering: an intersectional study. *International Journal of Engineering Education, 32,* 1742-1748.

Haase, S. (2014). Engineering students' sustainability approaches. *European Journal of Engineering Education, 39:3,* 247-271.

Hanning, A., Abelsson, A., Lundqvist, U., & Svanström, M. (2012). Are we education engineers for sustainability? Comparison between obtained competences and Swedish industry's needs. *International Journal of Sustainability in Higher Education, 13,* 305-320.

Hoffman, S. R., Pawley, A. L., Rao, R. L., Cardella, M. E., & Ohland, M. W. (2011). *Defining "sustainable engineering": a comparative analysis of published sustainability principles and existing courses*. Conference Proceeding from the 2011 ASEE Annual Conference & Exposition, Vancouver, BC.

Hutcheson, G., & Sofroniou, N. (1999). *The multivariate social scientist*. London: SAGE Publications.

Jaspar, J. C. (2008). *Teaching for sustainable development: teacher's perceptions.* (Master Thesis). Retrieved from Theses Canada. (TC-SSU-02042009212522)

Kagawa, F. (2007). Dissonance in students' perceptions of sustainable development and sustainability. Implications for curriculum change. *International Journal of Sustainability in Higher Education, 8*, 317-338.

Kim, J., & Mueller, C. W. (2011). Construction of factor scales. In *Factor Analysis* (61-73). Thousand Oaks: SAGE Publications.

Lattuca, L. R., Knight, D. B., & Brown, M. G. (2014). *Influences on Engineering Instructors' Emphasis on Interdisciplinarity in Undergraduate Courses.* Conference Proceeding from the 2014 ASEE Annual Conference & Exposition, Indianapolis, IN.

Litwin, M. *How to Measure Survey Reliability and Validity.* Thousand Oaks: SAGE Publications.

Lourdel, N., Grondran, N., Laforest, V., Debray, B. & Brodhag, C. (2007). Sustainable Development cognitive map: a new method of evaluating student understanding. *International Journal of Sustainability in Higher Education, 8:2*, 170–182.

McCormick, M., Bielefeldt, A. R., Swan, C. W., & Paterson, K. G. (2015). Assessing students' motivation to engage in sustainable engineering. *International Journal of Sustainability in Higher Education, 16:2,* 136-154.

McCormick, M., Lawyer, K., Wiggins, J., Swan, C. W., Paterson, K. G., & Bielefeldt, A. (2015b). Sustainable engineering assessment using rubric-based analysis of challenge question responses. *Journal of Professional Issues in Engineering Education and Practice, 141,* 1-10.

McMillan, J.H., & Schumacher, S. (2010). *Research in Education: Evidence-Based Inquiry.* Upper Saddle River, New Jersey: Pearson Education Inc.

Micangeli, A., Naso, V., Matrisciano, A., Fairoli, F., & Belfiore, N. P. (2013). *Attitude to sustainability issues related to some students learning characteristics.* Conference Proceeding from the 2013 Engineering Education for Sustainable Development Conference, Cambridge, UK.

Morse, J.M. (1991). Approaches to qualitative-quantitative methodological triangulation. *Nursing Research, 40,* 120-123.

Mulder, K. F., Ferrer, D., Coral, J. S., Kordas, O., Nikiforovich, E., & Pereverza, K. (2015). Motivating students and lecturers for education in sustainable development. *International Journal of Sustainability in Higher Education, 16,* 385-401.

Nicolaou, I., & Conlon, E. (2012). What do final year engineering students know about sustainable development? *European Journal of Engineering Education, 37,* 267-277.

Olsson, D., Gericke, N., & Rundgren, S. N. C. (2016). The effect of implementation of education for sustainable development in Swedish compulsory schools – assessing pupils' sustainability consciousness. *Environmental Education Research*, *22*, 176-202.

Palmer, B., Terenzini, P. T., Harper, B. J., & Merson, D. (2011). *Design in context: Where do the engineers of 2020 learn this skill?* Conference Proceeding from the 2011 ASEE Annual Conference & Exposition, Vancouver, BC.

Ro, H., Lattuca, L., Merson, D., & Terenzini, P. (2012). *Measuring engineering students' contextual competence*. Conference Proceeding from the 2012 ASEE Annual Conference & Exposition, San Antonio, TX.

Segalàs, J., Ferrer-Balas, D., & Mulder, K.F. (2008). Conceptual maps: measuring learning processes of engineering students concerning sustainable development. *European Journal of Engineering Education, 33*, 297-306.

Sheikh, S. N. S., Aziz, A. A., & Yusof, K. M. (2012). Perception on sustainable development among new first year engineering undergraduates. *Procedia - Social and Behavioral Sciences, 56,* 530-536.

Sims, L., & Falkenberg, T. (2013). Developing Competencies for Sustainable Development: A Case Study of Canadian Faculties of Education. *International Journal of Higher Education, 2:4,* 1-14.

Sogunro, O. A. (2015). Motivating factors for adult learners in higher education. *International Journal of Higher Education, 4,* 22-37.

Statistics Canada. (2017). *Estimates of population, Canada, provinces and territories* [Data file]. Retrieved from http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0510005&&pattern=&stByVal=1&p1=1&p2=31&tabMode=dataTable&csid=

Summers, M., Corney, G., & Childs, A. (2004). Student teachers' conceptions of sustainable development: the starting-points of geographers and scientists. *Educational Research, 46,* 163-182.

Swayze, N., Creech, H., Buckler, C., & Alfaro, J. (2012). *Education for sustainable development in Canadian faculties of education.* Retrieved from Council of Ministers of Education, Canada website:

http://www.cmec.ca/Publications/Lists/Publications/Attachments/279/ESD_Dean_reportEN.pdf

Trenor, J., Miller, M., & Gipson, K. (2011). *Utilization of a think-aloud protocol to cognitively validate a survey instrument identifying social capital resources of engineering undergraduates*. Conference Proceeding from the 2011 ASEE Annual Conference & Exposition, Vancouver, BC.

UNESCO. (2010). *Engineering: Issues Challenges and Opportunities for Development*. France: UNESCO Publishing.

Universities Canada. (2016). *2016 full-time and part-time fall enrolment at Canadian universities* [Data file]. Retrieved from http://www.univcan.ca/universities/facts-and-stats/enrolment-by-university/

UN. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development.* Retrieved from https://sustainabledevelopment.un.org/post2015/

WFEO. (2013). *WFEO Model Code of Practice for Sustainable Development and Environmental Stewardship* Retrieved from World Federation of Engineering Organizations website: http://www.wfeo.org/sustainabledevelopment/

Winter, J. C. F, and Dodou, D, (2012). Factor recovery by principal axis factoring and maximum likelihood factor analysis as a function of factor pattern and sample size. *Journal of Applied Statistics, 40,* 695-710.

World Commission on Environment and Development. (1986). *Our Common Future.* Oxford: Oxford University Press.

Wu, Y. J., & Chen, J. (2016). Higher education for sustainable development: a systematic review. *International Journal of Sustainability in Higher Education, 17,* 633-651.

Yong, A. G., & Pearce, S. (2013). A beginner's guide to factor analysis: Focusing on exploratory factor analysis*. Tutorials in Quantitative Methods for Psychology, 9,* 79-9

APPENDIX A

ETHICAL CLEARANCE DOCUMENTATION

This appendix includes the supporting documentation for the ethical clearance obtained from the Queen's University General Research Ethics Board (GREB). This includes the clearance letter, amendment letter, recruitment emails, Letters of Information, and Consent Forms. Ethical clearance was obtained from the Research Ethics Boards at the seven other participating institutions and other approval were obtained at each institution as applicable. Documentation for approvals from the other participating institutions is not included to protect the identity of the institutions.

August 19, 2016

Miss Natasha Lanziner
Master's Student
Department of Mechanical and Materials Engineering
Queen's University
Kingston, ON, K7L 3N6

GREB Ref #: GMECH-039-16; Romeo # 6018918
Title: "GMECH-039-16 Exploring Students' Motivation to Engage in Sustainable Engineering Practice"

Dear Miss Lanziner:

The General Research Ethics Board (GREB), by means of a delegated board review, has cleared your proposal entitled **"GMECH-039-16 Exploring Students' Motivation to Engage in Sustainable Engineering Practice"** for ethical compliance with the Tri-Council Guidelines (TCPS 2 (2014)) and Queen's ethics policies. In accordance with the Tri-Council Guidelines (Article 6.14) and Standard Operating Procedures (405.001), your project has been cleared for one year. You are reminded of your obligation to submit an annual renewal form prior to the annual renewal due date (access this form at http://www.queensu.ca/traq/signon.html/; click on "Events"; under "Create New Event" click on "General Research Ethics Board Annual Renewal/Closure Form for Cleared Studies"). Please note that when your research project is completed, you need to submit an Annual Renewal/Closure Form in Romeo/traq indicating that the project is 'completed' so that the file can be closed. This should be submitted at the time of completion; there is no need to wait until the annual renewal due date.

You are reminded of your obligation to advise the GREB of any adverse event(s) that occur during this one year period (access this form at http://www.queensu.ca/traq/signon.html/; click on "Events"; under "Create New Event" click on "General Research Ethics Board Adverse Event Form"). 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 implementation of new procedures. To submit an amendment form, access the application by at http://www.queensu.ca/traq/signon.html; click on "Events"; under "Create New Event" click on "General Research Ethics Board Request for the Amendment of Approved Studies". Once submitted, these changes will automatically be sent to the Ethics Coordinator, Ms. Gail Irving, at the Office of Research Services 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.

Sincerely,

John G. Freeman

John Freeman, Ph.D.
Chair
General Research Ethics Board

c: Dr. David Strong and Dr. Brian Frank, Supervisors

Figure 7

Queen's University GREB ethical clearance letter.

Queen's
UNIVERSITY

December 08, 2016

Miss Natasha Lanziner
Master's Student
Department of Mechanical and Materials Engineering
Queen's University
Kingston, ON, K7L 3N6

Dear Miss Lanziner:

RE: Amendment for your study entitled**: GMECH-039-16 Exploring Students' Motivation to Engage in Sustainable Engineering Practice;** TRAQ **# 6018918**

Thank you for submitting your amendment requesting the following changes:

1) To modify the survey instrument for undergraduate students based on the results of the pilot study;

2) To distribute the survey at a maximum of seven Canadian institutions with data indicating the institution of the participants;

3) Undergraduate Student Survey Questions (v. 2016/12/06).

By this letter you have ethics approval for these changes.

Good luck with your research.

Sincerely,

John G. Freeman

John Freeman, Ph.D.
Chair
General Research Ethics Board

c.: Dr. David Strong and Dr. Brian Frank, Supervisors

Figure 8

Queen's University GREB approval of amended survey instrument.

Pilot Study Documentation

Recruitment Email

STUDY PARTICIPANTS NEEDED

The purpose of this study is to explore students' motivation to engage in sustainable engineering practice. Graduate students in engineering and applied science are invited to participate in the pilot study of the survey instrument used for this study. If you agree to participate in this study, your involvement will be the completion of an anonymous online survey that will take a maximum of 35 minutes to complete. The survey will ask closed- and open-ended questions about your expectations for success when engaging in sustainable engineering practice and your value of sustainable engineering practice. At the end of the survey, you will be asked if you are interested in participating in a voluntary follow up interview lasting a maximum of 75 minutes. A percentage of students who agree to follow up interviews will be selected. You will be provided with a $15 gift card for the interview as a token of appreciation for your time. Please see the attached letter of information for more information.

This study has been granted clearance according to the recommended principles of Canadian ethics guidelines, and Queen's policies. Any questions about study participation or a request to withdraw from the study may be directed to Natasha K. Lanziner at natasha.lanziner@queensu.ca, the research supervisor Professor David S. Strong at strongd@queensu.ca, or Dr. Brian Frank at brian.frank@queensu.ca.

Your interest in participating in this research study is greatly appreciated. Thank you for your time and consideration.

Natasha Lanziner
MASc Candidate – Mechanical and Materials Engineering

Letter of Information and Consent for the Electronic Survey

This research is being conducted by Natasha K. Lanziner under the supervision of Professor David S. Strong in the Faculty of Engineering and Applied Science at Queen's University in Kingston, Ontario. This study has been granted clearance according to the recommended principles of Canadian ethics guidelines and Queen's policies.

What is this study about? The purpose of this study is to explore students' motivation to engage in sustainable engineering practice. The specific research questions are as follows: What are undergraduate students' expectations of success when engaging in sustainable engineering practice? What are undergraduate students' values of sustainable engineering practice? Among undergraduate engineering students, what is the relationship of engineering discipline and year of study on students' motivation to engage in sustainable engineering practice?

The first stage of the study is a pilot study of the survey instrument that will be used to collect data. The pilot study will use data from graduate engineering students. Graduate students will be surveyed on their self-concept of abilities in, previous experiences with, and values of sustainable engineering practice. Think-aloud interviews will be conducted with graduate students to understand how the survey questions are interpreted. The second stage of the study will collect responses from undergraduate students using the survey instrument with updates from the pilot study.

What will this study require? If you agree to participate in this study, your involvement will be the completion of an anonymous online survey that will take a maximum of 35 minutes to complete. The survey will ask closed- and open-ended questions about your expectations for success when engaging in sustainable engineering practice and your value of sustainable engineering practice. At the end of the survey, you will be asked if you are interested in participating in a voluntary follow up interview. A percentage of students who agree to follow up interviews will be selected. Students who are selected for interviews will be contacted with a new letter of information and will be required to sign a separate consent form.

What are the benefits of this study? Although there are no direct benefits to you as a participant, this research will benefit the engineering education and education for sustainable development communities by providing insight into students' motivation to engage in sustainable engineering practice. This research may be used to inform interventions for motivation for sustainable engineering practice or to improve sustainable engineering practice pedagogies and policies.

Is participation voluntary? Your participation is completely voluntary and choosing not to participate will not result in any adverse consequences. There are no known physical, psychological, economic, or social risks associated with this study. You have the ability to refuse to answer any questions posed by the study. You may withdraw from the survey by closing the internet browser before submitting the survey. By closing your browser before submission, your responses will not be recorded. There will be no negative consequences from survey withdrawal. Once the survey has been submitted, your data will not be able to be removed, but will remain anonymous.

How will my identity be protected? Survey participation will be anonymous. You will not be asked for any identifying information. Contact information will be requested if you agree to a follow up interview, but this information will only be used to contact interview participants regarding this research study and will not be associated with survey responses.

What if I have concerns? Any questions about study participation or a request to withdraw from the study may be directed to Natasha K. Lanziner at natasha.lanziner@queensu.ca, the research supervisor Professor David S. Strong at (613) 533-2606 or strongd@queensu.ca, or Dr. Brian Frank at brian.frank@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.

Your interest in participating in this research study is greatly appreciated. Thank you for your time and consideration.

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

Electronic Consent

Having read the above, I understand that by clicking the “Yes” button below, I agree to take part in this study under the terms and conditions outlined.

Yes	I agree to participate
No	I do not agree to participate

Letter of Information for the Think-Aloud Interviews

This research is being conducted by Natasha K. Lanziner under the supervision of Professor David S. Strong in the Faculty of Engineering and Applied Science at Queen’s University in Kingston, Ontario. This study has been granted clearance according to the recommended principles of Canadian ethics guidelines and Queen’s policies.

What is this study about? The purpose of this study is to explore students’ motivation to engage in sustainable engineering practice. The specific research questions are as follows: What are undergraduate students’ expectations of success when engaging in sustainable engineering practice? What are undergraduate students’ values of sustainable engineering practice? Among undergraduate engineering students, what is the relationship of engineering discipline and year of study on students’ motivation to engage in sustainable engineering practice?

The first stage of the study is a pilot study of the survey instrument that will be used to collect data. The pilot study will use data from graduate engineering students. Graduate students will be surveyed on their self-concept of abilities in, previous experiences with, and values of sustainable engineering practice. Think-aloud interviews will be conducted with graduate students to understand how the survey questions are interpreted. The second stage of the study will collect responses from undergraduate students using the survey instrument with updates from the pilot study.

What will this study require? If you agree to participate in this part of the study, your involvement will be a one-on-one interview that will take a maximum of 75 minutes to complete. The interview will be a think-aloud through the survey questions where you will be asked to explain your thoughts as you read through the survey questions. Interviews will take place on the Queen's University campus at a time that is convenient for you. With your permission the interviews will be audio recorded. Interviews will follow a standard protocol and will be conducted in a semi-structured format. You will be given a $15 gift card at the end of the interview as a token of appreciation for your time. The gift card will be given upon completion of the interview. Participants who withdraw from the study prior to completion of the interview will still receive the gift card.

What are the benefits of this study? Although there are no direct benefits to you as a participant, this research will benefit the engineering education and education for sustainable development communities by providing insight into students' motivation to engage in sustainable engineering practice. This research may be used to inform interventions for motivation for sustainable engineering practice or to improve sustainable engineering practice pedagogies and policies.

Is participation voluntary? Your participation is completely voluntary and choosing not to participate will not result in any adverse consequences. There are no known physical, psychological, economic, or social risks associated with this study. You have the ability to refuse to answer any questions posed by the study. You may withdraw from the study at any time with no negative consequences either during the interview or by contacting Natasha K. Lanziner at natasha.lanziner@queensu.ca to indicate your withdrawal. If you choose to withdraw, any interview data gathered from you will be removed from the study.

How will my identity be protected? Pseudonyms will be used in all publications of research data and findings. Any identifying information will be modified on interview data. All contact information will only be used for the purpose of contacting you about this research study only.

What if I have concerns? Any questions about study participation or a request to withdraw from the study may be directed to Natasha K. Lanziner at natasha.lanziner@queensu.ca, the research supervisor Professor David S. Strong at (613) 533-2606 or strongd@queensu.ca, or Dr. Brian Frank at brian.frank@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.

Your interest in participating in this research study is greatly appreciated. Thank you for your time and consideration.

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

Consent Form for the Think-Aloud Interviews

1. I have read the Letter of Information and have had any questions answered to my satisfaction.

2. I understand that I will be participating in the study called "Exploring Students' Motivation to Engage in Sustainable Engineering Practice". I understand that the purpose of this research is to develop a survey instrument for motivation to engage in sustainable engineering practice and to understand motivation to engage in sustainable engineering practice by exploring the perceptions of engineering graduate and undergraduate students. I understand that my participation in this part of the study will entail explaining my thoughts when answering the survey questions in a one-on-one interview format that will take a maximum of 75 minutes.
3. I understand that my participation in this study is voluntary and I may withdraw at any time.
4. I understand that the interview will be audio recorded.
5. I understand that every effort will be made to maintain the confidentiality of the data now and in the future. Only the researcher and respective supervisor will have access to collected data. 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. In any publications or presentations, research participants will be referred to by pseudonym. 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 Natasha K. Lanziner at natasha.lanziner@queensu.ca or the research supervisor Professor David S. Strong at (613) 533-2606 or strong@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.

I have read the above statements and had any questions answered. I freely consent to participate in this study.

Participant's Name (Please print): ____________________________
Participant's Signature: ____________________________
Date: ____________________________

Please retain a copy of this consent form for you records.

Study Documentation

Recruitment Email to University Contacts

Hello [insert contact name],

My name is Natasha Lanziner and under the supervision of David S. Strong from the Faculty of Engineering and Applied Science at Queen's University I am conducting a study to explore students' motivation to engage in sustainable engineering practice. A pilot study of the survey instrument has been conducted and I am now collecting data from undergraduate students at [x] universities across Canada.

I am writing to you to request that you forward the following survey recruitment email and survey link to undergraduate engineering students in your [university/department/course]. Completion of the survey is voluntary for students and the responses are collected anonymously. This study has been granted clearance according to the recommended principles of Canadian ethics guidelines, Queen’s University and [insert university name] policies.

Thank you for your help in conducting this research study.

Sincerely,

Natasha Lanziner

[insert undergraduate student recruitment email and survey link]

Recruitment Email to Undergraduate Students

STUDY PARTICIPANTS NEEDED

The purpose of this study is to explore students’ motivation to engage in sustainable engineering practice. Undergraduate students in engineering and applied science are invited to participate in this study. If you agree to participate in this study, your involvement will be the completion of an anonymous online survey that will take a maximum of 35 minutes to complete. The survey will ask closed- and open-ended questions about your expectations for success when engaging in sustainable engineering practice and your value of sustainable engineering practice.

This study has been granted clearance according to the recommended principles of Canadian ethics guidelines, and Queen's policies. Any questions about study participation or a request to withdraw from the study may be directed to Natasha K. Lanziner at natasha.lanziner@queensu.ca or the research supervisor Professor David S. Strong at strongd@queensu.ca.

Your interest in participating in this research study is greatly appreciated. Thank you for your time and consideration.

Natasha Lanziner
MASc Candidate – Mechanical and Materials Engineering

Letter of Information and Consent for Undergraduate Students

This research is being conducted by Natasha K. Lanziner under the supervision of Professor David S. Strong in the Faculty of Engineering and Applied Science at Queen's University in Kingston, Ontario. This study has been granted clearance according to the recommended principles of Canadian ethics guidelines and Queen's policies.

What is this study about? The purpose of this study is to explore students' motivation to engage in sustainable engineering practice. The specific research questions are as follows: What are undergraduate students' expectations of success when engaging in sustainable engineering practice? What are undergraduate students' values of sustainable engineering practice? Among undergraduate engineering students, what is the relationship of engineering discipline and year of study on students' motivation to engage in sustainable engineering practice?

What will this study require? If you agree to participate in this study, your involvement will be the completion of an anonymous online survey that will take a maximum of 35 minutes to complete. The survey will ask closed- and open-ended questions about your expectations for success when engaging in sustainable engineering practice and your value of sustainable engineering practice.

What are the benefits of this study? Although there are no direct benefits to you as a participant, this research will benefit the engineering education and education for sustainable development communities by providing insight into students' motivation to engage in sustainable engineering practice. This research may be used to inform interventions for motivation for sustainable engineering practice or to improve sustainable engineering practice pedagogies and policies.

Is participation voluntary? Your participation is completely voluntary and choosing not to participate will not result in any adverse consequences. There are no known physical, psychological, economic, or social risks associated with this study. You have the ability to refuse to answer any questions posed by the study. You may withdraw from the survey by closing the internet browser before submitting the survey. By closing your browser before submission, your responses will not be recorded. There will be no negative consequences from survey withdrawal. Once the survey has been submitted, your data will not be able to be removed, but will remain anonymous.

How will my identity be protected? Survey participation will be anonymous. You will not be asked for any identifying information.

What if I have concerns? Any questions about study participation or a request to withdraw from the study may be directed to Natasha K. Lanziner at natasha.lanziner@queensu.ca, the research supervisor Professor David S. Strong at (613) 533-2606 or strongd@queensu.ca, or Dr. Brian Frank at brian.frank@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.

Your interest in participating in this research study is greatly appreciated. Thank you for your time and consideration.

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

Electronic Consent

Having read the above, I understand that by clicking the "Yes" button below, I agree to take part in this study under the terms and conditions outlined.

Yes	I agree to participate
No	I do not agree to participate

APPENDIX B

PILOT STUDY RESULTS AND ANALYSIS

This appendix includes supporting documentation for the pilot study results and analysis. First, the example that was used for the think-aloud process for a survey questions is shown. The descriptive statistics are included for each question, including mean, standard deviation, skewness, and kurtosis. For all questions, the standard errors were 0.58 and 1.12 for the skewness and kurtosis, respectively. In this appendix, * denotes a skewness or kurtosis value outside of the acceptable range.

Example of the Think-Aloud Process

I do not have time for creativity in my engineering design projects.

SD			N			SA
1	2	3	4	5	6	7

How much time do I spend on my current design project? Okay 5 hours a week. How do I spend that time? I spend 1.5 hours in planning meetings with my team. I spend 1-2 hours documenting the work that I do. I spend the remaining time doing actual project work. How much of my actual project work is spent on something related to creativity? Only about 10% of the time. I could probably spend more of my actual work time being creative, but for me to really be creative I would have to spend more time on my project. Maybe an extra hour every week; I might have an extra hour to spend some weeks, but not every week. So, I think I have some time for creativity on my projects, but not enough. So I am going to answer 3.

Stereotypes and Previous Experiences

Table 42

Quantitative results for the TBL elements questions.

Initial Survey Question	Mean	SD	Skewness	Kurtosis
1. The social elements of sustainable engineering practice are the most important elements.	5.00	1.69	-0.21	-1.29
2. The environmental elements of sustainable engineering practice are the most important elements.	5.93	1.33	-1.11	0.10
3. The economic elements of sustainable engineering practice are the most important elements.	3.87	1.85	0.38	-0.72
4. The social, environmental, and economic elements of sustainable engineering practice are equally important.	4.27	2.15	-0.20	-1.36
5. Sustainable engineering practice is most useful to current generations.	5.00	1.96	-0.65	-0.89
6. Sustainable engineering practice is most useful to future generations.	6.13	1.30	-1.40*	1.03

Table 43

Question-by-question analysis and modifications for the TBL elements questions.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
1. The social elements of sustainable engineering practice are the most important elements.	- All participants referred to 2 and 3 - One participant referred to the definition of SD on the Canada Immigration website (external value for definition)	- These questions implied that one of the three elements is the most important (leading questions)	- Removed questions 1-4 - Added a question to rank the three elements in order of importance, with the possibility to rank them equally (e.g. 1, 1, 1; or 1, 1, 2)

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
2. The environmental elements of sustainable engineering practice are the most important elements.	- All participants referred to 1 and 3		
3. The economic elements of sustainable engineering practice are the most important elements.	- All participants referred to 1 and 2		
4. The social, environmental, and economic elements of sustainable engineering practice are equally important.	- All participants referred to 1, 2, and 3 - Some agreed with and some contradicted their previous responses	- This question contradicted 1-3 as they implied that one element is the most important	

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
5. Sustainable engineering practice is most useful to current generations.	- All participants referred to 6 - Terminology: one participant referred to sustainable engineering as being more important to future generations because of the results whereas another participant thought it was most important to current generations because it is a practice that must be completed by current engineers - Discussed impact on generations	- These questions may not provide additional value to the survey. Although they contribute to stereotypes, if participants strongly understand the role of current and future generations in SD, this would be evident in the open-ended definition questions - Note that responses for 6 were skewed, which indicated a ceiling effect	- Removed
6. Sustainable engineering practice is most useful to future generations.	- Participants referred to 5 to answer - Discussion of impact on generations and responsibility of engineers in each of the generations		- Removed

Table 44

Quantitative results for the disciplinary stereotypes questions.

Initial Survey Question	Mean	SD	Skewness	Kurtosis
7. Projects in my discipline have limited sustainability considerations.	3.47	1.85	0.22	-1.11
8. Sustainable engineering practice is applicable to every project in my discipline.	4.93	1.71	-0.38	-0.71
9. Other engineering disciplines have more sustainability considerations than my discipline.	4.53	1.73	-0.40	-0.17
10. Sustainable engineering practice is integrated into how we solve problems in my discipline.	3.87	1.60	-0.36	-1.16

Table 45

Question-by-question analysis and modifications for the disciplinary stereotypes questions.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
7. Projects in my discipline have limited sustainability considerations.	- Derek referred to course experiences only; Kevin referred to a past design project; Kate and Sarah referred to past course projects	- The context of this question was unclear, course projects or expectations of projects in general? - Some similarities to 14	- Course projects in my discipline have limited sustainability considerations.
8. Sustainable engineering practice is applicable to every project in my discipline.	- Some clarified the context, specifically if it was for all projects (past and future)	- Context clarification was needed for this question to ensure participants are thinking about all possible projects. (real-world projects)	- Sustainable engineering practice is easily applied to real-world projects in my discipline.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
9. Other engineering disciplines have more sustainability considerations than my discipline.	- Considered traditional disciplines (civil, electrical, mechanical) as well as disciplines more strongly associated with sustainability (civil, environmental, sustainable X) - Kevin skipped the question		- N/A
10. Sustainable engineering practice is integrated into how we solve problems in my discipline.	- Discussed problem solving approaches (some related to design, some purely mathematical) - Based primarily on course experiences, primarily assignments and projects in courses	- Did not necessarily measure the level of integration - Problem solving is not comprehensive enough to determine level of integration	- Sustainable engineering practice is deeply integrated into my discipline.
11. What are the most common sustainability considerations in your engineering discipline?	- Referenced past experiences in courses and projects and some consideration of info on projects in their discipline that they were not necessarily involved in		- No modifications needed

Table 46

Quantitative results for the academic experiences questions.

Initial Survey Question	Mean	SD	Skewness	Kurtosis
12. My course instructors are knowledgeable about sustainable engineering practice.	3.53	1.30	-0.08	0.02
13. Sustainable engineering practice is valued by my course instructors.	4.07	1.49	0.17	-0.43
14. I have many opportunities to apply sustainable engineering practice in my design projects.	4.07	1.44	-0.13	-1.16
15. I receive recognition in my courses for creating sustainable engineering solutions.	4.33	1.29	-0.72	-0.51
16. I have many opportunities to apply sustainable engineering practice in my technical courses.	3.73	1.53	-0.44	-1.16

Table 47

Question-by-question analysis and modifications for the academic experiences questions.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
12. My course instructors are knowledgeable about sustainable engineering practice.	- Assumed that because instructors are highly educated, they must be knowledgeable - Participants had difficulties in assessing this quality (if the course was on this topic, the instructor was knowledgeable, otherwise they could not specify)	- This question was meant to measure the quality of participants' exposure to SEP, use a more direct approach	- Removed - How many of your courses have discussed sustainable engineering practice? with drop down 1 through 8+

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
13. Sustainable engineering practice is valued by my course instructors.	- Difficulties in generalizing to all instructors - Sarah said some “did value it and some definitely did not”	- Although participants had to generalize to all instructors, this provided a perspective on the split	- N/A
14. I have many opportunities to apply sustainable engineering practice in my design projects.	- Discussed who created the opportunity, students or if it was explicit	- Context need for how the opportunity was created, either by the student or if it was a requirement - Just because students had an opportunity, they may have used it	- I have to create opportunities myself to apply sustainable engineering practice in my design projects. - I am expected to apply sustainable engineering practice in my design projects. - I could have applied more sustainable engineering practice in my design projects.
15. I receive recognition in my courses for creating sustainable engineering solutions.	- Considered expectations and some considered marks	- Explicit question needed on marks ask about marks (given addition of question on expectations in 14)	- I receive marks in my courses for creating sustainable engineering solutions.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
16. I have many opportunities to apply sustainable engineering practice in my technical courses.	- Some confusion of the term technical courses as some participants thought of design projects in courses	- Question on number of courses (see 12) was deemed to be more beneficial and reliable as a data source	- Removed

Table 48

Quantitative results for the professional engineering and industry stereotypes questions.

Initial Survey Question	Mean	SD	Skewness	Kurtosis
17. Engineers-In-Training in the workforce are encouraged to incorporate sustainable engineering practice in their projects.	4.33	1.50	-0.66	0.97
18. It is not practical to apply sustainable engineering practice to real-world engineering projects.	2.27	1.75	1.74*	2.97*
19. Practicing engineers do not apply sustainable engineering practice to every aspect of their projects.	4.27	1.53	-0.11	-1.61
20. Sustainability is just a word used in industry for promotion and public image.	3.53	1.64	-0.01	-1.02
21. Sustainability is a shared vision among all engineers working in a single company.	4.53	1.88	-0.32	-0.64

Table 49

Question-by-question analysis and modifications for the professional engineering and industry stereotypes questions.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
17. Engineers-In-Training in the workforce are encouraged to incorporate sustainable engineering practice in their projects.	- Participants had little experience on which to base their response: one thought they must because more people are aware of it, one thought they do from the little bit of research they have conducted on the Canadian licensing process, one did not answer because they have not had experience, and one referred to co-op experience	- Question was likely too advanced for lower year students as they do not have experience in industry and may not have knowledge on the EIT program in Canada.	- Removed
18. It is not practical to apply sustainable engineering practice to real-world engineering projects.	- Considered the present vs. the past in some responses to say that it may not have been practical in the past, but it is practical in the present. - Emphasized the term practical, and participants indicated that it definitely is practical (strongly disagree).	- Wording was too strong and resulted in skewness and kurtosis that showed a flooring effect - What would make something practical? (see relative cost questions)	- Removed

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
19. Practicing engineers do not apply sustainable engineering practice to every aspect of their projects.	- Participants focused on the phrase "every aspect of their projects" - Some discussed different aspects of engineering projects (i.e. CAD models) and determined that it was not practical to do this.	- The question was too strong because of the phrase "every aspect of their projects" - More beneficial to determine if participants think SEP is applied adequately by practicing engineers	- Practicing engineers should apply sustainable engineering practice to more elements of their projects.
20. Sustainability is just a word used in industry for promotion and public image.	- Consideration of the dependence of the type of industry. - Some discussion that it is used in this manner, but that doing so is also beneficial for a company.		- N/A
21. Sustainability is a shared vision among all engineers working in a single company.	- Considered the dependence on the company - Some considered whether this is necessary, or what level should be attained - Some considered the age of companies and how they may change over time	- Indication needed for present context (not past or future)	- Sustainability currently is a shared vision among all engineers working in a single company.

Self-Concept of Abilities

Table 50

Quantitative results for the TBL understanding questions. Questions were prefaced by the phrase; please indicate your level of confidence in your abilities to…

Initial Survey Question	Mean	SD	Skewness	Kurtosis
22. Understand the short-term social costs and benefits associated with engineering projects.	4.53	1.51	-0.65	-1.15
23. Understand the long-term social costs and benefits associated with engineering projects.	4.13	1.73	-0.24	-0.83
24. Understand the short-term environmental costs and benefits associated with engineering projects.	5.13	1.46	-0.90	0.25
25. Understand the long-term environmental costs and benefits associated with engineering projects.	4.67	1.88	-0.49	-0.67
26. Understand the short-term economic costs and benefits associated with engineering projects.	5.80	1.01	-1.44*	3.39*
27. Understand the long-term economic costs and benefits associated with engineering projects.	5.33	1.35	-1.52*	1.79
28. Understand the interdependency among the social, environmental, and economic elements of engineering projects.	3.93	1.83	0.19	-0.35

Table 51

Question-by-question analysis and modifications for the TBL understanding questions. Questions were prefaced by the phrase; please indicate your level of confidence in your abilities to…

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
22. Understand the short-term social costs and benefits associated with engineering projects.	- For all questions that included short-term or long-term, participants defined these durations in different manners - Some participants considered the other elements - Some participants did not consider costs and benefits in their discussions (for 22-27): some focused more on costs or on benefits	- Definition needed for short-term and long-term at the start of this section - Rephrased for Likert-type scale to limit confusion	- I understand the short-term social costs and benefits associated with engineering projects.
23. Understand the long-term social costs and benefits associated with engineering projects.	- Compared to 22		- I understand the long-term social costs and benefits associated with engineering projects.
24. Understand the short-term environmental costs and benefits associated with engineering projects.	- Some participants considered the other elements (social and economic)		- I understand the short-term environmental costs and benefits associated with engineering projects.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
25. Understand the long-term environmental costs and benefits associated with engineering projects.	- Compared to 24		- I understand the long-term environmental costs and benefits associated with engineering projects.
26. Understand the short-term economic costs and benefits associated with engineering projects.	- Some participants considered the other elements (social and environmental)		- I understand the short-term economic costs and benefits associated with engineering projects.
27. Understand the long-term economic costs and benefits associated with engineering projects.	- Compared to 26		- I understand the long-term economic costs and benefits associated with engineering projects.
28. Understand the interdependency among the social, environmental, and economic elements of engineering projects.	- Some participants considered the type of project		- I understand the interdependency among the social, environmental, and economic elements of engineering projects.

Table 52

Quantitative results for the sustainable engineering design process questions. Questions were prefaced by the phrase; please indicate your level of confidence in your abilities to…

Initial Survey Question	Mean	SD	Skewness	Kurtosis
29. Apply sustainable engineering practice throughout the engineering design process.	4.40	1.40	-0.30	-0.17
30. Seek expertise of others in areas where your own knowledge is not adequate to address sustainability issues.	5.87	0.92	-0.35	-0.48

Initial Survey Question	Mean	SD	Skewness	Kurtosis
31. Define sustainability indicators in parallel with technical specifications.	3.93	1.75	-0.80	-0.64
32. Identify analysis tools to generate data for sustainability indicators.	3.40	1.68	-0.42	-1.04
33. Incorporate environmental costs and benefits in economic analyses.	3.87	1.81	-0.61	-0.87
34. Incorporate social costs and benefits in economic analyses.	3.60	1.92	0.03	-1.08
35. Develop appropriate engagement processes for all stakeholders involved with a project.	3.87	2.03	-0.03	-0.96

Table 53

Question-by-question analysis and modifications to the sustainable engineering design process questions. Questions were prefaced by the phrase; please indicate your level of confidence in your abilities to…

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
29. Apply sustainable engineering practice throughout the engineering design process.	- There was some confusion surrounding the term engineering design process.	- Despite the confusion, the term could not be replaced	- I can apply sustainable engineering practice throughout the entire engineering design process.
30. Seek expertise of others in areas where your own knowledge is not adequate to address sustainability issues.	- Discussed whether or not they would ask for help, some considered pride and the ability to ask for help - One considered the type of person who may be an expert in another area	- Focus on the identification of experts (who to ask as opposed to if you would ask) - Focus on sustainable engineering with terminology	- I can identify experts in areas where my own knowledge is not adequate to address sustainable engineering issues.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
31. Define sustainability indicators in parallel with technical specifications.	- Some had difficulty with the terminology sustainability indicators and technical specifications - Some focused on the parallel element	- Simplification was needed for terminology	- I can define sustainability specifications for projects.
32. Identify analysis tools to generate data for sustainability indicators.	- Confused with the terms analysis tools, generate data, sustainability indicators	- Simplification was needed for terminology	- I can extract data to assess a project to see if it meets sustainability specifications.
33. Incorporate environmental costs and benefits in economic analyses.	- Some considered the ability to conduct economic analyses in general - Generally discussed in a hypothetical situation (no reference to past experiences)		- I can incorporate environmental costs and benefits in economic analyses.
34. Incorporate social costs and benefits in economic analyses.	- Some participants considered the ability to conduct economic analyses in general - Generally discussed in a hypothetical situation (no reference to past experiences)		- I can incorporate social costs and benefits in economic analyses.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
35. Develop appropriate engagement processes for all stakeholders involved with a project.	- Discussed context and normally involved a real-world project, but noted that they did not have previous experience - Some confused by the term engagement process - Some discussed the different potential types of stakeholders and some indicated a lack of understanding of stakeholders in projects in general	- Simplification was needed for terminology	- I can appropriately engage all types of stakeholders involved in a project.

Relative Value

Table 54

Quantitative results for the intrinsic value questions.

Initial Survey Question	Mean	SD	Skewness	Kurtosis
36. I am or would like to be enrolled in a sustainable engineering practice course.	5.87	1.64	-2.10*	5.09*
37. I enjoy solving problems that incorporate complex social, environmental, and economic elements.	5.67	1.68	-1.91*	3.76*
38. I would like to become a leader in sustainable engineering practice.	5.87	1.68	-1.93*	4.25*
39. I often discuss sustainable engineering topics with my peers.	4.47	2.23	-0.42	-1.05
40. My peers are more interested in sustainable engineering practice than I am.	3.27	1.49	-0.23	-0.43

Table 55

Question-by-questions analysis and modifications for the intrinsic value questions.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
36. I am or would like to be enrolled in a sustainable engineering practice course.	- Considered the utility value of doing so (i.e. for current work or future work)	- Skewness and kurtosis indicated a ceiling effect - From McCormick 2015: I would prefer to learn about sustainable engineering applications more than any other engineering concept	- I want to be enrolled in a sustainable engineering practice course. - I would prefer to learn about sustainable engineering more than any other engineering concept.
37. I enjoy solving problems that incorporate complex social, environmental, and economic elements.	- Did not always consider all three elements in responses.		- N/A
38. I would like to become a leader in sustainable engineering practice.	- Most discussed importance and thought it would be a good idea	- There was a potential for modification for consideration of future career goals - Considered questions from McCormick 2015: My future career will likely involve solving local or global problems that may involve social, economic, and environmental issues OR If income was not a factor, I would prefer a job related to sustainable development over other types of engineering	- My goal is to become a leader in sustainable engineering practice.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
39. I often discuss sustainable engineering topics with my peers.	- Discussion surrounding my peers often referred to friends and colleagues	- Terminology change was needed for context	- I often discuss sustainable engineering topics with my classmates.
40. My peers are more interested in sustainable engineering practice than I am.	- Discussion surrounding my peers often referred to friends and colleagues	- Terminology change was needed for context	- My classmates are more interested in sustainable engineering topics than I am.

Table 56

Quantitative results for the attainment value questions. Questions were prefaced by the phrase; it is important for me personally to…

Initial Survey Question	Mean	SD	Skewness	Kurtosis
41. Apply sustainable engineering practice to every project I work on.	5.53	1.68	-1.51*	2.54*
42. Contribute to global sustainable development through my professional work.	5.93	1.75	-1.91*	3.62*
43. Help others to learn to apply sustainable engineering practice in their projects.	5.67	1.68	-1.70*	3.32*
44. Preserve the natural environment by considering the potential impacts of a project over its lifecycle.	6.20	1.57	-2.95*	9.64*
45. Spread information to the general public on the impacts of projects to increase awareness and responsibility.	5.80	1.78	-1.84*	2.98*
46. Limit or avoid the use of non-renewable resources during a project's life cycle.	5.80	1.66	-1.92*	4.37*
47. Contribute towards a safe and healthy environment along all phases of a project's life cycle.	6.20	1.47	-2.10*	4.17*

Initial Survey Question	Mean	SD	Skewness	Kurtosis
48. Help customers discriminate needs from wants so they can truly increase their wellbeing.	5.93	1.49	-1.53*	2.22
49. Ensure that projects contribute towards the wellbeing of the people and the development of the communities impacted by the project.	6.33	1.40	-2.50*	6.64*
50. Distribute the benefits and costs from a project in a fair manner globally.	5.27	1.75	-0.47	-1.13
51. Maximize the positive impact of projects on the labour market and on the quality of jobs.	5.80	1.66	-1.92*	4.37*
52. Verify that the total benefits generated equal or exceed the total costs over the whole of a project's life cycle.	5.87	1.60	-2.18*	5.93*
53. Reinvest in innovation to ensure continuous development of quality goods and services.	6.13	1.55	-2.90*	9.49*

Table 57

Question-by-questions analysis and modifications for the attainment value questions. Questions were prefaced by the phrase; it is important for me personally to…

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
It is important for me personally to…	- Confused by context, personal in an academic or career, or in general	- Kurtosis and skewness indicated ceiling effect	- Removed
41. Apply sustainable engineering practice to every project I work on.		- Similarities to modifications for 38 - Kurtosis and skewness indicated ceiling effect	- Replaced with intrinsic question - I want to apply sustainable engineering practice to every project I work on.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
42. Contribute to global sustainable development through my professional work.	- Had difficulty with the phrase global sustainable development and discussed of global versus local	- Too complex - Kurtosis and skewness indicated ceiling effect	- Removed
43. Help others to learn to apply sustainable engineering practice in their projects.	- Considered if they want to teach, and how they could help others	- Similarities to 38 - Kurtosis and skewness indicated ceiling effect	- Removed
44. Preserve the natural environment by considering the potential impacts of a project over its lifecycle.	- Discussion centered on the term lifecycle for 2 participants	- Kurtosis and skewness indicated ceiling effect	- Removed
45. Spread information to the general public on the impacts of projects to increase awareness and responsibility.	- Considered different methods of spreading information (discussed spreading info versus advocating for SD)		- Removed
46. Limit or avoid the use of non-renewable resources during a project's life cycle.	- Sarah noted that you need to determine if the use of non-renewable resources is good or bad	- Similarities to 44 - Kurtosis and skewness indicated ceiling effect	- Removed
47. Contribute towards a safe and healthy environment along all phases of a project's life cycle.	- Safe and healthy environment created discussion of the quality of work environments (i.e. factories)	- Kurtosis and skewness indicated ceiling effect	- Removed

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
48. Help customers discriminate needs from wants so they can truly increase their wellbeing.	- Confused by the term wellbeing and some confused on how the discrimination of needs and wants connects to wellbeing	- Too complex - Kurtosis indicated ceiling effect	- Removed
49. Ensure that projects contribute towards the wellbeing of the people and the development of the communities impacted by the project.	- Noted similarities and differences between wellbeing of people and the development of communities impacted and considered variations in projects - Connected to the importance of the social element	- Multiple interpretations - Important question as it measures the social element, which has been shown in past studies to be neglected in EE - Kurtosis and skewness indicated ceiling effect	- Rephrased and incorporated into the intrinsic value questions. - I want to ensure that projects contribute towards the development of communities that are impacted by the project.
50. Distribute the benefits and costs from a project in a fair manner globally.	- Confused with the term globally - Some discussed the nature of costs and benefits and how this may be difficult to accomplish	- Too complex	- Removed
51. Maximize the positive impact of projects on the labour market and on the quality of jobs.	- Derek and Kevin had difficulty understanding the relevance - Kate considered the role of automation and technological advancement	- Multiple interpretations and too complex - Kurtosis and skewness indicated ceiling effect	- Removed

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
52. Verify that the total benefits generated equal or exceed the total costs over the whole of a project's life cycle.	- Derek and Kate considered from an economic perspective - Kevin and Sarah considered this as being the purpose	- Phrasing too complex - Kurtosis and skewness indicated ceiling effect	- Removed
53. Reinvest in innovation to ensure continuous development of quality goods and services.	- Some confused by context, as some considered the question as if they wanted to work in product development.	- Too complex - Kurtosis and skewness indicated ceiling effect	- Removed

Table 58

Quantitative results for the utility value questions.

Initial Survey Question	Mean	SD	Skewness	Kurtosis
54. Learning about sustainable engineering practice now will be useful for me in my career.	5.93	1.58	-1.63*	1.97
55. The ability to assess the social, environmental, and economic elements of projects is a useful skill that will make me stand out to potential employers.	5.67	1.35	-0.72	-0.76
56. Learning about sustainable engineering practice will help me to become a more responsible engineer.	6.20	1.37	-2.32*	6.09*
57. Applying sustainable engineering practice will help me to develop better engineering solutions.	5.80	1.61	-1.99*	5.13*

Table 59

Question-by-question analysis and modifications for the utility value questions.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
54. Learning about sustainable engineering practice now will be useful for me in my career.	- Considered importance of societal perspectives - Considered what they hope their career will be	- Skewness indicated ceiling effect	- I need to learn about sustainable engineering now to be successful in my career.
55. The ability to assess the social, environmental, and economic elements of projects is a useful skill that will make me stand out to potential employers.	- Two participants considered the dependence of who the potential employer is		- N/A
56. Learning about sustainable engineering practice will help me to become a more responsible engineer.	- Considered what the attributes of a responsible engineer are and determined that SEP is an attribute	- Skewness and kurtosis indicated ceiling effect - Consider if it is necessary to be a responsible engineer	- Learning about sustainable engineering practice is necessary to be a responsible engineer.
57. Applying sustainable engineering practice will help me to develop better engineering solutions.	- Interpretations of context varied	- Direct reference of general context needed (removed personal contextual elements)	- The application of sustainable engineering practice creates better engineering solutions.

Table 60

Quantitative results for the relative cost questions.

Initial Survey Question	Mean	SD	Skewness	Kurtosis
58. Incorporating sustainable engineering practice has a higher economic cost than not incorporating it.	3.87	2.23	-0.12	-1.46
59. I do not have enough time to engage in sustainable engineering practice.	2.80	1.78	0.70	-0.62
60. It is too difficult to understand the complex elements of sustainability.	2.27	1.28	0.37	-1.63
61. Learning about sustainable engineering practice will take too much of my attention away from learning about technical engineering topics.	2.93	1.67	0.44	-0.92
62. Learning about sustainable engineering practice will take too much of my attention away from learning about important professional skills for engineering.	2.60	1.24	0.38	-0.76
63. Understanding sustainable engineering practice will limit the industries I can work in.	2.33	1.88	1.38*	1.24

Table 61

Question-by-question analysis and modifications for the relative cost questions.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
58. Incorporating sustainable engineering practice has a higher economic cost than not incorporating it.	- Typically considered real-world projects in industry (hypothetical projects, not ones they had had experience with)	- Specific context was needed. - Practicality of application was addressed in this question	- Fully incorporating sustainable engineering practice into a real-world project is too expensive to be practical.

Initial Question	Think-Aloud Notes	Areas for Improvement	Modifications
59. I do not have enough time to engage in sustainable engineering practice.	- Some considered time spent in past projects, some considered how engineers may spend their time at work, and some considered time in general	- Context was needed to indicate if it is in the academic perspective or in real-world projects	- Fully incorporating sustainable engineering practice into a real-world project requires too much time to be practical.
60. It is too difficult to understand the complex elements of sustainability.	- Considered variation depending on the project - Most noted that it is difficult but it is necessary	- Context needed - Assessed intrinsic value, not relative cost	- Removed
61. Learning about sustainable engineering practice will take too much of my attention away from learning about technical engineering topics.	- Some confused by the term technical engineering topics.	- Phrasing too complex	- Technical engineering topics are more important to learn about than sustainable engineering practice.
62. Learning about sustainable engineering practice will take too much of my attention away from learning about important professional skills for engineering.	- Some confused by the term professional skills	- Phrasing too complex	- Engineering professional skills are more important to learn about than sustainable engineering practice.
63. Understanding sustainable engineering practice will limit the industries I can work in.	- Interpretation varied, either considered understanding or valuing	- Kurtosis indicated flooring effect - Understanding was the wrong term, perhaps valuing	- I will not work for companies that do not value sustainable engineering practice.

APPENDIX C

SURVEY RESULTS

This appendix includes the descriptive statistics for each question for the sample. For all questions, the standard errors were 0.16 and 0.32 for the skewness and kurtosis, respectively. Although the standard errors were small, the acceptable ranges were within ±1.00 and ±2.00 for the skewness and kurtosis, respectively (Field, 2013). In this appendix, * denotes a skewness or kurtosis value outside of the acceptable range.

Table 62

Descriptive statistics for the stereotypes and previous experiences questions.

Survey Question	***n***	$\bar{x}$	***s***	**Skewness**	**Kurtosis**
Social rank	241	1.95	0.77	0.08	-1.28*
Environmental rank	241	1.52	0.66	0.90	-0.31
Economic rank	240	2.45	0.76	-0.96	-0.60
Course projects in my discipline have limited sustainability considerations.	242	4.17	1.77	-0.22	-0.95
Sustainable engineering practice is easily applied to real-world projects in my discipline.	242	5.07	1.74	-0.65	-0.62
Other engineering disciplines have more sustainability considerations than my discipline.	242	4.04	1.74	-0.04	-0.78
Sustainable engineering practice is deeply integrated into my discipline.	242	4.17	1.76	0.00	-0.99
Number of Courses with SEP	226	3.08	2.06	1.01*	0.11
Sustainable engineering practice is valued by my course instructors.	241	4.63	1.56	-0.36	-0.36
I have to create opportunities myself to apply sustainable engineering practice in my design projects.	241	4.70	1.64	-0.44	-0.51
I am expected to apply sustainable engineering practice in my design projects.	242	4.64	1.72	-0.36	-0.87

Survey Question	*n*	$\bar{x}$	*s*	Skewness	Kurtosis
I receive marks in my courses for creating sustainable engineering solutions.	242	3.81	1.78	0.09	-0.85
I could have applied sustainable engineering practice more in my design projects.	242	4.89	1.40	-0.53	0.04
Practicing engineers should apply sustainable engineering practice to more elements of their projects.	241	6.24	1.15	-2.28*	6.64*
Sustainability is just a word used in industry for promotion and public image.	241	3.40	1.92	0.29	-1.11
Sustainability is currently a shared vision among all engineers working in a single company.	241	3.35	1.42	0.33	-0.03

Table 63

Descriptive statistics for the self-concept of abilities questions.

Survey Question	*n*	$\bar{x}$	*s*	Skewness	Kurtosis
I understand the short-term social costs and benefits associated with engineering projects.	239	4.99	1.39	-0.68	0.23
I understand the long-term social costs and benefits associated with engineering projects.	239	4.75	1.53	-0.38	-0.60
I understand the short-term environmental costs and benefits associated with engineering projects.	238	5.21	1.33	-0.94	0.92
I understand the long-term environmental costs and benefits associated with engineering projects.	238	5.10	1.56	-0.87	0.19
I understand the short-term economic costs and benefits associated with engineering projects.	236	5.36	1.34	-0.91	0.62
I understand the long-term economic costs and benefits associated with engineering projects.	238	5.00	1.41	-0.68	0.03
I understand the interdependency among the social, environmental, and economic elements of engineering projects.	238	5.04	1.50	-0.64	0.04
I can apply sustainable engineering practice throughout the engineering design process.	239	4.78	1.42	-0.43	-0.27

Survey Question	n	$\bar{x}$	s	Skewness	Kurtosis
I can identify experts in areas where my own knowledge is not adequate to address sustainable engineering issues.	239	4.42	1.69	-0.20	-0.94
I can define sustainability specifications for projects.	239	4.47	1.44	-0.42	-0.47
I can find information to assess a project to see if it meets sustainability specifications.	237	4.59	1.48	-0.36	-0.48
I can incorporate environmental costs and benefits in economic analyses.	238	4.24	1.56	-0.22	-0.75
I can incorporate social costs and benefits in economic analyses.	236	4.12	1.53	-0.12	-0.67
I can appropriately engage all types of stakeholders involved in a project.	238	4.55	1.51	-0.36	-0.44
Technical engineering topics are more important to learn about than sustainable engineering practice.	240	3.69	1.59	0.12	-0.54
Engineering professional skills are more important to learn about than sustainable engineering practice.	238	3.69	1.42	0.12	-0.27
I will not work for companies that do not value sustainable engineering practice.	240	4.77	1.71	-0.50	-0.54

Table 64

Descriptive statistics for the relative value questions.

Survey Question	n	$\bar{x}$	s	Skewness	Kurtosis
I want to be enrolled in a sustainable engineering practice course.	240	5.57	1.76	-1.27*	0.78
I would prefer to learn about sustainable engineering more than any other engineering concept.	240	4.37	2.01	-0.23	-1.12
I enjoy solving problems that incorporate complex social, environmental, and economic elements.	240	5.60	1.45	-1.19*	1.24

Survey Question	*n*	$\bar{x}$	*s*	Skewness	Kurtosis
My goal is to become a leader in sustainable engineering practice.	240	5.25	1.72	-0.87	0.02
I want to apply sustainable engineering practice to every project I work on.	239	5.92	1.46	-1.65*	2.63*
I want to ensure that projects contribute towards the development of communities that are impacted by projects.	240	6.03	1.19	-1.32*	1.83*
I often discuss sustainable engineering topics with my classmates.	240	4.43	1.92	-0.32	-1.00
My classmates are more interested in sustainable engineering practice than I am.	240	3.20	1.36	0.29	0.26
I need to learn about sustainable engineering now to be successful in my career.	239	5.11	1.69	-0.74	-0.28
The ability to assess the social, environmental, and economic elements of projects is a useful skill that will make me stand out to potential employers.	240	5.56	1.46	-1.09*	0.88
Learning about sustainable engineering practice is necessary to be a responsible engineer.	240	6.15	1.21	-2.08*	5.15*
The application of sustainable engineering practice creates better engineering solutions.	239	6.05	1.34	-1.72*	2.96*
Fully incorporating sustainable engineering practice into a real-world project is too expensive to be practical.	240	3.22	1.66	0.53	-0.55
Fully incorporating sustainable engineering practice into a real-world project requires too much time to be practical.	240	2.96	1.55	0.69	-0.02

APPENDIX D

FACTOR ANALYSES

This appendix includes the structure matrices for the final factor analysis attempts.

Table 65

Structure matrix for the stereotypes and previous experiences factor analysis.

Survey Question	Academic Experiences	Application of SEP Experiences	Applicability to Engineering Discipline
Number of Courses with SEP	0.55		-0.42
Sustainable engineering practice is valued by my course instructors.	0.75		-0.54
I am expected to apply sustainable engineering practice in my design projects.	0.88		-0.47
I receive marks in my courses for creating sustainable engineering solutions.	0.76		-0.33
I could have applied sustainable engineering practice more in my design projects.		0.43	
Practicing engineers should apply sustainable engineering practice to more elements of their projects.		0.60	
Course projects in my discipline have limited sustainability considerations.	-0.49	0.39	0.43
I have to create opportunities myself to apply sustainable engineering practice in my design projects.		0.64	
Sustainability is just a word used in industry for promotion and public image.			0.32

Survey Question	Academic Experiences	Application of SEP Experiences	Applicability to Engineering Discipline
Sustainable engineering practice is easily applied to real-world projects in my discipline.			-0.55
Other engineering disciplines have more sustainability considerations than my discipline.	-0.41		0.47
Sustainable engineering practice is deeply integrated into my discipline.	0.57		-0.79

Table 66

Structure matrix for the self-concept of abilities factor analysis.

Survey Question	TBL Understanding	SE Design Process Abilities
I understand the short-term social costs and benefits associated with engineering projects.	0.80	0.37
I understand the long-term social costs and benefits associated with engineering projects.	0.79	0.35
I understand the short-term environmental costs and benefits associated with engineering projects.	0.73	0.46
I understand the long-term environmental costs and benefits associated with engineering projects.	0.65	0.41
I understand the short-term economic costs and benefits associated with engineering projects.	0.65	
I understand the long-term economic costs and benefits associated with engineering projects.	0.76	
I understand the interdependency among the social, environmental, and economic elements of engineering projects.	0.65	0.47
I can apply sustainable engineering practice throughout the engineering design process.	0.35	0.76

Survey Question	TBL Understanding	SE Design Process Abilities
I can identify experts in areas where my own knowledge is not adequate to address sustainable engineering issues.		0.64
I can define sustainability specifications for projects.	0.34	0.81
I can find information to assess a project to see if it meets sustainability specifications.	0.41	0.61
I can appropriately engage all types of stakeholders involved in a project.	0.46	0.62

Table 67

Structure matrix for relative value factor analysis.

Survey Question	Intrinsic Value	Utility Value	Relative Cost
I want to be enrolled in a sustainable engineering practice course.	0.80	0.60	
I would prefer to learn about sustainable engineering more than any other engineering concept.	0.77	0.48	
I enjoy solving problems that incorporate complex social, environmental, and economic elements.	0.72	0.56	
My goal is to become a leader in sustainable engineering practice.	0.91	0.59	-0.39
I often discuss sustainable engineering topics with my classmates.	0.63	0.38	
I will not work for companies that do not value sustainable engineering practice.	0.51	0.45	
I want to apply sustainable engineering practice to every project I work on.	0.81	0.74	-0.35
I want to ensure that projects contribute towards the development of communities that are impacted by projects.	0.69	0.72	
I need to learn about sustainable engineering now to be successful in my career.	0.54	0.62	

Survey Question	**Intrinsic Value**	**Utility Value**	**Relative Cost**
Learning about sustainable engineering practice is necessary to be a responsible engineer.	0.52	0.89	
The application of sustainable engineering practice creates better engineering solutions.	0.56	0.82	
The ability to assess the social, environmental, and economic elements of projects is a useful skill that will make me stand out to potential employers.	0.41	0.63	
Fully incorporating sustainable engineering practice into a real-world project is too expensive to be practical.			0.86
Fully incorporating sustainable engineering practice into a real-world project requires too much time to be practical.			0.85
Technical engineering topics are more important to learn about than sustainable engineering practice.	-0.42		0.49
Engineering professional skills are more important to learn about than sustainable engineering practice.	-0.43		0.58