THE CDIO AS AN ENABLER FOR GRADUATE ATTRIBUTES ASSESSMENT IN CANADIAN ENGINEERING SCHOOLS

Robert W. Brennan

Schulich School of Engineering, University of Calgary

Ron J. Hugo

Schulich School of Engineering, University of Calgary

William D. Rosehart

Schulich School of Engineering, University of Calgary

ABSTRACT

Recent changes to the criteria for engineering accreditation in Canada emphasize continuous curriculum improvement through outcomes-based assessment. In this paper, we show how the CDIO approach not only enables continuous improvement, but can assist Canadian engineering programs with the overall graduate attributes assessment process.

Keywords – Accreditation, Graduate Attributes, Outcomes-based Assessment, CDIO Syllabus.

1. INTRODUCTION

In 2008, the CEAB (Canadian Engineering Accreditation Board) [1] updated their criteria and procedures [2], moving toward a model that emphasizes continuous improvement, and more specifically, program outcomes. Although outcomes-based assessment is a well-established component of many national engineering accreditation boards (e.g., ABET [3]), it is relatively new in the Canadian context. This is not to say that outcomes-based assessment is not practiced in Canada – other national accreditation boards (e.g., medicine) have been relying on outcomes-based assessment for years and many of our colleagues use it as part of their teaching and learning strategies – however, there is very little experience with outcomes-based assessment at the engineering programs level in Canada.

In this paper, we describe the process that is being followed at the Schulich School of Engineering to address the CEAB's new graduate attributes criterion (Figure 1), and show how the CDIO syllabus [4] can play an integral role in this process.

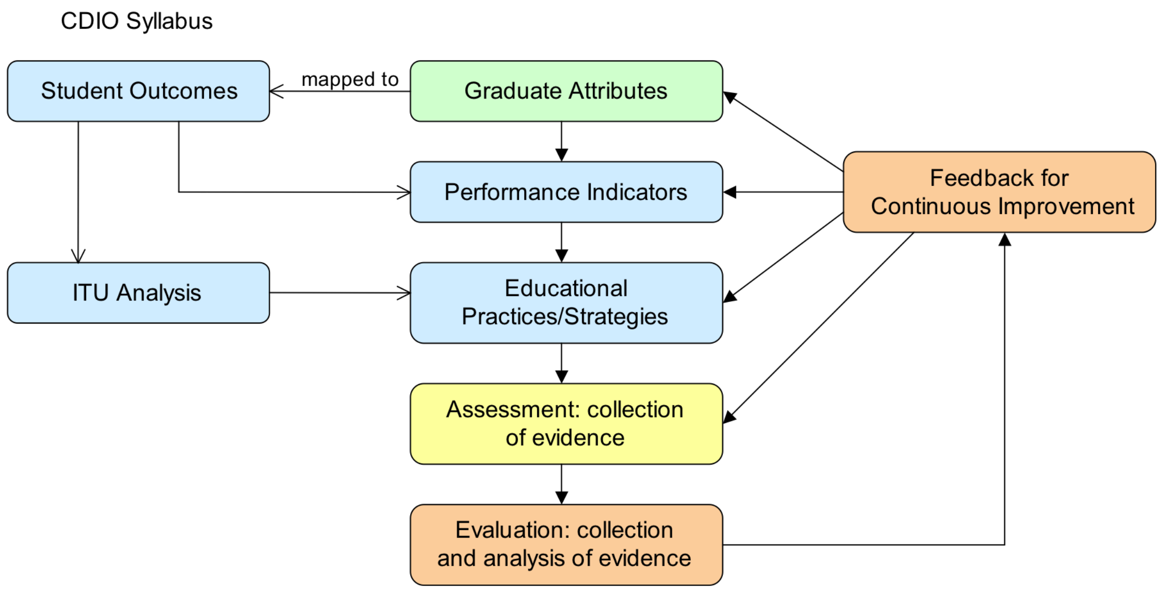

Figure 1. CEAB Graduate Attribute Planning and the CDIO Syllabus

The main advantage of this approach is that the CEAB's graduate attributes can be linked to the comprehensive CDIO syllabus [5]. More specifically, the CDIO syllabus can be viewed in the context of a typical program assessment planning flow chart [6] as follows:

CDIO Syllabus		Graduate Attributes Assessment
Level 1	⇔	Program Educational Objectives
Level 2	⇔	Student Outcomes / Graduate Attributes
Level 3	⇔	Performance Indicators

where "Level 1" refers to the first level of detail of the CDIO syllabus (e.g., "2 Personal and Professional Skills and Attributes") and "Level 2" and "Level 3" refer to the second and third level of detail respectively.

It should be noted that this approach does not discount the stakeholder engagement that is inherent to outcomes-based assessment. Instead, the CDIO syllabus is used as a starting point for program assessment and as a means of informing and focusing the discussions around program-specific outcomes and performance criteria. As illustrated in Figure 1, feedback is required at all stages of the process, involving input from educational researchers (e.g., assessment design, teaching and learning strategies), engineering educators (e.g., direct assessment, educational practices/strategies), engineering students (e.g., indirect assessment via self-efficacy surveys), and engineering employers (e.g., input on student outcomes, indirect assessment via surveys).

Although this addition to the CEAB accreditation requirements may at first appear onerous, if applied properly it can result in a positive environment for, and an enabler of curriculum reform. In this paper, we build on our previous work on curriculum mapping [7] to show how the CDIO approach can facilitate this overall process.

The paper is divided into two main sections. First, we describe the graduate attributes assessment process that is currently being followed at the Schulich School of Engineering. This process is built on the typical program assessment planning flow chart [6], but relies heavily on the CDIO approach given the B.Sc. in Mechanical Engineering's link to CDIO. Next, we comment on the overall continuous improvement process that is tightly linked to every step in the graduate attributes assessment process. The paper concludes with a short summary and comments on the CDIO and CEAB graduate attributes assessment.

GRADUATE ATTRIBUTES ASSESSMENT PROCESS

This section provides an overview of the process that is being used at the Schulich School of Engineering for graduate attributes assessment. We start at the top of Figure 1 with broad program objectives / graduate attributes, and refine the process to the collection of evidence on individual performance indicators. In order to provide a more concrete example, we focus on only one of the Schulich School of Engineering's undergraduate programs: the B.Sc. in Mechanical Engineering program.

Program Educational Objectives and Student Outcomes

In the context of outcomes-based assessment, CEAB graduate attributes are very similar to student outcomes or program outcomes: e.g., ABET defines "student outcomes" as "what students are able to do by the time of graduation … relate to the knowledge, skills, and behaviours that students acquire as they progress through the program" [3]. ABET encourages programs to establish their own student outcomes that are more reflective of their program's educational objectives, then map their program-specific outcomes to ABET's criteria.

This same process can be followed with respect to the CEAB's graduate attributes. More specifically, each program can develop its own set of student outcomes that are mapped directly to the CEAB graduate attributes as shown in Figure 1. Before looking at how this is done, it is useful to look at the relationship between "program educational objectives" and "student outcomes."

Like graduate attributes, student outcomes are focused on what students can do at the time of graduation. However, from an employer's perspective (e.g., industry, government, etc.), the interest is more in what graduates are expected to attain within a few years after graduation. These broader, "program educational objectives" are less in the program's control since our graduates' work and life experiences factor into these "outcomes." However, broad program educational objectives help to focus a program's more detailed student outcomes.

When starting from scratch, a department should consult with their constituents and stakeholders (e.g., industry, community, etc.) when developing their program educational objectives. As shown in Table 1, the CDIO syllabus can be used as a starting point for this work.

Table 1
The CDIO Syllabus and Program Educational Objectives

CDIO Syllabus (Level 1)		Mechanical Engineering Program Educational Objectives
1. Technical knowledge and reasoning	⇔	1. Demonstrate a deep working knowledge of technical fundamentals
2. Personal and Professional Skills and Attributes	⇔	2. Apply and master personal and professional skills and attributes
3. Interpersonal Skills: Teamwork and Communication	⇔	3. Communicate effectively and work in multidisciplinary teams
4. Conceiving, Designing, Implementing and Operating Systems in the Enterprise and Societal Context	⇔	4. Conceive, design, implement and operate systems in enterprise and social contexts

In this example, Level 1 of the CDIO syllabus is used as a starting point to develop more program-specific educational objectives for the Schulich School of Engineering's B.Sc. in Mechanical Engineering. As noted, these should be developed with the input of the program's constituents/stakeholders – however, the CDIO syllabus provides a good starting point for discussions.

In a similar manner, Level 2 of the CDIO Syllabus can now be used to describe how the program can be articulated in terms of program educational objectives and student outcomes. For example, as shown in Table 2, the second B.Sc. in Mechanical Engineering program educational objective "apply and master personal and professional skills and attributes" can be expanded into a set of program-specific student outcomes using Level 2 of the CDIO Syllabus.

Table 2
Student Outcomes for "Personal and Professional Skills and Attributes"

CDIO Syllabus (Level 2)		Mechanical Engineering Student Outcomes
2.1 - Engineering reasoning and problem solving	⇔	2.1 - Analyze and solve engineering problems
2.2 - Experimentation and knowledge discovery	⇔	2.2 - Conduct inquiry and experimentation in engineering problems
2.3 - System thinking	⇔	2.3 - Think holistically and systematically
2.4 - Personal skills and attitudes	⇔	2.4 - Master personal skills that contribute to successful engineering practice: initiative, flexibility, creativity, curiosity, and time management
2.5 - Professional skills and attitudes	⇔	2.5 - Master professional skills that contribute to successful engineering practice: professional ethics, integrity, currency in the field, career planning

As can be seen in Table 2, although the CDIO personal and professional skills and attributes have not been changed substantially to reflect those of the program, there is the opportunity to emphasize or de-emphasize topics at this stage to match the program's unique objectives.

Once the program has been described in terms of program educational objectives and student outcomes, the mapping between the CDIO Syllabus and the CEAB graduate attributes described by Cloutier et al. [5] can be applied. Figure 2 shows an example of this mapping for the B.Sc. in Mechanical Engineering program.

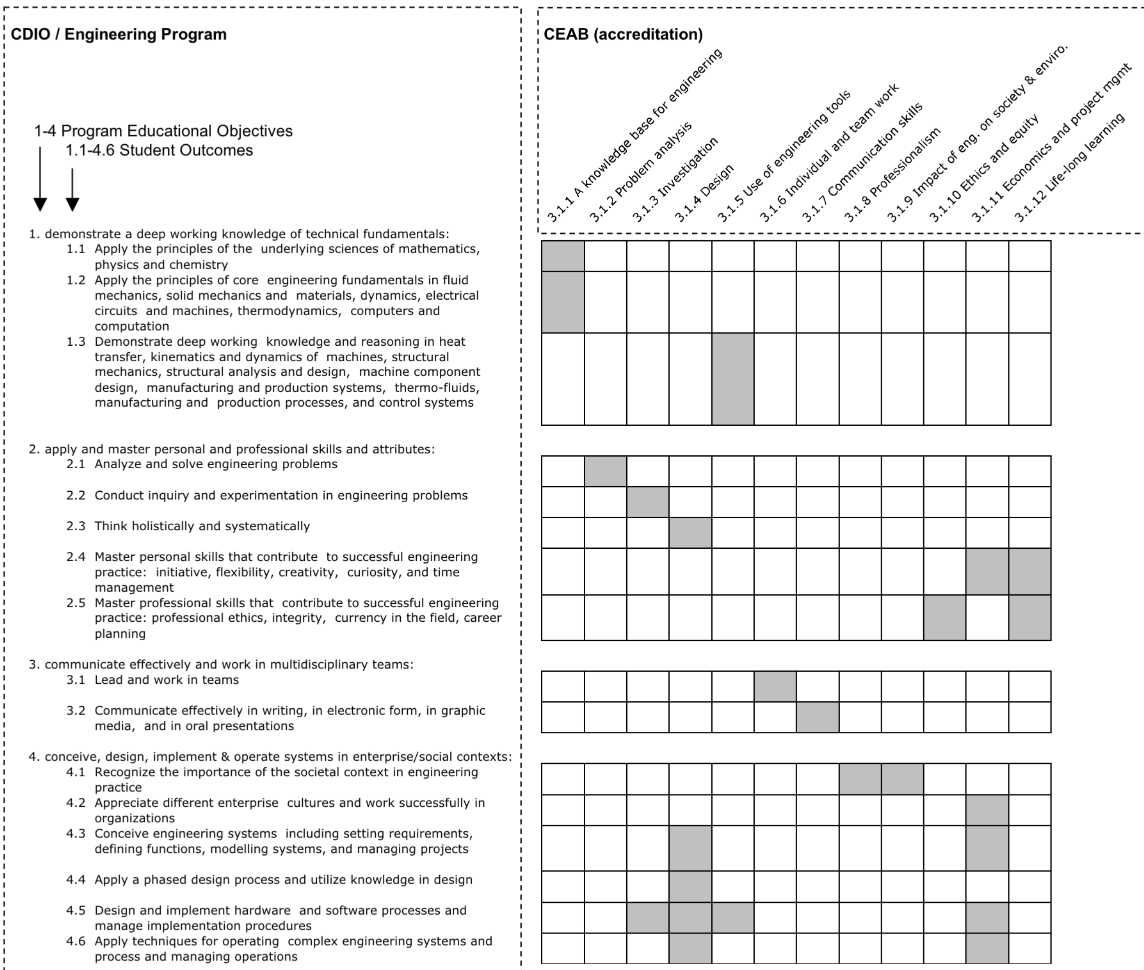

Figure 2. Student Outcomes / Graduate Attributes Mapping for the B.Sc. in Mechanical Engineering Program

The left side of Figure 2 describes educational objectives and student outcomes in the context of the engineering program (the B.Sc. in Mechanical Engineering program in this case) and the CDIO; the top right side of Figure 2 shows the engineering accreditation board's requirements with respect to student outcomes (CEAB "graduate attributes" in this case); the Cloutier et al. [5] mapping is illustrated by the grey squares.

A quick inspection of Figure 2 may lead one to the conclusion that a considerable amount of work has been done, yet we are now only at the starting point. In other words, why not forego the work described to this point, and just jump to the CEAB graduate attributes?

The strength of the approach described so far is that it results in a set of student outcomes that are generated by the department, rather than a set of student outcomes that are imposed by an external (accreditation) body. As a result, the student outcomes will more closely reflect the unique character of the program, and – since stakeholder input is part of this process – there should be greater ownership with the process when the hard work of assessment and evaluation begins.

Given that the Schulich School of Engineering's B.Sc. in Mechanical Engineering program is a CDIO program, the department did not have to start from scratch to generate the student outcomes listed on the left side of Figure 2. Instead, the CDIO Syllabus could be used as a starting point for this work, informing decisions around what set of student outcomes best reflect the program.

Performance Indicators and Course Mapping

In the same way that Program Educational Objectives and Student Outcomes could be generated from Level 1 and Level 2 of the CDIO Syllabus respectively, Level 3 of the syllabus was used to help with the generation of performance indicators (i.e., intended learning outcomes for individual courses). Ideally, faculty members who have interest/expertise in specific student outcomes / graduate attributes should refine the Level 3 learning outcomes (i.e., performance indicators) at this point; however, even without this initial work, curriculum mapping (i.e., "educational practices and strategies" in Figure 1) can begin.

In a pilot study of the Schulich School of Engineering's B.Sc. in Mechanical Engineering program [7], the work by Cloutier et al. [5] was extended to determine where the CEAB's twelve graduate attributes are introduced, taught, and/or utilized throughout the program. More specifically, a full introduce-teach-utilize (ITU) analysis (e.g., [8,9]) of the mechanical engineering curriculum was performed via a survey of the instructors of Fall 2008 and Winter 2009 courses. The survey was conducted by a series of one-hour meetings with all faculty involved in delivering the mechanical engineering program and involved a series of questions of two types. First, the instructors used the CDIO syllabus to map learning activities and student outcomes. For each category, the instructor was asked if the activity was introduced (i.e., superficial treatment to briefly expose the topic), taught (i.e., detailed coverage with assignments / exams) or utilized (i.e., assume the student is already skilled in this area) in their course. Secondly, eight questions were asked that focused on determining the intended learning outcomes (i.e., performance indicators) of the course.

Figure 3 provides an example of this mapping for the CEAB graduate attribute "3.1.4 Design." In this case, we show only two (of thirteen) of the CDIO Level 3 topics that map to this attribute as well as the associated course mapping generated from the ITU analysis [7].

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, and economic, environmental, cultural and societal considerations.				
		Courses		
CDIO Syllabus Topics	**CDIO Learning Outcomes**	**Introduce**	**Teach**	**Utilize**
4.3.1 Setting System Goals and Requirements	* Identify market needs and opportunities *** Elicit and interpret customer needs** * Identify opportunities that derive from new technology or latent needs * Explain factors that set the context of the requirements * Identify enterprise goals, strategies, capabilities and alliances * Locate and classify competitors and benchmarking information *** Interpret ethical, social, environmental, legal and regulatory influences** * Explain the probability of change in the factors that influence the system, its goals and resources available * Interpret system goals and requirements * Identify the language/format of goals and requirements * Identify initial target goals (based on needs, opportunities and other influences) * Explain system performance metrics * Interpret requirement completeness and consistency		ENGG 200 ENGG 513 ENME 538	ENGG 200 ENME 538
4.3.2 Defining Function, Concept and Architecture	* Identify necessary system functions (and behavioral specifications) *** Select system concepts** * Identify the appropriate level of technology *** Analyze trade-offs among and recombination of concepts** * Identify high level architectural form and structure *** Discuss the decomposition of form into elements, assignment of function to elements, and definition of interfaces**	ENGG 233	 ENGG 200 ENME 538	 ENGG 200 ENME 538

Figure 3. Example of a Curriculum Mapping for CEAB Graduate Attribute 3.1.4

Although it is tempting at this stage to simply use the “CDIO learning outcomes” as performance indicators and collect evidence in all of the courses where assessment occurs (i.e., courses where the topics are taught and/or utilized), it becomes clear very quickly that this process is not manageable. Given the detail of the CDIO Syllabus, this step results in a very large number of “CDIO learning outcomes”, mapped to a very large number of courses. For example, graduate attribute “3.1.4 Design” alone results in 63 CDIO learning outcomes mapped to 7 courses.

In order to make the process more manageable, the program’s teaching faculty were consulted to review the course mappings and help generate a (smaller) set of key performance indicators from the long list of CDIO learning outcomes that capture the most important aspects of teach of the CEAB’s graduate attributes. For example, the bold CDIO learning outcomes shown in Figure 3 were selected for the “3.1.4 Design” graduate attribute, resulting in the following performance indicators:

1. Elicit and interpret customer needs.

2. Interpret ethical, social, environmental, legal and regulatory influences.
3. Identify and explain system performance metrics.
4. Select concepts and analyze the trade-offs among and recombination of alternative concepts.
5. Decompose and assign function to elements, and define interfaces.
6. Use prototypes and test articles in design development.
7. Demonstrate iteration until convergence and synthesize the final design.
8. Demonstrate accommodation of changing requirements.

Given that the performance indicators were generated in collaboration with the teaching faculty, it also became apparent where the direct assessments should occur. For example, for the Design graduate attribute, the first-year design and communication course (ENGG 200 in Figure 3) appeared to be the best source for formative assessments, while the final-year capstone design course (ENME 538 in Figure 3) appeared to be the best source for summative assessments.

Collection of Evidence

The "assessment: collection of evidence" stage of the process shown in Figure 1 involves both the identification of forms of evidence of student learning, and the establishment of levels of student achievement. The basis for this work is the performance indicators discussed previously: i.e., evidence should be collected on each performance indicator.

At this stage of the process, specific courses are identified for direct assessment (using the curriculum maps described previously), and decisions are made about the forms of indirect assessment that will be used. It is best to identify at least two or three forms of evidence for each of the performance indicators in order to ensure that the results are aligned, and if not, to provide feedback to refine the measures (i.e., triangulation of results).

Typically, a sampling approach is used at this stage of the process. For example, a representative sample of graduating students can be given exit interviews in their final year of study, an alumni survey can be used provided that enough responses are received to reach conclusions about the results (e.g., 90% confidence interval), and in-class, summative assessments can be given to classes with representative numbers of students within a cohort (e.g., a project report in a core course).

Although, as discussed previously, the number of potential performance indicators was reduced to a more manageable set of key performance indicators, the number of assessments is still quite large: i.e., for each of the twelve graduate attributes, at least three forms of evidence must be collected on approximately five to eight performance indicators. To enable an ongoing graduate attribute assessment process that is reasonable and manageable, the Schulich School of Engineering chose to follow a multi-year data collection plan, shown in Figure 4.

CEAB Graduate Attribute Data Collection Plan

Graduate Attribute	**Academic Year**					
	2010-11	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2015-16**
3.1.1 A knowledge base for engineering						
3.1.2 Problem analysis						
3.1.3 Investigation						
3.1.4 Design						
3.1.5 Use of engineering tools						
3.1.6 Individual and team work						
3.1.7 Communication skills						
3.1.8 Professionalism						
3.1.9 Impact of engineering on society and environment						
3.1.10 Ethics and equity						
3.1.11 Economics and project management						
3.1.12 Life-long learning						

Notes:

1.		= direct assessment in courses (ENGG 200, ENGG 481, and capstone) and indirect assessment via surveys
2.		= indirect assessment via surveys

Figure 4. CEAB Graduate Attribute Data Collection Plan

This plan involves collecting data on four graduate attributes per year and results in two to three assessments of each of the CEAB graduate attributes by the next (and every subsequent) accreditation cycle. Table 3 on the next page provides an example of the graduate attribute assessment plans for four (of the eight) performance indicators used for CEAB graduate attribute 3.1.4.

CONTINUOUS IMPROVEMENT

As noted at the start of this paper, the overall purpose of graduate attribute assessment is to establish a process for the continuous improvement of each program's curriculum. However, as shown in Figure 1 and implied throughout this document, feedback for continuous improvement occurs at all stages of the process. In the remainder of this section, we summarize our thoughts on how continuous improvement can occur in the context of the process described in this section.

Performance Indicators and Educational Practices/Strategies

It is hoped that our initial efforts to establish meaningful and measurable performance indicators are successful. The real test of our efforts will occur when they are put to use. For example, faculty will need to work with their department's program assessment person (people) to develop forms of evidence: this work should provide feedback on the performance indicator (e.g., if it makes sense, can be assessed, etc.) and the course mapping (e.g., is this really an outcome of the course?). Similarly, indirect evidence like surveys will require some fine-tuning (e.g., rephrasing of ambiguous or leading questions).

As well, given that our focus is on a relatively small set of "key performance indicators", it is important to ask if the correct performance indicators were defined: are they representative of the graduate attribute? are new performance indicators required? should some performance indicators be removed?

Table 3. An Example of an Assessment Plan for Graduate Attribute 3.1.4 "Design"

Graduate Attribute: 3.1.4 Design						
Performance Indicators	**Courses**	**Method(s) of Assessment**	**Source of Assessment**	**Time of Data Collection**	**Assessment Coordinator**	**Evaluation of Results**
1. Elicit and interpret customer needs.	ENGG200, ENGG513, ENME538, ENME585	Faculty evaluations	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	Engineering Undergraduate Studies Committee
		Student surveys	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	
		Alumni surveys	Online survey	Winter	2011 – R. Brennan 2014 – R. Brennan	
2. Interpret ethical, social, environmental, legal and regulatory influences.	ENGG200, ENGG513, ENME538, ENME585	Faculty evaluations	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	Engineering Undergraduate Studies Committee
		Student surveys	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	
		Alumni surveys	Online survey	Winter	2011 – R. Brennan 2014 – R. Brennan	
3. Identify and explain system performance metrics.	ENGG200, ENGG513, ENME538, ENME585	Faculty evaluations	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	Engineering Undergraduate Studies Committee
		Student surveys	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	
		Alumni surveys	Online survey	Winter	2011 – R. Brennan 2014 – R. Brennan	
4. Select concepts and analyze the trade-offs among and recombination of alternative concepts	ENGG200, ENME337, ENME473, ENME493, ENME538, ENME585	Faculty evaluations	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	Engineering Undergraduate Studies Committee
		Student surveys	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	
		Alumni surveys	Online survey	Winter	2011 – R. Brennan 2014 – R. Brennan	

Collection of Evidence

Although the purpose of collecting evidence is to assess the program's graduates in the context of the graduate attributes, a considerable amount of information should also be available on the assessment process itself. For example:

- Forms of Evidence: Are the assessments appropriate (e.g., is a term test, a report, etc. the best way to assess the attribute)? Is the timing of the assessment appropriate (e.g., should the alumni survey be done during the Winter term)?
- Performance Targets: Do the performance targets need to be adjusted up or down?
- Triangulation: Are the various forms of evidence arriving at the same results?
- Number of Samples: Did we sample enough students/alumni/industry?

Curriculum

As noted, the information that is obtained from the graduate attributes assessment process should be used to inform discussions and actions about program's curriculum at various levels. Individual faculty members as well as department curriculum committee representatives should ask themselves what the results are telling them about:

- Course Design: the emphasis in lectures and/or labs may be misaligned with the courses' learning objectives; the assessments may be inappropriate (e.g., should ethics be assessed with a multiple choice exam?); the course may assume that students have prerequisite knowledge that they do not have; etc.
- Program Design: the course sequence may be incorrect; important program outcomes may be missed or underemphasized in the program; etc.
- Common Core Design: similar questions to "program design", but from a shared, faculty-wide perspective.

Data vs. Information

Finally, it is important to emphasize that the graduate attribute assessment process is intended to provide engineering programs with information that can be used to fine-tune the process and improve their undergraduate programs. There is always the temptation to collect as much data as possible, then cross one's fingers and hope that something can be learned. However, if the process is carefully planned from the start, and feedback is used to refine the process, we should be able to reach the point where all of our graduate attributes assessment efforts are meaningful (and manageable).

SUMMARY

Programs do not have to adopt the "CDIO Approach" [4] to take advantage of the CDIO syllabus for graduate attributes assessment. As noted, the CDIO syllabus is effectively a very detailed list of general engineering program outcomes that should apply to any engineering discipline. The advantage to the approach described in this paper is that the considerable amount of work that has been accomplished by an international community of engineering educators can be used as a starting point for a program's work on graduate attributes assessment.

To achieve an effective continuous improvement process though, it is still very important to engage faculty, students, and other stakeholders in the process to build on the CDIO work and thereby make the process specific to the School's individual programs.

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Biographical Information

Robert W. Brennan is an Associate Professor of Mechanical and Manufacturing Engineering and the Associate Dean (Academic, Planning & Research) at the Schulich School of Engineering. He has served on the steering committee of the Canadian Engineering Design Education Network (CDEN) and as chair of the Schulich School of Engineering’s Engineering Education Summit.

Ronald J Hugo is Professor and Head of Mechanical and Manufacturing Engineering at the University of Calgary. He is also the holder of the Engineering Education Innovation Chair in the Schulich School of Engineering. His research interests are in the areas of experimental fluid dynamics, energy systems and engineering education.

William D. Rosehart is Professor and Head of Electrical and Computer Engineering at the University of Calgary. Prof. Rosehart has won several teaching awards and was named to 2008’s list of Calgary’s Top 40 Under 40. In 2006 he won the Early Accomplishment Award from the Association of Professional Engineers, Geologists, and Geophysicists of Alberta (APEGGA). He received the 2008 IEEE Power and Energy Society Outstanding Young Engineer Award.

Corresponding author

Dr. Robert W. Brennan
Schulich School of Engineering
University of Calgary
2500 University Dr. N.W.
Calgary, AB, Canada, T2N 1N4
1-403-220-4192
rbrennan@ucalgary.ca