UNIVERSITY OF CALGARY

# Quantitative and Qualitative Techniques for Assessing Learning Outcomes in Engineering Education

by

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A THESIS

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## ABSTRACT

This thesis presents quantitative and qualitative techniques for assessing learning outcomes in engineering education, with specific focus on demonstrating compliance with Canadian Engineering Accreditation Board Graduate Attributes criteria. Through the application of Factor Analysis (an extension on traditional quantitative analysis) to the results from a closed-ended survey, correlations between the survey questions were identified. These correlations can be used to simplify attribute assessments, since by identifying correlated attributes in a course, the assessment of those attributes can be performed together. Meanwhile, the application of Grounded Theory (a form of qualitative analysis) to open-ended survey and interview responses identified learning outcomes that were not identified in the course's prescribed learning outcomes. Additionally, Grounded Theory was used to identify desired course improvements. Through these contributions to the CEAB assessment process, both Factor Analysis and Grounded Theory are demonstrated as viable techniques for performing learning outcomes assessment in engineering education.

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# CHAPTER 1: INTRODUCTION

## 1.1 Introduction

With the establishment of the Canadian Engineering Accreditation Board (CEAB) Graduate Attributes criteria (CEAB, 2010), there has been increased incentive for engineering undergraduate programs to develop effective and efficient methods to evaluate what their students are learning, particularly regarding non-technical skills. This thesis describes the use of both quantitative and qualitative research techniques, specifically Factor Analysis (Harman, 1976) and Grounded Theory (Glaser & Strauss, 1967), as techniques to aid in the assessment of learning outcomes achieved by engineering programs. Factor Analysis is a technique for identifying underlying correlations in quantitative data, while Grounded Theory is a qualitative data analysis technique, which employs the systematic categorization of responses to create a theory. Both of these techniques will be further explained in Chapter 2.

## 1.2 Literature Review

This section describes the previous work that has been done in the areas of engineering education research, data gathering techniques, quantitative analysis (particularly Factor Analysis), and qualitative analysis (particularly Grounded Theory Analysis).

### 1.2.1 Engineering Education Research

Engineering has long been thought of as the practice of critical thinking and problem solving, typically through the application of mathematical and scientific principles (Papastephanou and Angeli 2007; Sheppard et al., 2008). Additionally, engineers are expected to be flexible to the changing needs of society, to possess life-long learning skills, to work independently and as a member of a team, to understand the ethical consequences of their actions, to be able to communicate effectively in a wide variety of media, and to apply all of these skills across multiple disciplines and in an international context (McDonald & Welland, 2004; Coll & Zegwaard, 2006; Melsa et al., 2009; Grohowski-Nicometo et al., 2009). However, historically, undergraduate engineering programs have typically focused on teaching students the technical foundations in the sciences and mathematics, with only a small mention of application and design (Sheppard & Jenison, 1997).

The field of engineering education research has been around in North America for over one hundred years, after it was generally agreed that engineering disciplines needed to be taught with a certain level of rigour (ASEE, 2011). Traditional work in the field of engineering education research focused on the implementation of engineering education (ie. how the material was being taught) (Felder & Silverman, 1988; Perrin et al., 2005; Cady & Fortenberry, 2007; Wald, 2007; Baldwin, 2009; Smith et al., 2009; Trenas et al., 2010, ASEE, 2011; JEE, 2011), as well as methods of retaining students in undergraduate engineering programs (Cady & Fortenberry, 2007; Li et al., 2009; Lichtenstein et al., 2009; Smith et al., 2009).

In the past thirty years, there has been an increased emphasis on the need to provide engineering students with skills in design (Sheppard & Jenison, 1997; Tempelman & Pilot, 2010; Miller-Young, 2010), as well as with the non-technical skills engineers are expected to possess, as described above (Kelly 1983). While many universities/colleges began to modify their programs to support these new educational goals (Riley et al., 2004; Ellis et al., 2005; Williams et al., 2009; Heywood, 2010), there was no method of program standardization for ensuring that all engineering programs were producing engineering graduates with the same skillsets. Therefore, in 1997, the Accreditation Board for Engineering and Technology (ABET, 2009) altered their accreditation criteria for engineering programs in the USA to include requirements for engineering students to possess non-technical skillsets at the time of graduation, knows as the Engineering Criteria 2000 (aka. EC2000)(ABET, 2009). Commencing in 2014, the CEAB will require Canadian engineering programs to adhere to a similar set of learning outcomes, known as the Graduate Attributes criteria (CEAB, 2010), which are discussed in further detail in Chapter 2.

These new outcomes-based assessment criteria have posed a variety of challenges for engineering education researchers and administrators. One of these challenges is the need to shift the mindset of traditional engineering educators to a new outcomes-based paradigm (Splitt, 2003). Specific to the assessment process, challenges exist in developing common definitions of the accreditation criteria (Prados et al., 2005; Patil & Codner, 2007), developing measurable indicators of learning outcomes achievement (Kam & Lightner, nd), methods of gathering data (Prados et al., 2005), identifying areas within the program where the desired learning outcomes should be taught and assessed (Patil & Codner, 2007), utilizing the assessment results to perform continual improvements (Prados et al., 2005), and establishing timelines for performing the assessments (Kam & Lightner, nd). All of this led to "heavy workloads and the perception of accreditation as an onerous task" (Prados et al., 2005, p. 170). While flowcharts have been developed to help guide institutions through the outcomes-based assessment process (as shown in Appendix A), the process remains challenging and time-consuming (Prados et al., 2005; Patil & Codner, 2007; Kam & Lightner, nd).

Due to these challenges, two new fields of engineering education research have been established. The first field with a focus on evaluating if (and to what extent) students have learned the material they are being taught (Wald, 2007), and the second, most recent, field evaluating the undergraduate engineering programs and determining how to meet the new outcomes-based assessment criteria effectively and efficiently. Many assessment methods have been proposed.

Among the most highly regarded methods for improving engineering education is the Conceive-Design-Implement-Operate (CDIO) initiative, with over fifty collaborating institutions across the globe (CDIO, 2011). As demonstrated by Cloutier et al. (2010), Brennan & Hugo (2010) and Brennan et al. (2011), the CDIO Syllabus describes learning outcomes and metrics that are highly similar, and can be strongly mapped, to the student learning outcomes described by the CEAB Graduate Attributes assessment criteria. Through existing metrics provided by CDIO, the process of assessing learning outcomes can be done efficiently, without the need to start from scratch in defining assessment standards and metrics (Brennan et al., 2011).

Other existing assessment methods include: frameworks to categorize the criteria into measurable outcomes (Chong & Crowther, 2005), concept maps to graphically represent the relationships between outcomes (Turns & Atman, 2000), process management models for benchmarking educational quality (Llamosa-Villalba & Aceros, nd), fuzzy comprehensive evaluations (Gao et al., 2009), the development of student portfolios (Johnson et al., 2002; Williams, 2010), a Competing Values Framework (aka CVF) (Zafft, 2009), a Perry model (Marra et al., 2000), the Creative Engineering Design Assessment (Charyton & Merrill, 2009), as well as the development of entirely new metrics (McDonald & McDonald, 1999).

The quantitative portion of this thesis seeks to expand on the work of Chong & Crowther (2005) by using Factor Analysis to develop a framework for categorizing assessment criteria. Additionally the mapping criteria set forth by Cloutier et al. (2010), Frank (nd) and Harris et al. (2011) are employed in order to develop the data gathering techniques employed for the quantitative assessment. The qualitative portion of this thesis seeks to expand on the concept maps proposed by Turns & Atman (2000) by employing concept maps to visualize the application of Grounded Theory to identify high-level concepts in engineering education assessment, as well as to expand on the use of qualitative research in engineering education through the introduction of Grounded Theory Analysis into learning outcomes assessment.

#### 1.2.1.1 First-year Design Courses

First-year design courses have become increasingly predominant in engineering. PennState, for example, has instituted a first-year engineering course with foci on engineering problem solving, written, oral and graphical communication, and analysis and interpretation of data (Marra et al., 2000). Carnegie Mellon University offers a first-year design course to their mechanical engineering students with an emphasis on design problem-solving skills, and the application of physics and mathematics courses to engineering design (Ambrose & Amon, 1997). Michigan Technological University also offers first-year problem solving and design engineering courses, but with a revised focus on technical communication as of Fall 2010 (Kemppainen, 2011). James Madison University offers a six-course design curriculum with specific instruction on designing for environmental, social, economic, and technical sustainability (Pappas & Pierrakos, 2010).

### 1.2.2 Data Gathering

A review of existing literature in the field of engineering education revealed that the most common method of gathering data in engineering education is through surveys (Olds et al., 2005), particularly closed-ended surveys with Likert scale response options (Likert, 1932). However, there are several issues with closed-ended surveys that make them non-ideal. Firstly, surveys that accurately portray the research questions being examined are difficult to design properly (Olds et al., 2005), due to the phrasing of the survey questions, age-related and cultural predispositions of the participants, and the manner in which they are presented to the participants. Secondly, response rates for surveys are highly variable (Coll & Zegwaard, 2006).

There has been work in engineering education research to design proper surveys, primarily through the breakdown of research questions into subsidiary questions (Coll & Zegwaard, 2006; Li et al., 2009). Additionally, the survey questions are randomized so as not to bias the participants' responses (Coll & Zegwaard, 2006). Pilots of the surveys are often performed to ensure the readability/clarity off the survey (Coll & Zegwaard, 2006).

In order to provide more detail in statistical quantitative analyses, demographic data is typically collected from the survey participants, in order to identify trends in their responses (Coll & Zegwaard, 2006; Oware et al., 2006).

Interviews and observational data have been increasingly used in engineering education research, particularly for qualitative evaluations (Oware et al., 2006; Eames & Stewart, 2008; Lichtenstein et al., 2009).

### 1.2.3 Quantitative Analysis

Predominantly, survey results are quantitatively analyzed using a simple model by which the participants' responses to the survey questions are aggregated and/or compared with the participants' demographic responses (Todd et al., 1995; Coll & Zegwaard, 2006). The results are also commonly analyzed for statistical significances (Fink, 1995; Todd et al., 1995; Lethbridge, 1998; Lang et al., 1999; Coll & Zegwaard, 2006).

Specifically, Factor Analysis has been previously employed in engineering education research in order to group student competencies (Chong & Crowther, 2005). The objective of this thesis is to expand on that research by using Factor Analysis to categorize achieved student learning outcomes (from the students' perspectives), as measured by a closed-ended survey.

### 1.2.4 Qualitative Analysis

Qualitative research methods are commonly used in education and social sciences research (Taylor & Bogdan, 1984). More recently, qualitative methods have been used in the evaluation of software engineering metrics (Seaman, 1999), and have become increasingly common in engineering education assessments.

Many types of qualitative analyses have been applied in engineering education research. Trevelyan (2007) for example performed interviews with practicing engineers as part of an ethnographic study, in order to uncover factors for successfully coordinating technical work. Case study work has been performed by Cronje & Coll (2008) in order to determine student perceptions of teaching pedagogies in university-level science and engineering courses. Lichtenstein et al. (2009) employed a combination of quantitative and qualitative research methods in order to assess the students' career intentions after completing an undergraduate engineering degree. Oware et al. (2006) conducted interviews with graduate students in order to determine how they defined engineering education.

Specific to the evaluation of first-year engineering courses, numerous studies have been conducted that include qualitative data gathered from open-ended surveys (Courter et al., 1998; Lord et al., 2000), interviews (Courter et al., 1998; Marra et al., 2000), conversational analysis (Atman et al., 1999) and observational analysis (Dally & Zhang, 1991; Piket-May & Avery, 1997). However, while the studies above have stated that the data from the open-ended surveys and interviews have been analyzed (Courter et al., 1998; Marra et al., 2000; Lord et al., 2000), there was no specific mention as to the method applied to analyze this data.

#### 1.2.4.1 Grounded Theory Analysis

Grounded Theory is an obscure branch of qualitative analysis in engineering education research, with no records found to date explicitly citing Grounded Theory as their analysis methodology.

Glaser & Strauss (1967) first proposed Grounded Theory Analysis as a mechanism to perform comparative analysis in sociology. Grounded Theory has since been adopted for use in health research (Giske & Artinian, 2007; Harvey, 2010), cultural-historical research (Seaman, 2008), K-12 education research (Kennedy, 2009), general education research (Taber, 2000; Piantanida et al., 2004), and medical education research (Harris, 2003; Bowen, 2006).

## 1.3 Motivation

The majority of the quantitative results depend on the survey being designed properly, which has been stated to be extremely difficult to accomplish (Olds et al., 2005). While the Factor Analysis technique utilized in Chong & Crowther (2005) can be applied to overcome this issue, the Chong & Crowther (2005) article performs many extraneous operations on the results, and convolutes their framework (by creating additional factors), rather than simplifying it. This created the motivation to apply Factor Analysis in its simplest form, in order to demonstrate the linkages between assessment criteria, and how these correlations can simplify assessments.

While a significant amount of qualitative analysis has been employed in engineering education research, very little of that research reaches the engineering community (Cronje & Coll, 2008). It is thought that this is due to a perception of a lack of rigour in engineering education research, and particularly qualitative research, in comparison to the more established fields of engineering (Cronje & Coll, 2008; Valerdi & Davidz, 2009). This perception sparked the motivation to perform Grounded Theory Analysis in this thesis, as it is more rigourous than other forms of qualitative analysis (Haig, 1995).

As described in section 1.2, institutions prioritize a variety of learning outcomes in their design courses for first-year engineering programs. The variety of potential learnings from a first-year design course are so vast that the University of Alaska Fairbanks developed an entire process for selecting a model of teaching design to first-year engineering students (Burton & White, 1999). However, Burton and White (1999) focused on the implementation method of a first-year design course (ie. reverse engineering projects versus large scale projects versus small scale projects versus case studies), rather than on the content being learned by the students or administrative issues that first-year design courses are faced with. This motivated the research question of what attributes make up an effective first-year design and communications course in engineering.

## 1.4 Contribution

The research documented in this thesis seeks to contribute to the field of engineering education research by providing examples of quantitative and qualitative assessment techniques, that can be applied to effectively and efficiently help to satisfy outcomes-based assessment criteria, without requiring an extensive amount of additional work from the faculty. More specifically, the objective of this thesis is to deliver the following contributions to the field of engineering education:

1. Demonstrating Factor Analysis as a viable technique for simplifying learning outcomes assessment in engineering education.

2. Demonstrating Grounded Theory as a viable technique for enhancing learning outcomes assessment in engineering education.

Additionally this thesis seeks act as a proof-of-concept, by employing the Factor Analysis and Grounded Theory techniques, in order to accomplish the following goals:

3. Identifying learning outcomes[1] achieved by the ENGG 251/253 and ENGG 200 design and communications courses.
4. Establishing attributes of an effective first-year design and communications course.

**1.5 Thesis Layout**

Chapter 2 provides the background of this thesis, where previous research has been utilized in the preparation of this study. This chapter includes the methods by which the data was gathered, as well as a detailed explanation of the methodologies considered and used in the analysis of the data.

Chapter 3 describes the application of basic quantitative analysis and Factor Analysis to the survey results. These results are then analyzed to identify the trends in CEAB criteria for the first year design courses, and how these potential correlations can be used to simplify learning outcomes assessments for other courses and institutions.

Chapter 4 details the application of Grounded Theory Analysis to the results from the open-ended survey questions, as well as the interview and focus group data. These results, and their implications for outcomes-based assessment criteria are also discussed in this chapter.

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[1] Note: the term "learning outcomes" here is not specific to the CEAB Graduate Attributes criteria (as these are applicable to the skills the students should possess at the conclusion of their education). Rather, here "learning outcomes" refers to what was learned by the students during the first year design and communications course.

Chapter 5 summarizes the main results of this thesis and concludes with the contributions of this thesis to the field of engineering education research.

# CHAPTER 2: BACKGROUND

## 2.1 Introduction

This chapter provides a technical background of the qualitative and quantitative assessment techniques considered in this thesis. Specifically, this chapter provides a background of the first-year design courses implemented at the University of Calgary, as well as details the evaluation methods employed in this study, including data gathering techniques, quantitative assessment techniques and qualitative assessment techniques.

## 2.2 First-year Engineering Design Courses at the University of Calgary

This section describes the first-year design course implementations evaluated in this thesis. A first year course-based assessment was chosen over a program-wide assessment for several reasons, including the researcher's familiarity with the course, the relative simplicity of assessing learning outcomes in a course versus an entire program, and the belief that the students would be able to better distinguish the learning outcomes achieved in a specific course in their first year, rather than in a later year, where many skills from previous courses might be utilized.

### 2.2.1 ENGG 251/253 (2009 Survey)

In 2002, a pair of first-year courses in engineering design and communication were introduced at the Schulich School of Engineering, University of Calgary, known as ENGG 251/253: Engineering Design and Communication. Through these courses, the students were given 245 minutes of lab time each week to work on various open-ended design challenges, as well as 50 minutes each week for lectures, which taught primarily written and graphical communication skills. The course outline for this course can be found in Appendix B. Anecdotal student feedback revealed that the open-ended nature of the ENGG 251/253 projects did not provide enough support and direction as was needed for achieving some of the courses' learning objectives (such as design, project management, and communication skills). Additionally, the students had not taken a sufficient number of technical engineering courses, with instruction in the application of mathematical and scientific principles to engineering design problems, in order to undertake many of the challenges presented in the projects.

Anecdotal feedback, as well as the researcher's previous experience as a student of the ENGG 251/253 design courses, gave rise to this thesis' third goal: to determine which of the course's learning outcomes were achieved from the perspective of the students and instructors. This research question is explored and answered in Chapters 3 & 4.

### 2.2.2 ENGG 200 (2010 Survey)

In September 2010, the course structure was revised to consist of a single, consolidated design course, ENGG 200: Engineering Design and Communication. Working under the premise that providing a theoretical framework of design prior to the lab projects would improve the students' design skills (Atman & Bursic, 1996) the ENGG 200 course consists of 170 minutes of lab/workshop time and 150 minutes of lectures. In this revised structure, the lectures provide students with a theoretical foundation in design, project management, and communication. The workshops then contained short projects of increasing difficulty, allowing the students to apply their knowledge of the design process to new and unique challenges. Additionally, the projects were redesigned to utilize the students' abilities to apply a design process, rather than their technical knowledge. The outline for this course can be found in Appendix B.

## 2.3 Typical Accreditation Assessment Process

While there is no standardized assessment process, many institutions have developed similar processes for performing their accreditation assessments. Worcester Polytechnic Institute for example (Albano et al., 2000), performed the following tasks (p.2):

1. Compile baseline data to demonstrate the relationship between Program Outcomes and the current curriculum (including consideration of both courses and MQPs).
2. Identify Program Outcomes that are not well supported by the current Civil and Environmental Engineering curriculum.

3. Present specific recommendations to the Department for developing clearly defined and measurable Program Outcomes to assess the current Civil Engineering curriculum.
4. Establish a process to demonstrate, to evaluate, and to provide feedback regarding how graduates satisfy the Program Outcomes and how continuous improvement of the curriculum is addressed.
5. Summarize the outcomes from the Exit B Interviews (EBI) student satisfaction surveys for presentation to the CEE Department.

Meanwhile, the University of Calgary established the following process for CEAB accreditation assessment (Brennan, 2010).

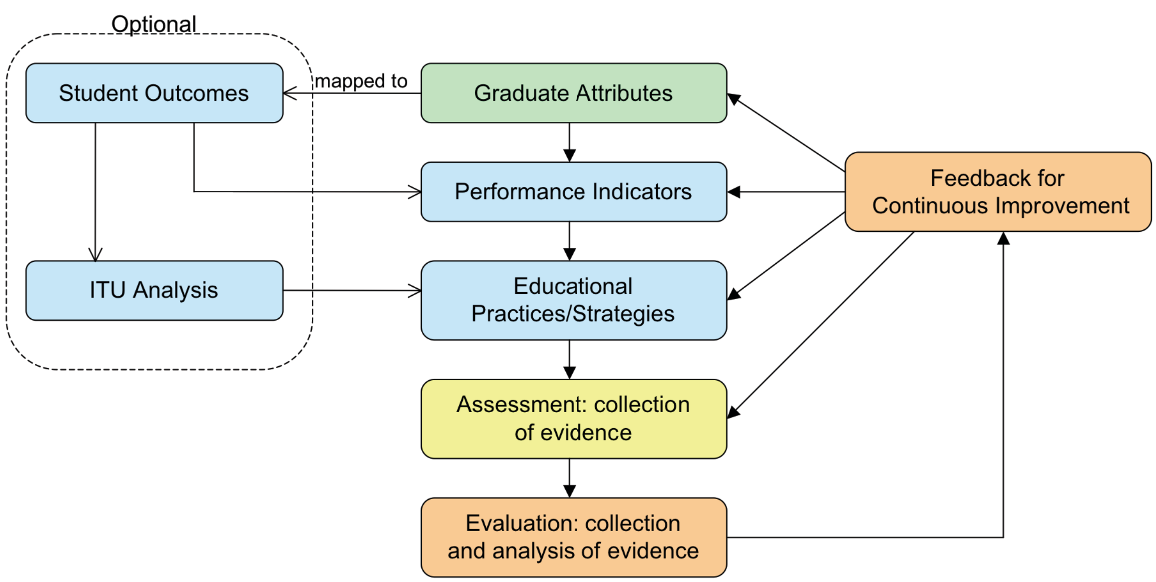


Figure 1: CEAB Graduate Attributes Planning at the University of Calgary

The research presented in this thesis seeks to contribute to this assessment process in two ways. Firstly, it seeks to utilize Factor Analysis within the "Assessment: collection of evidence" section by enabling institutions to better link specific attributes to individual courses. Secondly, it seeks to employ Grounded Theory to enhance the "Evaluation: collection and analysis of evidence" by eliciting more open-ended responses, and

"Feedback for Continuous Improvement", by enabling the students to provide input on the future improvements to the course.

### 2.4 Data Gathering Techniques

This section details the potential techniques that were considered for gathering data on the achieved learning outcomes of the course, as perceived by both the students and instructors.. According to Olds et al. (2005), there are two categories of assessment methodologies, descriptive studies, and experimental studies.

#### 2.4.1 Descriptive Studies

A descriptive study is used to describe the current state of a phenomenon (Olds et al., 2005), where in this instance, the phenomena being examined are the first year design courses. According to Olds et al. (2005), there are six techniques for gathering data: surveys, interviews/focus groups, conversational analysis, observation, ethnographic studies, and meta-analysis. In contrast, Grimes and Schulz (2002) describe five descriptive studies: case reports, case-series reports, cross-sectional (prevalence) studies, surveillance, and ecological correlational studies. Given that the study by Olds et al. (2005) pertains to engineering education, whereas the work by Grimes and Schulz (2002) pertains to Medicine, the work by Olds et al. (2005) will be the primary source for defining the descriptive studies.

##### 2.4.1.1 Surveys

Surveys are the most time and cost efficient technique of gathering data from a large pool of participants (Ader & Mellenbergh, 2008). Additionally, the self-reporting nature of surveys typically aids to capture information that cannot be observed, or gathered through other means (Olds et al., 2005). Surveys can consist of both quantitative and qualitative research questions, which are often described as closed-ended and open-ended questions (Reja et al., 2003). Closed-ended surveys commonly use a Likert-type scale, which allows the participant to select the degree with which they agree with a given statement (ie. Strongly Disagree, Disagree, Agree, Strongly Agree)(Likert, 1932). Other closed-ended survey questions allow the user to select from true/false statements

(DiClemente et al., 1986) and allowing the user to select as many responses as apply to the researcher’s statement (Fowler, 2009). Open-ended survey questions provide the research participants with more freedom to express their thoughts, by asking them open-ended questions (Geer, 1988).

While the self-reporting nature and difficulty of designing unambiguous survey questions pose challenges to surveys as a data gathering technique (Olds et al., 2005; Suskie, 1996; AERA, 1999), the validity of this type of study can be achieved through expert review (AERA, 1999). Furthermore, surveys can be disadvantageous due to their tendencies to low response rates, which can threaten the validity of the survey (Fowler, 2009). Finally, since the survey relies on the students reporting their self-efficacies, the results will likely contain some bias and should not be used as the sole method for program or course assessments.

#### 2.4.1.2 Interviews/Focus Groups

Interviews and focus groups are often considered as a single data gathering technique, as they both operate through the researcher personally asking questions to the research participant(s) (Morgan & Stewart, 1997). Interviews involve the researcher conversing with a single research participant, whereas focus groups involve the researcher conversing with multiple research participants. While focus groups enable the researcher to gather more data in an equivalent period of time as an interview, the collaborative (or potentially controversial) nature of focus groups may yield less insightful responses than an individual interview (Krueger & Casey, 2009). Both interviews and focus groups are more time-consuming to complete than surveys (Krueger & Casey, 2009), but the qualitative nature of these techniques provides increased opportunities for in-depth analysis (Tobin & Fraser, 1998).

Questions for interviews and focus groups can be structured (which consists solely of a set of fixed discussion questions), unstructured (which allows the participant to dictate the topics of conversation), or semi-structured (which employs a guideline set of questions, but permits the freedom to deviate from the questions in order to explore topics of conversation in greater depth) (Olds et al., 2005).

**2.4.1.3 Conversational Analysis**

Conversational analysis works by analyzing the thoughts of the research participants by examining how they converse with one another in a desired environment (Haller et al., 1999). For example, if person A asks the question "Is this yours?" and person B responds "No, it's my husband's", Sacks (1995) would say that the response "No" is routine, but by the addition of the comment "it's my husband's" person B has employed a correction initial device, which provides a strong tie to additional relevant information about the question asked by person A.

While conversational analysis may present a more accurate depiction of the participants' thought processes, conversational analysis is very time consuming to transcribe and analyze, and there is no guarantee that the participants will address the research question being examined (Johnstone, 2002).

**2.4.1.4 Observational Analysis**

The observational data gathering technique utilizes the researcher's observations of a scenario (Olds, et al., 2005; Stroup et al., 2008). This corresponds to the surveillance method described by Grimes and Schulz (2002). By applying an observational protocol (typically a checklist of items or behaviors for the researcher to look for) the researcher can ensure that the data being gathered is directly applicable to their research question, and does not risk the research becoming biased by the participants' biases in self-reporting techniques (Johnstone, 2002; Olds et al., 2005). However, the research can still be easily biased by the researcher's opinions, and the amount of time required to perform observational analysis is significant (Stroup et al., 2008).

**2.4.1.5 Ethnographic Studies**

In ethnographic studies, the researcher attempts to gather observational data by immersing themself in the research environment, as well as by combining observational and interview data gathering techniques (Seale, 2004). For example, Faulkner & Sparkes (1999) performed an ethnographic study in which they observed a ten-week exercise program in order to evaluate its effectiveness for treating schizophrenia. In this study, Faulkner & Sparkes (1999) observed the exercise program, and interviewed the caretakers of the schizophrenia patients, in order to determine the influence that the exercise regimes had on the patients' well beings.

Ethnographic studies are used particularly in early education, health services, and other areas where the research participants have some limitations that prevent them from self-reporting (Jacobs, 1974; Wright, 1986; Willett, 1995; Vlachou, 1997).

#### 2.4.1.6 Meta-Analysis

Meta-analysis is performed through the examination of previous studies that address a similar topic, in order to identify trends underlying the research (Hunter et al., 1982). By this definition, case-series reports, cross-sectional studies and ecological correlation studies are all meta-analysis studies to varying degrees. Meta-analysis can be employed to identify trends underlying many studies that may have been overlooked by the primary researchers (Grimes and Schulz, 2002; Olds et al., 2005). However, the tendency of researchers to publish only positive results can bias the study (Olds et al., 2005).

### 2.4.2 Experimental Studies

Experimental studies are a method of gauging the impact of an intervention in an existing phenomenon (Olds et al., 2005). Olds et al. (2005) describe five experimental studies: randomized controlled trials, matching, baseline data, post-test-only design, and longitudinal design.

#### 2.4.2.1 Randomized Controlled Trials

Randomized controlled trials (RCTs) employ the use of treatment and control groups, in order to minimize the variability between trials (Stolberg et al., 2004). While RCTs provide the best means of controlling random variables, it is often very difficult from an implementation perspective to ensure truly random assignments to the treatment and control groups.

#### 2.4.2.2 Matching

Matching studies employ the same techniques as RCTs, with the exception that research participants are not assigned randomly to the groups (Olds et al., 2005). While this method is more practical to implement, there is a greater likelihood of uncontrolled variables affecting the results (Olds et al., 2005).

#### 2.4.2.3 Baseline Data

In a baseline data study, data is gathered prior to the intervening factor, rather than performing two simultaneous trials (Altman & Dore, 1990). In this instance, the control group is the original group, whereas the treatment group is the group affected after the intervening factor (Altman & Dore, 1990).

#### 2.4.2.4 Post-Test-Only Design

Post-test-only design employs the same principal of treatment and control groups as the previous three experimental studies, but with a lack of a pre-test (Olds et al., 2005). If the intervening factor is not time dependent, then there is little difference between a post-test-only design and a matching study (Clariana & Wallace, 2002), with the exception that identifying the differences between the treatment and control groups cannot be performed (Olds et al., 2005).

#### 2.4.2.5 Longitudinal Design

A longitudinal design is meant to evaluate the impact of an intervention over an extended period of time (Keller et al., 1987). While longitudinal designs are highly insightful on evaluating long-term research goals, it is extremely challenging to maintain treatment and control groups over an extended period of time, particularly in engineering education research, as the research participants are often students (Olds et al., 2005).

## 2.5 Quantitative Analysis

This section describes the various techniques that were considered for the quantitative analysis.

### 2.5.1 Common Statistical Analyses

The most common method of evaluating quantitative data in engineering education is to perform simple statistical analyses (Fink, 1995; Todd et al., 1995; Lethbridge, 1998; Lang et al., 1999). In this process, identifying information about the participants (such as gender and age) are gathered and used to compare the responses of particular groups against other groups (Todd et al., 1995). Additionally, when the quantitative survey has a sufficiently high response rate, the means, mediums, and standard deviations are often calculated, in order to display a level of confidence in the results (Lethbridge, 1998).

### 2.5.2 Factor Analysis

Factor Analysis is used to simplify variables into a smaller subset of variables, according to the underlying correlations between the variables (Darlington, nd). Through Factor Analysis, the important attributes of the variables can be found, as they typically form the underlying structure that results in the created factor (Darlington, nd).

Given a set of vectors X and Y, the first step of Factor Analysis is to calculate the correlation coefficient between the two vectors as follows (Pearson, 1901):

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

where:

r = sample correlation coefficient

$X_i$ and $Y_i$ = sample data points of the vectors X and Y

$\bar{X}$ and $\bar{Y}$ = the means of the vectors X and Y

n = the number of elements in the vectors X and Y

In the context of this study, the vectors X and Y are two survey questions, which are populated with the responses from each of the 'n' research participants. The correlations coefficients are calculated for every pair of vectors X and Y, and organized into a symmetric correlation matrix (R), where element 1,2 and 2,1 of the matrix are both the correlation coefficient between the first and second survey question.

From this correlation matrix the eigenvalues are calculated, and placed into a diagonal matrix (Tabachnick & Fidell, 2001). From the eigenvalues, many types of Factor Analysis can be performed, as explained below. The reader is referred to Tabachnick & Fidell (2001) for more details.

#### 2.5.2.1 Exploratory Factor Analysis

Exploratory Factor Analysis (EFA) attempts to identify the underlying constructs of the survey questions, which caused the participants to answer a certain way (DeCoster, 1998). It does this by identifying the number of variables in a factor, and the degree to which these variables are correlated (DeCoster, 1998). From the correlation matrix, the number of factors can either be defined by the researchers, or experimentally determined, most often through either a scree plot, maximum likelihood extraction, and principal axis factoring (Costello & Osborne, 2005), which are described in greater detail below. The extracted components are then rotated through either an orthogonal rotation, or an oblique (nonorthogonal) rotation (DeCoster, 1998), both of which methods are described below.

#### 2.5.2.2 Confirmatory Factor Analysis

In confirmatory Factor Analysis (CFA), a predefined factor model is tested against a data set (DeCoster, 1998). Confirmatory Factor Analysis is utilized when a factor model already exists and its validity needs to be confirmed, or to test the significance of factor loadings (DeCoster, 1998). To perform CFA, the factor model must first be defined, including the number of factors, and the loadings between the assumed variables in each factor (DeCoster, 1998). The experimental data for each defined variable is then gathered, and the correlation matrix for the variables is calculated as described above (DeCoster, 1998). The gathered data is then attempted to be fit into the predefined model, most commonly through maximum likelihood estimation, described below. The discrepancy between the estimated factor loadings and the results of the resultant correlation matrix is indicative of the accuracy of the predefined model through a goodness-of-fit test (DeCoster, 1998).

#### 2.5.2.3 Scree Plot

In a scree plot, the eigenvalues are plotted against the number of potential factors (Cattell, 1966; Darlington, nd). At the place where the plot levels out is the number of factors formed by the variables. However, this method is not wholly conclusive for two reasons. Firstly, the scree plot may level out between two intervals, making it inconclusive as to how many factors there are (Jackson, 1993). Additionally, a scree plot does not distinguish which variables are belonging to which factors (Cattell, 1966). Therefore, it should not be solely used as a method of Factor Analysis.

#### 2.5.2.4 Maximum Likelihood Extraction

Maximum likelihood estimation (MLE) is applied in both EFA and CFA as a means to provide estimates to the model parameters. In MLE, the mean and variance can be taken as parameters and the first partial derivative of the log of the likelihood is taken for each parameter in the model and solved for the most probable value (MLE, nd).

#### 2.5.2.5 Principal Axis Factoring

Principal Axis Factoring (PAF) has been claimed to be the most widely employed method of factor extraction (Warner, 2007). In PAF, the diagonal matrix is calculated as follows (Tabachnick & Fidell, 2001):

$$L = V'RV$$

where:

L = Eigenvalue matrix (diagonalized)

V = Eigenvector matrix

R = Correlation matrix

V' = Transpose of eigenvector matrix

From this, the factors that have the most variance (the highest levels of correlation) will have the highest eigenvalues (Tabachnick & Fidell, 2001). This yields the factor loading matrix (A), as follows:

$$A = V\sqrt{L}$$

In the factor loading matrix (A), the first column denotes the correlations (factor loadings) between the first factor and each subsequent factor. Similarly, the second column denotes the correlations between second factor and each of the other factors.

Within the factor loading matrix (A), positive values reflect a positive correlation between factors (ie. if the participant answered “Strongly Agree” to a survey question, they likely also responded “Strongly Agree” to a survey question where the factor loading between the two questions is close to 1). Negative values reflect negative correlations, with larger negative values implying higher correlations (ie. if the participant answered “Strongly Agree” to a survey question, they likely responded “Strongly Disagree” to a survey question where the factor loading between the two questions is close to -1).

### 2.5.2.6 Orthogonal Rotations

Once the factors have been extracted, it is necessary to determine which variables belong to which factors. Varimax, Quartimax, and Equimax rotations are orthogonal rotations, which assume the factors to be uncorrelated (Kaiser, 1958). Varimax, being the oldest orthogonal rotation method of the three (Kaiser, 1958) seeks to place a small number of variables in each factor, such that the variables in each factor have high factor loadings. Conversely, Quartimax attempts to minimize the number of factors, while Equimax seeks to provide a balance between the two (Abdi, 2003). The most popular rotation method is the Varimax rotation (Darlington, nd; Abdi, 2003; Costello & Osborne, 2005). The Varimax rotation is performed as follows (Tabachnick & Fidell, 2001):

$$A_{rotatede} = A_{unrotated}\Lambda$$

where:

$A_{rotatede}$= The rotated factor loading matrix

$A_{unrotatede}$= The original factor loading matrix

$\Lambda$ = The transformation matrix $\begin{bmatrix} \cos\Psi & -\sin\Psi \\ \sin\Psi & \cos\Psi \end{bmatrix}$, where $\Psi$ is an angle that is iteratively determined to make $A_{rotatede}$contain maximal factor loadings.

**2.5.2.7 Oblique Rotations**

Oblimin, Quartimin, and Promax are oblique rotation methods, which are performed when the factors are assumed to be correlated (Kline, 1994). The Oblimin rotation method is the most common of these rotations (Abdi, 2003), and is given by (Harman, 1976):

$$B^* = \sum_{p<q=1}^{m} (n \sum_{j=1}^{n} v_{jp}^2 v_{jq}^2 - \gamma \sum_{j=1}^{n} v_{jp}^2 \sum_{j=1}^{n} v_{jq}^2)$$

where,

B* = Factor loading matrix from Oblimin rotation

v = elements of the original factor loading matrix V (defined as ‘A’ by Tabachnick & Fidell (2001))

n = number of entries in the matrix V (length)

m = number of vectors in the matrix V (width)

$\gamma = \beta/(\alpha + \beta)$, where $\alpha$ and $\beta$ are both angles in a two-dimensional space that are iteratively determined to make B* contain maximal factor loadings.

In this study, it was unknown whether the factors would be correlated or uncorrelated, since the survey was not designed with any intended correlation, but it was hypothesized that the graduate attributes on which the survey questions were developed, were inherently correlated. Therefore, both methods were explored in Chapter 3.

### 2.5.3 Principal Component Analysis

Shlens (2005) describes Principal Component Analysis as “a simple, non-parametric method for extracting relevant information from confusing data sets” (p. 1). More specifically, Principal Component Analysis (PCA) employs orthogonal transformation, in order to translate potentially correlated variables into uncorrelated variables, known as principal components (Jackson, 1991). PCA works to simplify redundant data sets into uncorrelated variables, and thus reveal the underlying structure of the gathered data (Shlens, 2005).

There is debate among academics as to whether PCA is a sub-branch of Factor Analysis, or a separate branch altogether (Arrindell & van der Ende, 1985; Kline, 1994; Steiger, 1994; Costello & Osborne, 2005). Essentially, Principal Component Analysis reduces the number of variables by combining variables with high correlations into a single component, whereas (other forms of) Factor Analysis attempts to reveal an underlying structure to the variables that would cause them to be attributed as a single factor, and thus the degree of confidence of the belonging of each variable to a factor (Costello & Osborne, 2005; Warner, 2007). However, for the practical purposes of this thesis, both methods will identify the number of components/factors created by the variables, and, since PCA is much less computationally difficult (Kaiser, 1960), PCA can be employed to verify the number of components/factors in this study.

### 2.5.4 Statistical Analysis Software

Factor Analysis, particularly with the application of rotation techniques, has been stated to be extremely confusing to even the highly educated (Steiger, 1994; Kline, 1994; Costello & Osborne, 2005). The application of it to a large number of variables without the use of software has been deemed extremely difficult, if not impossible (Kaiser, 1960; Harman, 1976). It is for this reason that a number of statistical/Factor Analysis softwares have come to market, most notably those of SAS, BMDP, and SPSS (MacCallum, 1983).

#### 2.5.4.1 SAS

The SAS software advertises itself as being able to manage large data sets, advanced statistical analysis capabilities, and results and processes that can be easily documented and verified (SAS, 2011). MacCallum (1983) rated the SAS software highly in the areas of clarity of the user manual, the large sample size supported, plotting ability and factoring methods available (including types of matrices, types of rotations, and types of extractions), but poorly in forms of input.

#### 2.5.4.2 BMDP

The BMDP statistical software package advertises itself as containing a comprehensive library of statistical routines, providing high-resolution graphics, highly rated for survival analysis modules, and user-friendly documentation (BMDP, 2011). MacCallum (1983) gave the BMDP software a mediocre rating, with lower ratings in data limitations, and communalities, but equivalent to SAS in every other respect.

#### 2.5.4.3 SPSS

The SPSS software advertises its large number of features, consisting of both linear and nonlinear models, as well as its ability to support customized tables (SPSS, 2011). MacCallum (1983) rated SPSS equally to BMDP with data limitations, communality estimates, and factor scores, but below both SAS and BMDP in rotations and plots. However, Lorenzo-Seva & Ferrando (2006) found a high congruence between the results of the SAS, BMDP, and SPSS softwares, and Potvin et al. (1990) did not mention a discernible difference when evaluating a data set using the three softwares.

## 2.6 Qualitative Analysis

This section describes the common methods of qualitative analysis, according to Johnstone (2002) and Creswell (2003).

### 2.6.1 Grounded Theory Analysis

Grounded Theory is a qualitative research technique in which comparative analysis between transcribed responses is employed to develop a theory through logical deduction (Glaser & Strauss, 1967). Rather than analyzing data in order to test a hypothesis, Grounded Theory creates a theory "from the ground up" (ie. the theory is formed from the data, rather than the data attempted to validate a hypothesis). While there are many variations of Grounded Theory, at the core, Grounded Theory involves the generation of four artifacts: codes, concepts, categories, and a theory (Glaser & Strauss, 1967).

#### 2.6.1.1 Codes

In the first stage of Grounded Theory, keywords are extracted from the qualitative data (in this instance the raw survey data from the open-ended survey questions, and the transcribed notes from the interviews and focus groups). The process of extracting keywords is known as open coding (Strauss & Corbin, 1990) or substantive coding (Glaser, 1978). Each code should only contain a single idea, although a single piece of data (response to a survey or interview question) may contain many different codes (Giske & Artinian, 2007).

#### 2.6.1.2 Concepts

In the second stage, relationships between codes are identified in order to form more generalized concepts (Glaser & Strauss, 1967). This artifact can be accomplished either through the traditional continual comparative analysis of substantive coding (Glaser, 1978), or axial coding (Strauss & Corbin, 1990). While Glaser (1978) advocates the continual induction of data until a theory can be formed, Strauss and Corbin (1978) employ axial coding with inductive reasoning, in order to reduce the number of codes being examined at a given time, thus increasing the systematic nature of Grounded Theory, and increasing its ability to be validated by other researchers (Heath & Cowley, 2004; Borgatti, 2005).

#### 2.6.1.3 Categories

The category artifact is most commonly created in the same process as concepts, through either selective coding (Strauss & Corbin, 1990) or continual comparative analysis in theoretical coding (Glaser & Strauss, 1967; Glaser, 1978). While some studies combine the creation of concepts and categories in a single process (Scott & Howell, 2008), concepts can be linked back inductively to the codes, while categories are formed more deductively and do not always have a clear link back to the raw data (Cummings, 2010).

#### 2.6.1.4 Theory

In the final stage of Grounded Theory, the core category, and its surrounding minor categories form the theory to answer the research question being asked (Glaser & Strauss, 1967). This typically involves the delimiting of the theory with higher-level concepts (Glaser & Strauss, 1967).

#### 2.6.1.5 Reliability and Validity of Grounded Theory

Qualitative research is often critiqued for its subjective nature, being largely dependent on the way in which the researcher chooses to interpret the data (Kirk & Miller, 1986; Morse et al., 2002; Creswell, 2003;). Furthermore, while qualitative research has been applied in engineering education research (as shown in Chapter 1), there can be confusion between anecdotal evidence gathered from qualitative methods, and rigourous qualitative analysis (Leydens et al., 2004). Combined with the fact that "classical engineering training also promotes a mindset that engineering research is only valid when is it quantified" (Valerdi & Davidz, 2007, p.5) results in many qualitative studies being disregarded (Singleton, 1999; Valerdi & Davidz, 2007). Recently, triangulation of results with multiple data sources has been employed to help provide additional reliability and credibility to their results (Morse et al., 2002; Golafshani, 2003). This triangulation technique has been adopted for this study, by comparing the prescribed learning outcomes (as dictated by the researcher, course coordinator, and course outline) with the student survey responses (quantitative and qualitative), the focus group results, and the results from the instructor interviews.

Grounded Theory was specifically designed to adhere to the canons of rigorous scientific research methodologies, specifically in consistency, reproducibility, and generalizability (Glaser & Strauss, 1967; Haig, 1995). As such, several guidelines have been established for increasing the rigour of Grounded Theory research, such as: using the participants' actual words in the coding process, delineating the scope of research, and maintaining the participants' remarks in the context of the whole statement and/or research question (Chiovitti & Piran, 2003). Other grounded theorists have offered the criteria of credibility, originality, resonance, and usefulness (Charmaz, 2006).

In order to make this thesis as accessible to a classical engineering mindset (Valerdi & Davidz, 2007), the original criteria of consistency, reproducibility and generalizability (Glaser & Strauss, 1967) will be attempted to be upheld. Grounded Theory is inherently generalizable, as the theory generated is meant to be delimited with higher-level concepts (Glaser & Strauss, 1967). However, as reproducibility and internal/external validity are not a common terms in qualitative research (Creswell, 2003), the validity of Grounded Theory resides in its explanatory coherence, such that it logically explains the phenomenon (Haig, 1995; Corbin & Strauss, 2008). Moreover, by detailing the steps undertaken in the creation of codes, concepts, and categories, Grounded Theory enables the audience to reverse engineer their findings, thus increasing its consistency (Heath & Cowley, 2004; Borgatti, 2005).

### 2.6.2 Phenomenology

Phenomenology is focused on the feelings of the research participants, as they pertain to specific experiences in the participants' lives (Johnstone, 2002). By studying several individuals who have experienced the same life events, researchers hope to uncover the "essence" (Creswell, 2003, p.79) of the experience as it is felt by all of the research participants (Creswell, 2003).

### 2.6.3 Ethnography

Ethnography, as described above in 2.3.1.5 requires the researcher to spend an extended period of time experiencing the environment they wish to study (Johnstone, 2002; Creswell, 2003; Olds et al., 2005).

### 2.6.4 Case Study

In a case study, the researcher seeks to develop a highly in-depth analysis of a single experience (Creswell, 2003). A case study examines a variety of data sources, including interviews, observations, and the analysis of other documents and artifacts (Creswell, 2003).

### 2.6.5 Narrative Research

Narrative research explores the experiences of the participant(s) through extensive interviews (Creswell, 2003). Through these interviews/stories, the researcher seeks to identify themes in the life of the participant, which are then reflected as a narrative about the individual and their life experiences (Creswell, 2003).

## 2.7 Summary

This chapter has provided descriptions of the course backgrounds, data gathering techniques and data analysis techniques employed in Chapters 3 & 4 of this thesis. Below is a brief summary of the material presented.

### 2.7.1 First-year Design Courses

The original motivation, and one of the key goals of this study, was to evaluate the achieved learning outcomes between the ENGG 251/253 courses (the 2009 survey) and the ENGG 200 course (the 2010 survey). The ENGG 251/253 design courses emphasized learning through open-ended design projects, whereas the ENGG 200 course emphasized learning through a combination of theoretical foundations taught in lectures and the application of the theoretical knowledge to a design project.

### 2.7.2 Data Gathering Techniques

Data gathering techniques split into two categories, descriptive studies, which evaluate an existing phenomenon, and experimental studies, which evaluate the result of a change in a phenomenon. Descriptive studies include surveys, interviews/focus groups, conversational analysis, observational analysis, ethnographic studies, and meta-analysis. Surveys are commonly used to gather data from a large number of participants. Closed-ended surveys typically employ a Likert scale rating system, while open-ended surveys pose open-ended questions, which allow the participants to answer with as much detail as they see fit. Interviews and focus groups are also commonly used due to their ability to gain greater insight than surveys. Experimental studies include randomized controlled trials, matching, baseline data, post-test-only design, and longitudinal studies.

### 2.7.3 Quantitative Analysis

Factor Analysis involves several complex matrix multiplications and matrix operations, which often necessitates the use of statistical analysis software. Scree plots, maximum likelihood estimation, principal axis factoring and principal component analysis can be used to determine how many factors are present among the variables. Most commonly, Varimax and Oblimin rotations can be used to determine which variables belong in which factors. Either Varimax or Oblimin can be applied depending on whether the factors are assumed to be uncorrelated or correlated, respectively.

### 2.7.4 Qualitative Analysis

Grounded Theory Analysis systematically applied continual comparative analysis across the raw data, in order to categorize the participant's responses into relatable elements. Through the creation of codes, concepts, and categories, a theory emerges which answers the research question being investigated. Additional qualitative techniques include phenomenology, ethnography, case study, and narrative research.

# CHAPTER 3: QUANTITATIVE ANALYSIS

## 3.1 Introduction

This chapter details the quantitative techniques employed in the evaluation of the two first-year design course implementations. This chapter will help to demonstrate achievement of the following thesis objectives:

- Demonstrating Factor Analysis as a viable technique for simplifying learning outcomes assessment in engineering education.
- Identifying learning outcomes achieved by the ENGG 251/253 and ENGG 200 design and communications courses.

In this chapter, the process of designing and distributing the closed-ended survey from which the data has been gathered is described and discussed. This chapter then presents the summarized results of the survey, and describes the advanced analysis of the results through the application of Factor Analysis. Finally, this chapter concludes with an interpretation of the Factor Analysis results, and its implications for future learning outcomes assessments.

## 3.2 Quantitative Data Gathering

This section describes the process of gathering the quantitative data, specifically the design and distribution of the closed-ended survey questions.

### 3.2.1 Selection of Data Gathering Technique

Since one of the primary goals of this thesis is to assess the learning outcomes achieved by the ENGG 251/253 and ENGG 200 courses, the current state of each course is assessed. Therefore, according to Olds et al. (2005), a descriptive study is the correct method of assessment. While it could be argued that an experimental study could be used, where the intervening factor in the phenomenon is the change in the design course structure, there are too many variables that have changed between the two courses to make a sufficiently controlled study.

A closed-ended survey was chosen as the method for gathering quantitative data, due to its ability to gather a large amount of data from many participants, in a limited period of time.

### 3.2.2 Survey Objectives

The primary intention of this survey was to determine to what learning outcomes were achieved (from the students' perspectives) in the first year design and communications courses.

### 3.2.3 Basis for Design of Survey Questions

Following the work of Felder and Brent (2003), the survey was designed such that the students were asked to rate their for various learning outcomes on a six-point Likert scale: Strongly Agree, Agree, Slightly Agree, Slightly Disagree, Disagree, and Strongly Disagree. Due to the increased risk of being able to identify survey participants in a minority demographic, particularly female students (CFREB, 2011), demographic information was not collected.

Through discussions with the course coordinators and instructors of the first-year design courses, anecdotal evidence suggested that the courses' desired learning outcomes were related to all of the CEAB Graduate Attributes. The CEAB Graduate Attributes were utilized as the basis for the survey design, rather than the course outline, in order to not bias students' response (as the course outline was readily available to the students). The attributes are listed as follows (CEAB, 2010):

> 3.1.1 A knowledge base for engineering: Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.
>
> 3.1.2 Problem analysis: An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.

3.1.3 Investigation: An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.
3.1.4 Design: An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, economic, environmental, cultural and societal considerations.
3.1.5 Use of engineering tools: An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.
3.1.6 Individual and team work: An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.
3.1.7 Communication skills: An ability to communicate complex engineering concepts within the profession and with society at large. Such abilities include reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.
3.1.8 Professionalism: An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.
3.1.9 Impact of engineering on society and the environment: An ability to analyse social and environmental aspects of engineering activities. Such abilities include an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society; the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.
3.1.10 Ethics and equity: An ability to apply professional ethics, accountability, and equity.

3.1.11 Economics and project management: An ability to appropriately incorporate economics and business practices including project, risk and change management into the practice of engineering, and to understand their limitations.
3.1.12 Life-long learning: An ability to identify and to address their own educational needs in a changing world, sufficiently to maintain their competence and contribute to the advancement of knowledge.

### 3.2.4 Initial Survey Design

Keywords/key phrases were extracted from the descriptions of each of these attributes, in order to form the preliminary survey questions, in consultation with the course coordinators and instructors. For example, from attribute 3.1.1 the keywords of 'mathematics' and 'natural sciences' were extracted, and drawing from Carleton University's (Harris et al., 2011) and Queens University's (Frank, nd) interpretations of the graduate attributes, the following survey was developed:

- This course enabled me to apply principles of mathematics and natural sciences to real-world problems.

In instances where the graduate attribute did not contain sufficient information to directly extract keywords for a survey question, the mappings between the CEAB graduate attributes and the CDIO Syllabus, as created by Cloutier et al. (2010) were consulted. The complete CDIO Syllabus can be found in Appendix C. For example, according to Cloutier et al. (2010), attribute 3.1.2 mapped to the CDIO Syllabus topics 2.1 "Analytical Reasoning and Problem Solving" and 2.3 "Systems Thinking". Furthermore, the CDIO Syllabus topics included sub-topics which further helped to describe the CEAB graduate attribute and provide additional keywords upon which to base the survey questions, such as CDIO sub-topic 2.1.1 "Problem Identification and Formulation) and CDIO sub-topic 2.3.4 "Trade-Offs, Judgement and Balance in Resolution. From these topics, the following survey questions were developed:

- This course helped to me identify problems.

- This course helped me to develop plausible solutions to problems.
- This course helped me to identify the solutions with the best chance of success and to justify by decision.

From attribute 3.1.3, the key phrase “analysis and interpretation of data, and synthesis of information in order to reach valid conclusions” was condensed to form the survey question:

- This course helped me to draw conclusions from analysis of data.

From attribute 3.1.4, the key phrase “An ability to design solutions for complex, open-ended engineering problems” spawned the survey question:

- This course helped me to design solutions for complex, open-ended engineering problems.

Additionally, discussions with the course coordinator indicated that the ability to follow a design process was important for this course. Therefore, the following survey question was added:

- This course helped me to follow a design process.

From attribute 3.1.5, the keywords “select”, “apply”, and “engineering tools” were used to form the survey question:

- This course helped me to select, and use, appropriate tools for completion of a task.

Attribute 3.1.6 correlated highly to the CDIO syllabus topic 3.1 “Teamwork” (Cloutier et al., 2010). From the CDIO subcategories 3.1.2 “Team Operation” and 3.1.4 “Leadership” (CDIO, 2007) the following survey questions were developed:

- This course helped me to work as a productive member of a team.
- This course helped me to lead a team.

Attribute 3.1.7, combined with the CDIO syllabus topic 3.2 “Communication” created the survey questions:

- This course helped me to communicate within a small group.
- This course helped me to communicate within a large group.
- This course helped me to write a technical report.
- This course helped me to employ graphics in presentations or reports.

Attribute 3.1.8 mapped strongly to the CDIO Syllabus Topic 2.5 “Ethics, Responsibilty, Equity, and Core Personal Values” (Courier et al., 2010), specifically to the sub-topics 2.5.1 and 2.5.2 (“Ethics, Integrity and Social Responsibility” and “Professional Behaviour and Responsibility”, respectively). These CDIO Topics also correlated highly with the CEAB attribute 3.1.10. Given the similarity in these attributes, and their extremely similar CDIO mappings (Cloutier et al., 2010), it was determined that these two attributes would lend to the following survey questions:

- I am confident in my ability to act in the public interest when undergoing a design project.
- I find logbooks valuable.
- I understand the consequences of poor engineering practices.

The keywords “economic”, “cultural”, “environmental”, and “safety” were taken from attribute 3.1.9 to form the survey question:

- This course helped me to take cultural, environmental, economical, and safety issues into consideration for the design solution.

The CDIO mappings from Cloutier et al. (2010) provided weak correlations between attribute 3.1.11 and a number of CDIO Syllabus topics, including 2.1 “Analytical Reasoning and Problem Solving”, 2.3 “Systems Thinking”, and 2.4 “Attitudes, Thought and Learning”. From the metrics of CDIO topic 2.4, and a portion of the CEAB Graduate Attribute criteria name, project management, the following survey questions were developed:

- This course helped me to manage personal time.
- This course helped me to manage project time.

The final attribute, 3.1.12, correlated with the CDIO Topic 2.4 “Attitudes, Thought and Learning” (Cloutier et al., 2010). By combining the descriptions of CEAB attribute 3.1.12 and CDIO topic 2.4, the following survey questions were created:

- I have a desire to independently learn more about technical engineering because of something I learned in this course.
- I have a desire to independently learn more about engineering practices and principles because of something I learned in this course.
- This course helped me to find resources to learn more about engineering.

#### 3.2.4.1 Initial Survey Design Summary

The following is a summary of the original survey questions, accompanied by the CEAB graduate attributes and CDIO syllabus topics that influenced them:

1. This course helped me to identify problems. (CEAB 3.1.2; CDIO 2.1.1)

2. This course helped me to develop plausible solutions to problems. (CEAB 3.1.2; CDIO 2.1)
3. This course helped me to identify the solutions with the best chance of success and to justify by decision. (CEAB 3.1.2; CDIO 2.3.4)
4. This course helped me to draw conclusions from analysis of data. (CEAB 3.1.3)
5. This course helped me to design solutions for complex, open-ended engineering problems. (CEAB 3.1.4)
6. This course helped me to follow a design process.
7. This course helped me to select, and use, appropriate tools for completion of a task. (CEAB 3.1.5)
8. This course helped me to work as a productive member of a team. (CEAB 3.1.6; CDIO 3.1)
9. This course helped me to lead a team. (CEAB 3.1.6; CDIO 3.1)
10. This course helped me to communicate within a small group. (CDIO 3.2)
11. This course helped me to communicate within a large group. (CDIO 3.2)
12. This course helped me to write a technical report. (CEAB 3.1.7)
13. This course helped me to employ graphics in presentations or reports. (CDIO 3.2)
14. I am confident in my ability to act in the public interest when undergoing a design project. (CEAB 3.1.8; CDIO 2.5)
15. I find logbooks valuable. (CEAB 3.1.10; CDIO 2.5.2)
16. I understand the consequences of poor engineering practices.(CEAB 3.1.8; CDIO 2.5)
17. This course helped me to take cultural, environmental, economical, and safety issues into consideration for the design solution. (CEAB 3.1.9)
18. This course helped me to manage personal time.(CDIO 2.4)
19. This course helped me to manage project time. (CEAB 3.1.11)
20. I have a desire to independently learn more about technical engineering because of something I learned in this course. (CEAB 3.1.12; CDIO 2.4)

21. I have a desire to independently learn more about engineering practices and principles because of something I learned in this course. (CEAB 3.1.12; CDIO 2.4)
22. This course helped me to find resources to learn more about engineering. (CDIO 2.4)

**3.2.5 Revised Survey Design**

After consultation with a professional survey designer and engineering education researcher (Lichtenstein, 2011), it was decided by the researcher that it was unreasonable for first-year students to have achieved all of the learning outcomes our survey questions sought to uncover. Additionally, Mr. Lichenstein (2011) pointed out that some of the survey questions were ambiguous, or too convoluted to garner an accurate answer from the survey participants. For example, the survey statement “I am confident in my ability to act in the public interest when undergoing a design project” would require the students to have a common definition of “acting in the public interest”, and the survey statement “this course helped me to design solutions for complex, open-ended engineering problems” would require the students to understand a common definition for “complex, open-ended engineering problems”. Therefore, the survey questions were re-examined and refactored to address the most simplistic goal of each question.

Moreover, since the primary goal of the survey was to determine the extent to which the students had achieved the desired learning outcomes, all of the survey questions were phrased as “The ENGG [200 or 251/253] Design course(s) introduced me to, or enabled me to further develop, the following skills:” followed by the refactored learning outcomes below. The original survey questions that influenced the revised survey questions are shown with brackets. The core intents of survey questions 3, 5, 7, 16, 20, 21, and 22 were omitted after it was determined that these concepts were likely too advanced for first-year students.

1. Apply principles of mathematics and natural sciences to real-world problems.

2. Evaluate a problem and brainstorm solutions. (1, 2)
3. Understand a design process. (6)
4. Apply a design process to a challenge. (6)
5. Analyze data in order to draw meaningful conclusions. (4)
6. Take cultural issues into consideration for the design solution. (14, 17)
7. Take environmental issues into consideration for the design solution. (14, 17)
8. Take economic issues into consideration for the design solution. (14, 17)
9. Take safety issues into consideration for the design solution. (14, 17)
10. Work in a team environment. (8, 9)
11. Understand techniques for time management. (18, 19)
12. Apply techniques for time management. (18, 19)
13. Communicate effectively in a verbal setting, such as team meetings or presentations. (10, 11, 13)
14. Communicate effectively in a written medium, such as reports. (12)
15. Understand the purpose of a logbook. (15)

A copy of this survey, as it was distributed to the students, can be found in Appendix D.

### 3.2.6 Survey Distribution

The survey was distributed to the approximately 750 students in each year of the design course. The 2009 (ENGG 251/253) survey was distributed electronically via the online survey tool SurveyGizmo at the end of the Winter semester (the conclusion of both courses). The 2010 (ENGG 200) survey was distributed and collected as a hardcopy in lecture at the end of the course (in the Fall semester). In both years, approximately 20% of the students responded. While the students of ENGG 251/253 gained an extra semester of experience prior to completing the survey, it is not expected that this extra time in undergraduate engineering biased the results, particularly since no other first year courses taught design or communications.

### 3.3 Survey Results

The responses from the 2009 and 2010 closed-ended surveys are displayed in Table 1 below. Following the survey analysis techniques of Brayfield & Rothe (1951), the combined percentages of the “Strongly Agree” and “Agree” responses are used to determine to what extent each desired learning outcome has been met. As shown in Table 1, the ability to work in a team environment was most strongly learned by both the students of ENGG 251/253 and ENGG 200. Also strongly ranked by both surveys were the abilities to understand and apply a design process, as well as evaluate a problem and brainstorm solutions. Weakly ranked among both years were the ability to apply principles of mathematics and natural sciences to real world problems. In the 2009 survey, students responded much more favourably to the ability to take cultural, environmental, economic, and safety issues into account than the participants of the 2010 survey. The remainder of the results, however, were relatively equivalent between the two course implementations. It is interesting to note that the students largely reported equal or greater agreement to achieving the desired learning outcomes in a single semester of the ENGG200 course as they did in the two semesters of the ENGG 251/253 courses.

Table 1: Summary of 2009 and 2010 Survey Results

| | Strongly Agree | | Agree | | Slightly Agree | | Slightly Disagree | | Disagree | | Strongly Disagree | | Declined to Answer | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 251/253 | 200 | 251/253 | 200 | 251/253 | 200 | 251/253 | 200 | 251/253 | 200 | 251/253 | 200 | 251/253 | 200 |
| Apply principles of mathematics and natural sciences to real-world problems | 3.6% | 6.4% | 10.7% | 17.0% | 17.0% | 30.4% | 19.6% | 16.4% | 19.6% | 13.5% | 28.6% | 13.5% | 0.9% | 2.9% |
| Evaluate a problem and brainstorm solutions | 32.1% | 39.8% | 30.4% | 35.7% | 17.9% | 15.8% | 5.4% | 2.9% | 7.1% | 2.9% | 4.5% | 1.2% | 2.7% | 1.8% |
| Understand a design process | 24.1% | 40.9% | 37.5% | 37.4% | 17.0% | 16.4% | 8.0% | 1.2% | 5.4% | 2.3% | 6.3% | 0.6% | 1.8% | 1.2% |
| Apply a design process to a challenge | 25.0% | 37.4% | 35.7% | 39.2% | 17.9% | 12.3% | 9.8% | 5.3% | 2.7% | 1.2% | 8.0% | 2.9% | 0.9% | 1.8% |
| Analyze data in order to draw meaningful conclusions | 7.1% | 13.5% | 17.0% | 25.1% | 28.6% | 31.0% | 14.3% | 11.7% | 17.0% | 8.2% | 14.3% | 6.4% | 1.8% | 4.1% |
| Take cultural issues into consideration for the design solution | 8.9% | 5.3% | 32.1% | 18.1% | 22.3% | 29.8% | 9.8% | 17.5% | 9.8% | 12.3% | 14.3% | 14.6% | 2.7% | 2.3% |
| Take environmental issues into consideration for the design solution | 8.9% | 7.6% | 25.9% | 26.9% | 24.1% | 33.3% | 12.5% | 11.7% | 12.5% | 9.4% | 13.4% | 8.8% | 2.7% | 2.3% |
| Take economic issues into consideration for the design solution | 8.0% | 15.2% | 30.4% | 37.4% | 26.8% | 31.0% | 7.1% | 4.1% | 10.7% | 4.7% | 14.3% | 5.8% | 2.7% | 1.8% |
| Take safety issues into consideration for the design solution | 6.3% | 17.5% | 18.8% | 30.4% | 23.2% | 29.2% | 17.9% | 11.1% | 13.4% | 6.4% | 17.9% | 3.5% | 2.7% | 1.8% |
| Work in a team environment | 62.5% | 62.0% | 20.5% | 23.4% | 5.4% | 5.8% | 2.7% | 2.9% | 1.8% | 2.9% | 6.3% | 1.2% | 0.9% | 1.8% |
| Understand techniques for time management | 33.0% | 38.0% | 26.8% | 35.7% | 18.8% | 9.4% | 3.6% | 5.3% | 3.6% | 5.3% | 12.5% | 2.9% | 1.8% | 3.5% |
| Apply techniques for time management | 29.5% | 36.8% | 21.4% | 33.3% | 19.6% | 12.9% | 7.1% | 5.8% | 7.1% | 5.3% | 14.3% | 2.9% | 0.9% | 2.9% |
| Communicate effectively in a verbal setting, such as team meeting or presentations | 28.6% | 40.4% | 32.1% | 36.8% | 16.1% | 9.4% | 10.7% | 4.1% | 3.6% | 4.7% | 7.1% | 2.3% | 1.8% | 2.3% |
| Communicate effectively in a written medium, such as reports | 25.9% | 25.7% | 23.2% | 32.7% | 19.6% | 19.3% | 9.8% | 8.2% | 9.8% | 3.5% | 10.7% | 5.8% | 0.9% | 4.7% |
| Understand the purpose of a logbook | 18.8% | 25.7% | 17.0% | 28.7% | 17.9% | 18.1% | 8.9% | 8.2% | 7.1% | 7.6% | 28.6% | 8.2% | 1.8% | 3.5% |

## 3.4 Quantitative Data Analysis and Results

This section details the analysis undertaken on the quantitative data.

### 3.4.1 Selection of Quantitative Analysis Techniques

As the relations between the survey questions were unknown, Exploratory Factor Analysis was chosen as the basis for the quantitative analysis. Additionally, due to the complexity of Maximum Likelihood Estimation, it was disregarded in favour of Scree plots and Principal Component Analysis. Furthermore, since the correlation between the factors was unknown, both Varimax and Oblimin rotations were employed to determine which rotation method would yield the highest factor loadings.

### 3.4.2 Selection of Statistical Analysis Software

With the exception of MacCallum's article (1983), there are no differences between the SAS, BMDP and SPSS softwares for the Factor Analysis techniques being employed in this study. However, due to the availability of a subject matter expert with familiarity with SPSS (Dr. Tak Fung, 2011), SPSS was chosen as the software through which to perform the Factor Analysis.

### 3.4.3 Scree Plot Results

Figure 1 shows the Scree plot of the 2009 survey results. The sharp drop between component numbers one and two likely indicates the presence of two factors. Similarly, the sharp drop between component numbers one and two in Figure 2 is a strong indication of there being two components in the 2010 survey results. However, in both cases, the scree plots show drops between the second and third components, which could indicate the presence of a third component. Therefore, these results should be verified through Principal Component Analysis, as shown in section 3.4.4.

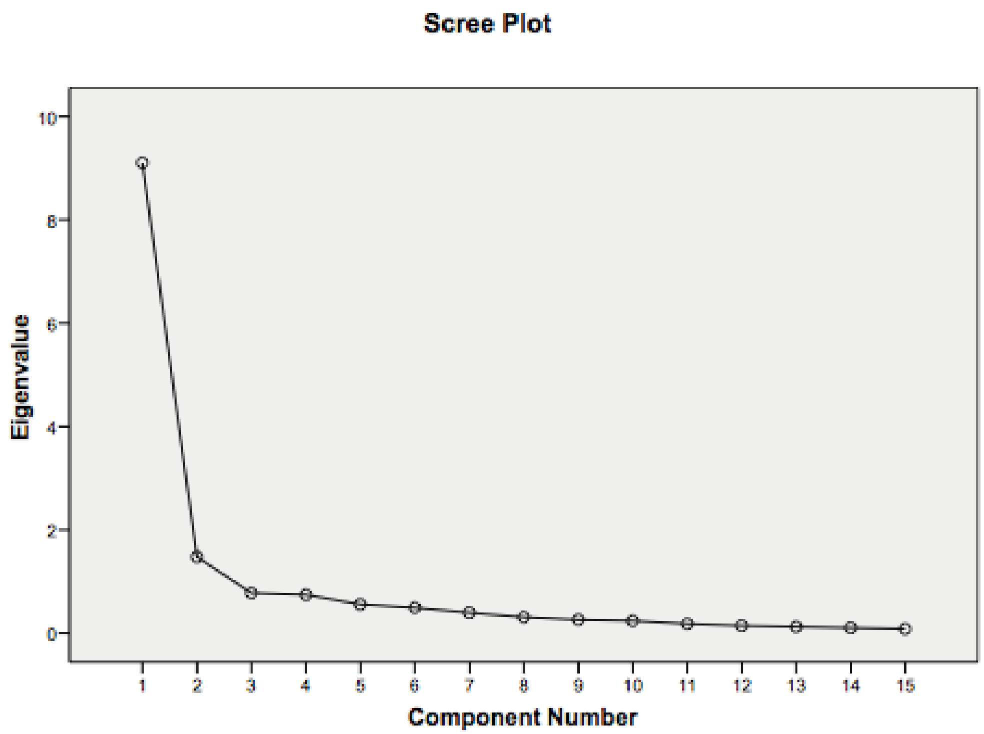


Figure 2: Scree Plot of 2009 Survey Results

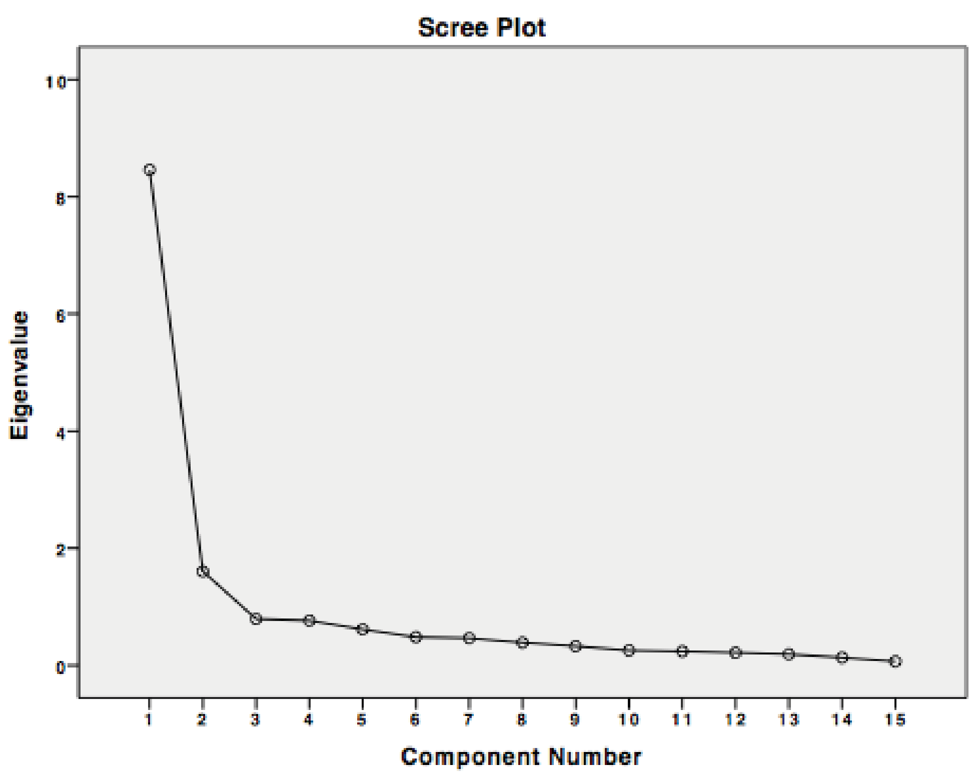


Figure 3: Scree Plot of 2010 Survey Results

### 3.4.4 Principal Component Analysis

In order to verify the two components indicated by the scree plots, principal component analysis was applied to the Factor Analysis correlation matrices. Table 2 presents the component matrix for the 2009 survey, which confirms that there are two components.

Table 2: Component Matrix of 2009 Survey Results

| | Component | |
|---|---|---|
| | 1 | 2 |
| Apply principles of mathematics and natural sciences to real-world problems | 0.604 | 0.406 |
| Evaluate a problem and brainstorm solutions | 0.763 | |
| Understand a design process | 0.864 | |
| Apply a design process to a challenge | 0.876 | |
| Analyze data in order to draw meaningful conclusions | 0.820 | |
| Take cultural issues into consideration for the design solution | 0.759 | 0.411 |
| Take environmental issues into consideration for the design solution | 0.737 | 0.543 |
| Take economic issues into consideration for the design solution | 0.770 | 0.449 |
| Take safety issues into consideration for the design solution | 0.721 | 0.330 |
| Work in a team environment | 0.748 | -0.409 |
| Understand techniques for time management | 0.855 | |
| Apply techniques for time management | 0.808 | |
| Communicate effectively in a verbal setting, such as team meeting or presentations | 0.772 | -0.314 |
| Communicate effectively in a written medium, such as reports | 0.815 | |
| Understand the purpose of a logbook | 0.729 | |

Similarly, the component matrix in Table 3 identified two components for the 2010 survey results, thus confirming the surmised results of the 2010 scree plot in Figure 3.

Table 3: Component Matrix of 2010 Survey Results

| | Component | |
|---|---|---|
| | 1 | 2 |
| Apply principles of mathematics and natural sciences to real-world problems | 0.665 | |
| Evaluate a problem and brainstorm solutions | 0.744 | |
| Understand a design process | 0.794 | |
| Apply a design process to a challenge | 0.872 | |
| Analyze data in order to draw meaningful conclusions | 0.757 | |
| Take cultural issues into consideration for the design solution | 0.568 | 0.610 |
| Take environmental issues into consideration for the design solution | 0.549 | 0.700 |
| Take economic issues into consideration for the design solution | 0.758 | 0.307 |
| Take safety issues into consideration for the design solution | 0.739 | 0.402 |
| Work in a team environment | 0.753 | |
| Understand techniques for time management | 0.865 | |
| Apply techniques for time management | 0.836 | |
| Communicate effectively in a verbal setting, such as team meeting or presentations | 0.846 | -0.309 |
| Communicate effectively in a written medium, such as reports | 0.820 | |
| Understand the purpose of a logbook | 0.591 | |

### 3.4.5 Varimax Rotation Results

Once the two components had been established, a Varimax rotation was performed on the correlation matrix, in order to determine which survey questions belonged to which factors. The results of the Varimax rotations are shown in Tables 4 and 5 (below).

Table 4: Rotated Component Matrix with Varimax Rotation of 2009 Survey Results

| | Component | |
|---|---|---|
| | 1 | 2 |
| Apply principles of mathematics and natural sciences to real-world problems | | 0.695 |
| Evaluate a problem and brainstorm solutions | 0.698 | 0.349 |
| Understand a design process | 0.765 | 0.427 |
| Apply a design process to a challenge | 0.762 | 0.450 |
| Analyze data in order to draw meaningful conclusions | 0.629 | 0.527 |
| Take cultural issues into consideration for the design solution | 0.337 | 0.795 |
| Take environmental issues into consideration for the design solution | | 0.884 |
| Take economic issues into consideration for the design solution | 0.321 | 0.831 |
| Take safety issues into consideration for the design solution | 0.358 | 0.708 |
| Work in a team environment | 0.840 | |
| Understand techniques for time management | 0.829 | 0.332 |
| Apply techniques for time management | 0.778 | 0.320 |
| Communicate effectively in a verbal setting, such as team meeting or presentations | 0.799 | |
| Communicate effectively in a written medium, such as reports | 0.819 | |
| Understand the purpose of a logbook | 0.573 | 0.450 |

Table 5: Rotated Component Matrix with Varimax Rotation of 2010 Survey Results

| | Component | |
|---|---|---|
| | 1 | 2 |
| Apply principles of mathematics and natural sciences to real-world problems | 0.486 | 0.473 |
| Evaluate a problem and brainstorm solutions | 0.762 | |
| Understand a design process | 0.760 | |
| Apply a design process to a challenge | 0.782 | 0.397 |
| Analyze data in order to draw meaningful conclusions | 0.533 | 0.570 |
| Take cultural issues into consideration for the design solution | | 0.821 |
| Take environmental issues into consideration for the design solution | | 0.886 |
| Take economic issues into consideration for the design solution | 0.468 | 0.670 |
| Take safety issues into consideration for the design solution | 0.401 | 0.740 |
| Work in a team environment | 0.792 | |
| Understand techniques for time management | 0.842 | |
| Apply techniques for time management | 0.813 | |
| Communicate effectively in a verbal setting, such as team meeting or presentations | 0.878 | |
| Communicate effectively in a written medium, such as reports | 0.778 | 0.307 |
| Understand the purpose of a logbook | 0.595 | |

By the general standards of Factor Analysis a factor loading of 0.7 or higher is a strong indicator of a variable belonging to a factor, while a factor loading of 0.3 to 0.7 is a moderate indicator, and a loading below 0.3 is very weak and is often omitted from the displayed results (Kaiser, 1958; Kim & Mueller, 1978; Kline, 1994). However, it has also been recognized that real world data does not always provide loadings as high as 0.7 for any factor (Rummel, 1970; Costello & Osborne, 2005).

As shown in Table 4, the majority of the Varimax results fall within the 0.7 threshold for a factor loading. However, the following variables did not display a strong enough belonging to either component:

- Apply principles of mathematics and natural sciences to real-world problems.
- Evaluate a problem and brainstorm solutions.
- Analyze data in order to draw meaningful conclusions.
- Understand the purpose of a logbook.

Similarly in Table 5, the following variables did not show sufficiently strong factor loadings to ensure the certainty of its placement in either factor:

- Apply principles of mathematics and natural sciences to real-world problems.
- Analyze data in order to draw meaningful conclusions.
- Take economic issues into consideration for the design solution.
- Understand the purpose of a logbook.

### 3.4.6 Oblimin Rotation Results

In this section, the results were analyzed with an Oblimin rotation, which assumes the factors to be correlated (Kaiser, 1958), and produces to matrices: a pattern matrix and a structure matrix. For the 2009 survey, the pattern matrix in Table 6 predominantly denotes loadings for each variable to be near to, or above .7 for both components, with the following two exceptions:

- Analyze data in order to draw meaningful conclusions.
- Understand the purpose of a logbook.

Table 6 - Pattern Matrix from Oblimin Rotation for 2009 Survey

| | Component | |
|---|---|---|
| | 1 | 2 |
| Apply principles of mathematics and natural sciences to real-world problems | | 0.740 |
| Evaluate a problem and brainstorm solutions | 0.708 | |
| Understand a design process | 0.757 | |
| Apply a design process to a challenge | 0.745 | |
| Analyze data in order to draw meaningful conclusions | 0.551 | 0.353 |
| Take cultural issues into consideration for the design solution | | 0.808 |
| Take environmental issues into consideration for the design solution | | 0.961 |
| Take economic issues into consideration for the design solution | | 0.858 |
| Take safety issues into consideration for the design solution | | 0.693 |
| Work in a team environment | 0.964 | |
| Understand techniques for time management | 0.875 | |
| Apply techniques for time management | 0.818 | |
| Communicate effectively in a verbal setting, such as team meeting or presentations | 0.878 | |
| Communicate effectively in a written medium, such as reports | 0.884 | |
| Understand the purpose of a logbook | 0.514 | |

In order to determine the appropriate component(s) for these variables, the results were cross-referenced with the structure matrix in Table 7.

Table 7 - Structure Matrix from Oblimin Rotation for 2009 Survey

| | Component | |
|---|---|---|
| | 1 | 2 |
| Apply principles of mathematics and natural sciences to real-world problems | 0.447 | 0.728 |
| Evaluate a problem and brainstorm solutions | 0.776 | 0.553 |
| Understand a design process | 0.865 | 0.648 |
| Apply a design process to a challenge | 0.871 | 0.669 |
| Analyze data in order to draw meaningful conclusions | 0.773 | 0.700 |
| Take cultural issues into consideration for the design solution | 0.593 | 0.861 |
| Take environmental issues into consideration for the design solution | 0.530 | 0.914 |
| Take economic issues into consideration for the design solution | 0.591 | 0.890 |
| Take safety issues into consideration for the design solution | 0.582 | 0.785 |
| Work in a team environment | 0.838 | 0.407 |
| Understand techniques for time management | 0.893 | 0.579 |
| Apply techniques for time management | 0.841 | 0.551 |
| Communicate effectively in a verbal setting, such as team meeting or presentations | 0.832 | 0.479 |
| Communicate effectively in a written medium, such as reports | 0.865 | 0.527 |
| Understand the purpose of a logbook | 0.694 | 0.610 |

As Table 7 illustrates, the first variable in question (analyze data in order to draw meaningful conclusions) now has factor loadings at or above 0.7 in both components. Since, in both the pattern matrix and the structure matrix the factor loading was higher in Component 1, Component 1 would be the appropriate categorization for this variable.

Similarly, while the second component in question (understand the purpose of a logbook) does not demonstrate a strong factor loading for either component, in either matrix, it comes very close to the 0.7 threshold as a member of Component 1 in the structure matrix of Table 7. Combined with the fact that this variable showed a moderate factor for Component 1, and no notable factor loading (above 0.3) for Component 2 in Table 6, then logically, this variable also belongs to Component 1.

The same process is then repeated on the results from the 2010 survey, as shown in Tables 8 and 9. However, in this instance, the loadings are significantly lower for many of the variables in the pattern matrix (below 0.7). Of particular interest are the following variables that have moderate factor loadings in both categories, (aka low factor loadings in neither):

- Apply principles of mathematics and natural sciences to real-world problems.
- Analyze data in order to draw meaningful conclusions.
- Take economic issues into consideration for the design solution.

Comparing to the structure matrix in Table 9, while the first variable in question (apply principles of mathematics and natural sciences to real-world problems) did not achieve a high factor loading in either matrix, its factor loadings are higher in both matrices for Component 1. Similarly, the factor loadings for the second variable in question (analyze data in order to draw meaningful conclusions) are slightly higher in both matrices for Component 1. For the third component in question (take economic issues into consideration for the design solution), the structure matrix provides a high factor loading (above 0.7) for Component 2.

Table 8 - Pattern Matrix from Oblimin Rotation for 2010 Survey

| | Component | |
|---|---|---|
| | 1 | 2 |
| Apply principles of mathematics and natural sciences to real-world problems | 0.427 | 0.352 |
| Evaluate a problem and brainstorm solutions | 0.814 | |
| Understand a design process | 0.787 | |
| Apply a design process to a challenge | 0.782 | |
| Analyze data in order to draw meaningful conclusions | 0.455 | 0.443 |
| Take cultural issues into consideration for the design solution | | 0.859 |
| Take environmental issues into consideration for the design solution | | 0.954 |
| Take economic issues into consideration for the design solution | 0.355 | 0.577 |
| Take safety issues into consideration for the design solution | | 0.678 |
| Work in a team environment | 0.856 | |
| Understand techniques for time management | 0.878 | |
| Apply techniques for time management | 0.847 | |
| Communicate effectively in a verbal setting, such as team meeting or presentations | 0.943 | |
| Communicate effectively in a written medium, such as reports | 0.802 | |
| Understand the purpose of a logbook | 0.630 | |

Table 9 - Structure Matrix from Oblimin Rotation for 2010 Survey

| | Component | |
|---|---|---|
| | 1 | 2 |
| Apply principles of mathematics and natural sciences to real-world problems | 0.607 | 0.570 |
| Evaluate a problem and brainstorm solutions | 0.785 | 0.360 |
| Understand a design process | 0.812 | 0.451 |
| Apply a design process to a challenge | 0.866 | 0.563 |
| Analyze data in order to draw meaningful conclusions | 0.681 | 0.676 |
| Take cultural issues into consideration for the design solution | 0.388 | 0.832 |
| Take environmental issues into consideration for the design solution | 0.345 | 0.881 |
| Take economic issues into consideration for the design solution | 0.650 | 0.759 |
| Take safety issues into consideration for the design solution | 0.607 | 0.811 |
| Work in a team environment | 0.804 | 0.336 |
| Understand techniques for time management | 0.891 | 0.475 |
| Apply techniques for time management | 0.861 | 0.459 |
| Communicate effectively in a verbal setting, such as team meeting or presentations | 0.898 | 0.394 |
| Communicate effectively in a written medium, such as reports | 0.835 | 0.475 |
| Understand the purpose of a logbook | 0.618 | |

### 3.5 Discussion of Results

In this section, the results from the SPSS software (presented above) are analyzed and discussed.

#### 3.5.1 Summarized Components

Tables 10 and 11 summarize the variables belonging to each component, as well as the Cronbach's alpha (Cronbach, 1951) reliability coefficient for each component. As it is believed among researchers (Bland & Altman, 1997; Zinbarg, 2005) that a Cronbach's alpha score of above 0.7 is satisfactory, and given that all of the components have reliability coefficients near to, or above 0.85, the Cronbach's alpha scores from this study are sufficiently high to be confident in the reliability of the generated components.

Table 10 - Summary of Component 1 Variables and Reliability Coefficients

| | **Component 1** | |
|---|---|---|
| | **2009 Survey** | **2010 Survey** |
| | Evaluate a problem and brainstorm solutions | Evaluate a problem and brainstorm solutions |
| | Understand a design process | Understand a design process |
| | Apply a design process to a challenge | Apply a design process to a challenge |
| | Analyze data in order to draw meaningful conclusions | Analyze data in order to draw meaningful conclusions |
| | Work in a team environment | Work in a team environment |
| | Understand techniques for time management | Understand techniques for time management |
| | Apply techniques for time management | Apply techniques for time management |
| | Communicate effectively in a verbal setting, such as team meeting or presentations | Communicate effectively in a verbal setting, such as team meeting or presentations |
| | Communicate effectively in a written medium, such as reports | Communicate effectively in a written medium, such as reports |
| | Understand the purpose of a logbook | Understand the purpose of a logbook |
| | | Apply principles of mathematics and natural sciences to real-world problems |
| **Cronbach's Alpha** | **0.947** | **0.937** |

Table 11 - Summary of Component 2 Variables and Reliability Coefficients

| | Component 2 | |
|---|---|---|
| | **2009 Survey** | **2010 Survey** |
| | Take cultural issues into consideration for the design solution | Take cultural issues into consideration for the design solution |
| | Take environmental issues into consideration for the design solution | Take environmental issues into consideration for the design solution |
| | Take economic issues into consideration for the design solution | Take economic issues into consideration for the design solution |
| | Take safety issues into consideration for the design solution | Take safety issues into consideration for the design solution |
| | Apply principles of mathematics and natural sciences to real-world problems | |
| **Cronbach's Alpha** | **0.898** | **0.848** |

While the courses' desired learning outcomes were very similar (as shown in the course outlines), the slightly different categorizations between the two survey years, as well as the variation of the factor loadings, are likely the result of the different teaching techniques employed between the two course implementations. Therefore, similarities in the components are most likely due to the latent correlations between the surveyed skillsets, and the underlying compulsion for the skills to be taught in tandem in this type of course.

### 3.5.2 Verification of Component Validity

While the variables in Component 2 for the 2010 survey seem intuitively correct, especially as they had originally been designed as a single question, there were concerns that too many factors were being included in Component 1, and whether these variables were as strongly correlated as they initially appeared. Therefore, in an attempt to force the variables to split into multiple, more specifically defined components, an additional Principal Component Analysis was performed solely on the factors from Component 1 in the 2010 survey, since this component contained the most variables. Table 12 presents the component matrix from this Principal Component Analysis.

Table 12 - Component Matrix for Subset of 2010 Survey Variables

| | Component |
|---|---|
| | 1 |
| Apply principles of mathematics and natural sciences to real-world problems | 0.654 |
| Evaluate a problem and brainstorm solutions | 0.776 |
| Understand a design process | 0.815 |
| Apply a design process to a challenge | 0.877 |
| Analyze data in order to draw meaningful conclusions | 0.725 |
| Work in a team environment | 0.780 |
| Understand techniques for time management | 0.884 |
| Apply techniques for time management | 0.858 |
| Communicate effectively in a verbal setting, such as team meeting or presentations | 0.882 |
| Communicate effectively in a written medium, such as reports | 0.836 |
| Understand the purpose of a logbook | 0.615 |

As shown in Table 12, all of the variables analyzed in this iteration of PCA remained in a single component, despite the two factor loadings slightly below 0.7. Additionally, the reliability coefficient of this factor is very high, with a Cronbach's alpha score of 0.936. This result confirms that the eleven variables belong as a single component for the 2010 Survey results, and by extension, the results of the other component categorizations are also valid.

### 3.5.3 Interpretation of Components

The components identified through Factor Analysis are named according to the factors that compose them. From this, Component 2 of the 2010 survey exemplifies the learning outcome "The application of global considerations to engineering", where global engineering includes social, cultural, economic, and environmental considerations. Similarly, with the addition of the variable "Apply principles of mathematics and natural sciences to real-world problems" to Component 2 of the 2009 survey, this component could be named "The application of technical and global considerations to engineering".

With the large number of variables in Component 1 of both the 2009 and 2010 surveys, it becomes more difficult to establish a component title that accommodates all of the variables. By returning to the original CEAB Graduate Attributes Criteria through which these variables were originally created, Component 1 of the 2009 survey exemplifies "The analysis, investigation, design, communication and management of engineering problems in a professional team environment", while Component 1 of the 2010 survey (which is only augmented by the "[application of] principles of mathematics and natural sciences to real-world problems") could be similarly titled "The analysis, investigation, design, communication, application of technical knowledge, and management of engineering problems in a professional team environment".

### 3.5.4 Implications for Future Assessments

As Cloutier et al. (2010) have already demonstrated with their CDIO mappings, there are inherent correlations between CEAB outcomes. While it is clear that a fully qualified engineering graduate would need to possess all of the CEAB Graduate Attributes (CEAB, 2010), this study provides a method to determine if some of the graduate attributes are taught together. For example, in some courses, it would be very difficult to teach engineering ‘Design’ (as defined by the CEAB), without first needing to teach the skills of Problem Analysis and Investigation. However, both intuitively, and as shown by the Factor Analysis, a student does not necessarily need to have a solid foundation in the Knowledge Base for Engineering, in order to perform Problem Analysis, Identification, or Design. Additionally, teaching these Problem Analysis, Identification, and Design skills in a Team Environment would likely rely on the students possessing some Communication Skills.

By using Factor Analysis in their own courses, institutions can identify whether multiple attributes are being taught in a course. The institutions can then use this information to design assessments for these correlated attributes. The institutions can then use the Factor Analysis results to describe how the metrics inherently map to multiple correlated attributes for that course.

### 3.6 Summary

Through the application of Factor Analysis, the following components involved in the first-year design courses are as follows:

- The application of global considerations to engineering.
- The application of technical and global considerations to engineering.
- The analysis, investigation, design, communication and management of engineering problems in a professional team environment.
- The analysis, investigation, design, communication, application of technical knowledge, and management of engineering problems in a professional team environment.

Or more generally (with the application of technical knowledge included in either component, depending on the course implementation):

- The application of global considerations to engineering.
- The analysis, investigation, design, communication and management of engineering problems in a professional team environment.

In a general sense, Factor Analysis can be used by institutions and instructors to identify correlations in the way Graduate Attributes are taught in their courses, thereby enabling institutions to design assessments to measure multiple attributes.

# CHAPTER 4: QUALITATIVE ANALYSIS

## 4.1 Introduction

This chapter describes the qualitative techniques employed in the evaluation of the two first-year design course implementations described in Chapter 2. Specifically, this chapter seeks to achieve the following thesis goals:

- Demonstrating Grounded Theory as a viable technique for enhancing learning outcomes assessment in engineering education.
- Identifying learning outcomes achieved by the ENGG 251/253 and ENGG 200 design and communications courses.
- Establishing attributes of an effective first-year design and communications course.

This chapter contains the following components:

- Gathering and Analysis of Qualitative Data - A justification of the data collection methods employed, as well as a justification of Grounded Theory as the qualitative research technique employed in the data's analysis.
- Survey Analysis - The application of Grounded Theory to the survey data, and the results yielded by this qualitative analysis.
- Interview Analysis - The application of Grounded Theory to the interview data, and the results yielded by this qualitative analysis.
- Discussion of Results - A summary of the theories emerging from the Grounded Theory analysis, its potential impact on the first-year design course implementation, and its potential impact on future assessments of learning outcomes in engineering education.

## 4.2 Gathering and Analysis of Qualitative Data

This section discusses the methods and justifications behind the gathering and analysis processes of the qualitative data.

### 4.2.1 Selection of Data Gathering Techniques

This section describes the data collection process of the qualitative data. As described by Olds et al. (2005), qualitative research methods commonly use descriptive assessment data gathering techniques, namely: surveys, interviews/focus groups, conversational analysis, observations, ethnographic studies, and meta-analysis (Olds et al., 2005). As Olds et al. (2005) points out, conversational analysis, observations, and ethnographic studies are particularly time and labour intensive, especially considering that there are over 1500 students as potential participants between the two years of this study. Additionally, meta-analysis works by examining, and identifying correlations between previous researches done in similar fields (Kadiyala & Cynes, 2000). Since Grounded Theory has yet to be applied to the assessment of learning outcomes in engineering education, and meta-analysis would not provide any insights into these particular implementations of a first-year design course, meta-analysis was deemed to be unsuitable for this study. Therefore, surveys and interviews/focus groups were selected as the research techniques for this study.

### 4.2.2 Design of Open-Ended Survey

An open-ended survey was selected as the primary research technique for collecting data regarding the first-year design course from a student perspective. A survey was chosen over interviews due to the speed through which data could be collected from the large participant pool, at the expense of the lack of ability to elicit elaboration on responses. The open-ended survey questions were delivered alongside the closed-ended survey questions discussed in Chapter 3. The students from the 2009 exit survey were asked to complete the survey online, while the students from the 2010 exit survey were asked to complete a paper survey at the end of a lecture. Both years of the survey had response rates of approximately 20%.

In addition to the survey goal of identifying the achieved learning outcomes of the first year design and communications course (as discussed in Chapters 2 & 3), this study also strove to identify areas where future iterations of the first year design and communications course could be improved. Therefore, the open-ended section of the 2009 exit survey solely asked the students to identify what they liked and disliked about the course. It was later determined that asking the students to identify their perceptions of the learning outcomes might provide additional insight into the success of the course, and its success in achieving the courses' desired learning outcomes. Therefore, three additional questions were added to the 2010 exit survey; a question regarding what the students learned in the course, a question regarding what the students felt the purpose of the course was, and a question regarding what the students would have liked to learn from the course. As shown later in this chapter, the survey data was then analyzed with the intent of answering the research question "what did the students learn in each of the course implementations". While it is not unusual for qualitative research questions to not directly speak to the goal of the study (Zaller & Feldman, 1992), it provides an additional challenge in translating the students likes and dislikes of the course to their perceptions of the learning outcomes, especially since, while there is some correlation between student enjoyment of a course and the achieved learning outcomes (Harms, 1994), it is not the sole indicator of what the students have truly learned.

### 4.2.3 Focus Groups

Originally, focus groups were intended to be conducted with the students, in order to gain additional insights into their perceptions of the course learning outcomes, to a level of granularity that could not be achieved by the open-ended surveys. Unfortunately, these focus groups received a much lower participant rate than expected, with only two focus groups in the 2010 course (a total of 7 students), and none in the 2009 course. Therefore, rather than analyzing the focus group data separately, it will be used to help validate the theory generated through the Grounded Theory Analysis of the survey data.

### 4.2.4 Interviews

Given that there were only a total of 32 instructors and teaching assistants in each of the 2009 and 2010 course implementations, it was feasible to perform the more time-consuming interview, which had the potential to offer greater insight than surveys.

### 4.2.5 Selection of Grounded Theory as Qualitative Analysis Technique

As discussed in Chapter 2, Grounded Theory provides the strongest level of rigour among qualitative research techniques (Glaser & Strauss, 1967; Haig, 1995). Furthermore, by following the systematic categorization of codes, concepts and categories, as proposed by Borgatti (2005) and Heath & Cowley (2004), the use of Grounded Theory in this thesis was intended to make the results of the qualitative analysis more accessible to more traditional engineers and engineering educators (Valerdi & Davidz, 2007).

## 4.3 Survey Analysis

This section details the process of the applying Grounded Theory to the open-ended survey data, and the resulting theory generated.

### 4.3.1 Open Coding / Creation of Codes

In the first stage of Grounded Theory, the keywords and key phrases of the raw data are extracted to form codes (Glaser & Strauss, 1967). It is possible for a single statement to be applicable to multiple codes. For example, one response to the question “What did you like about this course?” was “Challenges such as Predator vs Prey/Rube Goldberg which gave the greatest degree of design freedom”. This statement is applicable to addressing specific projects (Predator versus. Prey and Rube Goldberg), the challenge presented by a design project, and the design freedom afforded to the students from the project. The open codes are primarily portions of direct statements made by the students, with the exception of the “Instructor” code, in which the student has made a reference to a particular instructor, and has been generalized in order to maintain anonymity.

The remainder of this sub-section lists the codes generated from the open-ended survey data, as well as the percentage of students whose response(s) were applicable to that code. Due to the relatively small percentage of students who mentioned a common code, the percentages are displayed to a decimal, in order to illustrate more variability between the popularity of the responses. Following the work of Jackson & Trochim (2002), concept maps are utilized to visualize the coding process.

In accordance with the third goal of this thesis (identifying learning outcomes achieved by the ENGG 251/253 and ENGG 200 design and communications courses), the open coded responses reflect not only what the students have stated to like/dislike/learn etc... about the course, but additionally, the percentages attached to each code reflect the percentage of students who made a similar statement.

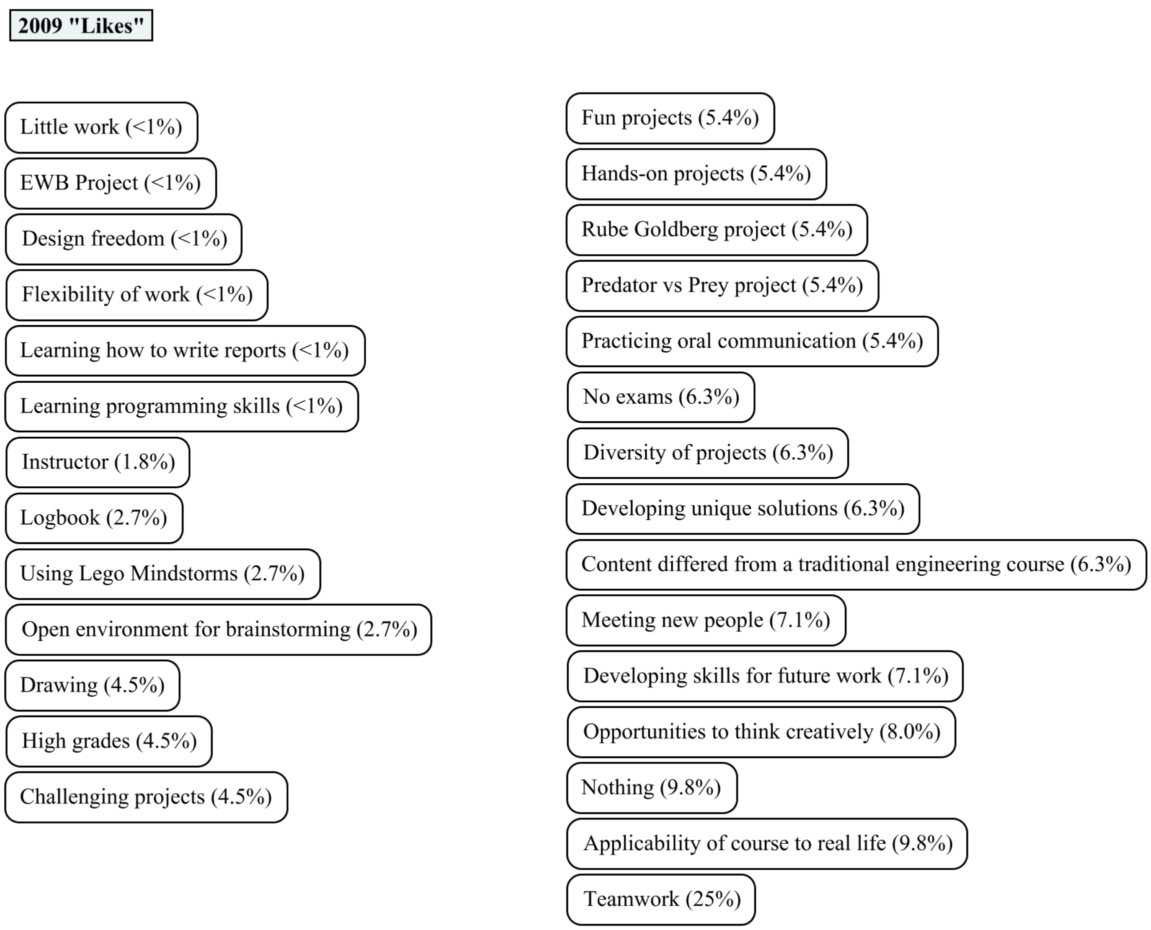


Figure 4: Open Coded Responses to the 2009 Survey Question: What did you like about this course?

Figure 4 illustrates the codes generated from the 2009 survey question, identifying what the students liked about the ENGG 251/253 courses. While what the students reported to like about the course does not correlated directly with their having achieved the desired learning outcomes, their ability to identify and comprehend the learning outcome well enough to state it as a survey response indicates that they have at least achieved the learning outcome to the first two levels of Bloom's Taxonomy (Bloom, 1956). Most popular among the self-reported responses was the opportunity for teamwork. While none of the remaining responses reached ten percent popularity, the wide variety in responses with greater than one percent popularity shows that a vast number of learning outcomes have been identified by the students, some of which having not been identified by the course coordinator or researcher. However, with the exception of teamwork and some aspects of communication, the students did not identify many of the learning outcomes surmised in Chapter 3.

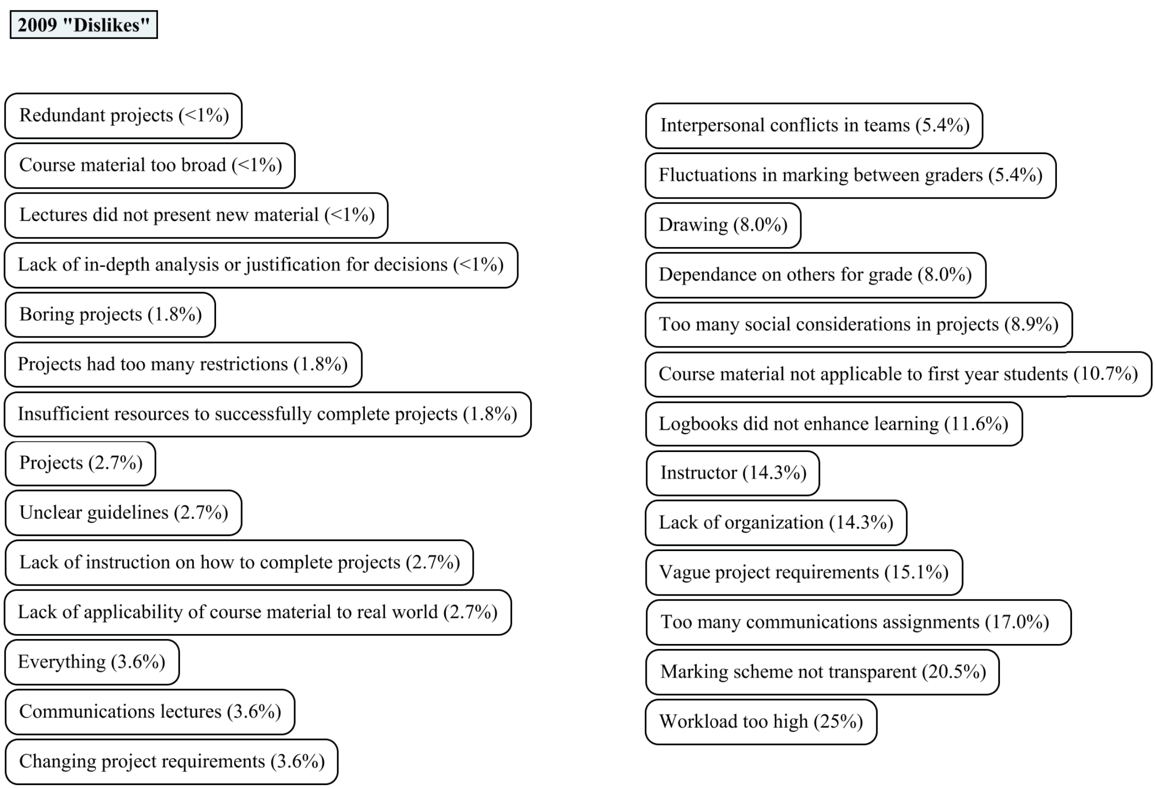


Figure 5: Open Coded Responses to the 2009 Survey Question: What did you dislike about this course?

In Figure 5, the open coded responses for the students' dislikes are displayed. The students seemed to largely concur with the aspects of the course they disliked, with eight codes above ten percent, as compared to the one code above ten percent from the 2009 "likes" codes. Unfortunately, many aspects of the course that were disliked are not related to the learning outcomes of the course, and thus cannot be used to satisfy the first goal of this thesis. However, the students reported disliked about the course can still be useful feedback, as it provides insight on administrative issues of a first-year design course, thus helping in the fourth goal of this thesis (to establish attributes of an effective first-year design and communications course).

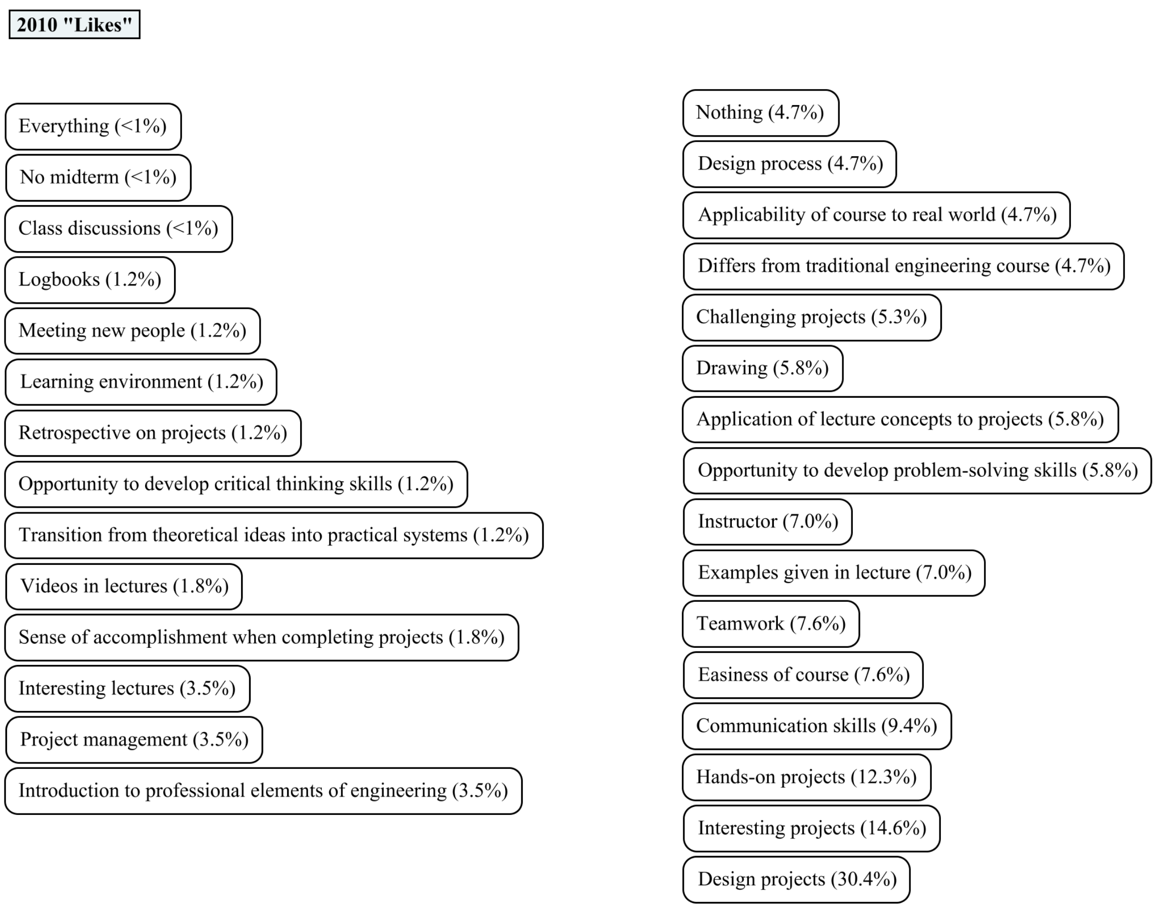


Figure 6: Open Coded Responses to the 2010 Survey Question: What did you like about this course?

Interestingly, as shown in Figure 6, the most popular responses for the open coded "likes" revolve around the projects, rather than around the teamwork "like" of the ENGG

251/253 courses (as shown in Figure 4). Additionally, the coded responses from the 2010 survey indicate a greater agreement from the students with the learning outcomes developed for the survey of Chapter 3, as well as the prescribed learning outcomes from the course outline, in terms of the learning outcomes achieved by the course.


Figure 7: Open Coded Responses to the 2010 Survey Question: What did you dislike about this course?

Figure 7 shows the open codes identifying what the students disliked about the 2010 course. In this instance, the most strongly disliked aspects of the course focused on the lectures and lecture material, without specific mention of any specific learning outcomes.

In examining the coded dislikes around the 2010 course, there are very few codes that address learning outcomes. This implies that what the students disliked about the course had little to do with whether or not the students felt they had achieved any specific learning outcomes, and more to do with the manner in which the course material was delivered.

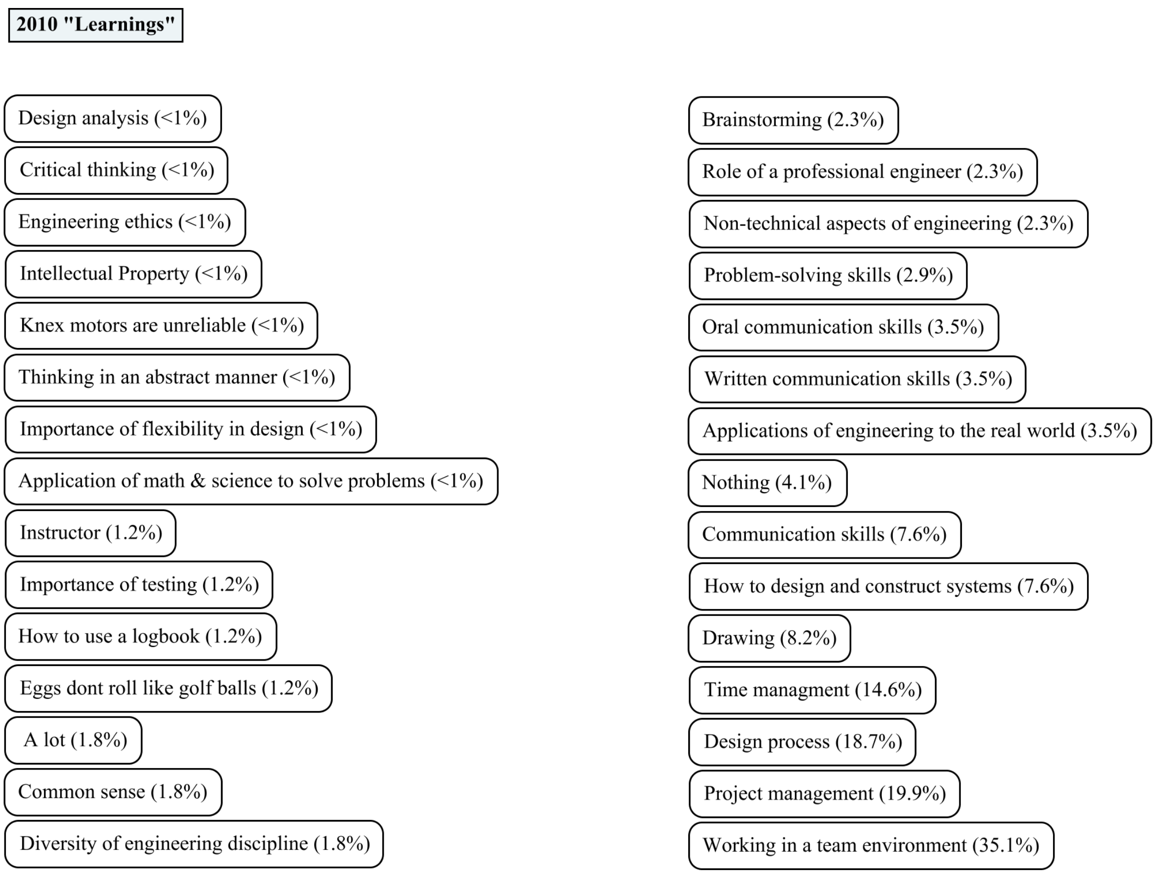


Figure 8: Open Coded Responses to the 2010 Survey Question: What did you learn in this course?

Figure 8 illustrates the coded responses to what the students stated to have learned in the ENGG 200 design and communications course. Similarly to the most liked aspect of the previous course (shown in Figure 3), the students most frequently stated that they learned how to work in a team environment. This indicates that in both courses, the students felt that they learned how to work in a team environment. This is also in agreement with the quantitative survey responses, as indicated in Table 1. Also strong among the self-reported learning outcomes are project management and the design process, both of which were learning outcomes highly emphasized by the course coordinator.

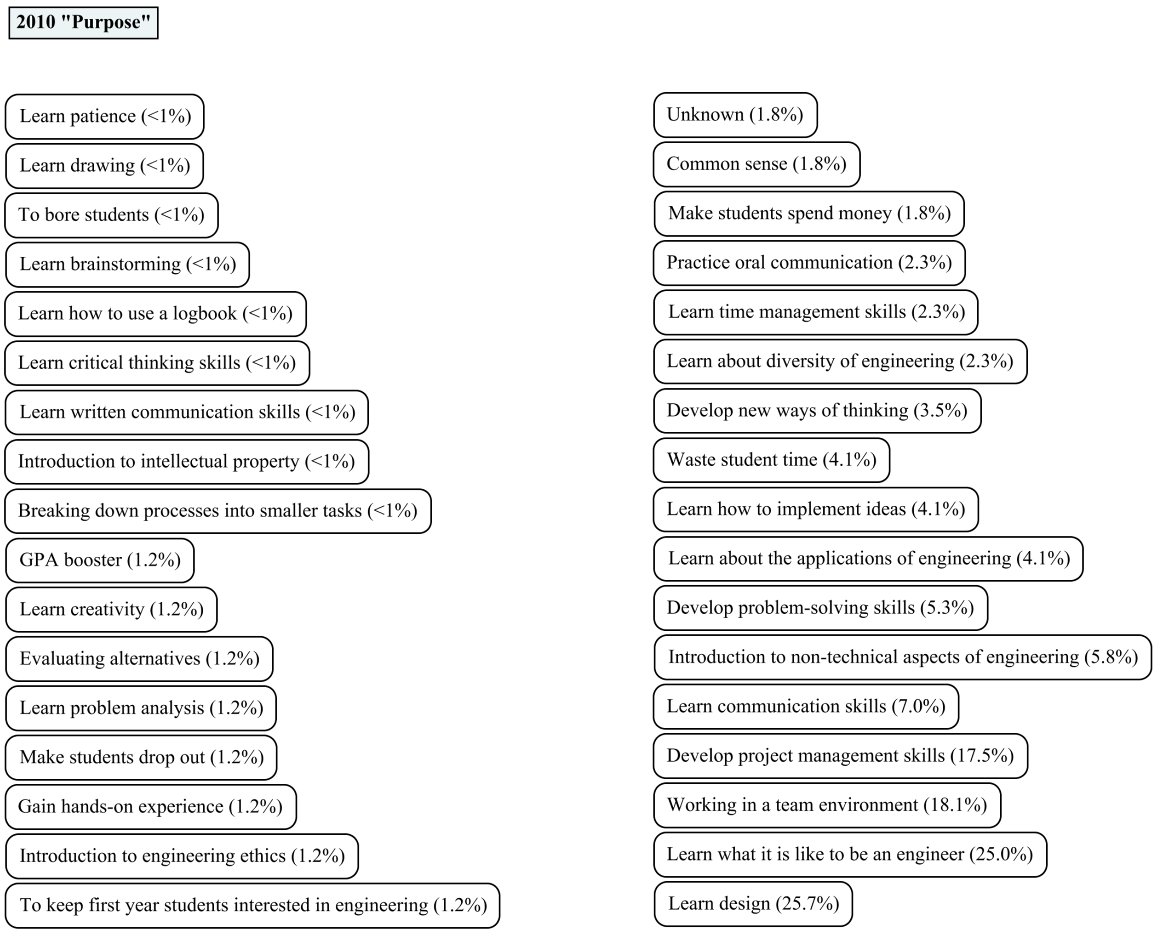


Figure 9: Open Coded Responses to the 2010 Survey Question: What do you think the purpose of this course was?

Figure 9 reveals what the students believed the purpose of the ENGG 200 course to be. While similar to the learning outcomes shown in Figure 8, the students in this instance placed the highest emphasis on learning design, and learning what it is like to be an engineer. However, some of the other highly emphasized aspects of the course, such as learning the proper use of a logbook, and learning written communication skills, were regarded to be a principal purpose of the course by fewer than one percent of the survey participants. That is not to say that these skills were not recognized as a course purpose, but that very few students identified it as a primary purpose, worthy of mention in a short open-ended survey response.

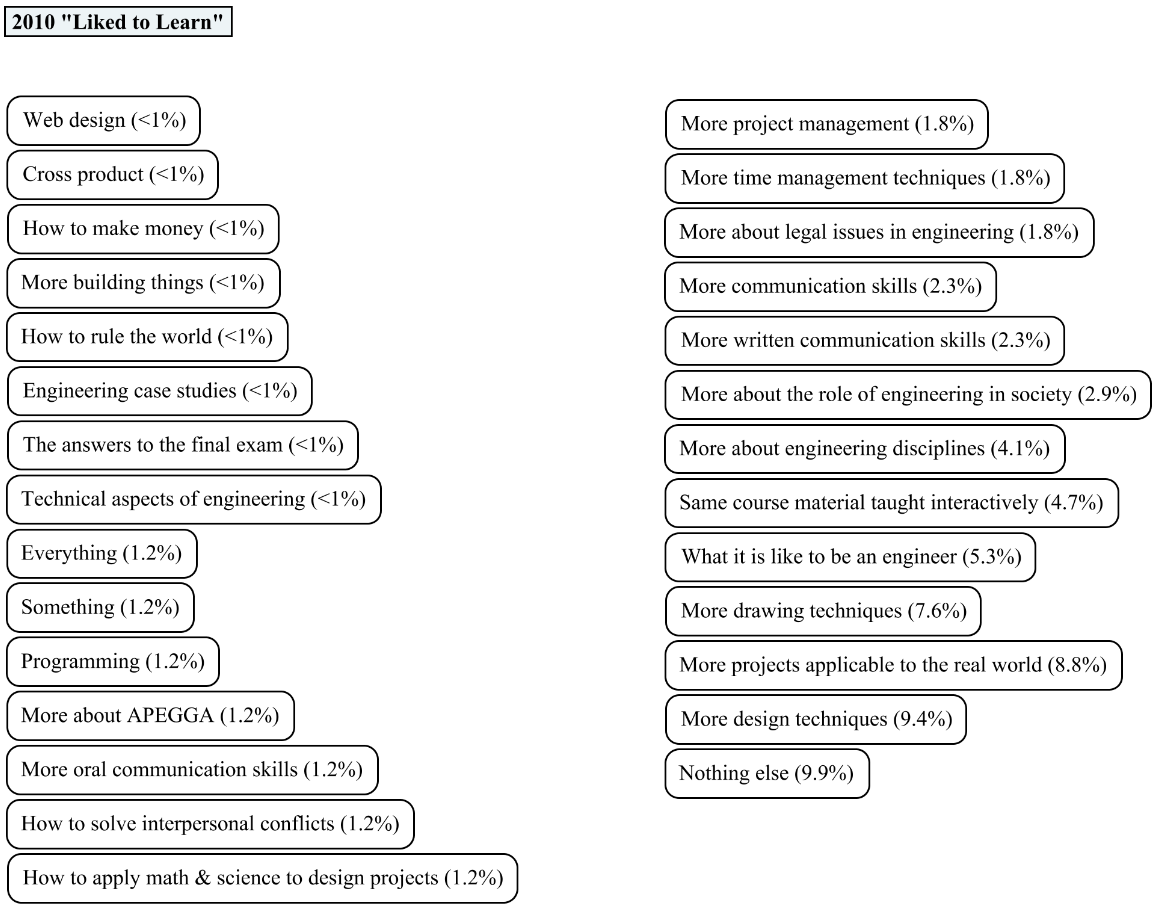


Figure 10: Open Coded Responses to the 2010 Survey Question: What would you have liked to learn from this course?

As shown in Figure 10, the students most frequently did not report a desire to learn anything additional from the ENGG 200 course. However, as with any course, the students provided a variety of responses (typically with very low popularity) of ways in which the course could have been improved.

### 4.3.2 Axial Coding / Creation of Concepts

In this section, axial coding is applied to the codes from the previous section, in order to form concepts. The concepts are created through the identification of similar key terms in the codes, or where the students' responses mentioned more than one code.

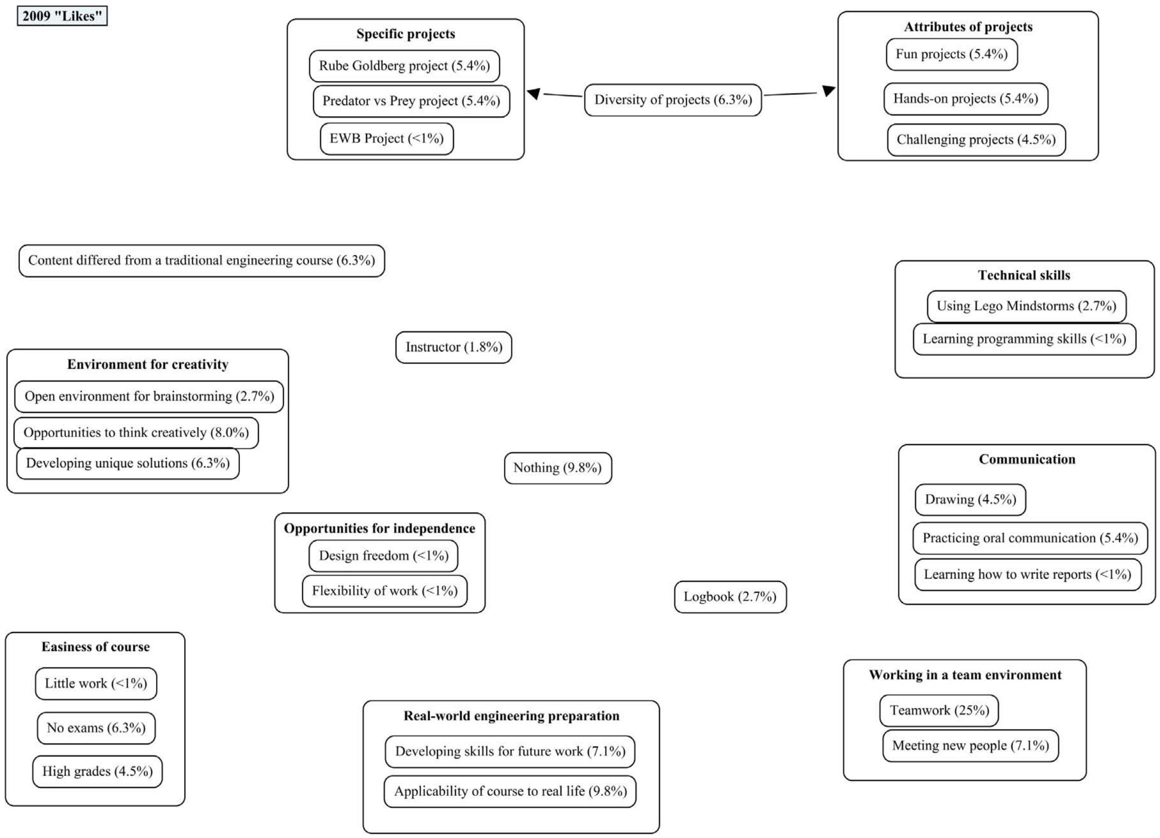


Figure 11: Axial Coded Responses to the 2009 Survey Question: What did you like about this course?

Figure 11 illustrates the concept generated by the axial coding to the student “likes” from the 2009 survey. As shown in Figure 11, the major concepts liked by the students of the course were related to a variety of course aspects. While majority of the learning outcomes that were identified as being “liked” by the students conformed to the course outline’s prescribed learning outcomes, the students identified a few additional “likes” of the could be considered learning outcomes, such as opportunities for independence and environment for creativity. This begins to show the added value of qualitative analysis, as it enabled the students to put forward learning achievements that were not identified by the prescribed learning outcomes.

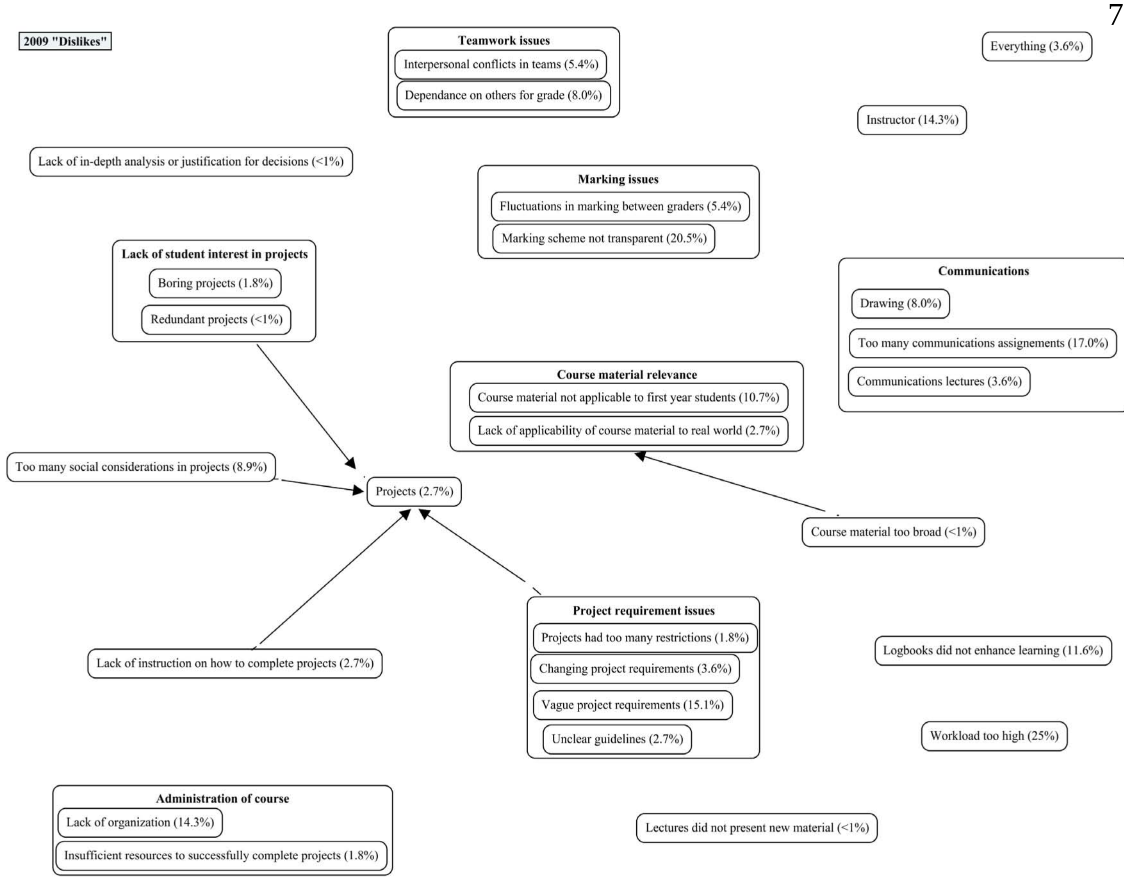


Figure 12: Axial Coded Responses to the 2009 Survey Question: What did you dislike about this course?

Figure 12 details the concepts generated regarding what the students disliked in the ENGG 251/253 courses. As shown in the figure, many of the concepts seem to be related to the general concept of the course projects. Furthermore, the student dislikes, particularly in regard to the projects, concentrate on the administrative details of the projects, rather than the learning outcomes achieved (or desired to be achieved) in the course.

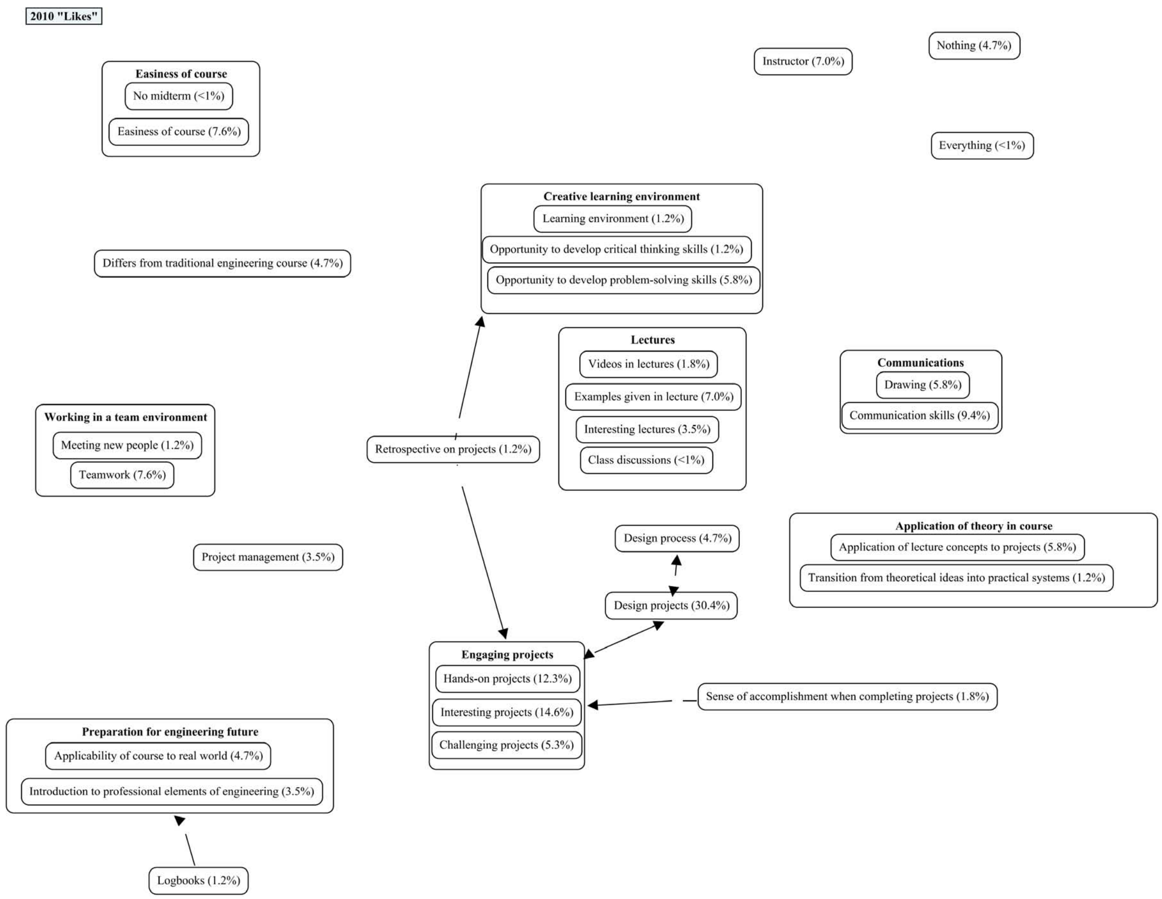


Figure 13: Axial Coded Responses to the 2010 Survey Question: What did you like about this course?

As shown in Figure 13, the concepts surrounding what the students liked about the ENGG 200 course are heavily inter-related. In this instance the students of the revised design course reported liking many concepts that are administrative details, rather than commenting on their achieved learning outcomes. This is likely due to the addition of the open-ended survey question “what did you learn in this course”, which afforded students more opportunities to opine on the course, and distinguish between their enjoyment of the course from an administrative perspective and their satisfaction in the learning outcomes they perceived to have learnt.

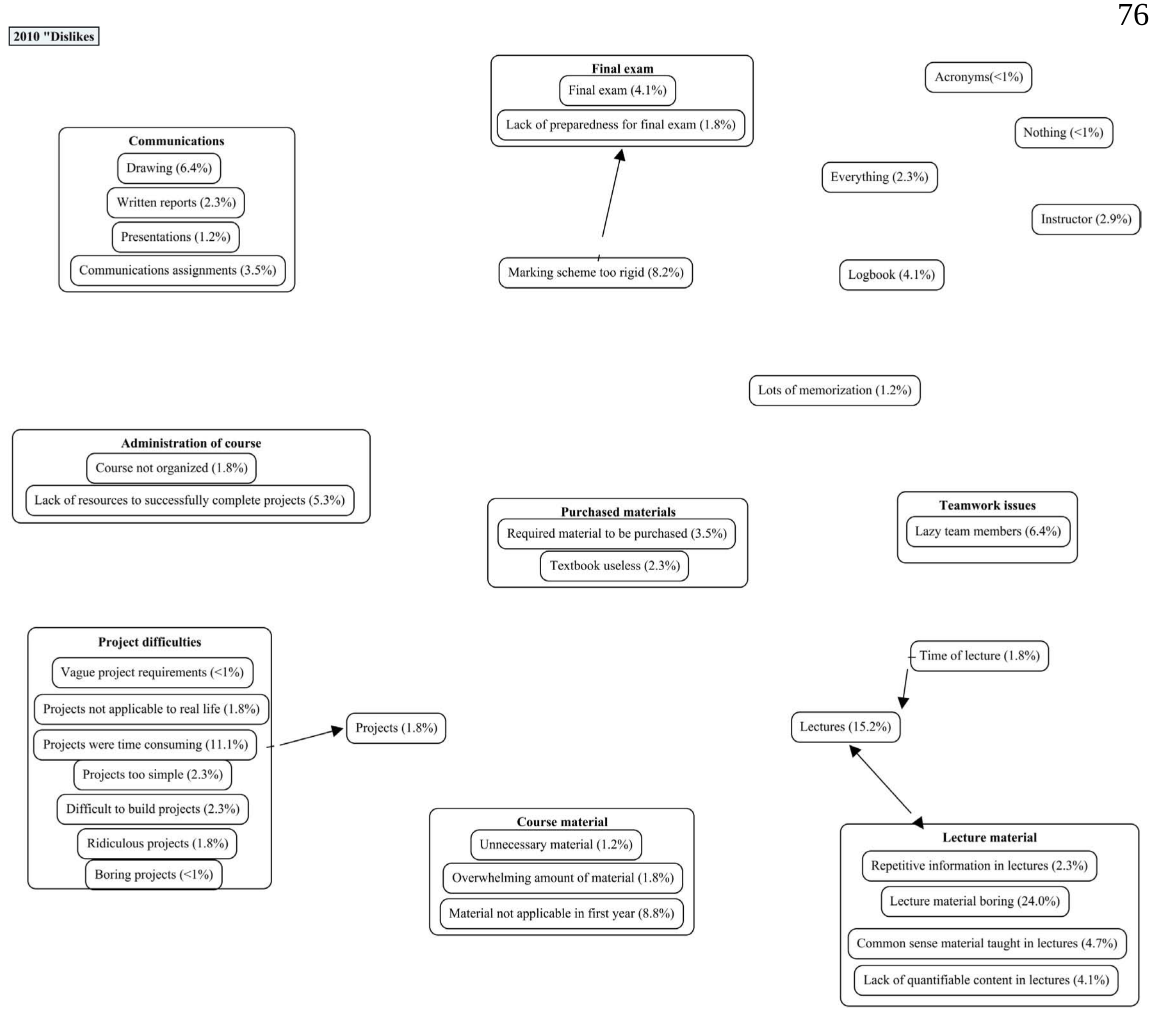


Figure 14: Axial Coded Responses to the 2010 Survey Question: What did you dislike about this course?

Figure 14 illustrates the concepts of what the students disliked about the ENGG 200 course. In contrast to the concepts shown previously, the concepts in Figure 14 are made up of many codes. This indicates that the students had strong agreements in what the students disliked about the course, most commonly with project difficulties, lecture material, and communications. This would indicate that by improving administrative details of the projects and communications assignments, as well the manner in which the lecture material is delivered could help to make the course more successful.

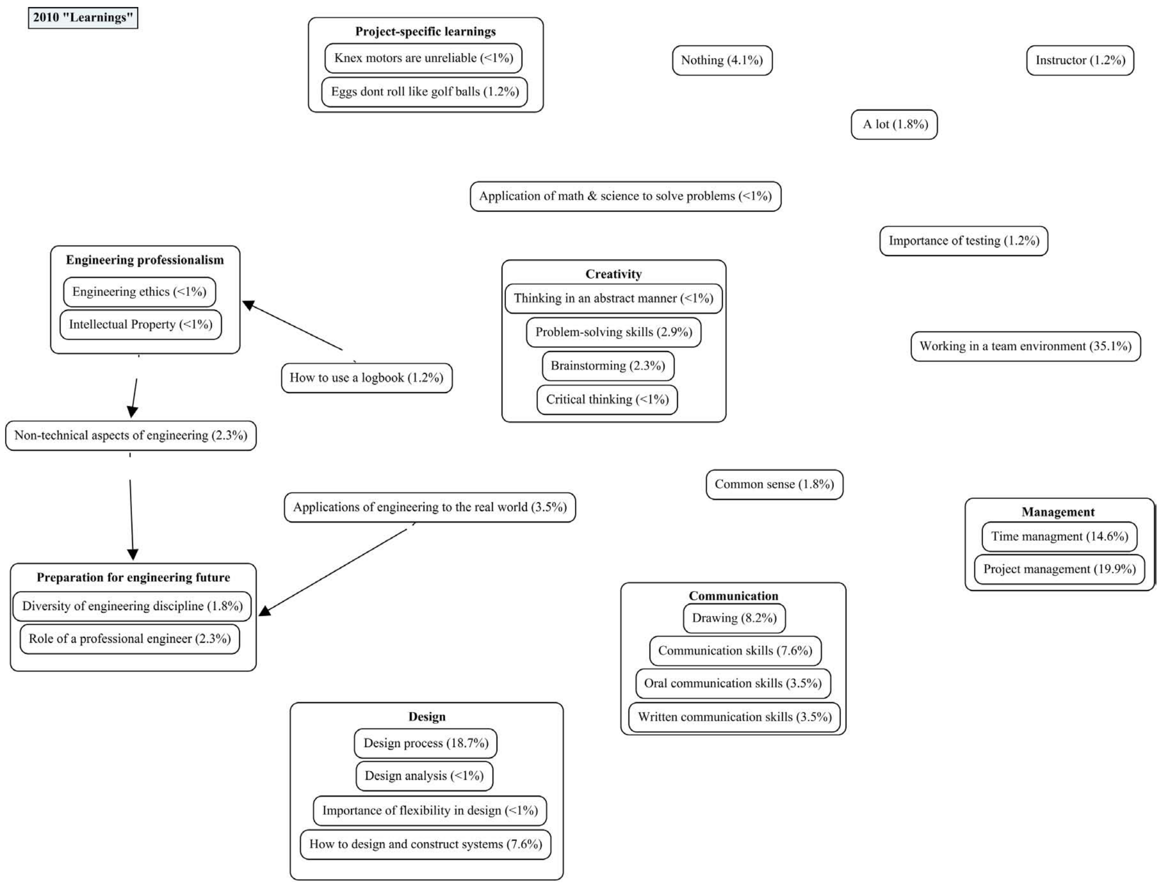


Figure 15: Axial Coded Responses to the 2010 Survey Question: What did you learn in this course?

Figure 15 shows the concepts generated in response to the survey question asking what the students learned in the ENGG 200 course. In this figure, the learning outcomes achieved by the course are shown by each of the concepts. Similarly to Figure 11, while the students "learnings" corresponded highly with many of the prescribed learning outcomes (design, communication, management, how to use a logbook, teamwork), the open-endedness of the survey enabled the students to discuss additional learning achievements, most notably regarding engineering professionalism, and preparation for an engineering future. This is important to note because recognition of engineering professionalism, and the desire to learn and prepare for an engineering future can be metrics of CEAB criteria 3.1.8 and 3.1.12, which, as discussed in Chapter 3, were considered to be too advanced for first-year undergraduate students.

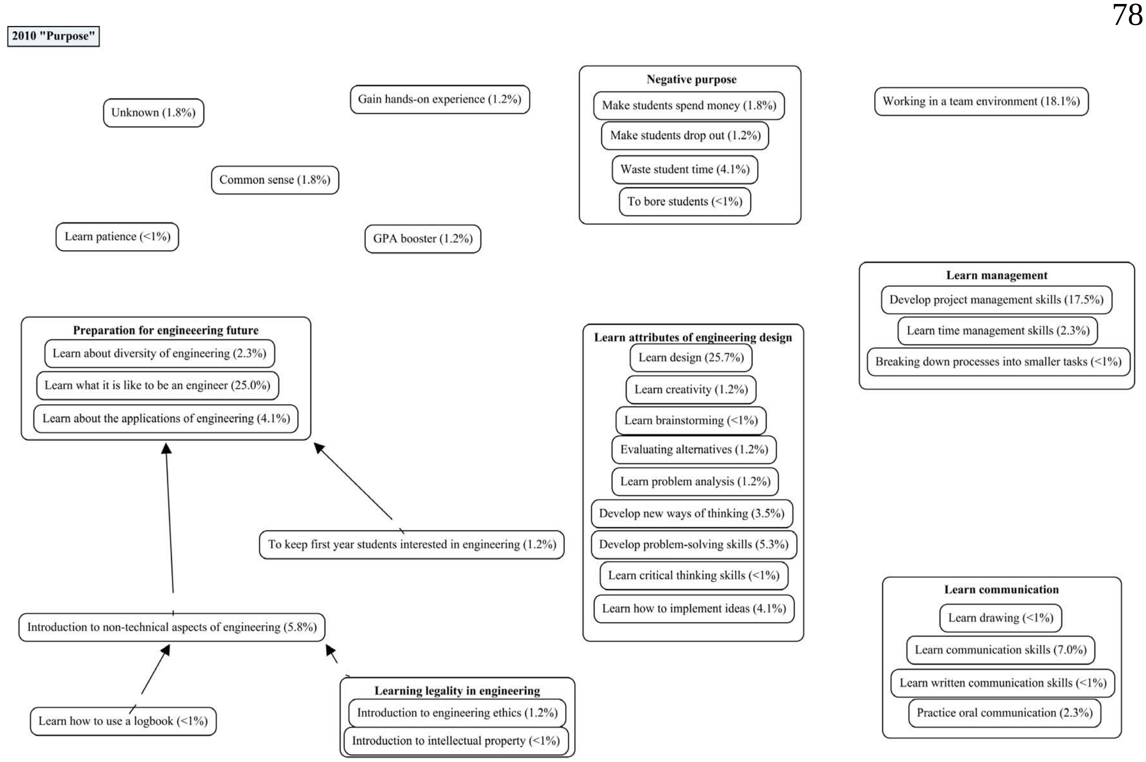


Figure 16: Axial Coded Responses to the 2010 Survey Question: What do you think the purpose of this course was?

In Figure 16, the concepts regarding the students' perceptions of the course purpose are displayed. In this instance, there are a large number of codes relating to the concept of learning attributes of engineering design. This helps to confirm the objective of the course coordinator to emphasize design in this course. There are additionally a large number of codes and concepts which center on the concept of preparation for an engineering future. This displays an additional learning outcome identified by the students that had not been thought to be assessed in the quantitative assessment.

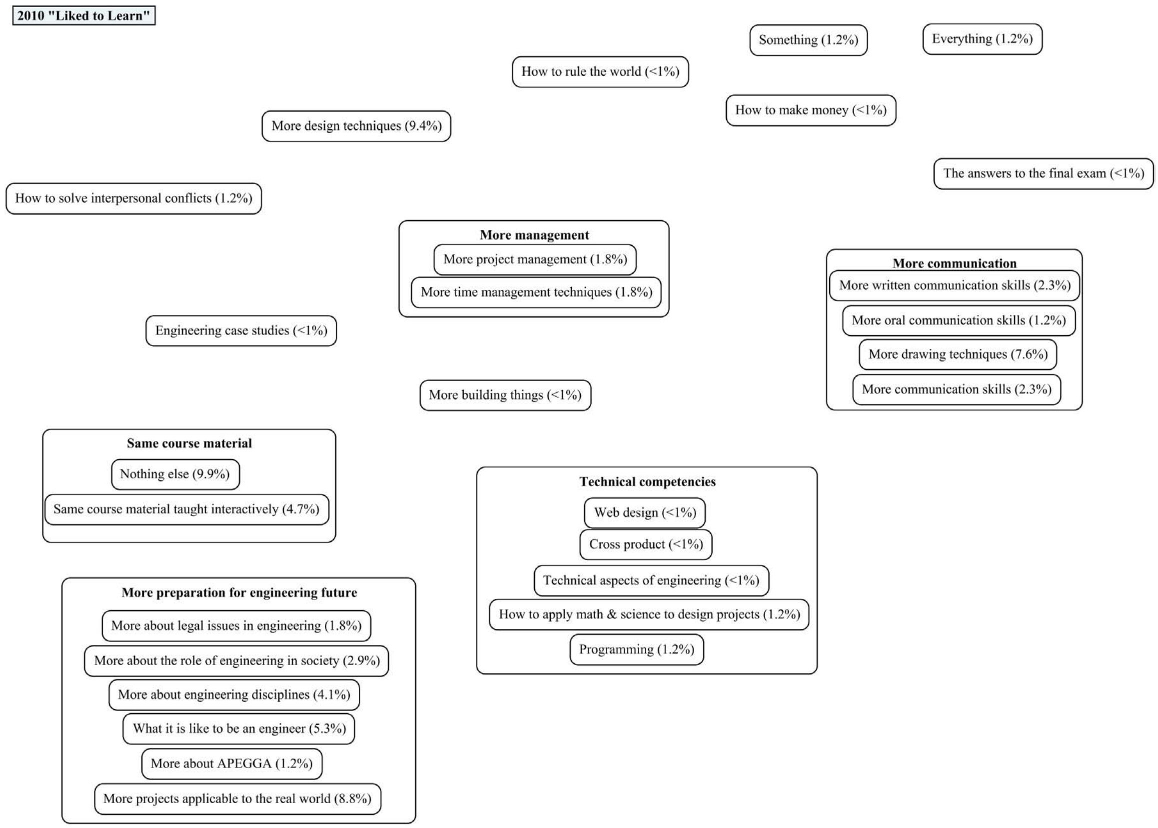


Figure 17: Axial Coded Responses to the 2010 Survey Question: What would you have liked to learn in this course?

Figure 17 shows the concepts generated in response to what the students would have liked to learn from the ENGG 200 course. In this instance, many of the codes related to a desire for more preparation for an engineering future. This is related to the desires for more technical competencies, management skills, communication skills, as well as many of the lesser codes, which did not have enough similarity with other codes to become concepts, such as “how to make money” and “how to rule the world”. However, these codes were left out of the “more preparation for engineering future” concept, due to the context in which they were reported by the students, with a lack of seriousness in responding to the survey.

### 4.3.3 Selective Coding / Creation of Categories

In this section, the concepts are grouped into categories, in the selective coding process. For this process, the focus of identifying the achieved learning outcomes is emphasized.

Therefore, the concepts from the “liked”, “learnings” and “purpose” concept maps are combined to form the “learnings” categories, while the “disliked” and “liked to learn” concepts are combined to form the “desired learnings” category. As the concept grouping at this stage no longer directly follows the survey questions, some of the participant responses are no longer applicable, as they related more to administrative details of the course, rather than learning outcomes. Additionally, since the students responses could have formed multiple codes, the percentages of the coded responses are not summative, and are therefore not included in the selective coding process.

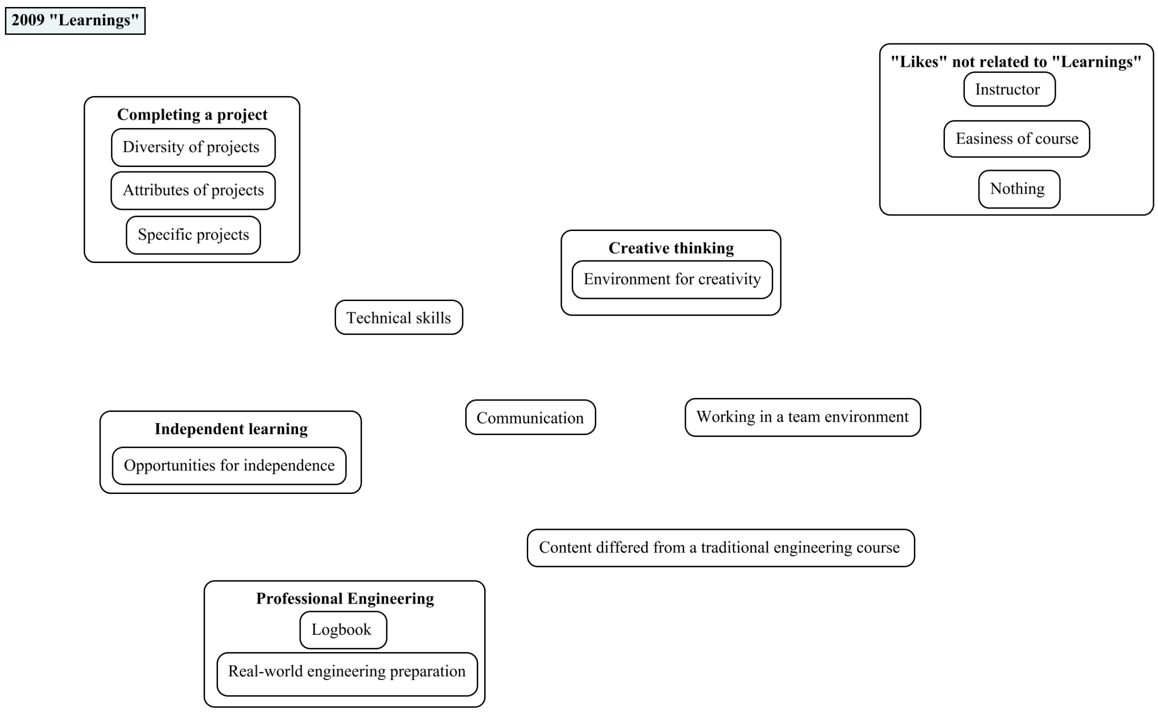


Figure 18: Selective Coded Responses to the 2009 Survey Results - Identifying “What did the students learn?”

Figure 18 identifies the categories of what the students perceived to have learnt in the ENGG 251/253 courses by attempting to correlate what the students reported to have liked about the course with the course’s achieved learning outcomes. As described above, aspects of the course that students liked that are not related to the achieved learning outcomes (in this instance, a preference for an instructor, the easiness of the course, and nothing) are grouped into a single category to be omitted when the achieved learning outcomes of the course are determined. From the categories created, the learning outcomes achieved by the ENGG 251/253 courses somewhat correspond to the prescribed learning outcomes. However, the students overlooked the major prescribed learning outcomes of design and project management, while they identified the additional learning outcomes of creative thinking, professional engineering, independent learning, and completing a project.

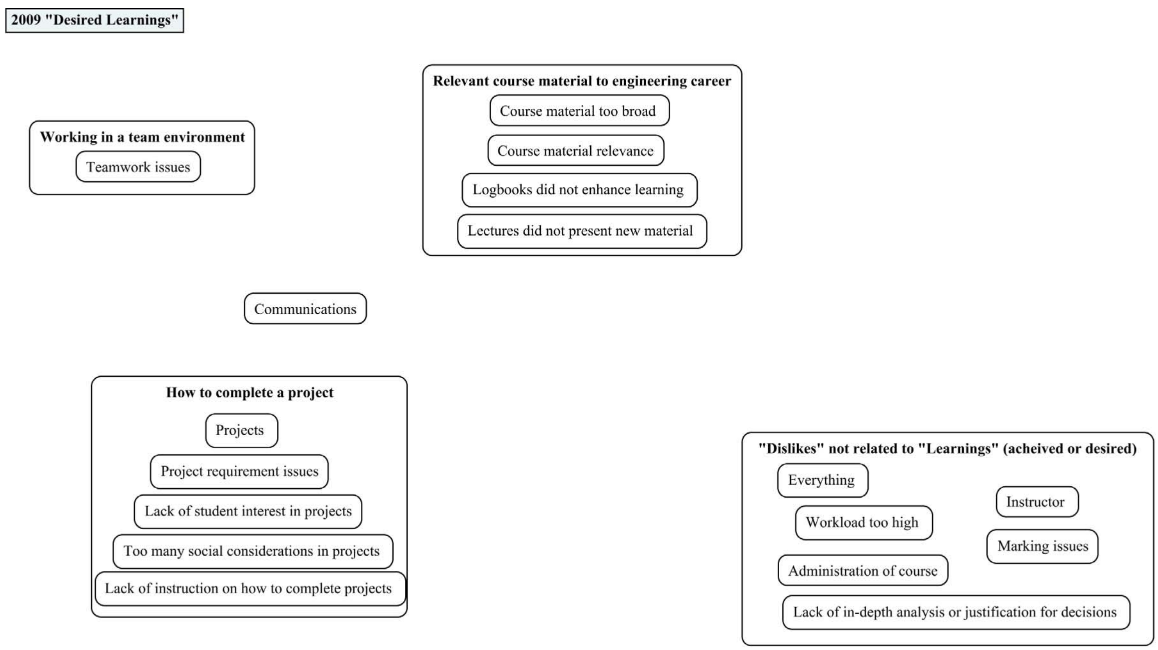


Figure 19: Selective Coded Responses to the 2009 Survey Results - Identifying “What did the students desire to learn?”

Figure 19 illustrates the translation from the “dislikes” of the ENGG 251/253 courses, into “desired learnings”. In this instance, there are many more aspects of the course that the students disliked that are not related to learning outcomes, than in the previous figure. This indicates that the students were relatively satisfied with what they learned in the course, and their dislikes were more related to other course aspects, such as the way in which the learning outcomes were taught, and administrative details.

As shown in Figure 19, the student disliked the lone concept “Communications”. Returning to Figure 12 shows that the most popular code within the “Communications” concept is the issue of “too many communications assignments”, with an agreement frequency of 17%. Therefore, rather than “Communications” being a desired learning outcome, it is likely that the students felt that the amount of communications learning outcomes were excessive, and are not desired learnings.

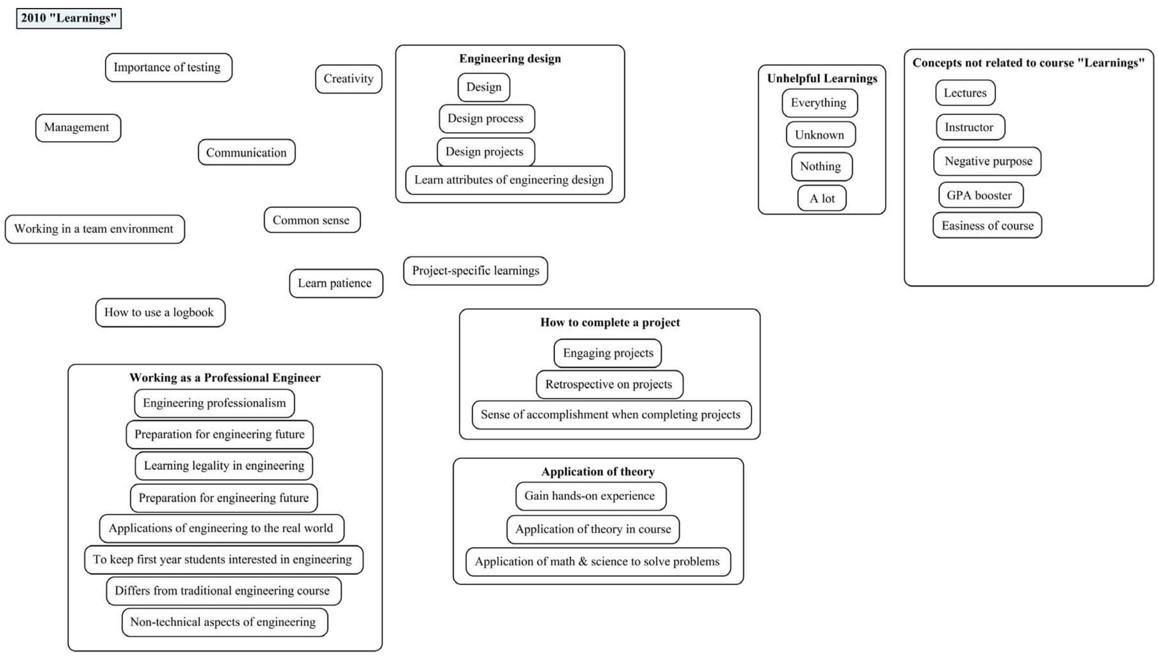


Figure 20: Selective Coded Responses to the 2010 Survey Results - Identifying “What did the students learn?”

In Figure 20, the concepts of “likes”, “learnings” and “purpose” are combined to form the category of “learnings” for the ENGG 200 course. In this instance, the prescribed learning outcomes which were most strongly emphasized (and explicitly stated throughout the course) were mentioned by the students, such as engineering design, communication, working in a team environment, and management. However, many of these prescribed concepts did not group into a larger category. The lack of grouping of these concepts suggests that they are not as interdependent as originally surmised. Additionally, many of the concepts grouped into the category “Working as a Professional Engineer”, which indicates that many of the students identified this as being a core component of the course, despite its lack of mention in the course outline. As with Figure 18, the students identified learning outcomes that were not prescribed in the course outline, or mentioned in the quantitative survey, such as learning patience, creativity, and the importance of testing. This lends further credence to the earlier statement that qualitative analysis, and the inclusion of student perspectives provides greater insight than assessing learning outcomes from a single, quantitative, perspective.

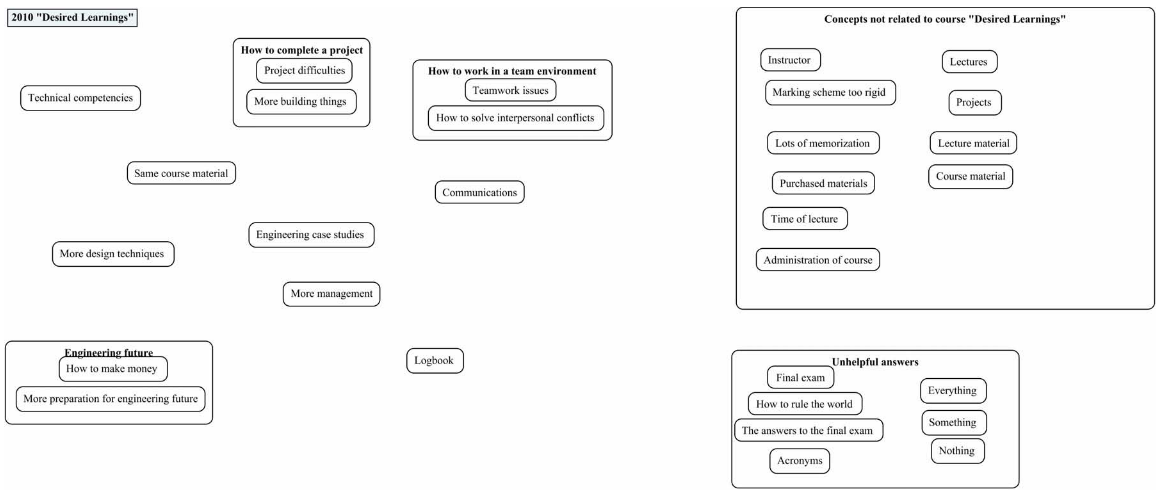


Figure 21: Selective Coded Responses to the 2010 Survey Results - Identifying “What did the students desire to learn?”

Figure 21 illustrates the desired learning outcomes of the course, which is a combination of the students “dislikes” and “liked to learn” concepts. In addition to the omitted category of concepts that are not related to “desired learnings”, an additional category was formed of unhelpful answers, where there was not enough detail in the students’ responses to understand the context in which they desired to learn more. In this figure, there are only one or two concepts forming each category, suggesting a wide variability in what the students would hope to learn from this course.

### 4.3.4 Theory Generation

In the final stage of Grounded Theory, the core category is identified and the theory is generated from the core category and its interactions with the other categories. In this thesis, the theories being generated are twofold. The primary theory sought to address the question of what the students learned in the ENGG 251/253 and ENGG 200 courses. Additionally, through a combination of the “learnings”, “desired learnings”, “likes” and "dislikes" for each course, the attributes (both in terms of learning outcomes and administrative details) of an effective first-year design and communications course will be identified, in conjunction with the fourth goal of this thesis. Finally, by combining the theories on the learning outcomes achieved by the courses, and establishing desired traits of a first-year design and communications course, the demonstration of Grounded Theory as a viable technique for enhancing learning outcomes assessment in engineering education will be achieved. Most notable of this contribution is that, by identifying the desired learning outcomes in the traits of a successful first-year design and communications course, Grounded Theory can further help to demonstrate compliance with CEAB Graduate Attributes criteria by demonstrating a continual strive for course improvement (CEAB, 2010).

For the ENGG 251/253 courses, no one category contains enough concepts, or connections with other categories to decidedly establish a core category. Therefore, all of the categories are combined to form the theory "The ENGG 251/253 courses achieved in teaching the students the following skills:"

- How to complete a project
- Learning independently
- Aspects of Professional Engineering
- Technical competencies
- Creative thinking
- Communication
- Working in a team environment
- Content that differs from traditional engineering courses.

It is interesting to note that, with the exception of communication and working in a team environment, the students identified highly different learning outcomes than those surmised by the course coordinator and researcher (as discussed in Chapter 3). This demonstrates the added value of qualitative research, and particularly Grounded Theory, in identifying learning outcomes that may be overlooked in quantitative assessments. The second theory to be generated from this study is to establish traits of an effective first-year design and communications course. For this, the learning outcomes achieved (as discussed above) is combined with the desired learning outcomes in Figure 19 to form the partial theory “An effective first-year design and communications course consists of the following aspects:”

- How to complete a project
- Learning independently
- Aspects of Professional Engineering
- Technical competencies
- The importance of testing
- Communication
- Working in a team environment
- Non-traditional course material that is relevant to an engineering career.

Additionally, by including the concepts that were unrelated to learning outcomes from Figures 11 and 12, other attributes regarding an appropriate workload, the delivery of information, marking expectations and marking transparency are also shown to be aspects of an effective first-year design and communications course.

For the ENGG 200 course, the core category is identified as “working as a Professional Engineer” due to its large number of related concepts. Combing the core category with the other categories, the theory would be “The ENGG 200 course achieved in teaching students how to apply theoretical principals of engineering design, communication, management, common sense, patience, testing, and working in a team environment in order to complete a project as a Professional Engineer”.

Combining the aspects of an effective first-year design and communications course from the 2009 study, with the learnings and desired learnings from the 2010 study, the theory of what aspects compose a successful first-year design and communications course is as follows:

- Learning independently
- Creative thinking
- Patience
- Aspects of Professional Engineering
- Technical competencies
- Engineering design
- Communication
- Management
- Logbook skills
- Working in a team environment
- Non-traditional course material that is relevant to an engineering career.

All of which are integrated and applied in order to complete a practical project that one might face as Professional Engineer.

Similarly to the implementation aspects of the course identified in Figures 11 and 12, Figures 13-17 provide additional, implementation and administration attributes that form an effective first-year design and communications course, and includes:

- The delivery of the material, most notably the manner in which lecture content in communicated.
- An appropriate balance of depth versus breadth of content delivered.
- Fair and transparent assessment methods.
- The amount of resources provided to the students to aid in their project completion.

- The amount of material that the student is required to purchase.
- The difficulty of the projects.

### 4.3.5 Verification with Focus Group Data

As shown in Figure 22, the majority of the key phrases identified by the focus group as being important aspects of a first-year design and communications course belong to the general theory described above, with the exception of accounting for discipline specific and interdisciplinary engineering.

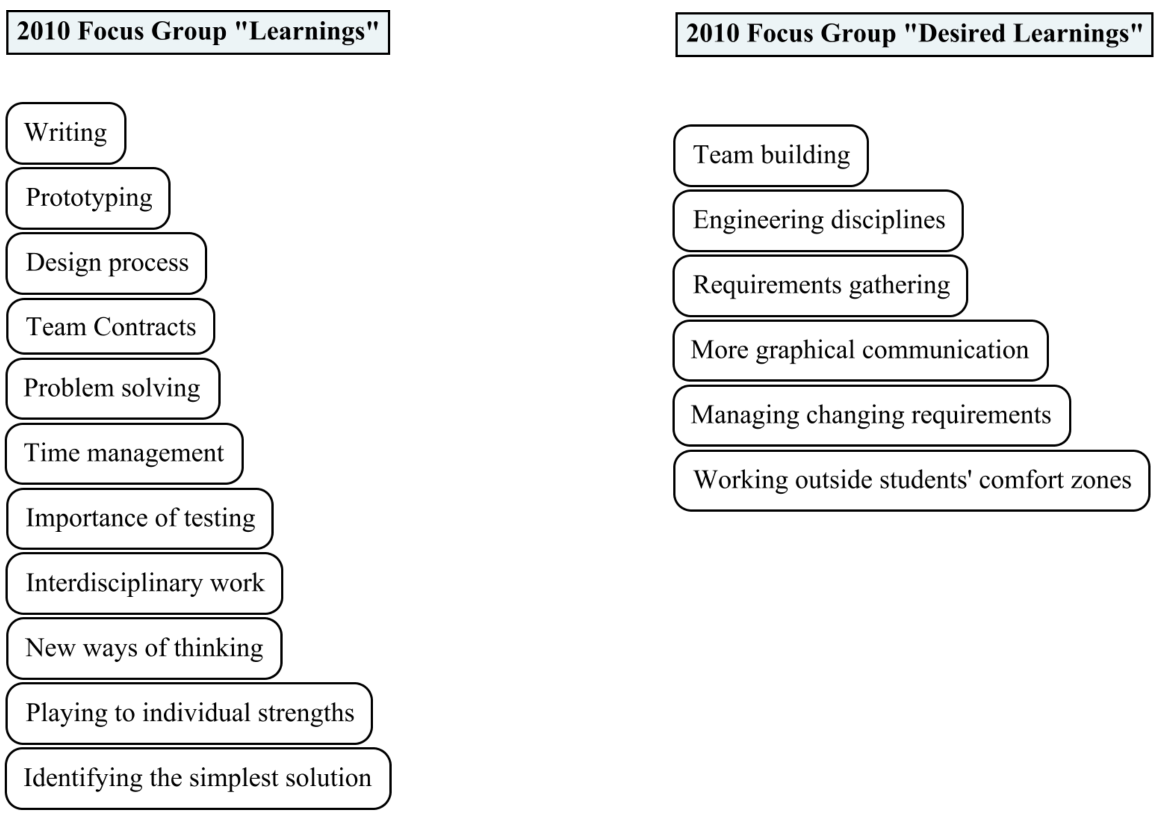


Figure 22: Open Coded Responses to the 2010 Focus Group - Identifying "What did the students learn?" and "What did they desire to learn?"

As the focus groups were voluntary, it is likely that the focus group participants were more enamoured with the course than an average student. However, this bias does not pose a threat to the validity of this study, since it is being used to confirm the results from the survey, which was completed by students who both loved and hated the course (as betrayed by the language and content of their comments).

## 4.4 Interview Analysis

In this section, the interviews with the instructors and teaching assistants were analyzed with Grounded Theory, in order to determine what learning outcomes were achieved by the ENGG 251/253 and ENGG 200 courses, from the perspective of the instructors.

### 4.4.1 Open Coding / Creation of Codes

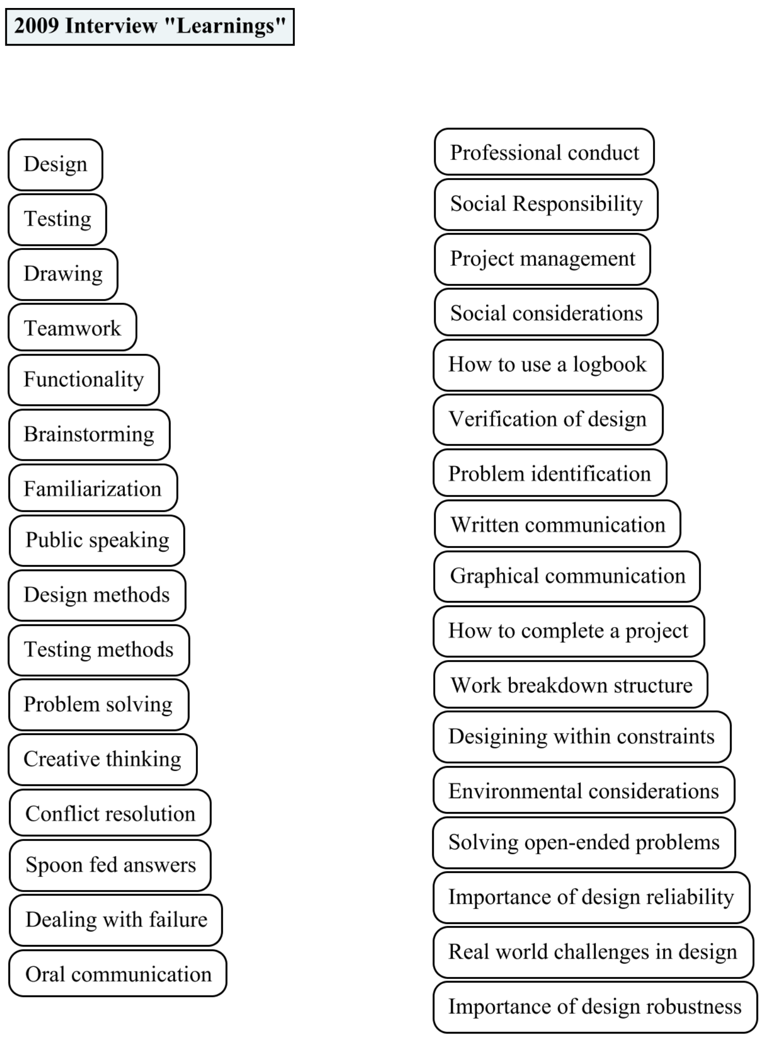


Figure 23: Open Coded Responses to the 2009 Interviews - Identifying “What did the students learn?”

Figure 23 shows what the instructors and teaching assistants have identified as what the students have learned in the ENGG 251/253 courses.

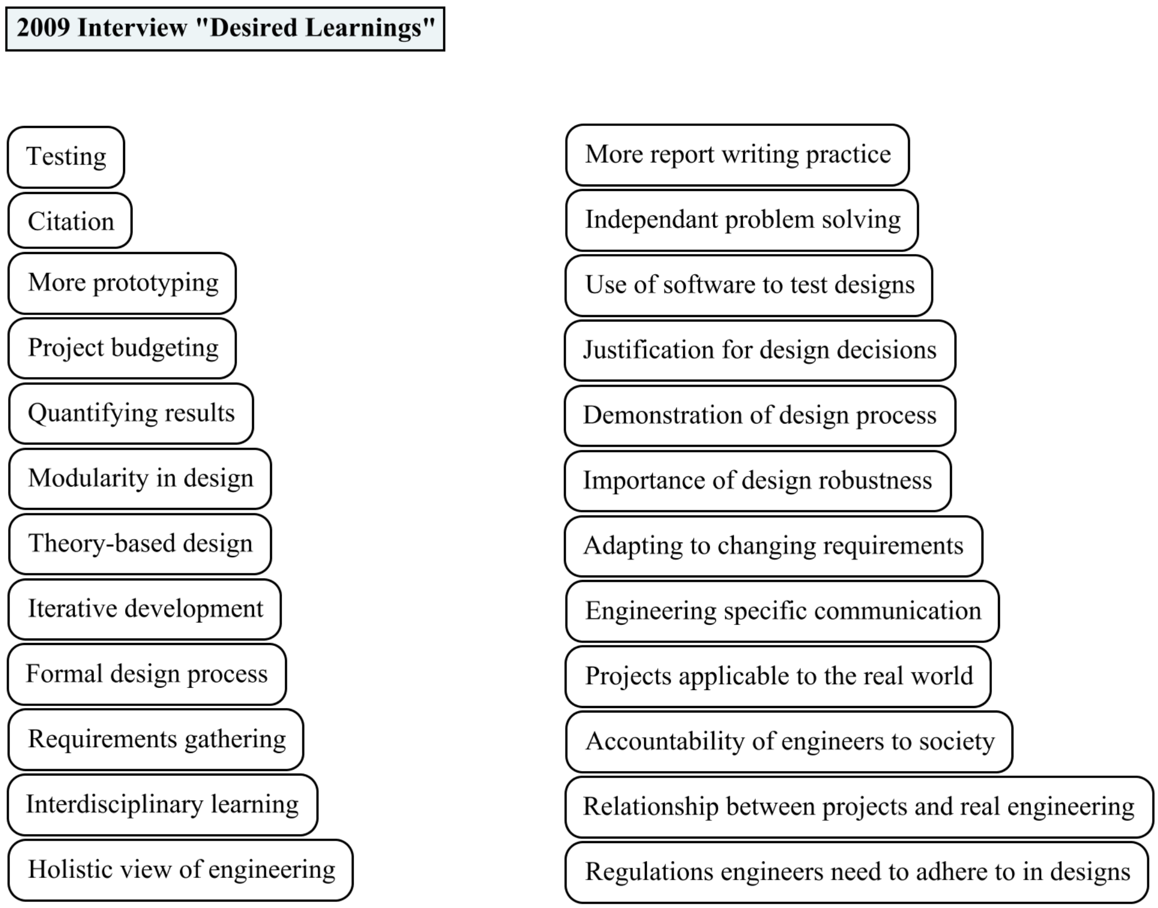


Figure 24: Open Coded Responses to the 2009 Interviews - Identifying “What should students learn / what should they have learned?”

In Figure 24, the instructors’/TAs’ responses to the questions “what should the students have learned” and “what should the students learn in future design courses” is illustrated. The majority of the codes presented include the keywords of “design”. This is confirmatory of anecdotal evidence that spawned the new emphasis of design in the ENGG 200 course.


Figure 25: Open Coded Responses to the 2010 Interviews - Identifying “What did the students learn?”

Figure 25 shows the keywords extracted from interviews with the instructors/TAs, regarding what the students learned in the ENGG 200 course. The responses appear to be numerous and widely varied.

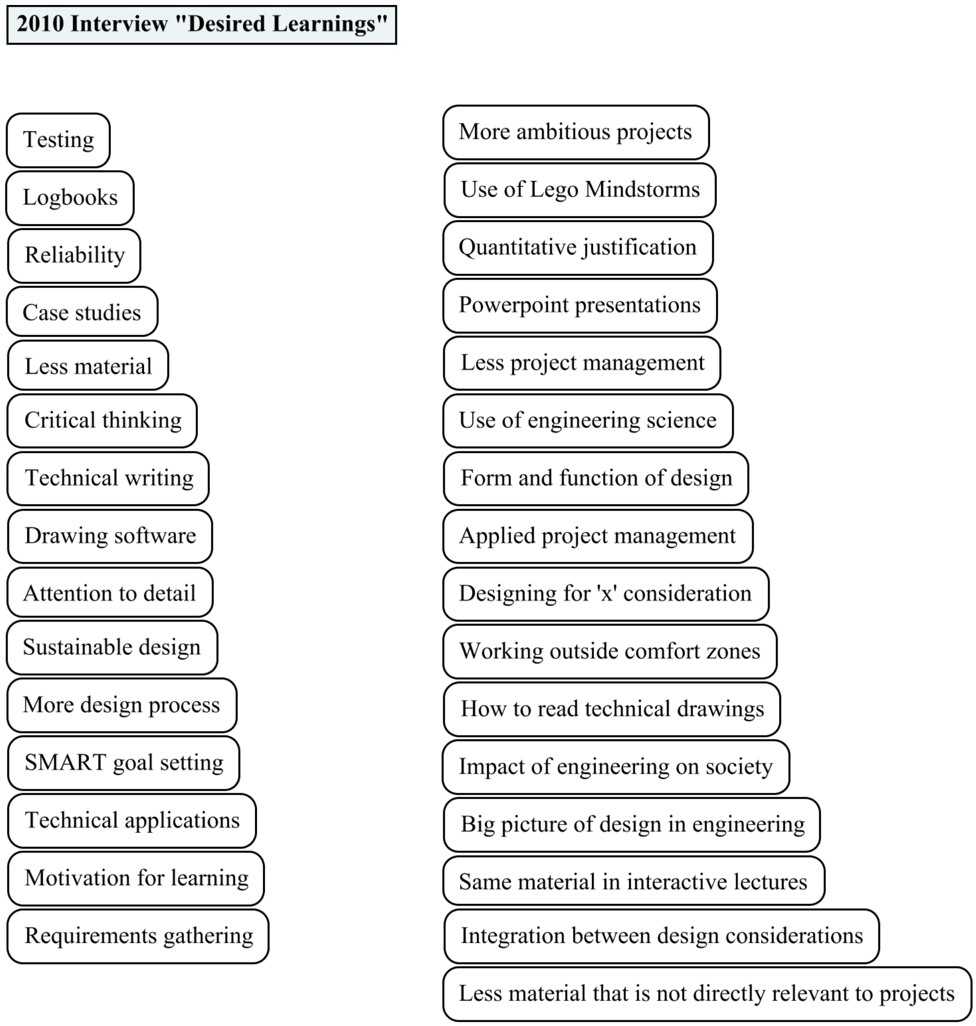


Figure 26: Open Coded Responses to the 2010 Interviews - Identifying “What should students learn / what should they have learned?”

Figure 26 shows what the instructors desired for the students to learn from the design course. Similarly to Figure 24, the instructors/TAs have identified several more desired learnings than the students. This could be indicative of the students having less recognition of what they should be learning than the instructors, or of the increased potential for insightful answers offered by interviews in comparison to surveys.

### 4.4.2 Axial Coding / Creation of Concepts

This section illustrates the axial coding process of the interview results.

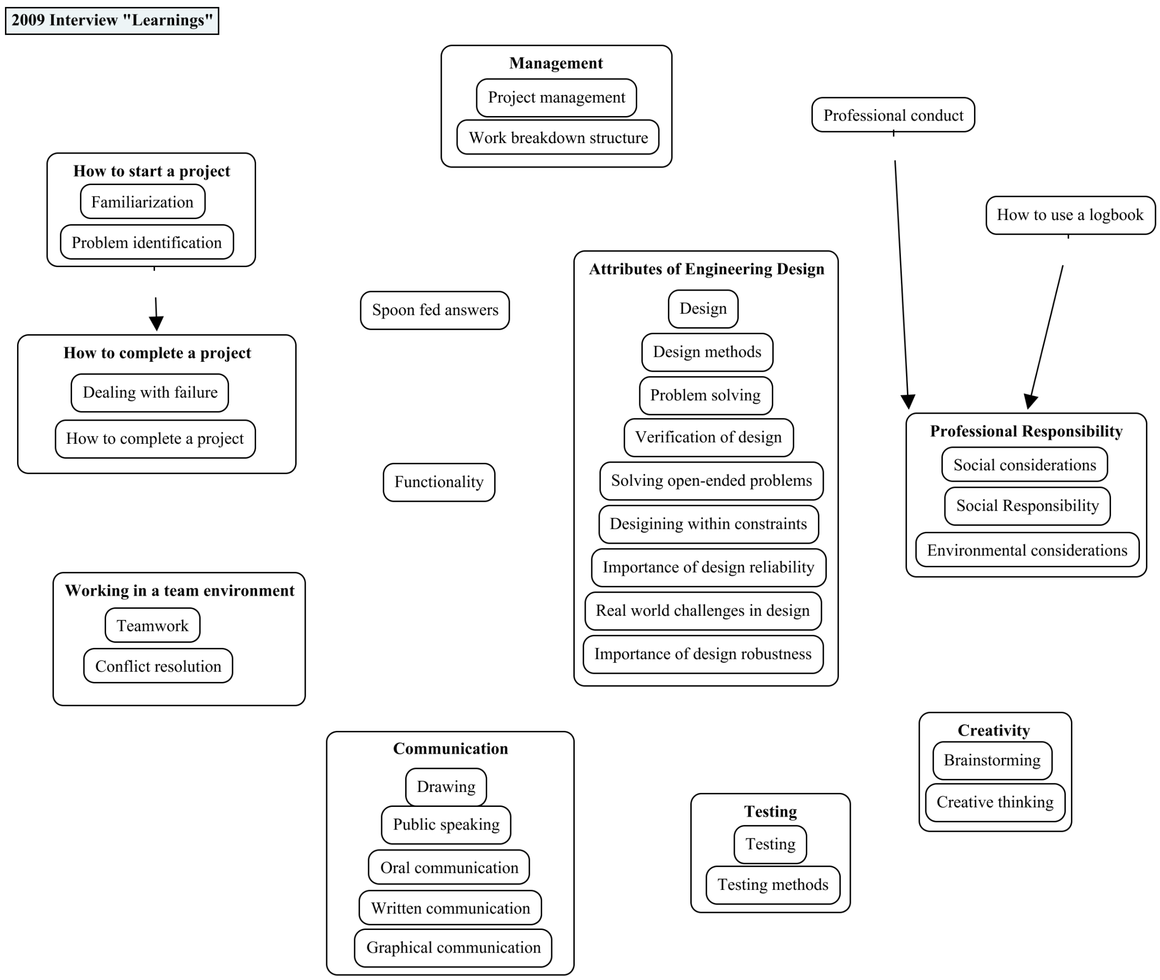


Figure 27: Axial Coded Responses to the 2009 Interviews - Identifying “What did the students learn?”

Figure 27 shows the concepts generated to address what the students learned from the ENGG 251/253 courses.  Contrary to the learnings stated by the students in the previous section, the instructors have focused largely on the course learning outcomes as declared by the course coordinator, namely engineering design, working in a team environment, communication, management, and professional responsibility.

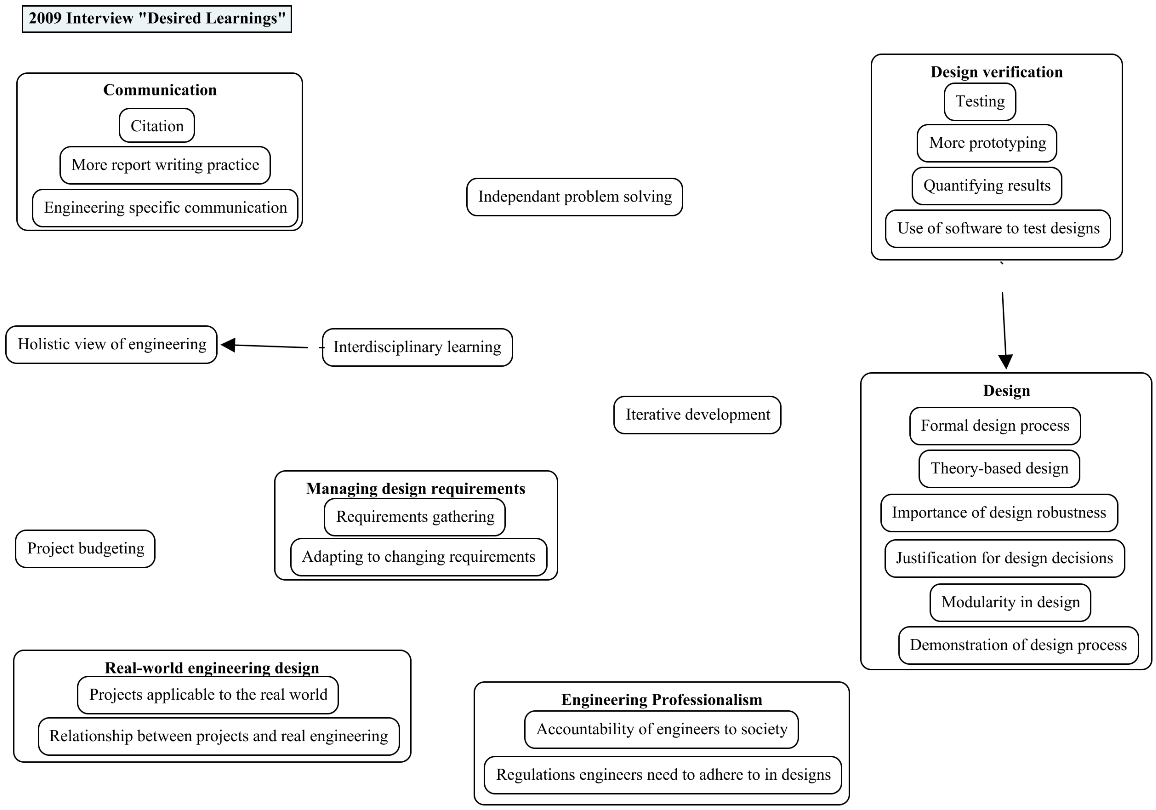


Figure 28: Axial Coded Responses to the 2009 Interviews - Identifying "What should students learn / what should they have learned?"

Figure 28 illustrates the concepts that the instructors/TAs desired the students to learn/have learned in the ENGG 251/253 courses. Comparing to Figure 27, the instructors/TAs desired the students to learn largely similar skills as to those they have already learned, but with greater depth in some of the skills, while omitting some of the achieved learnings previously mentioned in Figure 27.

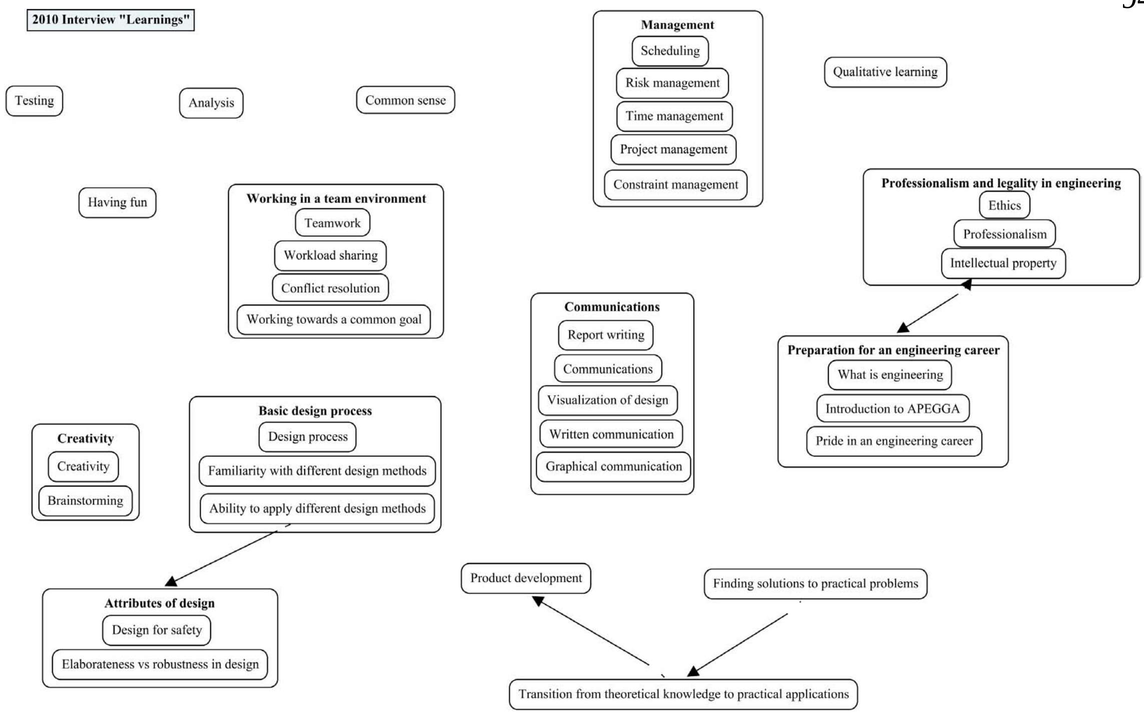


Figure 29: Axial Coded Responses to the 2010 Interviews - Identifying “What did the students learn?”

In Figure 29, the achieved learning outcome concepts are shown.  Once again, a wide variety of learning outcomes are mentioned, the majority of which correspond to the intended learning outcomes designated by the course coordinator.

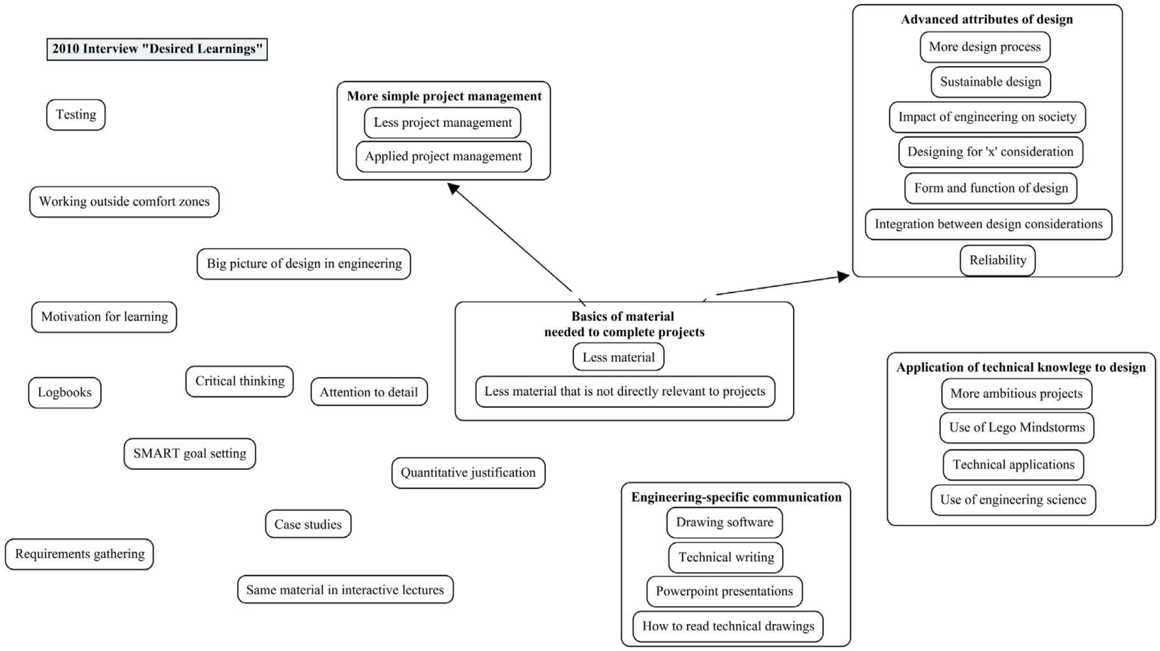


Figure 30: Axial Coded Responses to the 2010 Interviews - Identifying “What should students learn / what should they have learned?”

Figure 30 illustrates the concepts of what the instructors/TAs desired the students to learn. Contrary to the desired learning outcomes of the ENGG 251/253 course, the instructors/TAs identified a wide variety of desired learning outcomes. While some of the concepts express a desire for the students to learn existing learning outcomes in more detail, other concepts describe a desire for the existing material to be taught in less detail.

### 4.4.3 Selective Coding / Creation of Categories

In this section, the concepts are further generalized into categories, identifying the "learnings" and "desired learnings" of both design course implementations.

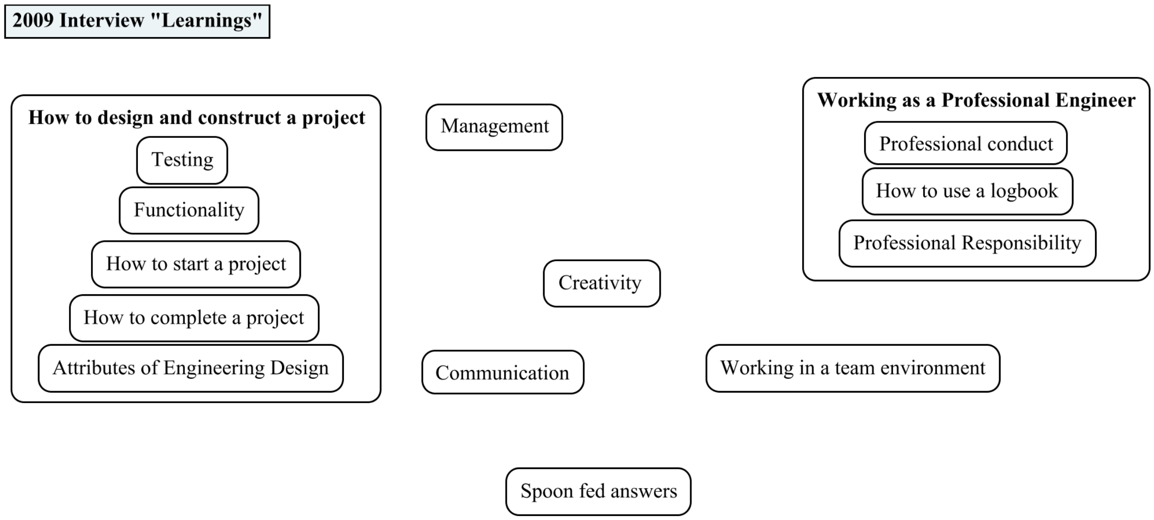


Figure 31: Selective Coded Responses to the 2009 Interviews - Identifying "What did the students learn?"

In Figure 31, the codes and concepts from Figures 23 and 27, respectively, are greatly simplified to form two major categories, working as a professional engineer and how to design and construct a project, as well as five minor categories: management, creativity, communication, working in a team environment, and learning the behavior of being spoon fed answers (or not learning how to think independently). These are still largely consistent (with the exception of being spoon fed answers) with the intended learning outcomes dictated by the course coordinator.

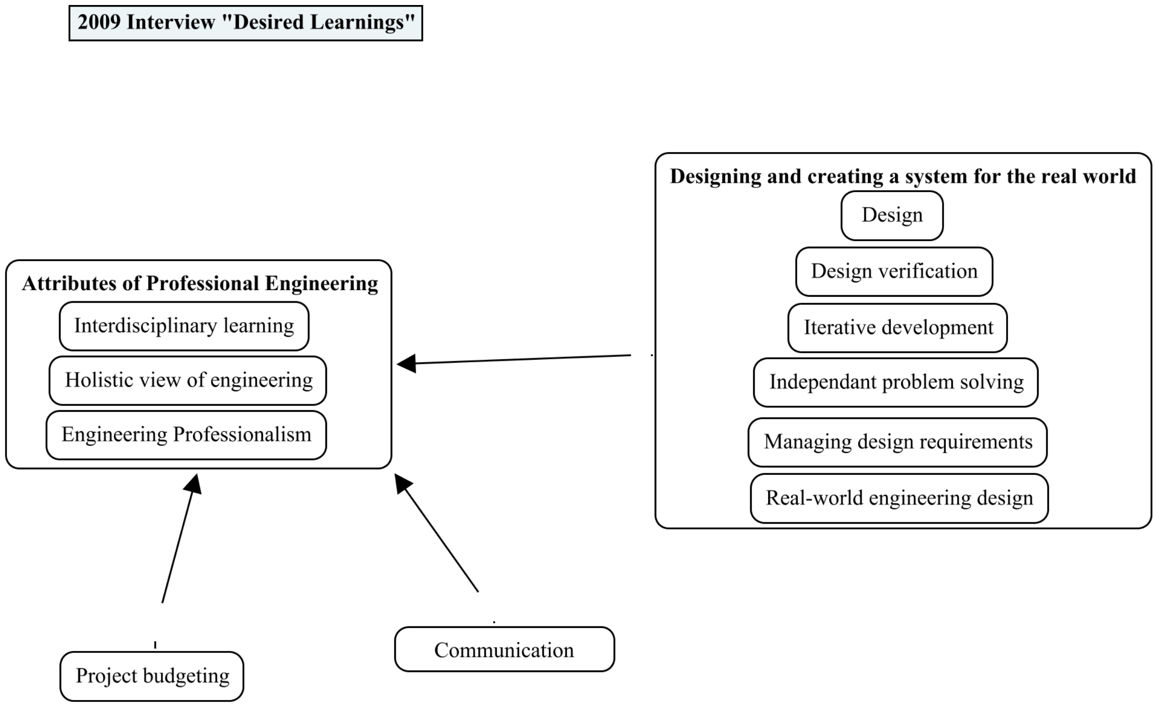


Figure 32: Selective Coded Responses to the 2009 Interviews - Identifying “What should students learn / what should they have learned?”

In Figure 32, the generalized categories of the desired learning outcomes for the ENGG 251/253 courses are illustrated. Once again, the concepts from Figure 27 have been efficiently condensed into four categories: project budgeting, communication, designing and creating a system for the real world, and attributes of Professional Engineering. Where originally the number of codes and concepts were highly varied, the selective coding process shows how these concepts are tightly interrelated. This is in support of the claims made in Chapter 3, regarding the simplification of learning outcomes assessment by considering the correlations between learning outcomes.

Figure 33 illustrates the categories generated regarding the achieved student learning outcomes from the ENGG 200 course, while Figure 34 illustrates the categories identifying the desired learning outcomes of the ENGG 200 course. Interestingly, a core category of both figures is the preparation for Professional Engineering, indicating that the instructors perceived this to be a key learning outcome of the course, but they strive to provide even more instruction on this topic.

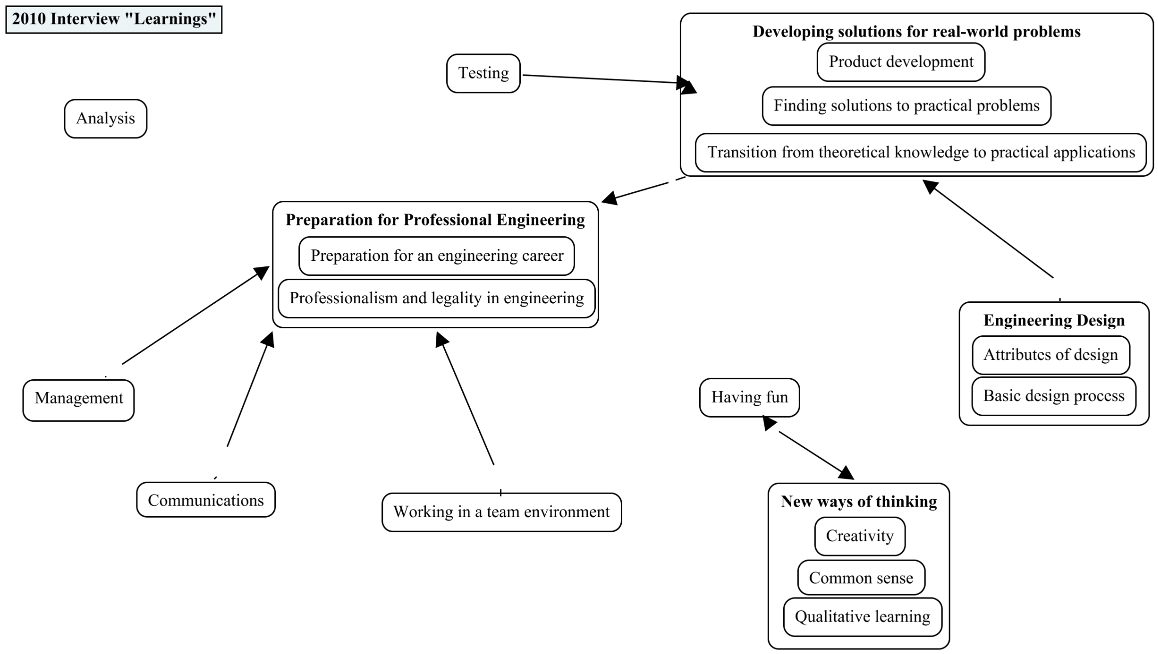


Figure 33: Selective Coded Responses to the 2010 Interviews - Identifying “What did the students learn?”

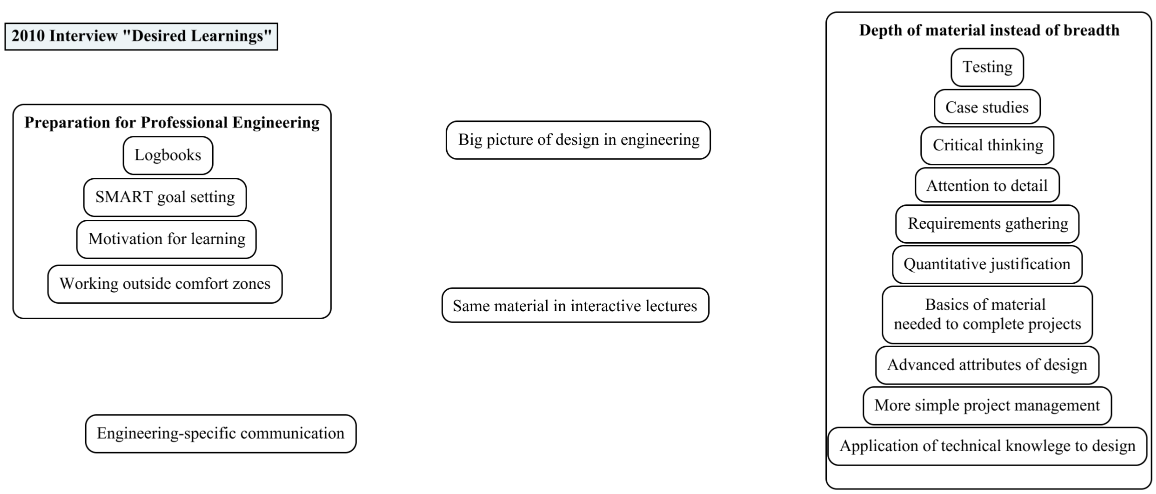


Figure 34: Selective Coded Responses to the 2010 Interviews - Identifying “What should students learn / what should they have learned?”

### 4.4.4 Theory Generation

From Figure 31, two core categories have been identified, and working as a Professional Engineer. Therefore, the theory generated would be “the ENGG 251/253 students learned how to apply management, creativity, communication, and working in a team environment, in order to design and construct a project in a Professional Engineering capacity.”

From Figure 33, while there are numerous categories identified by the instructors, they generally converge on the core category of preparation for Professional Engineering. Separately, an additional set of categories exists focused on the learning environment and its affect on the enjoyment of learning. This generates the theory “the ENGG 200 course employed a fun and creative learning environment, through which the students learned the necessary skills in communication, management, engineering design, testing, and working in a team environment, in order to enable the students to develop solutions for real-world problems, in preparation for their careers as Professional Engineers”.

Finally, in combining Figures 31-34, according to the instructors/TAs, an effective first-year design and communications course should teach the students the following skills:

- Management
- Creativity
- Communication
- Working in a team environment
- How to design and construct a project
- Analysis
- Testing
- Engineering design
- New ways of thinking

Moreover, a successful first-year design and communications course should teach the combination and application of these skills to the extent that they will be most often applied in a real-world, Professional Engineering environment, in an interactive learning environment.

### 4.5 Discussion of Results

This section discusses the theories generated through the Grounded Theory analysis, and describes how this chapter has succeeded in achieving its thesis goals.

#### 4.5.1 Comparison of Survey/Student and Interview/Instructor Theories

From the 2009 study, the students identified the key learning outcomes to be as follows:

- How to complete a project
- Learning independently
- Aspects of Professional Engineering
- Technical competencies
- Creative thinking
- Communication
- Working in a team environment
- Content that differs from traditional engineering courses.

In contrast, the instructors identified the following learnings:

- The behavior of being spoon fed answers
- Management
- Creativity
- Communication
- Working in a team environment
- How to design and construct a project
- Working as a Professional Engineering

While the course coordinator, students, and instructors all agreed that communications and working in a team environment were learned by the students in these courses, there is no unanimous agreement to the remainder of the achieved learning outcomes. For instance, while both the students and instructors identified creativity as a learned outcome, it was not identified by the researcher in the quantitative survey of Chapter 3, nor by the ENGG 251/253 course outlines. This demonstrates the added benefit of qualitative analysis at gathering learning outcomes that were not perceived by the course coordinator or researcher. Furthermore, the discord between the students' perceptions that they were being learning to think independently, versus the instructors' perceptions that the students were learning the behavior of being spoon fed the answers provides an interesting insight to the different perspectives on the effects of content delivery.

Similarly, the students from the 2010 study identified the following learning outcomes achieved by the ENGG 200 course:

- apply theoretical principals of:
    - engineering design
    - communication
    - management
    - common sense
    - patience
    - testing
    - working in a team environment
- how complete a project
- working as a Professional Engineer

whereas the instructors/TAs identified the following learning outcomes:

- engineering design

- communication
- management
- testing
- working in a team environment
- develop solutions for real-world problems
- working as a Professional Engineers

In this instance, the course coordinator, students and instructors/TAs largely identified the same learning outcomes achieved by the ENGG 200 course, despite the fact that some learning outcomes, such as ‘patience’ were not identified in the course outline.

**4.5.2 Reflection on First-year Design Courses**

By combining the student and instructor perspectives, the following skills are/should be present in an effective first-year design and communications course:

- Learning independently
- Creative thinking
- Patience
- Aspects of Professional Engineering
- Technical competencies
- Engineering design
- Communication
- Management
- Logbook skills
- Working in a team environment
- Non-traditional course material that is relevant to an engineering career.
- How to design and construct a project
- Analysis
- Testing

However, as indicated in the student responses in Figures 10-13, the way in which these skills are taught is of high importance, and should be communicated in an interactive manner, at a level that is both suitable for first-year engineering students and applicable to the general tasks of a Professional Engineer, and assessed with transparency and consistency.

### 4.5.3 Implications for Future Assessments

While the time and labour required for qualitative assessments is generally greater than for quantitative assessments (Pope et al., 2000), qualitative assessments has the potential to identify more learning achievements than a rigid quantitative study, as has been demonstrated in this chapter. Furthermore, with the advent of technology, software such as NVivo can be utilized to aid in the Grounded Theory process (Bringer et al., 2006). Therefore, Grounded Theory analysis can be used to help identify the learning outcomes achieved by a course (in compliance with CEAB Graduate Attributes criteria) from a wide range of perspectives, thus offering greater insight into the actual learning outcomes achieved. However, since this qualitative technique elicits an unstructured response, the participants may overlook learning outcomes achieved that they would have agreed with in a quantitative assessment (as shown in Chapter 3). Therefore, qualitative assessment would best serve to augment quantitative assessments rather than replacing them completely.

## 4.6 Summary

In this chapter, Grounded Theory Analysis was applied to open-ended surveys as well as interview and focus group transcripts, in order to determine what the students learned in the first-year design and communications courses. Through this analysis, a variety of learning outcomes were identified by the students and the instructors, not all of which corresponded to the learning outcomes established by the course coordinators and research from the quantitative survey.

By comparing what the students liked and disliked about the course, as well what the students and instructors/TAs identified as the courses' achieved learnings and desired learnings, the traits of a successful first-year design and communications course were identified, both in the skills that should be learned by the students, and the manner in which the skills should be taught and assessed. Furthermore, by gathering data from both students and instructors/TAs, the variance in perceptions of the course's learning outcomes can be examined and create a more holistic picture of what learning outcomes have been truly achieved.

Through this chapter, Grounded Theory has been demonstrated as a viable technique for enhancing learning outcomes assessment in engineering education, as well as for identifying areas where the course can be improved.

# CHAPTER 5: SUMMARY AND CONCLUSIONS

The focus of this thesis was to demonstrate new applications of quantitative and qualitative techniques, specifically Factor Analysis and Grounded Theory Analysis, as means to assess learning outcomes in engineering education. More specifically, this thesis sought to accomplish the following goals:

1. Demonstrating Factor Analysis as a viable technique for simplifying learning outcomes assessment in engineering education.
2. Demonstrating Grounded Theory as a viable technique for enhancing learning outcomes assessment in engineering education.

In order to demonstrate these new quantitative and qualitative techniques in the field of engineering education, a case study evaluating two first year design courses was used as a proof-of-concept for the Factor Analysis and Grounded Theory techniques. Through these techniques, the following additional goals were sought:

3. Identifying learning outcomes achieved by the ENGG 251/253 and ENGG 200 design and communications courses.
4. Establishing attributes of an effective first year design and communications course.

In Chapter 2, the background of the courses evaluated in this thesis were described, and the technical backgrounds of data gathering techniques, Factor Analysis, and Grounded Theory Analysis were presented.

In Chapter 3, the development of a quantitative survey and its analysis using Factor Analysis was described. While the plain statistical data helped to assess the extent to which the perscribed learning outcomes had been acheived, Factor Analysis demonstrated how the graduate attributes, as described by the CEAB, can be taught in tandem, and thus can be assessed together. This leads to the conclusion that, in certain situations, Factor Analysis can be applied to help simplify the CEAB assessment process, by enabling institutions to combine their assessment procedures for correlated attributes. Therefore, it is concluded that the Factor Analysis technique can be used to simplify learning outcomes assessment in engineering education.

In Chapter 4, Grounded Theory Analysis was applied to open-ended survey results, as well as interviews and focus groups. This study had a primary focus of determining what the students learned in the ENGG 251/253 and ENGG 200 courses, and a secondary focus of determining attributes of an effective first-year design and communications course. This chapter demonstrated that by using qualitiative analysis, specifically Grounded Theory, enriching information regarding achieved learning outcomes could be gained. Furthermore, by gathering qualitative data from the student perspective on what they liked and disliked about the course, as well as the learnings and desired learnings identified by both the students and the instructors, attributes of a favourable and effective first-year design and communications course can be established. The presence of desired learning outcomes could further aid compliance with the CEAB Graduate Attributes criteria by providing evidence of future directions for course improvements. By identifying learning outcomes that may be overlooked in quantitative assessments, establishing attributes of an effective first-year design and commmunications course, and providing simplified methods of evaluating learning outcomes, it is concluded that Grounded Theory is a viable technique for enhancing learning outcomes assessment in engineering education, by supplementing quantitative assessments.

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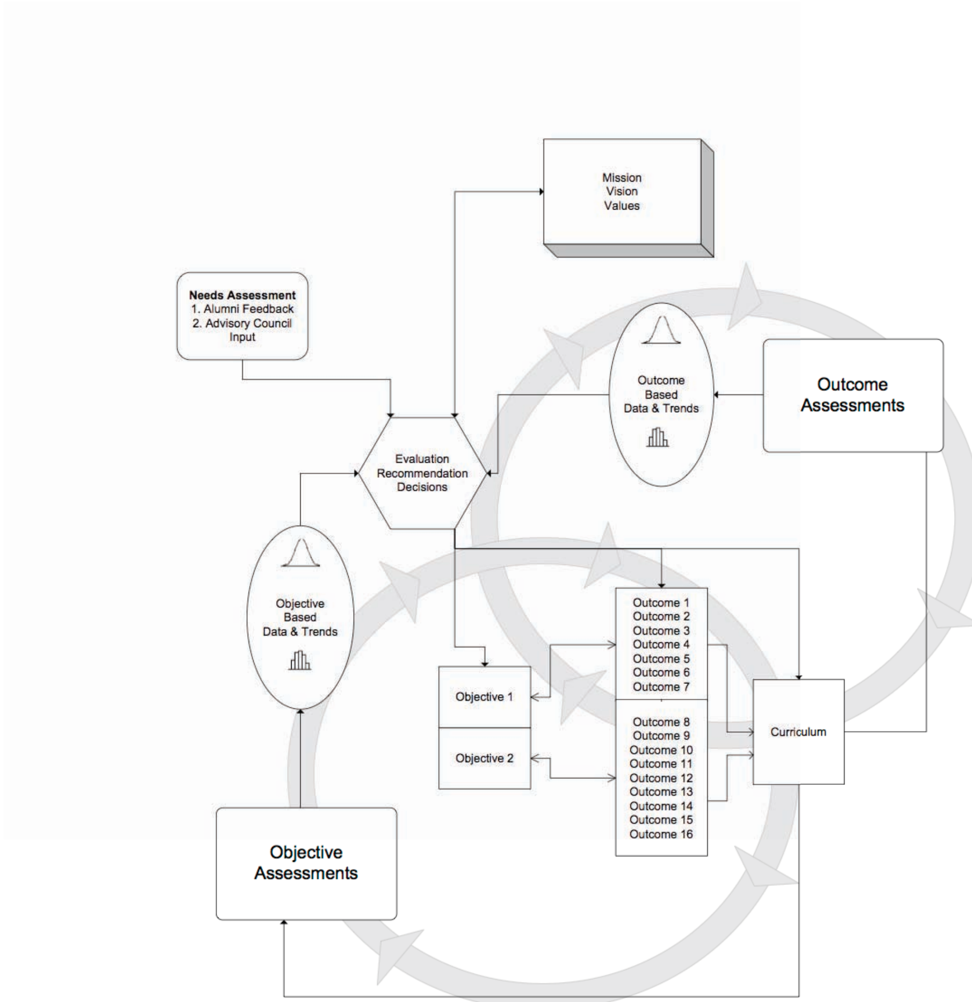
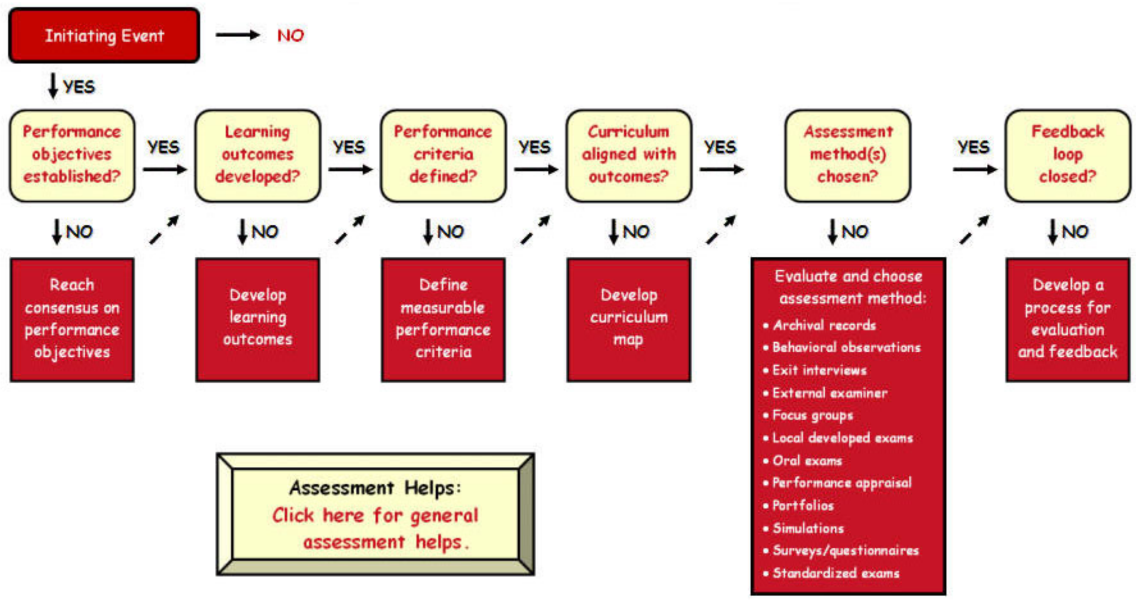
# APPENDIX A: ABET ASSESSMENT FLOWCHARTS




(BAE, 2011)


Initiating Event
NO
YES
Performance objectives established?
YES
Learning outcomes developed?
YES
Performance criteria defined?
YES
Curriculum aligned with outcomes?
YES
Assessment method(s) chosen?
YES
Feedback loop closed?
NO
Reach consensus on performance objectives
Develop learning outcomes
Define measurable performance criteria
Develop curriculum map
Evaluate and choose assessment method:
• Archival records
• Behavioral observations
• Exit interviews
• External examiner
• Focus groups
• Local developed exams
• Oral exams
• Performance appraisal
• Portfolios
• Simulations
• Surveys/questionnaires
• Standardized exams
Develop a process for evaluation and feedback
Assessment Helps:
Click here for general assessment helps.

(ABET, 2011)

# APPENDIX B: COURSE OUTLINES

**ENGG 251 $**
**Engineering Design and Communication 1**
**Course Outline**

Engineering 251 H(1-4.5) - Design and Communication I

The principles of engineering design, engineering graphics and written communication learned within a hands-on project-based experience for engineering students. Safety in the laboratory; working in a team environment; core skills for engineering students; process of engineering design; graphical communication: theory of projection, multiview representation, descriptive geometry, sketching, information for manufacturing; written communication: style, format, organization, preparation and presentation skills. Real-life examples of design and engineering practice across all disciplines. Core competencies will be learned primarily within the context of team-based design projects.

Note: Not open to students with credit in Engineering 215.

**Course Coordinators and Class Details**

Dr. Daryl Caswell
Office: ICT 255
Phone: 210-9886
Email: djcaswel@ucalgary.ca

Dr. Clifton Johnston
Office: ICT 254
Phone: 210-9887
Email: johnston@enme.ucalgary.ca

Lecture periods: (Room EN A 201)

L01 Tues. 11:00 AM to 11:50 AM

L02 Wed. 12:00 PM to 12:50 PM

Laboratory periods: (Rooms ICT 219, 220, 221, 224)

| | |
|---|---|
| B01 to B04: | Tues. 12:30 AM to 2:00PM<br>Thurs. 11:00 AM to 2:00 PM |
| B05 to B08: | Mon. 11:00 AM to 2:00 PM<br>Wed. 11:00 AM to 12:30 PM |
| B09 to B12: | Tues. 2:00 PM to 5:00PM<br>Fri. 11:00AM to 12:30 PM |
| B13 to B16: | Tues. 11:00 AM to 12:30 PM<br>Thurs. 2:00 PM to 5:00 PM |

**Textbooks and Tools**

The following texts and tools are required for the course and are available through the U of C Bookstore:
1. A special edition of "Technical Drawing" by Giesecke et al., Prentice Hall.
2. A special set of drawing tools is available for this course from the Bookstore.
3. "Power Tools for Technical Communication" by David A. McMurrey. (Harcourt, 2002)

**Grading Criteria**
Grading in this course will different from that in some other engineering courses because *many communication and design problems have answers which cannot be deemed 'right' or 'wrong', but rather 'appropriate' or 'inappropriate'*

Satisfactory performance (a passing grade) requires mastery of core competencies in the following categories:

Category 1 - Ability to function as a member of a team

Category 2 - Ability to contribute effectively to product or process design

Category 3 - Ability to communicate effectively using the written word

Category 4 - Ability to communicate effectively through the medium of drawing

Most graded work will receive one of the following assessments:
- Excellent (A)
- Good (B)
- Unsatisfactory (D)
- Not Submitted (F)

Students who receive an "Unsatisfactory" in any core competency will have the opportunity to improve their performance in two ways. The first is an opportunity during scheduled times at mid-term (Nov. 13, 6:00 PM to 10:00PM) and end of term (Dec. 3, 6:00PM to 10:00 PM) to redo materials from the problem areas. Should this not result in a "Good" performance, and the student has at least 50% in the course, he/she must successfully fulfill the requirements of those remaining unsatisfactory core competencies by the end of ENGG 253. No student will receive a grade higher than F in ENGG 253 unless s/he has demonstrates all the core competencies as outlined in the course outlines for ENGG 251 and ENGG 253. Should the student have a grade of less than 50% in the course, he/she will receive a grade of F for ENGG 251.

**Grade Distribution**

| Project | Description | Design | Drawing | Comm |
|---|---|---|---|---|
| Leave No Trace | Written Design Justification | 2% | | 2% |
| Perpetual Motion A | Loci and Orthographic | | 4% | |
| | Written Instructions | | | 2% |
| Perpetual Motion B | Written Critique | | | 2% |
| DFX #1 | Written Instructions | | | 2% |
| | Oral Report | 2% | | 2% |
| | Isometric Drawing | | 4% | |
| | DFX | 4% | | |
| Library Research | Bibliography | | | 2% |
| DFX #2 | 1 & 2 Point Perspective | | 8% | |
| | Testing for DFX, Targets/Specs | 6% | | |
| Main Project | Loci | | 4% | |
| | Conceptual Designs | 2% | | |
| | Proposal Outline | | | 2% |
| | Symmetry and Tessellations | | 8% | |
| | Progress Status Report | 2% | | 2% |
| | Final Proposal | | | 4% |
| | Sign, Image & Symbol | | 4% | |
| | Final Oral Report | 4% | | 4% |
| | Final Project Report | 12% | | 10% |
| | | 34% | 32% | 34% |

**Assignments submitted after the deadline will only be accepted under exceptional circumstances and at the discretion of the Course Instructor.**

**Core Competencies**

*Visual Communication Core Competencies:*

- Sketching
- Orthographic projection
- Isometric projection
- Perspective (one and two point)
- Symmetry (axial, rotational) & Tessellation
- Loci (motion)
- Symbol, image, sign
- Dimensioning and Tolerancing
- Rudimentary knowledge of a high level CAD package (e.g. Solidworks, Autocad)

Competence in these areas will carry over into the Winter session where students will study descriptive geometry and its application (Auxiliary views, Topographic Mapping, etc. as time permits)

*Engineering Design Core Competencies:*

- The architecture of creative problem solving
- Problem/ Need identification
- Familiarization/information gathering
- Roles of client, resources (library, tech, marketplace)
- Solution Generation (
  - Lateral thinking
  - Role of and access to intuition
  - Brainstorming (
- Functionality
- Product Design Specification
- Constraints/Requirements/Targets/Specs
- Feasibility
- Role of evidence/verification/analysis/assessment
- product life cycle (DFX case studies)
- project management/documentation
- role of build/test
- teamwork training
- design reviews
- real world, team oriented design project(s)

*Written Communication Core Competencies:*

- Basic writing skills as required for success in post-secondary education
- Specific writing skills as they pertain to technical report writing
    - Concise, clear and accurate content
    - Descriptions
    - Summaries
    - Instructions
    - Audience analysis
- Use of graphics with text
- Concepts of heading format
- Page and document design
- Research strategies
- Proposals
- Understanding the writing process in project assignments
- Business letters and memos (including transmittals)
- Documentation of sources
- Revision and editing techniques
- Evaluation of electronic resources
- Oral presentations
- Strategies for success with group assignments

**Description (Please see the Student Manual for further details on the course)**
Substantial team-based projects are at the core of this course. Scheduled class time (lecture, laboratory) will be used for a variety of components including lectures, seminars, and in-class project work. Because meeting time, working space, and opportunities for feedback are at a premium, **full attendance at scheduled class times is expected.**

It has been said that a design engineer is only as good as the failures he/she has experienced. The goal of this course is to allow the students to experience failure as a part of learning to do good design. Therefore, the focus of the course is inquiry-based teaching and learning, where the search for the solution is often more important than the solution itself. This requires that both students and faculty adopt non-traditional roles in the laboratory and classroom.

**Structure of Lectures and Labs.**
Although the times available for ENGG 251/253 are given the titles of Lectures and Laboratories, the actual use of the time ! will vary greatly depending on the need. All lecture and lab times will be used every week to allow sufficient time to ! practice drawing, develop designs and to learn from other students. Most portfolio work must be completed in the lab room, during the lab session. The actual design projects will require work outside of lab time. !
In order to adapt to the large size of the class without neglecting the need for collaborative learning, some fairly unusual methods and requirements will be employed: !

**Lectures**

- If a group is selected to make a presentation and is absent or unprepared, each member of the group will be assessed a penalty (strike). If an individual member of a team is not present, that person alone will receive a strike. **Any student receiving three strikes, individual or group, will be assessed an 'F' for the course.**
- Following each successful presentation, each member of the group will sign the instructor's logbook as evidence of individual contribution. Any group members absent will be penalized with a strike. This loss cannot be regained unless an exceptional reason for absence is presented.
- Each entry into the student portfolio must be signed or stamped by a member of the instructional team in order to get credit for the work. The students will be responsible for keeping track of this work which will make up the drawing and writing portfolios for each student.

**Labs**

- The working groups will be coordinated with the lab sessions. Working groups are expected to work together in the lab, although much of the work handed in at the end of the lab will be marked individually.
- It is expected that students will complete their drawings/writing/design through consultation with the course coaches and other students.

## Note:

1. + **Safewalk/Campus Security: 220-5333:** Campus Security will escort individuals day or night. Use any campus phone, emergency phone or the yellow phone located at most parking lot pay booths.
2. **Withdrawal and Refunds:** Until September 20, 2002 a student will be able to drop a course and get a full refund with no record of the course on their transcript. **AFTER SEPTEMBER 20, 2002 THERE WILL BE NO REFUNDS.**
3. **Freedom of Information:** Please see the attached " Policy for Implementation of FOIP Requirements"
4. **Academic Commissioner:** Chris Blaschuk (enggrep@su.ucalgary.ca) – 220-3913

**ENGG 253 $**
**Design and Communication II**
**Course Outline**

Engineering 253 H(1-4.5) - Design and Communication II

A continuation of Engineering 251. Students will perform more advanced team-based projects that integrate mathematical, scientific and engineering knowledge and skills. Issues that play critical roles in engineering design will be introduced, such as project management, societal and environmental awareness, health and safety, design for safety, sustainable development, information access.

**Prerequisite:** Engineering 251.

**Course Coordinators and Class Details**

Dr. Daryl Caswell
Office: ICT 255
Phone: 210-9886
Email: djcaswel@ucalgary.ca

Dr. Clifton Johnston
Office: ICT 254
Phone: 210-9887
Email: johnston@enme.ucalgary.ca

Lecture periods: (Room EN A 201)

L01 Tues. 1:00 AM to 1:50 PM

L02 Thurs. 11:00 PM to 11:50 AM

Laboratory periods: (Rooms ICT 219, 220, 221, 224)

| | |
|---|---|
| B01 to B04: | Wed. 2:00 PM to 5:00PM<br>Thurs. 12:30 AM to 2:00 PM |
| B05 to B08: | Tues. 9:30 AM to 11:00 AM<br>Thurs. 2:00 PM to 5:00 PM |
| B09 to B12: | Tues. 3:30 PM to 5:00PM<br>Fri. 9:00AM to 12:00 PM |
| B13 to B16: | Mon 9:00 AM to 12:00 PM<br>Tues. 12:30 PM to 2:00 PM |

**Textbooks and Tools**

The texts and tools used in ENGG 251 are also used in this course. Students will also require a Logbook, where all of there individual project and course work should be recorded. The Logbook can be any hard bound notebook. Students may reuse an existing Logbook (e.g. their ENGG 251 logbook) if they wish.

**Grading Criteria**
Grading in this course will different from that in some other engineering courses because *many communication and design problems have answers which cannot be deemed 'right' or 'wrong', but rather 'appropriate' or 'inappropriate'*

Satisfactory performance (a passing grade) requires mastery of core competencies in the following categories:

Category 1 - Ability to function as a member of a team

Category 2 - Ability to contribute effectively to product or process design

Category 3 - Ability to communicate effectively using the written word

Category 4 - Ability to communicate effectively through the medium of drawing

Most graded work will receive one of the following assessments:

- Excellent (A)
- Good (B)
- Unsatisfactory (D)
- Not Submitted (F)

During the semester, assignments related to the term project will be given to the students. Students will be expected to complete these assignments by a specified deadline. These assignments will then be evaluated by the instructors and coaches and given an initial assessment using the above classifications. At this time the assignment will be returned to the student without the assessment being recorded. Any student who receives "Unsatisfactory" must redo their work. A

Student who receives a "Good" can also redo their work. All students can receive an "Excellent" on any resubmissions. All term work will be submitted in Portfolios at two times in the term. Assessments will be officially recorded for each Portfolio hand-in. All work completed before March 4 will be submitted on March 7 by 4:00PM. All work from March 4 to the end of term will be submitted in a Portfolio on April 17 by 4:00PM. Any work resubmitted must have the original work and any subsequent revisions attached. Work submitted in the mid-term portfolio on March 7 can be resubmitted at the end of term; however, any work missing from the mid-term portfolio can not be submitted after March 7. This situation will result in the student receiving a grade of F for the course. For example, a drawing submitted with the mid-term Portfolio that received Unsatisfactory or Good could be resubmitted with the end-of-term Portfolio for re-evaluation. However, if that drawing was not included in the mid-term Portfolio the student would not be allowed to submit it with the end-of-term Portfolio and would receive a grade of F for ENGG 253.

Students can attend two scheduled redo nights at mid-term (March 4, 6:00 PM to 10:00PM) and end of term (April 15, 6:00PM to 10:00 PM) if they require help in problem areas. Students must receive at least a "Good" assessment on all assignments by the end of term to receive a passing grade for ENGG 253. No student will receive a grade higher than F in ENGG 253 unless s/he has demonstrates all the core competencies as outlined in the course outlines for ENGG 251 and ENGG 253.

**Grade Distribution**

| | |
|---|---|
| **DRAWING:** | |
| Skeleton | 8% |
| Muscles/Nerves | 8% |
| Motion | 8% |
| Drawing Collection | 8% |
| **COMMUNICATION:** | |
| Weekly Writing Assignments | 12% |
| Proposal | 4% |
| Oral Presentation | 5% |
| Final Report | 10% |

| | |
|---|---|
| **DESIGN:** | |
| Milestone 1 – Control & State | 2% |
| Milestone 2 – Ability to Skate | 4% |
| Proposal | 4% |
| Oral Presentation | 5% |
| Final Report | 10% |
| Evidence of Progress (Logbooks, WebCT, Website) | 12% |
| Performance & Aesthetics | 5% |

**Assignments submitted after the assigned Portfolio submission deadline will NOT be accepted under any circumstances. This can result in the student receiving a grade of F fro ENGG 253.**

**Core Competencies**

*Visual Communication Core Competencies:*

- Sketching
- Orthographic projection
- Isometric projection
- Perspective (one and two point)
- Symmetry (axial, rotational) & Tessellation
- Loci (motion)
- Symbol, image, sign
- Dimensioning and Tolerancing
- Rudimentary knowledge of a high level CAD package (e.g. Solidworks, Autocad)

Competence in these areas will carry over into the Winter session where students will study descriptive geometry and its application (Auxiliary views, Topographic Mapping, etc. as time permits)

*Engineering Design Core Competencies:*

- The architecture of creative problem solving
- Problem/ Need identification
- Familiarization/information gathering
- Roles of client, resources (library, tech, marketplace)
- Solution Generation
  - Lateral thinking
  - Role of and access to intuition
  - Brainstorming
- Functionality
- Product Design Specification
- Constraints/Requirements/Targets/Specs
- Feasibility
- Role of evidence/verification/analysis/assessment
- product life cycle (DFX case studies)
- project management/documentation
- role of build/test
- teamwork training
- design reviews
- real world, team oriented design project(s)

*Written Communication Core Competencies:*

- Basic writing skills as required for success in post-secondary education
- Page and document design

- Specific writing skills as they pertain to technical report writing
  - Concise, clear and accurate content
  - Descriptions
  - Summaries
  - Instructions
  - Audience analysis
- Use of graphics with text '
- Concepts of heading format
- Research strategies
- Proposals
- Understanding the writing process in project assignments
- Business letters and memos (including transmittals)
- Documentation of sources
- Revision and editing techniques '
- Evaluation of electronic resources
- Oral presentations
- Strategies for success with group assignments

**Description (Please see the Student Manual for further details on the course)**
Substantial team-based projects are at the core of this course. Scheduled class time (lecture, laboratory) will be used for a variety of components including lectures, seminars, and in-class project work. Because meeting time, working space, and opportunities for feedback are at a premium, **full attendance at scheduled class times is expected.**

It has been said that a design engineer is only as good as the failures he/she has experienced. The goal of this course is to allow the students to experience failure as a part of learning to do good design. Therefore, the focus of the course is inquiry-based teaching and learning, where the search for the solution is often more important than the solution itself. This requires that both students and faculty adopt non-traditional roles in the laboratory and classroom.

**Structure of Lectures and Labs.**
Although the times available for ENGG 251/253 are given the titles of Lectures and Laboratories, the actual use of the time ' will vary greatly depending on the need. All lecture and lab times will be used every week to allow sufficient time to ' practice drawing, develop designs and to learn from other students. Most portfolio work must be completed in the lab room, during the lab session. The actual design projects will require work outside of lab time. '
In order to adapt to the large size of the class without neglecting the need for collaborative learning, some fairly unusual ' methods and requirements will be employed: '

**Lectures**
- If a group is selected to make a presentation and is absent or unprepared, each member of the group will be assessed a penalty (strike). If an individual member of a team is not present, that person alone will receive a strike. **Any student receiving three strikes, individual or group, will be assessed an 'F' for the course.**
- Following each successful presentation, each member of the group will sign the instructor's logbook as evidence of individual contribution. Any group members absent will be penalized with a strike. This loss cannot be regained unless an exceptional reason for absence is presented.
- Each entry into the student portfolio must be signed or stamped by a member of the instructional team in order to get credit for the work. The students will be responsible for keeping track of this work which will make up the drawing and writing portfolios for each student.

**Labs**
- The working groups will be coordinated with the lab sessions. Working groups are expected to work together in the lab, although much of the work handed in at the end of the lab will be marked individually.
- It is expected that students will complete their drawings/writing/design through consultation with the course coaches and other students.

## Note:
1. **Safewalk/Campus Security: 220-5333:** Campus Security will escort individuals day or night. Use any campus phone, emergency phone or the yellow phone located at most parking lot pay booths.
2. **Withdrawal and Refunds:** Until January 24, 2003 a student will be able to drop a course and get a full refund with no record of the course on their transcript. **AFTER JANUARY 24, 2003 THERE WILL BE NO REFUNDS.**
3. **Freedom of Information:** Please see the attached " Policy for Implementation of FOIP Requirements"
4. **Academic Commissioner:** Chris Blaschuk (enggrep@su.ucalgary.ca) – 220-3913

**COURSE OUTLINE**
**Fall 2010**

## 1. Calendar Information

**ENGG 200 Engineering Design and Communication**

An interdisciplinary course involving the application of engineering principles, design, communications, leadership and project management concepts through a sequence of team-based design projects.

Course Hours: H(3-3)

Calendar Reference:
http://www.ucalgary.ca/pubs/calendar/current/engineering.html#30141

## 2. Learning Outcomes

At the end of this course, you will be able to:

Design

- Describe engineering design fundamentals and techniques.
- Describe and apply techniques for creative problem-solving.
- Evaluate and selectively apply various engineering design processes to solve open-ended design problems.
- Justify and defend a design solution
- Describe and apply project management principles to engineering projects.
- Account, and plan for risks.
- Account for safety in design.
- Describe the engineering profession, its various disciplines, and the purpose of APEGGA.
- Describe the different types, and purposes, of Intellectual Property.
- Elicit and interpret customer needs.
- Interpret ethical, social, environmental, legal and regulatory influences.
- Identify and explain system performance metrics.
- Select concepts and analyze the trade-offs among and recombination of alternative concepts
- Decompose and assign function to elements, and define interfaces
- Use prototypes and test articles in design development
- Demonstrate iteration until convergence and synthesize the final design.
- Demonstrate accommodation of changing requirements

Individual and team work

- Work effectively in a small team.
- Identify the stages of team formation and life-cycle as well as the roles and responsibilities of team members.
- Analyze the strengths and weaknesses of the team.
- Execute the planning and facilitation of effective meetings.
- Practice conflict negotiation and resolution.

Communications Skills

- Produce engineering drawings and sketches.
- Produce CAD drawings of designs.
- Produce technical reports.
- Give individual and group presentations.
- Construct logical and persuasive arguments
- Practice conciseness, crispness, precision and clarity of language
- Practice writing with correct spelling, punctuation and grammar
- Demonstrate sketching and drawing

Impact of engineering on society and the environment

- Analyze the impact of engineering on the environment, social, knowledge and economic systems in modern culture

# APPENDIX C: CDIO SYLLABUS (CDIO, 2011)

## The CDIO Syllabus v2.0
## June 2011

**1 DISCIPLINARY KNOWLEDGE AND REASONING (UNESCO: LEARNING TO KNOW)**

**1.1 KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCES [3a]**

*1.1.1 Mathematics (including statistics)*
*1.1.2 Physics*
*1.1.3 Chemistry*
*1.1.4 Biology*

**1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE [3a]**

**1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS [3k]**

**2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES (UNESCO: LEARNING TO BE)**

**2.1 ANALYTIC REASONING AND PROBLEM SOLVING [3e]**

*2.1.1 Problem Identification and Formulation*
Data and symptoms
Assumptions and sources of bias
Issue prioritization in context of overall goals
A plan of attack (incorporating model, analytical and numerical solutions, qualitative analysis, experimentation and consideration of uncertainty)

*2.1.2 Modeling*
Assumptions to simplify complex systems and environment
Conceptual and qualitative models
Quantitative models and simulations

*2.1.3 Estimation and Qualitative Analysis*
Orders of magnitude, bounds and trends
Tests for consistency and errors (limits, units, etc.)
The generalization of analytical solutions

*2.1.4 Analysis with Uncertainty*
Incomplete and ambiguous information
Probabilistic and statistical models of events and sequences
Engineering cost-benefit and risk analysis
Decision analysis
Margins and reserves

*2.1.5 Solution and Recommendation*
Problem solutions
Essential results of solutions and test data
Discrepancies in results
Summary recommendations
Possible improvements in the problem solving process

**2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY [3b]**

*2.2.1 Hypothesis Formulation*
Critical questions to be examined
Hypotheses to be tested
Controls and control groups

*2.2.2 Survey of Print and Electronic Literature*
The literature and media research strategy

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Information search and identification using library, on-line and database tools
Sorting and classifying the primary information
The quality and reliability of information
The essentials and innovations contained in the information
Research questions that are unanswered
Citations to references

*2.2.3 Experimental Inquiry*

The experimental concept and strategy
The precautions when humans are used in experiments
Investigations based on social science methods
Experiment construction
Test protocols and experimental procedures
Experimental measurements
Experimental data
Experimental data vs. available models

*2.2.4 Hypothesis Test and Defense*

The statistical validity of data
The limitations of data employed
Conclusions, supported by data, needs and values
Possible improvements in knowledge discovery process

**2.3 SYSTEM THINKING**

*2.3.1 Thinking Holistically*

A system, its function and behavior, and its elements
Transdisciplinary approaches that ensure the system is understood from all relevant perspectives
The societal, enterprise and technical context of the system
The interactions external to the system, and the behavioral impact of the system

*2.3.2 Emergence and Interactions in Systems*

The abstractions necessary to define and model the entities or elements of the system
The important relationships, interactions and interfaces among elements
The functional and behavioral properties (intended and unintended) that emerge from the system
Evolutionary adaptation over time

*2.3.3 Prioritization and Focus*

All factors relevant to the system in the whole
The driving factors from among the whole
Energy and resource allocations to resolve the driving issues

*2.3.4 Trade-offs, Judgment and Balance in Resolution*

Tensions and factors to resolve through trade-offs
Solutions that balance various factors, resolve tensions and optimize the system as a whole
Flexible vs. optimal solutions over the system lifetime
Possible improvements in the system thinking used

**2.4 ATTITUDES, THOUGHT AND LEARNING**

*2.4.1 Initiative and Willingness to Make Decisions in the Face of Uncertainty*

The needs and opportunities for initiative
Leadership in new endeavors, with a bias for appropriate action
Decisions, based on the information at hand
Development of a course of action
The potential benefits and risks of an action or decision

*2.4.2 Perseverance, Urgency and Will to Deliver, Resourcefulness and Flexibility*

Sense of responsibility for outcomes
Self-confidence, courage and enthusiasm
Determination to accomplish objectives

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

The importance of hard work, intensity and attention to detail
Definitive action, delivery of results and reporting on actions
Adaptation to change
Making ingenious use of the resources of the situation or group
A readiness, willingness and ability to work independently
A willingness to work with others, and to consider and embrace various viewpoints
An acceptance of feedback, criticism and willingness to reflect and respond
The balance between personal and professional life

2.4.3 *Creative Thinking*
Conceptualization and abstraction
Synthesis and generalization
The process of invention
The role of creativity in art, science, the humanities and technology

2.4.4 *Critical Thinking*
Purpose and statement of the problem or issue
Assumptions
Logical arguments (and fallacies) and solutions
Supporting evidence, facts and information
Points of view and theories
Conclusions and implications
Reflection on the quality of the thinking

2.4.5 *Self-Awareness, Metacognition and Knowledge Integration*
One's skills, interests, strengths and weaknesses
The extent of one's abilities, and one's responsibility for self-improvement to overcome important weaknesses
The importance of both depth and breadth of knowledge
Identification of how effectively and in what way one is thinking
Linking knowledge together and identifying the structure of knowledge

2.4.6 *Lifelong Learning and Educating* **[3i]**
The motivation for continued self-education
The skills of self-education
One's own learning styles
Relationships with mentors
Enabling learning in others

2.4.7 *Time and Resource Management*
Task prioritization
The importance and/or urgency of tasks
Efficient execution of tasks

**2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES [3f]**

2.5.1 *Ethics, Integrity and Social Responsibility*
One's ethical standards and principles
The moral courage to act on principle despite adversity
The possibility of conflict between professionally ethical imperatives
A commitment to service
Truthfulness
A commitment to help others and society more broadly

2.5.2 *Professional Behavior*
A professional bearing
Professional courtesy
International customs and norms of interpersonal contact

2.5.3 *Proactive Vision and Intention in Life*
A personal vision for one's future
Aspiration to exercise his/her potentials as a leader
One's portfolio of professional skills

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Considering one's contributions to society
Inspiring others

*2.5.4 Staying Current on the World of Engineering*
The potential impact of new scientific discoveries
The social and technical impact of new technologies and innovations
A familiarity with current practices/technology in engineering
The links between engineering theory and practice

*2.5.5 Equity and Diversity*
A commitment to treat others with equity
Embracing diversity in groups and workforce
Accommodating diverse backgrounds

*2.5.6 Trust and Loyalty*
Loyalty to one's colleagues and team
Recognizing and emphasizing the contributions of others
Working to make others successful

## 3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION (UNESCO: LEARNING TO LIVE TOGETHER)

### 3.1 TEAMWORK [3d]

*3.1.1 Forming Effective Teams*
The stages of team formation and life cycle
Task and team processes
Team roles and responsibilities
The goals, needs and characteristics (works styles, cultural differences) of individual team members
The strengths and weaknesses of the team and its members
Ground rules on norms of team confidentiality, accountability and initiative

*3.1.2 Team Operation*
Goals and agenda
The planning and facilitation of effective meetings
Team ground rules
Effective communication (active listening, collaboration, providing and obtaining information)
Positive and effective feedback
The planning, scheduling and execution of a project
Solutions to problems (team creativity and decision making)
Conflict mediation, negotiation and resolution
Empowering those on the team

*3.1.3 Team Growth and Evolution*
Strategies for reflection, assessment and self-assessment
Skills for team maintenance and growth
Skills for individual growth within the team
Strategies for team communication and reporting

*3.1.4 Team Leadership*
Team goals and objectives
Team process management
Leadership and facilitation styles (directing, coaching, supporting, delegating)
Approaches to motivation (incentives, example, recognition, etc.)
Representing the team to others
Mentoring and counseling

*3.1.5 Technical and Multidisciplinary Teaming*
Working in different types of teams:
Cross-disciplinary teams (including non-engineer)

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Small team vs. large team
Distance, distributed and electronic environments
Technical collaboration with team members
Working with non-technical members and teams

**3.2 COMMUNICATIONS [3g]**

*3.2.1 Communications Strategy*

The communication situation
Communications objectives
The needs and character of the audience
The communication context
A communications strategy
The appropriate combination of media
A communication style (proposing, reviewing, collaborating, documenting, teaching)
The content and organization

*3.2.2 Communications Structure*

Logical, persuasive arguments
The appropriate structure and relationship amongst ideas
Relevant, credible, accurate supporting evidence
Conciseness, crispness, precision and clarity of language
Rhetorical factors (e.g. audience bias)
Cross-disciplinary cross-cultural communications

*3.2.3 Written Communication*

Writing with coherence and flow
Writing with correct spelling, punctuation and grammar
Formatting the document
Technical writing
Various written styles (informal, formal memos, reports, resume, etc.)

*3.2.4 Electronic/Multimedia Communication*

Preparing electronic presentations
The norms associated with the use of e-mail, voice mail, and videoconferencing
Various electronic styles (charts, web, etc)

*3.2.5 Graphical Communications*

Sketching and drawing
Construction of tables, graphs and charts
Formal technical drawings and renderings
Use of graphical tools

*3.2.6 Oral Presentation*

Preparing presentations and supporting media with appropriate language, style, timing and flow
Appropriate nonverbal communications (gestures, eye contact, poise)
Answering questions effectively

*3.2.7 Inquiry, Listening and Dialog*

Listening carefully to others, with the intention to understand
Asking thoughtful questions of others
Processing diverse points of view
Constructive dialog
Recognizing ideas that may be better than your own

*3.2.8 Negotiation, Compromise and Conflict Resolution*

Identifying potential disagreements, tensions or conflicts
Negotiation to find acceptable solutions
Reaching agreement without compromising fundamental principles
Diffusing conflicts

*3.2.9 Advocacy*

Clearly explaining one's point of view

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Explaining how one reached an interpretation or conclusion
Assessing how well you are understood
Adjusting approach to advocacy on audience characteristics

*3.2.10 Establishing Diverse Connections and Networking*

Appreciating those with different skills, cultures or experiences
Engaging and connecting with diverse individuals
Building extended social networks
Activating and using networks to achieve goals

**3.3 COMMUNICATIONS IN FOREIGN LANGUAGES**

*3.3.1 Communications in English*
*3.3.2 Communications in Languages of Regional Commerce and Industry*
*3.3.3 Communications in Other Languages*

## 4 CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS (UNESCO: LEARNING TO DO)

**4.1 EXTERNAL, SOCIETAL AND ENVIRONMENTAL CONTEXT [3h]**

*4.1.1 Roles and Responsibility of Engineers*

The goals and roles of the engineering profession
The responsibilities of engineers to society and a sustainable future

*4.1.2 The Impact of Engineering on Society and the Environment*

The impact of engineering on the environmental, social, knowledge and economic systems in modern culture

*4.1.3 Society's Regulation of Engineering*

The role of society and its agents to regulate engineering
The way in which legal and political systems regulate and influence engineering
How professional societies license and set standards
How intellectual property is created, utilized and defended

*4.1.4 The Historical and Cultural Context*

The diverse nature and history of human societies as well as their literary, philosophical and artistic traditions
The discourse and analysis appropriate to the discussion of language, thought and values

*4.1.5 Contemporary Issues and Values* **[3j]**

The important contemporary political, social, legal and environmental issues and values
The processes by which contemporary values are set, and one's role in these processes
The mechanisms for expansion and diffusion of knowledge

*4.1.6 Developing a Global Perspective*

The internationalization of human activity
The similarities and differences in the political, social, economic, business and technical norms of various cultures
International and intergovernmental agreements and alliances

*4.1.7 Sustainability and the Need for Sustainable Development*

Definition of sustainability
Goals and importance of sustainability
Principles of sustainability
Need to apply sustainability principles in engineering endeavors

**4.2 ENTERPRISE AND BUSINESS CONTEXT**

*4.2.1 Appreciating Different Enterprise Cultures*

The differences in process, culture, and metrics of success in various enterprise cultures: Corporate vs. academic vs. governmental vs. non-profit/NGO

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Market vs. policy driven
Large vs. small
Centralized vs. distributed
Research and development vs. operations
Mature vs. growth phase vs. entrepreneurial
Longer vs. faster development cycles
With vs. without the participation of organized labor

*4.2.2 Enterprise Stakeholders, Strategy and Goals*

The stakeholders and beneficiaries of an enterprise (owners, employees, customers, etc.)
Obligations to stakeholders
The mission, scope and goals of the enterprise
Enterprise strategy and resource allocation
An enterprise's core competence and markets
Key alliances and supplier relations

*4.2.3 Technical Entrepreneurship*

Entrepreneurial opportunities that can be addressed by technology
Technologies that can create new products and systems
Entrepreneurial finance and organization

*4.2.4 Working in Organizations*

The function of management
Various roles and responsibilities in an organization
The roles of functional and program organizations
Working effectively within hierarchy and organizations
Change, dynamics and evolution in organizations

*4.2.5 Working in International Organizations*

Culture and tradition of enterprise as a reflection of national culture
Equivalence of qualifications and degrees
Governmental regulation of international work

*4.2.6 New Technology Development and Assessment*

The research and technology development process
Identifying and assessing technologies
Technology development roadmaps
Intellectual property regimes and patents

*4.2.7 Engineering Project Finance and Economics*

Financial and managerial goals and metrics
Project finance – investments, return, timing
Financial planning and control
Impact of projects on enterprise finance, income and cash

**4.3 CONCEIVING, SYSTEM ENGINEERING AND MANAGEMENT [3c]**

*4.3.1 Understanding Needs and Setting Goals*

Needs and opportunities
- Customer needs, and those of the market
- Opportunities that derive from new technology or latent needs
- Environmental needs

Factors that set the context of the system goals
- Enterprise goals, strategies, capabilities and alliances
- Competitors and benchmarking information
- Ethical, social, environmental, legal and regulatory influences
- The probability of change in the factors that influence the system, its goals and resources available

System goals and requirements
- The language/format of goals and requirements
- Initial target goals (based on needs, opportunities and other influences)
- System performance metrics

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Requirement completeness and consistency

4.3.2 *Defining Function, Concept and Architecture*

Necessary system functions (and behavioral specifications)
System concepts
Incorporation of the appropriate level of technology
Trade-offs among and recombination of concepts
High-level architectural form and structure
The decomposition of form into elements, assignment of function to elements, and definition of interfaces

4.3.3 *System Engineering, Modeling and Interfaces*

Appropriate models of technical performance and other attributes
Consideration of implementation and operations
Life cycle value and costs (design, implementation, operations, opportunity, etc.)
Trade-offs among various goals, function, concept and structure and iteration until convergence
Plans for interface management

4.3.4 *Development Project Management*

Project control for cost, performance and schedule
Appropriate transition points and reviews
Configuration management and documentation
Performance compared to baseline
Earned value recognition
The estimation and allocation of resources
Risks and alternatives
Possible development process improvements

**4.4 DESIGNING [3c]**

4.4.1 *The Design Process*

Requirements for each element or component derived from system level goals and requirements
Alternatives in design
The initial design
Life cycle consideration in design
Experimental prototypes and test articles in design development
Appropriate optimization in the presence of constraints
Iteration until convergence
The final design
Accommodation of changing requirements

4.4.2 *The Design Process Phasing and Approaches*

The activities in the phases of system design (e.g. conceptual, preliminary and detailed design)
Process models appropriate for particular development projects (waterfall, spiral, concurrent, etc.)
The process for single, platform and derivative products

4.4.3 *Utilization of Knowledge in Design*

Technical and scientific knowledge
Modes of thought (problem solving, inquiry, system thinking, creative and critical thinking)
Prior work in the field, standardization and reuse of designs (including reverse engineering and refactoring, redesign)
Design knowledge capture

4.4.4 *Disciplinary Design*

Appropriate techniques, tools and processes
Design tool calibration and validation
Quantitative analysis of alternatives

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Modeling, simulation and test
Analytical refinement of the design

*4.4.5 Multidisciplinary Design*
Interactions between disciplines
Dissimilar conventions and assumptions
Differences in the maturity of disciplinary models
Multidisciplinary design environments
Multidisciplinary design

*4.4.6 Design for Sustainability, Safety, Aesthetics, Operability and Other Objectives*
Design for:
- Performance, quality, robustness, life cycle cost and value
- Sustainability
- Safety and security
- Aesthetics
- Human factors, interaction and supervision
- Implementation, verification, test and environmental sustainability
- Operations
- Maintainability, dependability and reliability
- Evolution, product improvement
- Retirement, reusability and recycling

**4.5 IMPLEMENTING [3c]**

*4.5.1 Designing a Sustainable Implementation Process*
The goals and metrics for implementation performance, cost and quality
The implementation system design:
- Task allocation and cell/unit layout
- Work flow
- Considerations for human user/operators

Consideration of sustainability

*4.5.2 Hardware Manufacturing Process*
The manufacturing of parts
The assembly of parts into larger constructs
Tolerances, variability, key characteristics and statistical process control

*4.5.3 Software Implementing Process*
The break down of high-level components into module designs (including algorithms and data structures)
Algorithms (data structures, control flow, data flow)
The programming language and paradigms
The low-level design (coding)
The system build

*4.5.4 Hardware Software Integration*
The integration of software in electronic hardware (size of processor, communications, etc.)
The integration of software with sensor, actuators and mechanical hardware
Hardware/software function and safety

*4.5.5 Test, Verification, Validation and Certification*
Test and analysis procedures (hardware vs. software, acceptance vs. qualification)
The verification of performance to system requirements
The validation of performance to customer needs
The certification to standards

*4.5.6 Implementation Management*
The organization and structure for implementation
Sourcing and partnering
Supply chains and logistics
Control of implementation cost, performance and schedule

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Quality assurance
Human health and safety
Environmental security
Possible implementation process improvements

**4.6 OPERATING [3c]**

*4.6.1 Designing and Optimizing Sustainable and Safe Operations*
The goals and metrics for operational performance, cost and value
Sustainable operations
Safe and secure operations
Operations process architecture and development
Operations (and mission) analysis and modeling

*4.6.2 Training and Operations*
Training for professional operations:
Simulation
Instruction and programs
Procedures
Education for consumer operation
Operations processes
Operations process interactions

*4.6.3 Supporting the System Life Cycle*
Maintenance and logistics
Life cycle performance and reliability
Life cycle value and costs
Feedback to facilitate system improvement

*4.6.4 System Improvement and Evolution*
Pre-planned product improvement
Improvements based on needs observed in operation
Evolutionary system upgrades
Contingency improvements/solutions resulting from operational necessity

*4.6.5 Disposal and Life-End Issues*
The end of useful life
Disposal options
Residual value at life-end
Environmental considerations for disposal

*4.6.6 Operations Management*
The organization and structure for operations
Partnerships and alliances
Control of operations cost, performance and scheduling
Quality and safety assurance
Possible operations process improvements
Life cycle management
Human health and safety
Environmental security

## The Extended CDIO Syllabus: Leadership and Entrepreneurship

This extension to the CDIO Syllabus is provided as a resource for programs that seek to respond to stakeholder expressed needs in the areas of Engineering Leadership and Entrepreneurship

**4.7 LEADING ENGINEERING ENDEAVORS**

Engineering Leadership builds on factors already included above, including:

- **Attitudes of Leadership – Core Personal Values and Character,** including topics in Attitudes, Thought and Learning (2.4), and in Ethics, Equity and Other Responsibilities (2.5)

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

- **Relating to Others**, including topics in Teamwork (3.1), Communications (3.2) and potentially Communications in Foreign Languages (3.3)
- **Making Sense of Context**, including topics in External, Societal and Environmental Context (4.1), Enterprise and Business Context (4.2) Conceiving, Systems Engineering and Management (4.3) and System Thinking (2.3)

In addition there are several topics that constitute creating a **Purposeful Vision**:

*4.7.1 Identifying the Issue, Problem or Paradox (which builds on Understanding Needs and Setting Goals 4.3.1)*

Synthesizing the understanding of needs or opportunities (that technical systems can address)
Clarifying the central issues
Framing the problem to be solved
Identifying the underlying paradox to be examined

*4.7.2 Thinking Creatively and Communicating Possibilities (which builds on and expands Creative Thinking 2.4.3)*

How to create new ideas and approaches
New visions of technical systems that meet the needs of customers and society
Communicating visions for products and enterprises
Compelling visions for the future

*4.7.3 Defining the Solution (which builds on and expands Understanding Needs and Setting Goals 4.3.1)*

The vision for the engineering solution
Achievable goals for quality performance, budget and schedule
Consideration of customer and beneficiary
Consideration of technology options
Consideration of regulatory, political and competitive forces

*4.7.4 Creating New Solution Concepts (which builds on and expands 4.3.2 and 4.3.3)*

Setting requirements and specifications
The high-level concept for the solution
Architecture and interfaces
Alignment with other projects of the enterprise
Alignment with enterprise strategy, resources and infrastructure

And several topics that lead to **Delivering on the Vision:**

*4.7.5 Building and Leading an Organization and Extended Organization (which builds on 4.2.4 and 4.2.5)*

Recruiting key team members with complementary skills
Start-up of team processes, and technical interchange
Defining roles, responsibilities and incentives
Leading group decision-making
Assessing group progress and performance
Building the competence of others and succession
Partnering with external competence

*4.7.6 Planning and Managing a Project to Completion (which builds on 4.3.4)*

Plans of action and alternatives to deliver completed projects on time
Deviation from plan, and re-planning
Managing human, time, financial and technical resources to meet plan
Program risk, configuration and documentation
Program economics and the impact of decisions on them

*4.7.7 Exercising Project/Solution Judgment and Critical Reasoning (which builds on 2.3.4 and 2.4.4)*

Making complex technical decisions with uncertain and incomplete information
Questioning and critically evaluating the decisions of others
Corroborating inputs from several sources

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Evaluating evidence and identifying the validity of key assumptions
Understanding alternatives that are proposed by others
Judging the expected evolution of all solutions in the future

*4.7.8 Innovation – the Conception, Design and Introduction of New Goods and Services (which is the leadership of 4.3 and 4.4)*

Designing and introducing new goods and services to the marketplace
Designing solutions to meet customer and societal needs
Designing solutions with the appropriate balance of new and existing technology
Robust, flexible and adaptable products
Consideration of current and future competition
Validating the effectiveness of the solution

*4.7.9 Invention – the Development of New Devices, Materials or Processes that Enable New Goods and Services (which builds on 4.2.6)*

Science and technology basis and options
Imagining possibilities
Inventing a practical device or process that enables a new product or solution
Adherence to intellectual property regimes

*4.7.10 Implementation and Operation – the Creation and Operation of the Goods and Services that will Deliver Value (which are the leadership of 4.5 and 4.6)*

Leading implementing and operating
Importance of quality
Safe operations
Operations to deliver value to the customer and society

These last three items are in fact the leadership of the core processes of engineering: conceiving, designing, implementing and operating

**4.8 ENGINEERING ENTREPRENEURSHIP**

Engineering Entrepreneurship includes by reference all of the aspects of Societal and Enterprise Context (4.1 and 4.2), all of the skills of Conceiving, Designing, Implementing and Operating (4.3 – 4.6) and all of the elements of Engineering Leadership (4.7).

In addition, there are the entrepreneurship specific skills:

*4.8.1 Company Founding, Formulation, Leadership and Organization*

Creating the corporate entity and financial infrastructure
Team of supporting partners (bank, lawyer, accounting, etc.)
Consideration of local labor law and practices
The founding leadership team
The initial organization
The board of the company
Advisors to the company

*4.8.2 Business Plan Development*

A need in the world that you will fill
A technology that can become a product
A team that can develop the product
Plan for development
Uses of capital
Liquidity strategy

*4.8.3 Company Capitalization and Finances*

Capital needed, and timing of need (to reach next major milestone)
Investors as sources of capital
Alternative sources of capital (government, etc.)
Structure of investment (terms, price, etc.)
Financial analysis for investors
Management of finances
Expenditures against intermediate milestones of progress

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

*4.8.4 Innovative Product Marketing*
Size of potential market
Competitive analyses
Penetration of market
Product positioning
Relationships with customers
Product pricing
Sales initiation
Distribution to customers

*4.8.5 Conceiving Products and Services around New Technologies*
New technologies available
Assessing the readiness of technology
Assessing the ability of your enterprise to innovate based on the technology
Assessing the product impact of the technology
Accessing the technologies though partnerships, licenses, etc.
A team to productize the technology

*4.8.6 The Innovation System, Networks, Infrastructure and Services*
Relationships for enterprise success
Mentoring of the enterprise leadership
Supporting financial services
Investor networks
Suppliers

*4.8.7 Building the Team and Initiating Engineering Processes (conceiving, designing, implementing and operating)*
Hiring the right skill mix
Technical process startup
Building an engineering culture
Establishing enterprise processes

*4.8.8 Managing Intellectual Property*
IP landscape for your product or technology
IP strategy – offensive and defensive
Filing patents and provisional patents
IP legal support
Entrepreneurial opportunities that can be addressed by technology
Technologies that can create new products and systems
Entrepreneurial finance and organization

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

## APPENDIX D: SURVEY QUESTIONNAIRE

### Student Learning Outcomes – Questionnaire for ENGG 200

**This survey will help us improve the Engineering curriculum. This questionnaire and all of the questions herein, are completely voluntary. You are free to withdraw at any time. This questionnaire will in no way affect your grade in this course or your academic record. Your survey is anonymous.**

**1) Please rate to what extent you agree or disagree with the following statements.**

**The ENGG 200 Design course introduced me to, or enabled me to further develop, the following skills:**

| | Strongly Agree | Moderately Agree | Slightly Agree | Slightly Disagree | Moderately Disagree | Strongly Disagree |
|---|---|---|---|---|---|---|
| Apply principles of mathematics and natural sciences to real-world problems | | | | | | |
| Evaluate a problem and brainstorm solutions. | | | | | | |
| Understand a design process. | | | | | | |
| Apply a design process to a challenge. | | | | | | |
| Analyze data in order to draw meaningful conclusions. | | | | | | |
| Take cultural issues into consideration for the design solution. | | | | | | |
| Take environmental issues into consideration for the design solution. | | | | | | |
| Take economic issues into consideration for the design solution. | | | | | | |
| Take safety issues into consideration for the design solution. | | | | | | |
| Work in a team environment. | | | | | | |
| Understand techniques for time management. | | | | | | |
| Apply techniques for time management. | | | | | | |
| Communicate effectively in a verbal setting, such as team meetings or presentations. | | | | | | |
| Communicate effectively in a written medium, such as reports. | | | | | | |
| Understand the purpose of a logbook. | | | | | | |

**2) What did you like about this course?**

**3) What did you not like about this course?**

**4) What did you learn from this course?**

**5) What do you think the purpose of this course was?**

**6) What would you have liked to learn from this course?**

**Please place me in the dropbox at the front of the room ☺**