AC 2012-4488: EVOLVING A RUBRIC FOR USE IN ASSESSING ENGINEERING GRADUATE ATTRIBUTES IN A STUDENT SENIOR RESEARCH THESIS

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Evolving a Rubric for Use in Assessing Engineering Graduate Attributes in a Student Senior Research Thesis

Abstract: This paper describes the process of developing and utilizing a rubric for graduate attributes assessment in a large senior research thesis course in a multidisciplinary engineering program. Each year, nearly 200 students work with over 100 supervisors from across several academic departments at the university on the thesis, which is designed to provide students with opportunity to conduct, document, and experience engineering related research as an undergraduate student.

Recently, changes to the Canadian Engineering Accreditation requirements, following the example set by the ABET, have called for the measurement of 12 graduate attributes in the engineering curriculum. Given that thesis is a requirement for all senior students in the program, and that it serves as a capstone experience, capitalizing on students' earlier work in engineering communication and experimentation, it stands as an ideal place in which to measure students' skills in these areas at graduation.

However, the variability of these projects presents significant challenges for common rubric development and by implication, our ability to retrieve reliable data on student performance in these categories/attributes. This variability also brings unique challenges to the development of a single rubric that is 1) flexible enough to apply to a variety of engineering thesis projects, 2) reflective of the learning objectives of the thesis course, and also 3) appropriate for use in gathering reliable data about students' graduate attributes.

This paper describes the development of the rubric, and the inherent challenges in designing a valid and reliable tool that provides flexibility to a diverse group of projects and supervisors, and serves the needs of the graduate attribute reporting. Despite these tensions, the results provided by this process provide insight about the rubric design, supervisors' assessment strategies and the students' strengths and weaknesses within the two graduate attributes, providing valuable information to feed back into the curriculum and thesis experience. The process of assessing graduate attributes within a curricular context also highlights the opportunity in allowing major curricular components to help define the learning outcomes associated with the graduate attributes, rather than relying only on a top-down process, focused on centrally-developed learning outcomes.

Introduction

Many undergraduate engineering programs include one or more significant "capstone" experiences, designed to give students an opportunity to demonstrate significant learning through the integration of knowledge and skills from across the degree[1, 5]. Such a learning experience, an independent research project required for all senior students in a large, Canadian multi-disciplinary engineering program, forms the context for this paper. This thesis course gives senior undergraduate students an opportunity to work with a faculty member to define and design an original research project, as well as to conduct and communicate engineering-related research. In the 2010-11 school year, nearly 200 students in the program worked with 112 unique supervisors from 22 distinct academic departments, and across theoretical, clinical, design and laboratory settings, demonstrating a vast breadth of project scope. Outside of the student-supervisor relationship, students are provided with assignment guidelines, workshops, and rubrics to scaffold the documentation and communication of the research, which includes four deliverables: a proposal, an interim report, presentation and final research report. The stated learning objectives, taken from the course syllabus, are as follows:

- Write a strong research proposal, identifying and developing a gap in a science/engineering related field, and develop a plan/method for addressing that gap
- Conduct and write a literature review, summarizing the state of a science/engineering related field
- Execute a major, independent research project in a relevant field of study
- Generate and analyze data as part of a major research project
- Present research methods, designs, results, and claims effectively, orally and in writing
- Incorporate feedback from a variety of audiences to help improve the communication of scientific ideas

While students apply their engineering knowledge to their thesis work, the primary focus of the assessment of the four deliverables is on engineering communication and investigation skills. One of the major challenges for a wide-ranging independent study style course such as this one lies in maintaining some degree of consistency in student workload and experience, as well as in supervisor expectations across projects. An attempt to facilitate consistency in approach and assessment was launched in 2009-2010, with the help of faculty from the Engineering Communication Program, through the development of a set of rubrics for course deliverables. These rubrics were designed with the input of engineering faculty members from a diverse set engineering disciplines to measure aspects of "communication" and "investigation" relevant to the undergraduate thesis experience: they were also intended to help students and supervisors arrive at a common understanding of expectations and requirements. However, the variability of the students' research projects presented significant challenges for common rubric development, demanding a rubric that is both (1) flexible enough to apply to a variety of engineering thesis projects, (2) authentically reflective of the learning objectives of the thesis course and (3) capable of facilitating common assessment practices and inter-rater reliability across a large number of supervisors who serve as primary assessors.

These challenges were even more complicated by recent changes to the Canadian Engineering Accreditation requirements that, following the example set by the ABET, called for the

measurement of 12 graduate attributes in the engineering curriculum[4]. Some attributes, such as "Knowledge Base," lend themselves to quantitative measurement; others, such as "Investigation" and "Communication" are inherently difficult to measure quantitatively and comprehensively. For these attributes, a major issue involves identifying an appropriate experience in which to measure them. Given that the undergraduate thesis is a requirement for all students in the program, and that it serves as a capstone experience, capitalizing on students' earlier work in engineering communication and experimentation, it appears an ideal place in which to measure students' skills in these areas at graduation. Capstone experiences, because of these characteristics, are often used for program assessment purposes[15, 18]. The newly developed common rubric, coincidentally, also provided an opportunity for the purpose of measuring graduate attributes, a fact not missed by divisional and faculty administrators.

Through this project, we set out to answer the following research questions:

1) How can a complex, multidisciplinary undergraduate thesis course be used for the measurement of graduate attributes?
2) What are the assessment tools needed to facilitate the measurement of the attributes in the undergraduate thesis course?
3) How does the existing curriculum impact our understanding of the graduate attributes?

More specifically, this paper describes the development of the rubric as an assessment tool designed to provide flexibility to a diverse group of projects and supervisors, as well as a tool worthy of utilizing in the graduate attribute assessment process, which should demonstrate how a cohort performs across the various indicators, or learning outcomes, that comprise an attribute. Yet while a seemingly ideal place for graduate attribute assessment, developing a rubric capable of generating useful data posed significant challenges, especially in relation to ensuring rubric validity and reliability. These challenges included mapping newly defined attributes to an existing assessment scheme, covering a diversity of projects in a large and complex undergraduate learning experience, as well as developing methods for addressing questions of inter-rater reliability within a large assessment team. Despite these tensions, the results provided by this process provide insight about the rubric design, supervisors' assessment strategies and the students' strengths and weaknesses within the two graduate attributes, providing valuable information to feed back into the curriculum and thesis experience. The process of assessing graduate attributes within a curricular context also demonstrates the importance in allowing major curricular components to help define the learning outcomes associated with the graduate attributes, rather than relying only on a top-down process, focused on centrally-developed learning outcomes.

Engineering Graduate Attribute Development

The Canadian Engineering Accreditation Board (CEAB) has outlined 12 graduate attributes, which describe both the engineering knowledge base, and engineering-related skills expected of graduates. Programs are required to demonstrate that students are graduating with the demonstrated attributes, and that a continual improvement process is in place, "that demonstrate(s) that program outcomes are being assessed in the context of the graduate attributes, and that the results are applied to the further development of the program" (CEAB). The CEAB has described the investigation and communication attributes as follows:

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

Communication Skills: An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.

Engineering schools across Canada are working to develop their own desired learning outcomes associated with each of the Graduate Attributes[6]. In the institution under study, a Faculty-wide "Graduate Attribute Committee" was constructed to further develop learning objectives associated with each of the 12 Graduate Attributes. The Graduate Attribute Committee, or GAC, includes representation from all undergraduate programs along with the Engineering Communication Program, first year and undergraduate studies officers, and graduate studies. The committee members hold strong engineering, teaching and administrative experiences.

Within the committee, learning objectives were developed at two levels: first, a few global outcomes were developed to describe the broader objectives associated with an attribute. Secondly, more specific "indicators" were developed for each of the global outcomes, which were designed to more precisely measure student learning in a specific course or assignment context. This process was followed because it was found to be difficult to move directly from the attributes provided by the CEAB, which are quite general, to clear, measurable outcomes that can be applied directly to a learning experience. This process assisted the committee in better developing a shared definition of each Attribute, and provided all working group members – and their respective departments and units – with a clear and shared understanding of each attribute. The process developed and carried out by the Graduate Attributes Committee has lead to a lot of useful discussion, and reflection, on what we are teaching, and what we need to be teaching.

The Graduate Attributes Committee commissioned a series of expert subcommittees to develop global outcomes and indicators for each of the 12 Graduate Attributes. In the case of the Communication Attribute, faculty from the Engineering Communication Program developed a set of indicators, and in the case of Investigation, a group of cross-disciplinary faculty members who are active in research and teaching – and in particular the teaching of investigative laboratories – served on the expert committee. The expert groups brought their suggested outcomes and indicators back to the entire Graduate Attributes Committee for review. The committee required at least three passes through in order to converge on a clear set of indicators for each attribute. The Global Outcomes and Indicators for Investigation and Communication are listed below, in Tables 1 and 2.

Table 1: Investigation Global Outcomes and Indicators

Global Objectives	Indicators

Ability to define the problem	• State the problem, its scope and importance • Describe the previous work • State the objective of the work
Ability to devise and execute a plan to solve the problem	• Select a set of tests to be conducted • Select, plan and apply the methods for collecting the results • Identify limitations of the methods used and their impact on the results.
Ability to use critical analysis to reach valid conclusions supported by the results of the plan	• Analyze the results • Formulate the conclusions • Validate conclusions by induction or deduction • Compare conclusions with previous work • Characterize the limitations and implications of the conclusions

Table 2: Communication Global Outcomes and Indicators

Global Objectives	Indicators
Ability to identify and credibly communicate engineering knowledge	• Situate, in document or presentation, the solution or design in the world of existing engineering, taking into account social, environmental, economic and ethical consequences • Recognize a credible argument (reading) • Construct a credible argument in written or spoken form – to persuasively present evidence in support of a claim • Organize written or spoken material– to structure overall elements so that their relationship to a main point and to one another is clear • Create “flow” in document or presentation – flow is a logical progression of ideas, sentence to sentence and paragraph to paragraph
Ability to incorporate visual elements in communication	• Incorporate visual material that enhances communication without detracting from it • Incorporate various media appropriately • Incorporate principles of visual design appropriately
Ability to develop communication through an iterative process	• Use iteration to clarify and amplify understanding of issues being communicated • Use reflection to determine and guide self-development

The approach of starting with a centralized committee, rather than examining existing assessment tools, was used for a few reasons. First, this allowed the Faculty to build capacity on existing expertise in outcomes development and assessment. Our instructors are not required to develop learning outcomes for their courses, so building expertise within a smaller group who can then make an impact on their respective units was a more suitable approach. This approach also allowed the faculty to develop a set of common global outcomes and indicators; it was determined that some commonality across programs was important, and that individual

engineering programs can subsequently adjust, add or eliminate indicators that are not relevant to their program.

The outcomes and indicators associated with the Graduate Attributes were developed by a central committee. However, when it comes to actually measuring whether our students are meeting the Graduate Attributes, they need to be integrated into new assessment tools within the curriculum – or, in the case of the current work, mapped to existing tools. To understand the process of utilizing the existing assessment measures associated with an undergraduate thesis course for the measurement of the Graduate Attributes, we shall first examine more closely the development of the rubrics themselves.

Rubric Development in the Thesis Course

Simply choosing to employ rubrics, in a sense, bypasses the debate about the value of rubrics for assessment and instructional purposes. However, the many debates in the literature do help illuminate the value and weaknesses of rubrics, many of which have become important considerations in the development of this rubric[11,12,13,17]. Rubric design guidelines found in the literature were a starting point[7,8,11,12], but the initial premise was that no existing rubric would be imported or adjusted for this particular context, and that the exercise had to begin with initial needs and context assessment. Understanding audience and purpose allowed us to make important design decisions while considering guidelines drawn from the literature. Because the attempts to help standardize the thesis experience started prior to the changes in CEAB accreditation, the thesis rubric development was initially done without consideration of the Graduate Attributes; however, revisions of the rubric have attempted to facilitate its use in attributes assessment while still allowing supervisors to emphasize project-specific constructs in the assessment of the thesis. While this paper describes the rubric development activity for a highly specific course, rhetorical situation, and set of needs, the principles and design issues considered certainly apply to a large number of engineering projects, including cap and cornerstone design. Furthermore, rubrics were provided for each of the four deliverables mentioned above – the proposal, interim report, oral presentation, and final thesis document – but the bulk of the discussion in this paper surrounds the rubric for the final document.

Audience and Purpose

In crafting the rubrics for the thesis course, we started with a rhetorical analysis of the context, starting by asking questions of audience and purpose for the documents. While the genre of the rubric as an educational tool is well established, its effectiveness depends highly on a deeper understanding of the purpose of the document as well as its audience. Our rubric needed to do more than simply provide metric for assessment: it needed to serve at least three audiences in multiple ways.

First, the rubric was designed to be a useful tool for students new to the thesis genre. The performance categories and criteria described in the rubric needed to establish a clear set of expectations for students for content, structure, and tone, while also allowing for variations in project type and nature. At the same time, it was imperative that the rubric not prescribe questions to answer, a particular structure, or provide a template for students to fill out, since

improvising within the thesis genre for a given topic was an essential part of the learning experience for the course. Negotiating this balance is essential to the rubrics ability to serve as "instructional illuminators"[11], as well assessment pieces.

Supervisors formed the second and equally important audience for the rubric. The rubric was also intended to serve as a useful tool for supervisors who may not have experience directly assessing communication or investigation, as they would typically assess engineering knowledge. Tied to the assignment descriptions, these rubrics were meant to develop a common set of expectations, if not around the thesis work itself, then at least around the documentation. The majority of thesis supervisors' work with 1 or 2 students in the program, and assessing the work of a thesis student is a significant undertaking. Most students undertake a year-long project, culminating in a major report (with scaffolding provided by a proposal, interim report and oral presentation). The rubric must capture the depth of the work and its requirements while also maintaining a sense of usability for the 112 supervisors engaged in the project.

Because supervisors were the ones ultimately filling out the rubric, they were also considered the primary user in the design of document. Taking into consideration the fact that in the past, supervisors had only contributed a final mark, without any required breakdown and only optional commentary, we were aware that such a document had to carefully weigh usability against completeness. Unfortunately, given the number and range of supervisors, we were already aware traditional methods for ensuring inter-rater reliability – such as benchmarking and cross assessment - would likely not be possible. Instead, we focused on the validity of the performance categories and criteria identified in the rubric as a means of pushing both a common understanding of expectations and assessment.

Finally, the rubric also serves departmental administrators who needed, as mentioned above, to develop a common set of expectations for thesis students across a wide range of activities as well as to collect data on student learning outcomes - both for the department itself and the Graduate Attributes. While the graduate attributes themselves were not a driving force in the construction of the categories and requirements described in the rubric, subsequent revisions of the rubric certainly considered how each category might map on to each of the Graduate Attributes as well as how each attribute - in particular investigation and communication - could be measured through the rubric.

Rubric Design

These multiple purposes, audiences and variability in projects make for a complex rubric development process in which competing agendas inform our design decisions. While the rubric was informed by many concepts for effective rubric development, this paper will focus on four central design considerations: (1) Number and naming of performance categories, (2) Numerical equivalents, (3) Generality versus specificity in the language of the performance criteria, (4) Simplicity vs. completeness and rubric usability. The results of this process can be seen in Figures 1: Final Thesis Document Rubric 2009-10, Figure 2: Final Thesis Document Rubric 2010-11 (revised) and Figure 3: Thesis Rubric Rough Guide to Performance Categories and Criteria below, after discussion of the key design decisions. In describing our rubric, we employ the term Performance Category to refer to different levels of achievement for each Performance

Criterion, which we use to refer to each requirement on which the student work is assessed.

One important design decision in formulating a rubric involves the number of performance categories. Most rubric guides advocate the use of an even, rather than odd, number of performance categories in order to avoid the tendency for assessors to overuse – or to default to – a middle category[9]. Using an even number of categories means that assessors must make a conscious decision and commit to a level of performance, rather than defaulting to an in-between state. An even number of categories does not preclude default categories, however; naming those categories is an essential design decision as well. Because our initial rubric did not provide verbal descriptions of each level of performance, we used descriptive terms to designate each level of performance rather than generic ones. Appropriately calibrated and named categories are still required to help avoid assessors selecting defaults. For example, our initial design employed Poor-Average-Good-Excellent as categories. These categories both skew towards the higher end of performance, and unfortunately demonstrated the problem identified above: even though an even number of categories was used, "Average" or "Good" can easily serve as a default category. Our second iteration of this rubric changed the categories to Fails-Adequate-Good-Exceeds Expectations. We maintained four category names that skewed towards higher performance largely because performance in a fourth year individual study course in this particular program had historically come in at a higher than normal average. A different type of course, in which student performance might require more differentiation at the middle or lower levels of performance, would require different considerations. By using Fails-Adequate at the bottom end of the scale, we felt we were more clearly demarcating these categories, and were presenting less of a default option than by using Average.

Another key decision involved whether or not to provide numerical equivalents for the performance categories as well as the sections of the rubric, a common practice especially in rubrics used in assessment of science and engineering work. Rubrics with precise numerical values for both the performance categories and sections can be used to calculate final grade values, as well as provide students with an indication of the relative importance of each section and provide a clear quantitative assessment across the board. While such rubrics are often favored by students, precisely because they provide a highly quantitative analysis of the work performed, we believe that such a strategy is contraindicated in this particular situation, for the following reasons. First, thesis supervisors had already voiced some opposition to moving to a rubric based assessment, largely because they favored a holistic assessment of the students work. In such cases, supervisors would start with a numerical grade, and try to use the rubric to justify such a grade, an exercise that is largely counterproductive. Given the nature and variety of the work being done in the course, a holistic assessment is also preferred - because it allows supervisors to weigh the sections according to the nature of the work. For example, if a research thesis focused primarily on a performing a literature review in the development of a new conceptual design, the results and discussion might play a smaller role than in a straightforward experimental thesis. Furthermore, while a separate category for communication exists, communication comes into play in the assessment of all of the sections, from the introduction to discussion and conclusions. Establishing a value solely for communication would be misleading, since it plays into how each of the section is graded.

Our solution, in this case, was to fix performance ranges for each of the individual performance

categories - see Figure 2. In this case, we chose to identify the categories with the following ranges Fail (0-60), Adequate (60-70), Good (70-80), and Exceeds Expectations (80+). For supervisors, a thesis scoring a majority of categories in the good range would score between 70-80, with some leeway in determining the weighting of their performance in each of the separate rubric sections. This allows for a guided holistic assessment more suited to the variability in work done for the thesis course; a stricter numerical approach would likely be more appropriate in a course where work would be more uniform.

As mentioned several times above, one of the key challenges for the development of a universal rubric for the thesis course involves the range of activities that constitutes a thesis. Because the thesis project is negotiated between the student and supervisor, and because students are free to pursue topics of their own interest (that in some way utilizes their engineering science and engineering design knowledge and skills), the language in the rubric needed to remain fairly broad. The rubric needed to be applicable to work ranging from a complex mathematical proof to lunar rover design to a straightforward lab report. However, rubric validity[8,11,16] relies on maintaining a balance between "excessive generality" and "dysfunctional detail" in the definition of the requirements and performance criteria. In balancing these two rather contradictory needs in identifying requirements, we started with the IMRAD (introduction-methods-results and discussion) model for experimental scientific work, but adjusted those categories in order to allow for other types of projects. An examination of previous projects had demonstrated that engineering design and experimental research formed the large majority of the thesis work done, and we were careful to insert language that would allow each section to apply to both types of theses. For example, we defined both "research gap" or "design problem" as key aspects for framing the thesis work - in this case providing the motivation - and looked for results from both experimental "research or design evaluation." These genre-related requirements could be deemed to cover most projects, though they might be valued differently in varying contexts.

Furthermore, while the rubric primarily assesses the document, a separate category was required to assess the nature of the project itself, which was required due to the variability in level of difficulty and challenge of thesis projects. Here, the supervisor could allow assessments of the students' motivation, drive, and the project difficulty to factor into the assessment of the grade. The design of the rubric criteria, overall, was informed by discussions with thesis supervisors, a review of past final thesis projects, a review of other relevant rubrics used for similar curricular contexts, and a review of feedback provided to students, to help form an understanding of the learning that matters in the thesis experience.

A final but key consideration in the development and design of the rubric involved its usability; in satisfying many of the desired requirements for the rubric, it would have been easy to develop a highly complex and detailed document that would not be usable. Our first revision, then, focused on developing short descriptions for each requirement within each section, and limiting those requirements to a minimum for each section, especially for the content requirements. The requirements would describe the expectations for the sections, and supervisors would be able to choose between each of the performance categories on their own.

While such a structure was developed for simplicity's sake, requests came in to help differentiate between levels of performance, from all audiences, students and supervisors looking for a better

sense of how to differentiate between sections, and from administrators looking to be clear on how these might be used in assessing graduate attributes, and ensuring that the attribute performance actually matched the description provided in the rubric. If included within the rubric, however, this information would make the rubric largely unusable - instead, we chose to develop a guide to the rubric that provided the differentiation between these levels. This optional "rough guide" distinguished between levels of performance on a more granular level than the categories names could, focusing on identifying the "amount, intensity, or frequency"[14] of that trait that mapped to that level. Students and supervisors comfortable with a simpler rubric could go without the guide, but those looking for more guidance could use the guide in understanding how those requirements broke down into the specific performance categories (see Figure 3).

Such an approach, however, presents problems for one important metric for rubric quality, as well as its ability to serve as an effective measure for student learning and performance: inter rater- reliability. But given the specific nature of this course, effectively an independent study assessed almost exclusively by their supervisors, this problem will be difficult to negotiate. Two factors may help to mitigate this concern for in the context of graduate attributes assessment. First, the students are being assessed by full faculty members, rather than by teaching assistants. While the consistency of the data across the cohort may still be under question, each individual student is being given the professional judgment of an expert in the field. Second, our attempt to be more granular in the "rough guide" can be viewed an attempt to help create clarity across assessors. Writing descriptions of performance levels as a way of increasing inter-rater reliability has been discussed in previous research[9] and in fact, research has found that rubric design itself can offer the clarity needed for use by evaluators with substantial levels of agreement, potentially eliminating the need for formal norming[3]. However, it remains an important challenge to address in revisions of this assessment activity, and a limitation to the data derived from the project. In the assessment of the oral presentation for the thesis, inter-rater reliability issues were more easily addressed because a small team of raters were deployed across the entire cohort: benchmarking and cross assessment was performed. In the future, assessment of certain criteria for the final thesis document - those around engineering communication, for example - could be performed by trained graders rather than the supervisors themselves. Alternatively, benchmarking sessions could be held among supervisors from common research areas, to both test and encourage the development of inter-rater reliability within disciplinary contexts.

Draft versions of the rubric were circulated to select members of two groups of end users, supervisors and administrators. Questions about applicability to specific types of projects, criteria and performance categories, rubric design and usability, as well as expected numerical equivalents were addressed, and resulted in the documents shown in Figures 1: Initial Final Thesis Document Rubric, 2: Current Final Thesis Document Rubric and 3: Thesis Rubric Guide to Performance Categories. Major changes from the initial rubric involved the addition of numerical equivalent for the categories (though not for each of the criteria as outlined above), addition of new criteria in place to help assessment of project scope and breadth, and the development of the thesis rubric guide to performance categories, an optional tool which we hope will help validity and reliability. The rubric remains under constant revision, however, as we learn from our assessment practices, our users, and other demands come into play.

Student Name: _____ **Supervisor:** _____

Component	No	Yes	Excep -tional	Requirement	Comments *(Please use back if necessary)*
Introduction	☐	☐	☐	Establishes context necessary to facilitate thorough understanding of thesis work in a concise manner	
	☐	☐	☐	Establishes a clear research gap, makes a convincing case for the significance of proposed research work	
	☐	☐	☐	Identifies goal for thesis work that explicitly addresses the research gap; provides clear purpose statement	
Literature Review / Background	☐	☐	☐	Explains theoretical concepts important to understanding of thesis work	
	☐	☐	☐	Identifies, summarizes, and synthesizes relevant research in constructing an understanding of current state of field	
	☐	☐	☐	Enables deeper understanding of research question/ design problem through analysis of research in the field, indicating a path for moving research forward	
Methods and Findings	☐	☐	☐	Describes methods or design in sufficient detail to enable understanding of work done	
	☐	☐	☐	Provides justification for methods chosen or design decisions made	
	☐	☐	☐	Results displayed clearly in organized manner, using appropriate figures or graphics; key results highlighted	
Discussion and Conclusions	☐	☐	☐	Engages with and explains results intelligently	
	☐	☐	☐	Identifies key claims to be drawn from results of research or design evaluation, qualifies them appropriately	
	☐	☐	☐	Outlines significance of research done, identifies potential future work that arises from thesis work	
Overall Document Design:	☐	☐	☐	Abstract concisely summarizes purpose, methods, key results of research, and presents conclusions clearly	
	☐	☐	☐	Document length, formatting, structure meets stated requirements, and specific demands of thesis topic	
	☐	☐	☐	Organized well, with content in discrete and appropriate positions in paper, structure clearly laid out, transitions that create flow in document	
	☐	☐	☐	Demonstrates coherent prose that concisely and clearly communicates complex topics in well designed paragraphs	
	☐	☐	☐	Demonstrates grammatical correctness and clarity in sentence design	
	☐	☐	☐	Provides clear attribution of ideas throughout paper using a known referencing standard; uses references effectively to help establish context, back claims, or justify decisions	
Project Experience	☐	☐	☐	Work has contributed to scholarship in field / made a measurable impact	
	☐	☐	☐	Demonstrated initiative and ownership of work throughout thesis project	
	☐	☐	☐	Demonstrated an ability to work independently and manage their work plan, meeting all critical deadlines	
	☐	☐	☐	Quality of effort and thesis work indicative of potential for future research success	

Numerical Score : **/ 100**

FINAL THESIS REPORT RUBRIC – I – ESC499

Student Name: _____ **Supervisor:** _____ **Grade:** _____ **/100**

Component	1	2	3	4	Requirement	Comments *(Use back if necessary)*
Introduction	☐	☐	☐	☐	Establishes context necessary to facilitate thorough understanding of thesis work in a concise manner	
	☐	☐	☐	☐	Establishes a clear research gap/design problem, makes a convincing case for the significance of proposed research work	
	☐	☐	☐	☐	Identifies goal for thesis work that explicitly addresses this gap/problem; provides clear purpose statement	
Literature Review / Background	☐	☐	☐	☐	Explains theoretical concepts important to understanding of thesis work	
	☐	☐	☐	☐	Identifies, summarizes, and synthesizes relevant research in constructing an understanding of current state of field	
	☐	☐	☐	☐	Enables deeper understanding of research question/design problem through analysis of research in the field, indicating a path for moving research forward	
Methods and Findings	☐	☐	☐	☐	Describes methods or design in sufficient detail to enable understanding of work done	
	☐	☐	☐	☐	Provides justification for methods chosen or design decisions made	
	☐	☐	☐	☐	Results displayed clearly in organized manner, using appropriate figures or graphics; key results highlighted	
Discussion and Conclusions	☐	☐	☐	☐	Engages with and explains results intelligently	
	☐	☐	☐	☐	Identifies key claims to be drawn from results of research or design evaluation, qualifies them appropriately	
	☐	☐	☐	☐	Outlines significance of research done, identifies potential future work that arises from thesis work	
Overall Document Design:	☐	☐	☐	☐	Abstract concisely summarizes purpose, methods, key results of research, and presents conclusions clearly	
	☐	☐	☐	☐	Document length, formatting, structure meets stated requirements, and specific demands of thesis topic	
	☐	☐	☐	☐	Organized well, with content in discrete and appropriate positions in paper, structure clearly laid out, transitions that create flow in document	
	☐	☐	☐	☐	Demonstrates grammatically correct, coherent prose that concisely and clearly communicates complex topics in well designed paragraphs and sentences	
	☐	☐	☐	☐	Uses and integrates well-designed visuals effectively to communicate key concepts / results	
	☐	☐	☐	☐	Provides clear attribution of ideas throughout paper using a known referencing standard; uses references effectively to help establish context, back claims, or justify decisions	
Project Experience	☐	☐	☐	☐	Work has contributed to scholarship in field / made a measurable impact	
	☐	☐	☐	☐	Demonstrated initiative, ability to work independently, time management skills and ownership of work throughout thesis project	
	☐	☐	☐	☐	Thesis work posed a significant challenge, requiring superb engineering & scientific knowledge and skills	
	☐	☐	☐	☐	Quality of effort and thesis work indicative of potential for future research success	

*1 - Fails (0-60%); 2 - Adequate (60-70%); 3 - Good (70-80%); 4 - Exceeds expectations (80-100%). These numerical equivalents are only approximate; final grade and value of each component is up to the supervisor.

Component	Fails	Adequate	Good	Exceeds Expectations
Introduction	Missing key elements of context necessary to understand thesis work	Establishes just sufficient context necessary to facilitate a basic understanding of thesis work	Establishes context necessary to facilitate understanding of thesis work	Develops context appropriately and concisely in facilitating through understanding of thesis work
	Research gap or design problem remains unarticulated or unclear	Research gap or design problem is identified, but too broad or general to define project clearly	Identifies a clear research gap/design problem	Establishes a clear research gap/design problem, makes a convincing case for the significance of proposed research work
	Goal of thesis work is difficult to identify, or unrelated to gap or problem statement	Stated goal for thesis work is vague, imprecise, or not clearly related to gap/ problem statement	Identifies goal for thesis work that addresses this gap/problem	Explicitly identifies goal for thesis work in a clear purpose statement for the project that addresses gap/problem
Literature Review / Background	Missing key explanations of theoretical concepts important to thesis work	Most theoretical concepts important to work are identified and briefly explained	Identifies and explains theoretical concepts important to understanding of thesis work	Explains theoretical concepts clearly, concisely, in context of thesis work
	Fails to acknowledge or reference key research/prior work in the field	Identifies some important research/prior work in the field, but misses a few essential developments	Identifies and summarizes most of the key research/prior work in developing a nearly complete understanding of the field	Identifies, summarizes, and synthesizes relevant research in constructing an understanding of current state of field
	Analysis of field is incomplete and fails to further develop the research gap/design problem	Analysis of field is mostly complete, and helps to further develop research gap/design problem	Enables understanding of research question/design problem through analysis of research in the field	Enables deep understanding of research question/design prob. via thorough analysis of research in the field, indicating path for moving forward
Methods and Findings	Fails to explain key elements of methods or design	Most elements of methods or design are explained in sufficient detail; missing elements may hamper understanding of work done	Describes methods or design in sufficient detail to enable understanding of work done	Detailed description of methods or design helps facilitate a thorough understanding of project
	Fails to justify key elements of method or design decisions	Provides some justification for most methods chosen/design decisions made	Provides sufficient justification for methods chosen / design decisions made	Justification for methods chosen/design decisions clearly and convincingly articulated, warranting validity of project
	Results not displayed in organized or appropriate manner	Most results are displayed in an organized manner, using appropriate figures or graphics	Results displayed clearly in organized manner, using appropriate figures or graphics	Results displayed clearly in organized manner, using appropriate visuals that help highlight key results and findings
Discussion and Conclusions	Engages with results only superficially, without explanation of significance	Engages with and provides explanation for most results	Engages with and explains key results intelligently	Employs and explain results clearly in the context of research / design claims made
	Fails to make key claims from results of research or design evaluation	Makes appropriate claims from results of research or design evaluation, though claims may not be fully warranted	Identifies and explains key claims to be drawn from results of research or design evaluation	Identifies and warrants key claims to be drawn from results of research or design evaluation, qualifies them appropriately
	Fails to identify significance of research or design work done	Summarizes research / design work done, but fails to place it in context of prior or future work	Clearly identifies significance of research/ design work done in context of past work	Outlines significance of research/design work done, identifies potential future work that arises from thesis work
Overall Document Design:	Abstract fails to adequately describe nature and conclusions of project	Abstract provides a vague description of nature and conclusions of project	Abstract summarizes key elements of thesis sufficiently	Abstract concisely and completely summarizes purpose, methods, key results of research, presenting conclusions clearly
	Document length or formatting fails to meet many of the stated requirements	Some inconsistencies in formatting, but mostly meets the stated requirements	Document length, formatting, structure meets stated requirements	Document length, formatting, structure meets stated requirements, and specific demands of thesis topic
	Poorly organized throughout, lacking clear structure and flow throughout document	A few organizational problems detract from an otherwise well structured thesis	Organized well, with content in discrete and appropriate positions in paper, and structure clearly laid out	Organized well, with logical and explicit structure, and transitions that create flow throughout document

*1 - Fails (0-60%); 2 - Adequate (60-70%); 3 - Good (70-80%); 4 - Exceeds expectations (80-100%). These numerical equivalents are only approximate; final grade and value of each component is up to the supervisor.

Component	Fails	Adequate	Good	Exceeds Expectations
	Grammatical problems hamper understanding of key elements of the document	Some grammatical problems hamper readability of prose, but not understanding of document	Demonstrates grammatically correct, coherent prose throughout	Demonstrates grammatically correct, coherent prose that concisely and clearly communicates complex topics in well designed paragraphs and sentences
	Visuals not used appropriately or well integrated into document	Visuals employed appropriately, but may not be well integrated into document	Uses and integrates visuals effectively to communicate key concepts / results	Uses and integrates well-designed visuals effectively to communicate key concepts / results
	Poor attribution of ideas throughout, missing key references and failing to use an appropriate referencing standard	Provides clear attribution of ideas throughout paper using a known referencing standard, with only a few gaps	Provides clear and thorough attribution of ideas throughout paper using a known referencing standard	Provides clear attribution of ideas throughout paper using a known referencing standard; references used effectively to help establish context, back claims, or justify decisions
Project Experience	Work makes no contribution to the field, and is only marginally relevant to current good scholarship	While no significant impact is made, work is relevant to good scholarship in the field	Work advances the possibility for future advancements in the field	Work has contributed to scholarship in field / made a measurable impact
	Student lacks the ability to take initiative, work independently, manage their time and/or take ownership over the project, negatively impacting the thesis experience	Student sometimes shows the ability to take initiative, work independently, manage their time and take ownership over the project	Student takes initiative and works independently, demonstrating good time management skills and project ownership	Demonstrated initiative, ability to work independently, time management skills and ownership of work throughout thesis project
	Thesis work completed did not meet expectations, nor showcase the knowledge and skills expected from an undergraduate engineering student	Thesis work required the knowledge and skills expected of an undergraduate engineering student	Thesis work posed a reasonable challenge, requiring engineering & scientific knowledge typical of a senior undergraduate or junior graduate student	Thesis work posed a significant challenge, requiring superb engineering & scientific knowledge and skills
	Student does not demonstrate potential for future research work	Quality of effort and thesis work indicative of some potential for future research work, with more study and experience	Quality of effort and thesis work indicative of some potential for future research success	Quality of effort and thesis work indicative of potential for future research success

*1 - Fails (0-60%); 2 - Adequate (60-70%); 3 - Good (70-80%); 4 - Exceeds expectations (80-100%). These numerical equivalents are only approximate; final grade and value of each component is up to the supervisor.

Mapping the Graduate Attributes to the Rubric

As part of the adjustments to an outcome-based accreditation process, all programs are mapping the constructed indicators to existing or new course assessment tools, and identifying connections between the criteria on existing rubrics, and the indicators developed by the Graduate Attribute Committee. Because the rubric was initially developed for the assessment of an undergraduate thesis, its criteria differ from the precise parameters associated with investigation and communication in the graduate attributes. While a new rubric could have been created for the undergraduate thesis that reflected the exact indicator wording provided by the Graduate Attribute Committee, it remains important to maintain the essence of the thesis deliverables, and the specific priorities of the thesis supervisors and undergraduate program as a whole in the assessment process. As a result, there is not a perfect one-to-one match between the rubric and the indicators. The challenges of linking curriculum and assessment with Graduate Attributes, which include: the selection of appropriate assessment pieces; efficient methods of data collection and analysis; and suitable rubric design, have been discussed and documented widely by other institutions[2,9,10].

While the attributes and subsequent indicators offer some general ways to assess the constructs, they are not rooted in the context of a particular assignment or discipline. It is important to note that the outcomes and indicators associated with each graduate attribute, which have been developed by a central committee, are relatively general and are out-of-context. When they are actually applied to the curriculum, we must allow for a certain degree of latitude in application and interpretation. To make an analogy, when we examine teacher knowledge, we consider "pedagogical knowledge" and "pedagogical content knowledge" as distinct; that is, teaching processes and outcomes change with disciplinary context. We argue that the same principle applies here, in that a graduate attribute in practice may present as distinct from a graduate attribute outside of a curricular context.

The mapping exercise undertaken is represented in the following Tables. In considering how the attributes under study map to the thesis course, it is important to note that while all global outcomes (listed in the far left of the tables) must be measured, programs may choose which indicators (listed in the column second from the left) to use. Also, the graduate attributes will be mapped to various aspects of the curriculum, and so the thesis course serves as but one instance of at least 2-3 measurement points in the undergraduate program. In the following tables, some rubric criteria are numbered, which link to the data presented in figures 4 and 5, while other criteria, signified by a +, have been added for 2011-12 and/or matched after the data compilation for this paper.

Table 3: Mapping Investigation Skills to Thesis Rubric Criteria

Investigation Attribute (From Table 1)		**Rubric Criteria (from Figure 1)**
Ability to define the problem	Describe the previous work	(1) Establishes context necessary to facilitate thorough understanding of thesis work in a concise manner
		+ Explains theoretical concepts important to understanding of thesis work
		+ Identifies, summarizes and synthesizes relevant research in constructing an understanding of current state of field
		+Enables deeper understanding of research question/design problem through analysis of research in the field, indicating a path for moving research forward
	State the problem, its scope and importance	(2) Establishes a clear research gap/design problem, makes a convincing case for the significance of proposed research work
	State the objective of the work	(3) Identifies goal for thesis work that explicitly addresses this gap/problem; provides clear purpose statement
Ability to devise and execute a plan to solve the problem	Select a set of tests to be conducted	(4) Describes methods or design in sufficient detail to enable understanding of work done
		(5) Provides justification for methods chosen or design decisions made
	Select, plan and apply the methods for collecting the results	(4) Describes methods or design in sufficient detail to enable understanding of work done
		(5) Provides justification for methods chosen or design decisions made
	Identify limitations of the methods used and their impact on the results.	(5) Provides justification for methods chosen or design decisions made
Ability to use critical analysis to reach valid conclusions supported by the results of the plan	Analyze the results	(6) Results displayed clearly in organized manner, using appropriate figures or graphics; key results highlighted
		(7) Engages with and explains results intelligently
	Formulate the conclusions	(8)Identifies key claims to be drawn from results of research or design evaluation, qualifies them appropriately
	Validate conclusions by induction or deduction	
	Compare conclusions with previous work	+ Outlines significance of research done, identifies potential future work that arises from thesis work

	Characterize the limitations and implications of the conclusions	

In examining the mapping of the investigation attribute indicators to the rubric criteria, we see a set of relatively clear links. However, there are some distinctions to consider. For example, take the indicators “Select a set of tests to be conducted” and “Select, plan and apply the methods for collecting the results”. These indicators have been mapped to two rubric criteria: 1) Describes methods or design in sufficient detail to enable understanding of work done, and 2) Provides justification for methods chosen or design decisions made. Here, we have made an assumption that if the student can describe and justify methods, that they have likely selected them, or at least demonstrated the potential to make their own selections, though this may not be the case. In the case of the third global outcome, four indicators have been mapped to two of the rubric criteria, which suggests there may be challenges in demonstrating that we have met each of the distinct indicators. However, as noted earlier, the process that we are following requires us only to demonstrate that we’ve met each of the global outcomes, and not each and every indicator noted. In examining the investigation attribute table, it is noted that the rubric criteria offer a higher degree of precision. For example, the indicator “Describe the previous work” is linked to four rubric criteria, all of which can be considered important dimensions of the indicator. By situating the Graduate Attribute within the thesis course and this assessment tool, we have provided a more precise description of what it means to “Describe the previous work”. Given that the graduate attributes and their associated outcomes and indicators are new, we would argue that there is still fluidity at play. By using more specific assignment criteria, we may develop a better understanding of what each indicator means, which could have implications beyond the assessment of the thesis. While the graduate attribute process in our Faculty started as “top down”, with a central committee outlining the outcomes and indicators, perhaps it is now time to use a bottom-up approach to refine, and better define the graduate attributes of the undergraduate engineer.

Table 4: Mapping Communication Skills to Thesis Rubric Criteria

Communication Attribute (From Table 2)		**Rubric Criteria (From Figure 1)**
Ability to identify and credibly communicate engineering knowledge	Situate, in document or presentation, the solution or design in the world of existing engineering, taking into account social, environmental, economic and ethical consequences	Not assessed in rubric
	Recognize a credible argument (reading)	(1) Explains theoretical concepts important to understanding of thesis work
		(2) Identifies, summarizes, and synthesizes relevant research in constructing an understanding of current state of field

	Construct a credible argument in written or spoken form – to persuasively present evidence in support of a claim	(3) Identifies key claims to be drawn from results of research or design evaluation, qualifies them appropriately
		(4) Outlines significance of research done, identifies potential future work that arises from thesis work
	Organize written or spoken material– to structure overall elements so that their relationship to a main point and to one another is clear	(5) Document length, formatting, structure meets stated requirements, and specific demands of thesis topic
		(6) Organized well, with content in discrete and appropriate positions in paper, structure clearly laid out, transitions that create flow in document
		(7) Demonstrates coherent prose that concisely and clearly communicates complex topics in well designed paragraphs
		(8) Demonstrates grammatical correctness and clarity in sentence design
	Create "flow" in document or presentation – flow is a logical progression of ideas, sentence to sentence and paragraph to paragraph	(6) Organized well, with content in discrete and appropriate positions in paper, structure clearly laid out, transitions that create flow in document
Ability to incorporate visual elements in communication	Incorporate visual material that enhances communication without detracting from it	+Uses and integrates well-designed visuals effectively to communicate key concepts/results
	Incorporate various media appropriately	
	Incorporate principles of visual design appropriately	

		(9) Demonstrated initiative and ownership of work throughout thesis project
		(10) Demonstrated an ability to work independently and manage their work plan, meeting all critical deadlines
	Use iteration to clarify and amplify understanding of issues being communicated	+ Has incorporated feedback and additional research on initial deliverables to improve final thesis document and work
Ability to develop communication through an iterative process		(9) Demonstrated initiative and ownership of work throughout thesis project
	Use reflection to determine and guide self-development	(10) Demonstrated an ability to work independently and manage their work plan, meeting all critical deadlines

In the case of the Communication Attribute, we see more challenges. First, some of the communication indicators as developed by the Graduate Attribute Committee – for example, the incorporation of visual communication – were not initially assessed in the rubric, although this has been added to the 2011-12 iteration. The relationship between the indicators around the third global outcome, “Ability to develop communication through an iterative process” and the corresponding rubric criteria are problematic, although this has encouraged the addition of a new criterion. Again, by contextualizing the graduate attributes within the thesis assignment, we can provide more precise descriptions of some of the indicators.

After the thesis supervisors had completed the assessment of their students’ work in May 2011, all rubrics were collected and data was compiled on each of the relevant indicators, using the mapping structure in tables 3 and 4. This data compilation allowed us to review the competencies of the entire cohort on the two Graduate Attributes. This is represented by the following Figures, in which rubric criteria are mapped according to the numbering system in tables 3 and 4:

Figure 4 Investigation Attribute Mapping Results

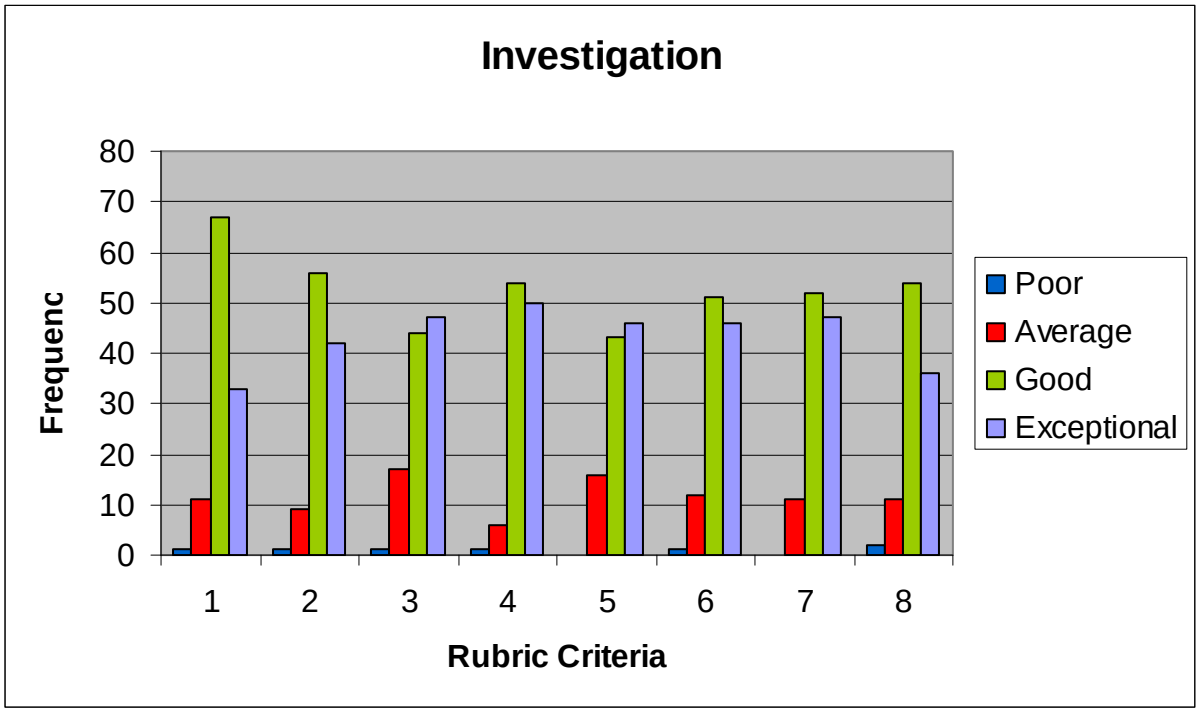
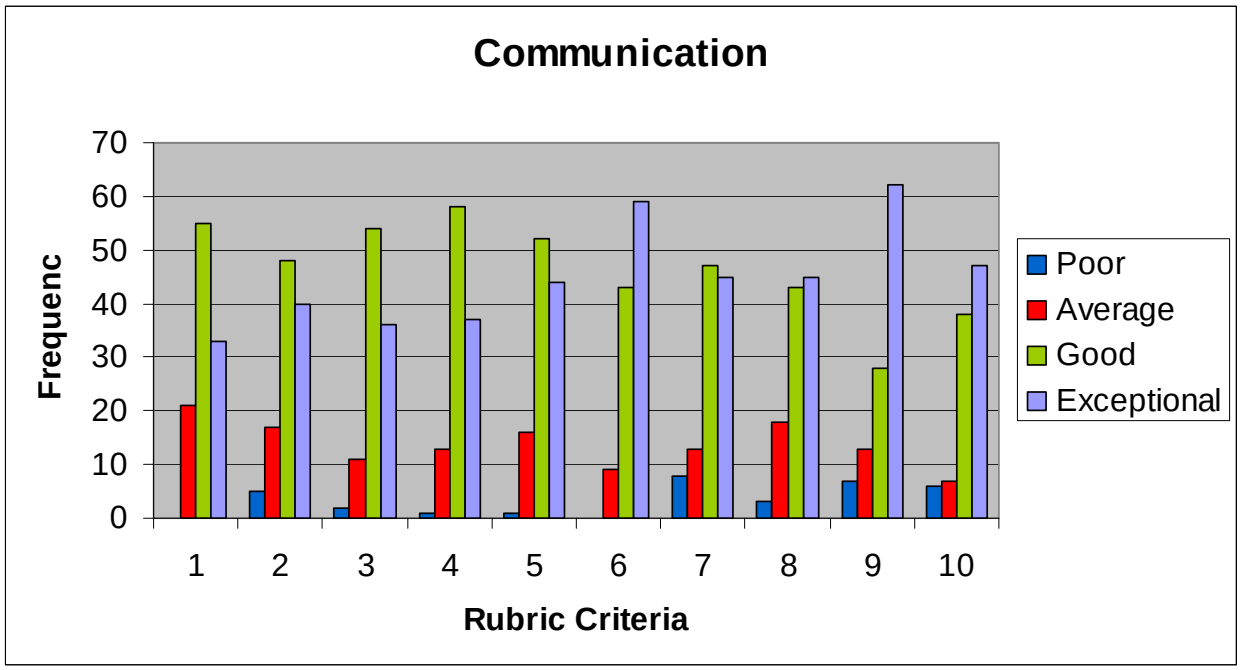


Figure 5 Communication Attribute Mapping Results



In the initial rubric, supervisors were asked to rate the students on each of the rubric criteria as poor, average, good and exceptional. In the figures above, the total number of responses for each

relevant criterion, and the four levels, are plotted. Clearly, the supervisors have rated the work as very strong across the board. However, this plotting allowed us to examine where the students need improvement, which can be strengthened in the curriculum. For example, in the case of investigation, we see a higher proportion of students weaker in the indicator, "State the objective of the work"; or on the rubric, "Identifies goal for thesis work that explicitly addresses this gap/problem; provides clear purpose statement". In the case of communication, we see the strongest need for improvement in "Explains theoretical concepts important to understanding of thesis work". It should be noted that this data was collected before numerical values were added to the performance categories, and before the rough guide was created to describe each performance level, and increase inter-rater reliability.

Conclusions and Discussion

Through the exercise of mapping the indicators to the rubric and determining deficiencies, alongside the process of collecting feedback from students and supervisors about the rubrics, as discussed earlier, we were able to determine where to make adjustments – to the rubric, and to the curriculum as a whole. As indicated by the + symbol in two tables, new criteria have been added to the rubric to address deficiencies. We have also added a criterion to recognize the engineering and science knowledge base applied by the student, as this was cited as an important component to the supervisors.

As noted, we don't have perfect matching between the rubric and the indicators, and so one may ask, why not simply measure the indicators, as developed by the Graduate Attribute Committee, directly? We must consider the unique nature of our assessment pieces before taking this approach. As the specific global outcomes and indicators associated with the Graduate Attributes change over time, especially in these early stages of graduate attribute development, assignments will need to change, and we expect there to be an ongoing, iterative process between the development of accreditation-related outcomes and course-based assessment tools. Also, the outcomes and indicators developed by the Graduate Attribute Committee are, in some cases, quite general, and do not provide sufficient detail for direct insertion in an assignment rubric.

The question of the validity of the data derived from the rubric remains an important one. As stated above, the specific nature of the thesis course precludes any real promise of inter-rater reliability in the assessment and use of the rubric. We believe, however, that for the purposes of the thesis course as well as for graduate attributes assessment, this concern is somewhat mitigated by the fact that students are assessed by supervising professors – experts in their respective fields – with the authority to speak to industry and academic expectations. Furthermore, we have attempted to develop a flexible and modular approach to rubric development that provides both appropriate generality – in the rubric itself – and detail – in the published "rough guide" – for different types of users.

In initially developing the rubric, we set out to create something that authentically described the thesis experience, but was flexible enough to allow thesis supervisors to apply their own needs, and the unique features of their project, in the rubric. When the use of the rubric is shifted away from scaffolding one-to-one feedback, to the measurement of a set of collaboratively-constructed graduate attribute indicators, tensions arise, and adjustments need to be made. This work is in-

progress, and further efforts will be placed on improving inter-rater reliability, and continuing to explore measures of validity that ensure the rubric is a good fit for both the individual assessments of the thesis experience, and the Graduate Attributes. Likewise, in measuring the graduate attributes, we must always consider that the attributes are to be contextualized in real learning experiences, and in turn, we can only demonstrate that students have met the attributes in the context of a specific assignment. However, there are also opportunities here, to use our curriculum to better define the learning outcomes associated with the graduate attributes, utilizing both a top-down and bottom-up approach to outcomes planning and measurement.

Bibliography

1. Anthony, D.K., Magleby, S.P., Sorensen, C.D., Swan, B.R. & Todd, R.H. (1995). A survey of capstone engineering courses in North America. *Journal of Engineering Education, 84*(2): 165-174.

2. Banta, T.W., Lund, J.P., Black, K.E. & Oblander, F.W. (1996). *Assessment in Practice*. San Francisco: Jossey-Bass.

3. Bresciani, M.J., Oakleaf, M., Kolkhurst, F., Nebeker, C., Barlow, J., Duncan, K., Hickmott, J. (2009). Examining design and inter-rater reliability of a rubric measuring research quality across multiple disciplines. *Practical Assessment, Research & Evaluation, 14*(12). Available online: http://pareonline.net/pdf/v14n12.pdf.

4. Canadian Engineering Accreditation Board (2010). *Accreditation Criteria and Procedures.* Retrieved from http://www.engineerscanada.ca/e/files/acc_Manual_Accreditation_Procedures.pdf.

5. Dutson, A.J., Magleby, S.P., Sorensen C.D. & Todd, R.H. (1997). A review of literature on teaching engineering design through project-oriented capstone design courses. *Journal of Engineering Education, 86*(1): 17-28.

6. Frank, B., Fostaty-Young, S., McCahan, S., Wolf, P., Ostafichuck, K, Watts, C. & Saleh, N. (2011). Engineering graduate attribute development (EGAD) project. *Proceedings of the 2nd Annual CEEA Conference: Memorial University St. John's, Newfoundland June 6-8 2011.* Retrieved from http://library.queensu.ca/ojs/index.php/PCEEA/article/view/3566.

7. Mertler, C.A. (2001). Designing scoring rubrics for your classroom. *Practical Assessment, Research, & Evaluation, 7*(25). Available online: http://www.pareonline.net/getvn.asp?v=7&n=25.

8. Moskal, B. M. & Leydens, J.A. (2000). Scoring rubric development: Validity and reliability. *Practical Assessment, Research & Evaluation, 7*(10). Available online: http://pareonline.net/getvn.asp?v=7&n=10.

9. Newell, J.A., Dahm, K.D. & Newell, H.L. (2002). Rubric development and inter-rater reliability issues in assessing learning outcomes. *Chemical Engineering Education, 36*(3): 212-15.

10. Newell, J.A., Newell, H.L., Owens, T.C., Erjavec, J., Hasan, R. & Sternberg, S.P.K. (2000). Issues in developing and implementing an assessment plan in chemical engineering departments. *Chemical Engineering Education, 34*(3): 268-271.

11. Popham, W.J. (1997). What's wrong - and what's right - with rubrics. *Educational Leadership, 55*(2): 72-75.

12. Reddy, Y.M. & Andrade, H. (2010). A review of rubric use in higher education. *Assessment & Evaluation in Higher Education, 35*(4): 435-448.

13. Reed, Y. (2008). No rubric can describe the magic: Multimodal designs and assessment challenges in a postgraduate course for English teachers. *English Teaching: Practice and Critique, 7*(3): 26-41.

14. Rohrmann, B. (2007). *Verbal Qualifiers for Rating Scales: Sociolinguistic Considerations and Psychometric Data.* Retrieved from http://www.rohrmannresearch.net/pdfs/rohrmann-vqs-report.pdf.

15. Shaeiwitz, J.A. (2002). Mining capstone engineering experiences for program assessment results. *International Journal of Engineering Education, 18*(2): 193-198.

16. Tierney, R. & Simon, M. (2004). What's still wrong with rubrics: Focusing on the consistency of performance criteria across skill levels. *Practical Assessment, Research & Evaluation, 9*(2). Retrieved from http://pareonline.net/getvn.asp?v=9&n=2.

17. Turley, E. D. & Gallagher, C.W. (2008). On the "uses" of rubrics: Reframing the great rubric debate. *English Journal, 97*(4): 87-92.

18. Welch, H., Suri, D. & Durant, E. (2009). Rubrics for assessing oral communication in the capstone design experience: Development, application, analysis and refinement. *International Journal of Engineering Education, 25*(5): 952-961.