THE CDIO SYLLABUS AND OUTCOMES-BASED ASSESSMENT: A CASE STUDY OF A CANADIAN MECHANICAL ENGINEERING PROGRAM

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ABSTRACT

This paper presents the results of a pilot study on using the CDIO syllabus as a starting point for Canadian Engineering Accreditation Board (CEAB) graduate attribute assessment. The CDIO syllabus provides a comprehensive set of engineering learning outcomes that can be used to move from general performance objectives (i.e., CEAB graduate attributes) to specific learning outcomes (i.e., CDIO syllabus). In this paper, the authors use this mapping in combination with an introduce-teach-utilize (ITU) analysis as a basis for in-program graduate attribute assessment of the Schulich School of Engineering's B.Sc. in Mechanical Engineering program. The results of the case study show that the ITU analysis provides an effective tool to align learning outcomes to a specific engineering curriculum.

KEYWORDS

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

INTRODUCTION

In Canada, engineering program accreditation falls under the jurisdiction of the Canadian Engineering Accreditation Board (CEAB) [1]. Historically, the CEAB accreditation process has been very quantitative, focusing heavily on curriculum component minimums, however since 2005, the CEAB has been working towards updating their criteria in order to move towards a model that emphasizes continuous improvement, and more specifically, program outcomes. In this paper, we present the results of a survey of the Schulich School of Engineering's B.Sc. in Mechanical Engineering program in the context of the CEAB's new outcomes-based program assessment.

Under the new CEAB criteria [2], Canadian engineering programs are required to assess student graduate attributes in 12 general areas as noted below, and demonstrate that a process is being followed to continuously improve the programs.

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

Although these new requirements are closely aligned with the outcomes-based assessments required by other engineering accreditation bodies [3], they represent a significant change for Canadian engineering schools. As a result, work is currently being done through the Education committee of the National Council of Deans of Engineering and Applied Science (NCDEAS) on how Canadian engineering schools can prepare for this new requirement when it comes into effect in 2014 [4].

In this paper, we describe how the CDIO syllabus can be used as a starting point for graduate attribute assessment. We begin with a brief overview of the process that is being followed at the University of Calgary's Schulich School of Engineering for in-program graduate attribute assessment and show how the CDIO syllabus can form a basis for this work. Next, we present the results of a pilot study of this process that was performed in the spring/summer 2009 for the Schulich School of Engineering's B.Sc. in Mechanical Engineering program. The paper concludes with a short section on our next steps in this process.

GRADUATE ATTRIBUTES AND THE CDIO SYLLABUS

The recent changes to the CEAB's criteria and procedures [2] require Canadian engineering schools to develop new processes aimed at outcomes assessment and curriculum improvement. Given the CDIO initiative's strong focus in these areas, the authors felt it would be logical to build on this work – rather than re-inventing the wheel – when developing the Schulich School of Engineering's graduate attribute assessment process. In this section, we provide a summary of our current work on this process.

At the Schulich School of Engineering, graduate attribute assessment will take the form of in-program assessment (i.e., student assessments within undergraduate courses), industry surveys, and graduate surveys. Our focus in this paper is on in-program assessment, which follows a process similar to the ABET Assessment Planning Flowchart© [5]. For each Schulich School of Engineering program, in-program assessment will involve the following general steps:

1) develop learning outcomes and performance criteria;
2) align learning outcomes to the curriculum;
3) evaluate and choose assessment methods; and
4) implement the assessments.

In this paper, we focus on the first two steps in this process.

Like ABET's program outcomes [6], the CEAB's graduate attributes are described in broad terms that do not immediately lend themselves to outcomes assessment. For example, the CEAB's "design" attribute is described as follows:

> "an ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, economic, environmental, cultural and societal considerations" [2].

Although this relatively broad definition of the "design" attribute is very appropriate as a learning outcome for an engineering program, there is arguably, considerable room for interpretation when compared with an individual course's desired learning outcomes. For example, many engineering instructors would agree that their course is intended to provide students with "an ability to design solutions for complex, open-ended engineering problems".

One approach that could be used to move from the CEAB's general graduate attributes descriptions to learning outcomes and performance criteria (i.e., step 1 noted above) is to consult with faculty (e.g., engineering design instructors in this case), students, and industry to develop a list of learning outcomes that could then be mapped to specific courses (i.e., step 2 noted above). Although this process has the advantage of engaging the School's stakeholders in the process, it has the disadvantage of being resource-intensive and time-consuming.

An alternative, but complementary, approach is to build on work that has already been done in this area. In particular, the CDIO syllabus [7] is effectively a very detailed list of general engineering program outcomes that has been used to expand on ABET's program outcomes for US engineering schools. CDIO collaborators developed the syllabus and validated it via focus-group discussions, document research, surveys, workshops, and peer review that involved faculty, students, industry leaders, and senior engineering academics from a variety of universities [7].

Figure 1 shows a detail of the expanded CDIO syllabus: i.e., one topic (Experimentation and Knowledge Discovery) and a portion of its subtopics (e.g., Hypothesis Formation) and learning outcomes (e.g., select critical questions to be examined) are shown. The "[b]" beside the topic heading shows the mapping to the ABET program outcome (i.e., "an ability to design and conduct experiments, as well as to analyze and interpret data").

The power of this syllabus is that it is comprehensive and can be directly mapped to ABET's program outcomes. Similarly, as described by Cloutier et al. [8], the CDIO syllabus can be mapped directly to the CEAB's graduate attributes (for details of this mapping, please refer to [8] in these proceedings). Once the mapping is performed, the learning outcomes can be directly mapped to program courses and used as a basis for assessment.

It should be noted that this approach does not discount the stakeholder engagement that is inherent with the first approach. Instead, the CDIO syllabus is used as a starting point for in-program assessment and as a means of informing and focusing the discussions around program-specific learning outcomes and performance criteria.

2. Personal & Professional Skills & Attributes

…

2.2 Experimentation and Knowledge Discovery [b]

2.2.1 Hypothesis Formation

- Select critical questions to be examined
- Formulate hypotheses to be tested
- Discuss controls and control groups

2.2.2 Survey of Print & Electronic Literature

- Choose the literature research strategy
- Demonstrate information search and identification using library tools (online catalogues, databases, search engines)
- Demonstrate sorting and classifying the primary information
- Question the quality and reliability of information
- Identify research questions that are unanswered
- List citations to references

2.2.3 Experimental Inquiry

- …

Figure 1. A detail of the expanded CDIO syllabus [7]

In the next section, we describe a pilot study of this process that was performed at the Schulich School of Engineering.

MAPPING LEARNING OUTCOMES IN AN UNDERGRADUATE PROGRAM

In a pilot study of the Schulich School of Engineering's B.Sc. in Mechanical Engineering program, the authors built on the work by Cloutier et al. [8], 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., [9,10]) 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 authors and instructors used the CDIO syllabus [7] to map learning activities and 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 of the course.

Although the process of performing an ITU analysis of the mechanical engineering program, then transferring these results to the CEAB graduate attributes using Cloutier et al.'s mapping may at first appear to be overly complex, the authors felt that there were some key benefits to this approach. The most obvious benefit is the higher level of detail of the CDIO syllabus compared to the CEAB's list of graduate attributes as discussed in the previous section. For example, Cloutier et al. map the "design" attribute to twenty-three CDIO syllabus topics, allowing for a much more comprehensive analysis of this attribute in the areas of system thinking, conceiving, designing, implementing, and operating.

Another key benefit of starting with the ITU analysis is that it forces the instructor to think about how course material is delivered (i.e., introduced or taught), or alternatively, if the student needs to bring knowledge and skills to the course (i.e., utilized). This has the potential to move the survey from a simple information gathering exercise to a learning tool for the course instructor.

The results of the ITU analysis of the mechanical engineering program and the mapping to the CEAB graduate attributes are shown in Figures 2 to 4. Each figure shows the number of courses in each year of the program where each CEAB graduate attributed is introduced (Figure 2), taught (Figure 3), and utilized (Figure 4).

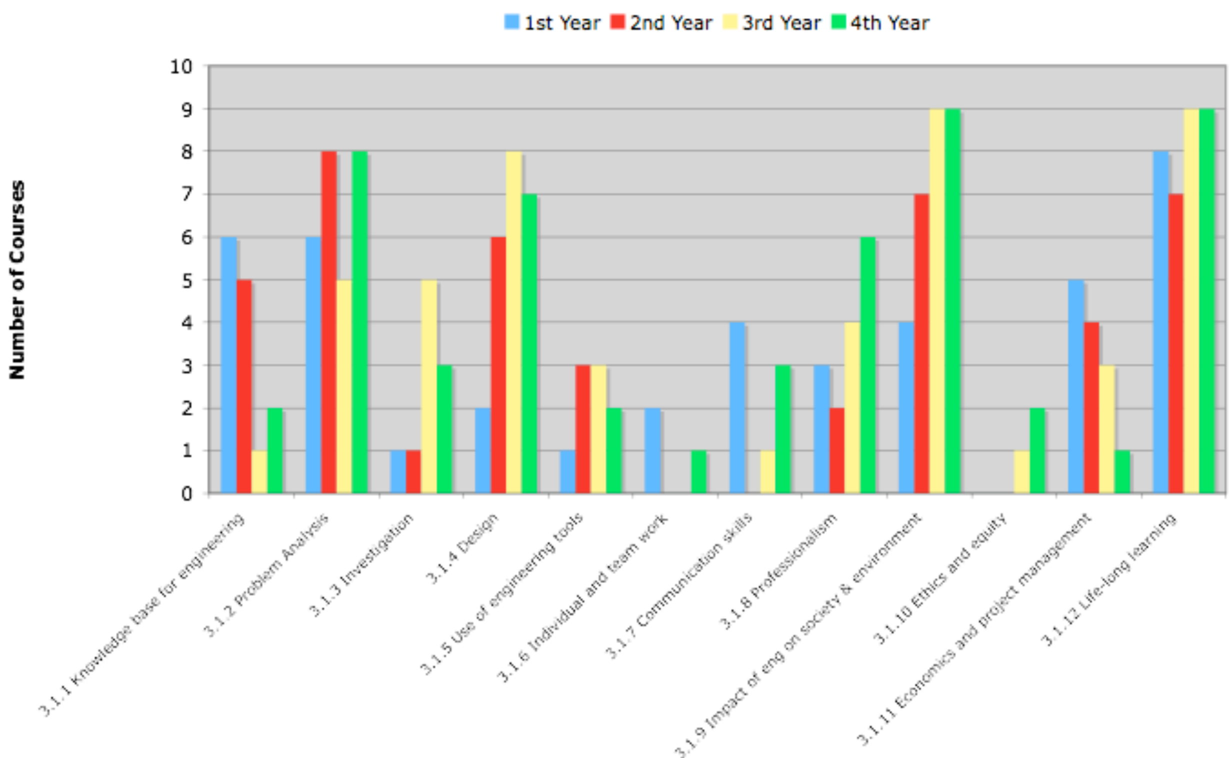

Figure 2. Number of courses where CEAB graduate attributes are introduced

As expected, foundational attributes such as “a knowledge base for engineering” are more heavily taught early in the program, then utilized more in the senior years; attributes that rely on the integration of engineering science fundamentals such as “design” are introduced early in the program, then taught and utilized more in the senior years.

The results also shed light on how the CEAB’s graduate attributes relate to the mechanical engineering program. For example, the ITU analysis helped to highlight potential mismatches in how aspects of the curriculum are delivered (e.g., “teamwork” is utilized in many courses but taught in few). As well, by classifying each attributed in terms of introduce-teach-utilize, the results have the potential to show where it is best to assess the attribute in the program (i.e., in courses where the topic is taught, and as a result, formally assessed).

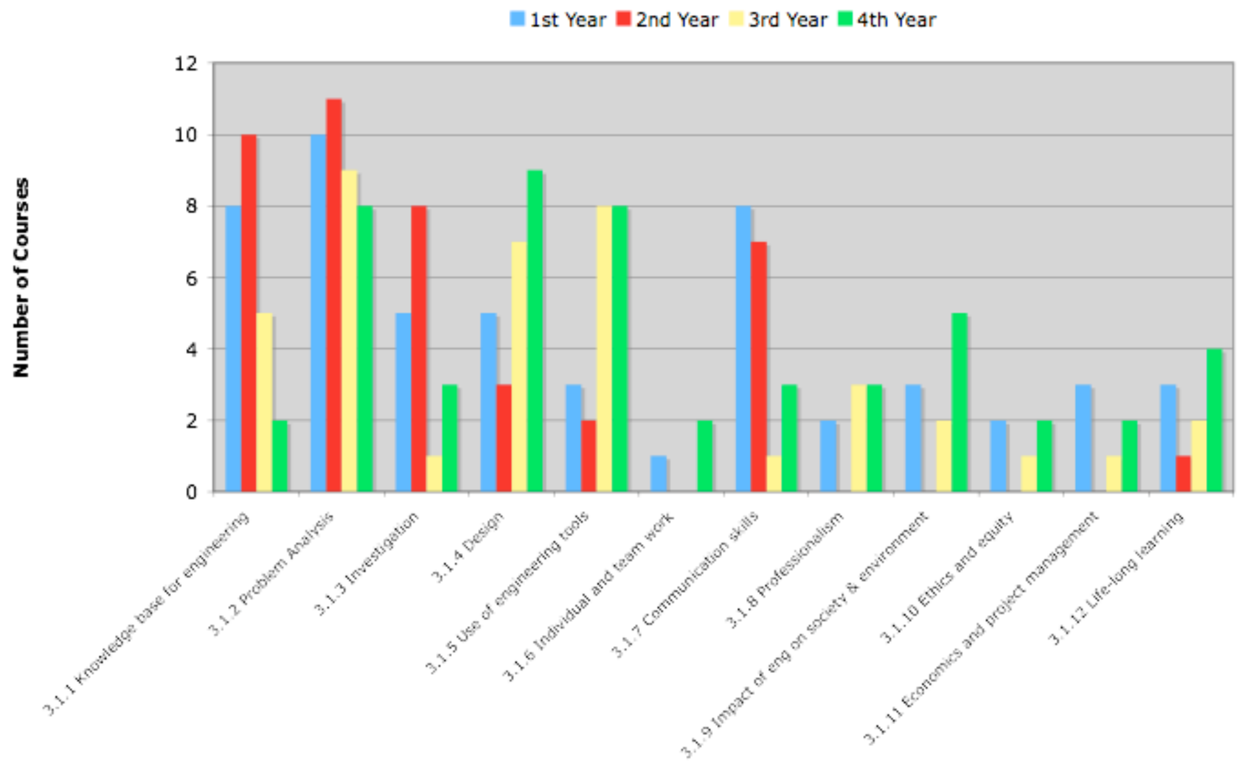

Figure 3. Number of courses where CEAB graduate attributes are taught

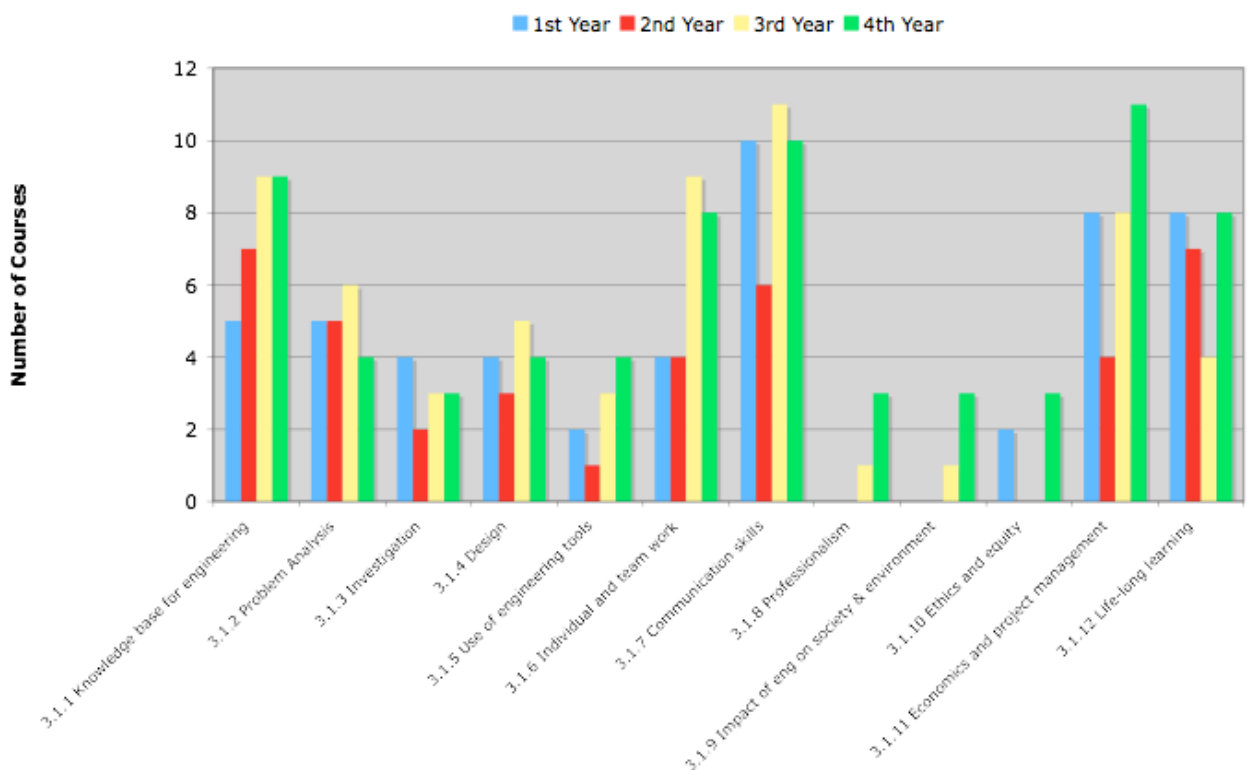

Figure 4. Number of courses where CEAB graduate attributes are utilized

As discussed previously, the results can also be used to plan graduate attribute assessment. More specifically, the ITU analysis yields a much more detailed mapping of courses to CDIO syllabus learning outcomes than Figures 2 to 4 imply. For example, Figure 5 shows a detail of the mapping between the CDIO syllabus and mechanical engineering courses for one year of the program (first year in this case).

CEAB 3.1.3 Investigation: An ability to conduct investigations of complex problem by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.		
CDIO Syllabus Topics	**CDIO Learning Outcomes**	**Courses**
2.2.1 Hypothesis Formation	Select critical questions to be examined Formulate hypotheses to be tested Discuss controls and control groups	CHEM 209 (T) ENGG 201 (T) ENGG 200 (T,U)
2.2.2 Survey of Print & Electronic Literature	Choose the literature research strategy Demonstrate information search and identification using library tools (online catalogues, databases, search engines) Demonstrate sorting and classifying the primary information Question the quality and reliability of information Identify research questions that are unanswered List citations to references	CHEM 209 (U) ENGG 201 (I) ENGG 200 (T,U)
2.2.3 Experimental Inquiry	Formulate the experimental concept and strategy Discuss the precautions when humans are used in experiments Execute experiment construction Execute test protocols and experimental procedures Execute experimental measurements Analyze and report experimental data Compare experimental data vs. available models	CHEM 209 (T) ENGG 201 (T) ENGG 233 (U) PHYS 259 (T)
2.2.4 Hypothesis Test, and Defense	Discuss the statistical validity of data Discuss the limitations of data employed Prepare conclusions, supported by data, needs and values Appraise possible improvements in knowledge discovery process	CHEM 209 (T) ENGG 201 (I) PHYS 259 (T)
4.5.5 Test, Verification, Validation, and Certification	Discuss test and analysis procedures (hardware vs. software, acceptance vs. qualification) Discuss the verification of performance to system requirements Discuss the validation of performance to customer needs Explain the certification to standards	ENGG 233 (U)

Figure 5. Aligning learning outcomes to program courses

This detailed mapping can be used to identify both the most promising courses where assessments can occur, and potential assessment methods (i.e., step 3 of the in-program assessment process noted previously). More specifically, courses where learning outcomes are taught or utilized are the most likely candidates for assessment (e.g., ENGG 200 for syllabus topics 2.2.1 and 2.2.2). Once identified, the CDIO learning outcome can be used as a starting point for adapting existing or creating new assessment methods in conjunction with the course instructor(s).

NEXT STEPS

The results of the pilot study have shown that the CDIO syllabus provides an excellent basis for CEAB graduate attribute assessment by providing a comprehensive snapshot of a program's intended learning outcomes. In order to apply the results directly to in-program graduate attribute assessment though, further work is required on: (1) identifying a subset of courses in the program where assessment should occur; (2) adapting the CDIO's learning outcomes to program-specific courses; and, (3) evaluating and choosing appropriate assessment methods.

The work by Cloutier et al. [8] provides a basis to move from general performance objectives (the CEAB graduate attributes) to specific learning outcomes (the CDIO syllabus). The ITU analysis then serves as a tool to align learning outcomes to the curriculum; however, this mapping is very detailed as illustrated by the sample in Figure 5. To identify a manageable set of courses where assessments will occur, it will be necessary to first identify courses where the outcomes are already being assessed (i.e., courses where the topic is taught or utilized), and secondly, where more than one learning outcome is mapped. It is also important to identify graduate attributes that are addressed at various stages in the program from first year to final year. Although the CEAB is interested in the attributes of graduates of engineering programs, it will be important from a curriculum review perspective to assess how the attributes are developed over the four years of study.

As noted previously, the graduate attributes process will involve various stakeholders in the program. For example, through discussions with the instructors of the courses identified in this process, the CDIO learning outcomes will be adapted to more accurately reflect specific Schulich School of Engineering courses and also refined so that they can be framed in terms of measurable performance criteria. As the graduate attribute assessment process evolves and is applied to the curriculum review process, the feedback from instructors, students, and industry will be used to further refine learning outcomes, performance criteria, curriculum mapping, and assessment tools.

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