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Outcomes Assessment and Curriculum Improvement
Through the Cyclical Review of Goals and Results –
A Model to Satisfy CEAB-2009 Accreditation Requirements

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Abstract

In Canada, engineering programs will soon have to show that: i. graduates possess specific attributes, ii. outcomes are assessed in their context, iii. results are used to improve the program. This paper presents a model to meet all three criteria, and provides curriculum control options to fulfil CEAB conditions. It defines proficiency levels and information flow, from stakeholders' surveys to the fusion of data. Control modules, pre-graduation work experience and post-graduation reviews gather internal and external observations. Coverage of the CEAB attributes by the CDIO Syllabus is summarised. Its utility for meeting objectives about the 12 attributes is clarified. An XML tool upholds coherence between learning objectives and targeted proficiency levels. More than merely instructive, this model displays the characteristics of a convincing demonstration for the CEAB.

1 Introduction

Engineers Canada co-signed the Washington Accord in 1989 in response to higher mobility of knowledge-based personnel, signalling an interest for outcomes-based assessment. This emphasis is evident with the Conceive – Design – Implement – Operate organisation (CDIO) [1], the International Engineering Alliance (IEA) [2], the Accreditation Board for Engineering and Technology (ABET) [3], the Canadian Engineering Accreditation Board (CEAB) [4], and the European Accreditation of Engineering Programmes (EUR-ACE) [5].

Outcomes-based assessment focuses on what is learned. Some value such assessment throughout an entire program [6], or even down to a single lecture. Others question its aptness when the level of detail is such that the mastery of a complex assessment is debatable [7]. Common issues remain [8]: a) linking broad outcomes to specific indicators in assessable activities, b) ensuring coverage, and c) defining suitable *proficiency levels* upon graduation.

The paper presents a model to address such issues. It focuses on program outcomes, and outlines three of the CEAB requirements: *i.* that graduates *possess* specific attributes, *ii.* that outcomes are being assessed *in the context* of these attributes, and *iii.* that results are made available for the improvement of the programs (see [4], p. 12). The paper refers to the CDIO Syllabus extensively, but the model adapts itself to other itemisations that an institution may prefer.

The paper begins with an overview of the model and the flow of information within it. Tools to gather information from a variety of internal and external inputs are next discussed. Feedback loops using different levels of granularity at given program stages are presented. A model by which feedback information can be fused with internal and external inputs is discussed. The paper concludes by describing methods to implement the model.

2 Overview of the Flow of Information

Figure 1 presents the proposed flow of information within the model. Surveyed "Needs" help define minimum and desirable final proficiency levels. They provide "Curriculum design" criteria. This assignment

involves faculty, program managers, educational specialists, and industrial advisors. Faculty plan the details of "Module X", its learning objectives, and associated rating instruments. "Data capture" extracts the decentralised formulations of learning objectives and outcomes from distinct modules across the program, and feeds it to "Curriculum Design", ensuring adequacy and coverage. A "Capstone" project closes the curriculum, with a (quasi-) real world assignment within a regulated environment.

Various controls and appraisal methods are applied by internal and external observers within the second half of the curriculum, to confirm planned outcomes have been reached. These may rely on global attributes ("CEAB" boxes), or on detailed itemised indicators ("CDIO" boxes). For the sake of the discussion, three possible feedback loops ("1" to "3") are described.

The complex task of "Data fusion" follows. Information is scaled, and granularity is merged into a single picture of the program. "Data capture" provides reference criteria and levels into this synthesis. The result is fed back to the courses and to the curriculum design process: inconspicuous arrows in Figure 1, with broad consequences.

3 Input of Information

3.1 Needs of stakeholders

Surveys of stakeholders must help set the proficiency levels graduates should attain against a codified understanding of expected knowledge and abilities. Questions then arise: how best to categorise the expected knowledge, skills and attitudes (*i.e.* attributes); who are the relevant stakeholders and how to ensure convergence; finally, how to define manageable proficiency levels meaningful to all?

3.1.1 CDIO Syllabus – Categorising "engineering"

The CDIO Syllabus [9] presents a discipline-independent breakdown of the expectations for the contemporary engineer. It provides room for 1. Engineering knowledge, and descriptors for 2. Personal and professional skills and attributes, 3. Interpersonal skills, and 4. **C**onceiving, **D**esigning, **I**mplementing, and **O**perating systems in the enterprise, societal and environmental context – innovation. These order-one groups contain 14 order-two classes, and hundreds of topics. All are expressed as subjects, without inducing proficiency levels. The CDIO Syllabus has been used successfully to satisfy ABET outcomes-based conditions (see [1]).

A correlation study has shown that the CDIO Syllabus is a superset of the 12 CEAB attributes [10]. On its own, the detail of the syllabus facilitates a structured process for meeting these CEAB attributes.

3.1.2 Stakeholders – Relevancy and convergence

Relevant stakeholders include employers, industry advisors, alumni, faculty, students, and —in Canada— the CEAB, representing provincial licensing bodies. Surveys of recent alumni supply information that coincide with the current state of the program.

There is a worldwide common understanding of what an engineer is. Many programs surveyed the needs of stakeholders with the CDIO Syllabus [11]. The result is a natural convergence of profiles from all bodies involved, across institutions and countries.

3.1.3 Defining proficiency levels

The proficiency levels of Table 1, a "working engineer's perspective", will avoid disparities in interpretation. Institutions seek accreditation for more than one engineering program. This task benefits from stakeholders of all specialties using a common scale for proficiency. Specialised scales pertaining to other disciplines (like Bloom's or Krathwohl's levels) should be avoided. These often represent strong taxonomies but weaker hierarchies (*e.g.* Bloom's class 6 can describe outcomes within the K12 years of study, and although classes 1 to 3 stand more as a hierarchy, classes 4 to 6 are often pursued in parallel). Levels like those of Table 1 have shown to be of value in numerous surveys in many countries.

3.2 Curriculum, Courses and Data Capture [12]

Word processors and data bases form the current tools to describe a module plan: overview, objectives, assessment instruments, etc. When these are produced from a web-based application which guides the instructor, the use of a proper underlying model will enable both import and edit/export XML integration with an information system. This contributes to the mapping of learning objectives and assessment instruments in modules to program outcomes, to help ensure the inclusive coverage of all intended results.

The model would provide assistance to faculty members in the formulation of learning outcomes: require evocative verbs about a topic to be qualified by the description of a context and of the expected autonomy, for consistency with targeted proficiency levels that include both aspects.

The distributed nature of the XML model fits decentralised multi-levels approvals. Program modules evolve as faculty update contents and methods. Not all changes require official approvals. Program heads usually know about the existence of a dynamic gap between the static documentation of the program and its current form, although they may not be fully aware of its nature or magnitude. The stated XML model under test allows for fast local feedback loops within a

self-regulatory system. In all institutions, self-regulatory concepts will require but also foster the consent, the participation and the empowerment of the faculty members involved.

4 Introduce, Teach/Utilise, and Control

The teaching, training and evaluation of students must be designed so the degree threshold levels are assured by observed proficiency in key modules, or *control* courses, projects, and/or pre-graduation work experience. *Learning* is a complex non-linear evolution, the bridging of gaps, and the physical transformation of the mind. "Teaching" thus covers many meanings. A topic is included in an activity, but not rated (***I**ntroduce*); it is shown, practiced and rated on its own (***T**each*); embedded into other "teachings or learnings", it is put to use (*Utilise*) (see [1]). A set of related topics has been utilised in context, and with the required autonomy. This ITU prepares students for control. *Control* concerns a few well chosen modules only (control points). The whole of the program must embrace the *preparation* for control, and this requires the organised involvement of all instructors.

5 Feedback Loops

Three major loops supply results to the fusion of data and information. To increase efficacy, each uses tools well-suited to the assessor, and aims at aspects of his/her core-business: detailed topics and skills (loop 1), global pre-graduation attributes (loop 2), and post-graduation competencies[1] (loop 3). This feedback, coupled with stakeholder input, provides holistic coverage of all 12 attributes provided the assessments from the different sources can be reconciled.

5.1 Loop 1 – Controlled coverage of intermediate to final attainments under regulated conditions

Through an ITU matrix, modules that influence the proficiency level of students on any of the attributes are known. A small number of control points follow, after analysing best conditions and locations for exercising final control of results (ITU-C).

Capstone projects are appropriate control points for many of the 12 attributes. Projects, however, may lack predictability. Suitability for the observation of a few specific attributes may vary between semesters, and an analysis over time will reveal which are at risk. From ITU, courses that complete the coverage of all attributes at the targeted proficiency levels are known.

These internal controls are exercised against the CDIO topics that provide ramified measures, and are directly associated to the needs expressed by the stakeholders. Difficulties in merging various topics into a single attribute are overcome by the use of the correlation shown in Table 2, between the CDIO order-two (and three) topics, and the CEAB attributes (see [10]).

5.2 Loop 2 – Full/Sample evaluations of pre-control attainments under field conditions

Some programs add a mandatory *pre-graduation work experience* at various levels of their curriculum. Students are selected by employers for one or more work terms, or *internships*. From the onset, immediate supervisors are asked for *expected* proficiency levels, on CEAB attributes. Following each, the supervisor evaluates the *observed* proficiency levels. Data and comments about expected and observed levels are gathered for all students.

Surveying the needs of stakeholders helped express target levels upon graduation. Pre-graduation work evaluations provide intermediate levels, valuable to either a *full outcomes-based* or a more limited *control point outcomes-based* program design. Identifying supervisors of student-interns in the global surveys of stakeholders allows strata of results to be isolated and correlated. Consistent *intermediate levels* can then be defined for internal assessments. This calibration is an important undertaking, although it will take time.

5.3 Loop 3 – Sample appraisal of final outcomes under unregulated "field" conditions

This loop serves both feedback and preparation for future involvement. Professional engineers appraise the *competencies* of graduates as engineers-in-training. Loyal respondents reduce to a sample. Although only some 10-20 % of graduates end-up being covered, loyal respondents are also more likely to contribute as stakeholders or as industrial advisors for the program.

Updating a pool of loyal respondents is an ongoing effort. Current engineers-in-training are thus also asked to undergo a reflective process, and evaluate what they think their qualifications were at the time of graduation. They are amongst the few people to have both an "insider and outsider" view of the program. Highly valuable comments are found to stem from their ongoing adaptation to real world conditions. In so doing, young graduates are being prepared to act as better evaluators of pre-graduation work experience: another meta-process for long term improvements.

Both input sources are surveyed using the 12 CEAB attributes, complemented on demand by the correlated CDIO topics to provide further insight and to ensure long term consistency.

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[1] Discussing the "true" nature of *competencies*, compared to skills or aptitudes is beyond the scope of this paper.

Curriculum Design – Process, criteria and standards of attainment

Course 1 | Course 2 | Project 1 | **Data capture** | Course N | Cap-stone

Student Flow Through the Curriculum

to CDIO

CDIO | Work exp.

Data fusion
Interpret, link and synthesise controls, assessments, appraisals, and targets

to CEAB

Needs – CDIO surveys

to CEAB

Loop 1: Internal control of attainments

Loop 2: Evaluation of professional qualifications — CEAB

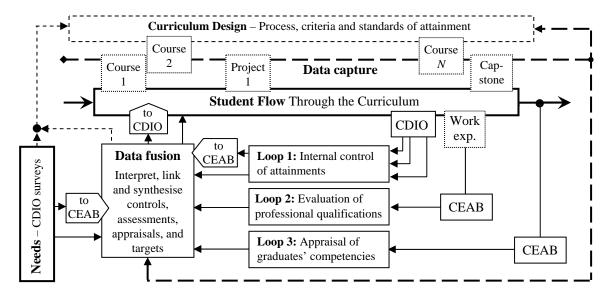**Loop 3:** Appraisal of graduates' competencies — CEAB

Figure 1. Graphical model, from the needs of stakeholders to trainee engineer competencies

Table 1. Proficiency levels, a "working engineer's perspective".

"1. Has been exposed to...": Knows it exists. This may orient quest for information. May replicate simple sequences, no insight.

"2. Participates and contributes to...": Servile participation. Replicates long sequences or simple branching thoroughly enough. Closely supervised, numerous validations of his work if unforeseen conditions develop.

"2½. Executes, while providing signs of judgement...": Reasonable gauging of 'some' unexpected finely shaded ramifications. Relaxed supervision, but premature to encourage initiative on his own.

"3. Delivers and provides full explanations for his...": Perceptive and relevant contribution. Expectations include finely shaded ramifications. Encouraged to demonstrate initiative while seeking approval.

"3½. Performs and justifies, could exercise initiative without detriment...": Decides and acts for good reasons that he/she exposes. Encouraged to take initiatives, and to judge whether or not approval should be sought.

"4. Ready for professional practice of..." (Reference level: P.Eng.): Would be ready to practice on his/her own, were it not for legal constraints. "Rubber-stamping" approval for... (a specific topic in surveys, and a specific attribute in assessments).

"5. Can lead or innovate in...": Can be trusted with supervision of others or in situations never encountered. for specific topics.

Table 2. Correlations between the order-two topics of the CDIO Syllabus and the 3.1.1 to 3.1.12 attributes of CEAB.

CDIO Syllabus v2.10 / CEAB 2009	1	2	3	4	5	6	7	8	9	10	11	12
1.1 **Knowledge of Underlying Math. and Sciences**	1											
1.2 **Core Engineering Fundamental Knowledge**	1											
1.3 **Adv. Eng. Fund. Knowledge, Methods and Tools**	0.5				1							
2.1 **Analytical Reasoning and Problem Solving**		1			0.25						0.5	
2.2 **Experimentation, Investigation and Discovery**			1		0.25		0.5					
2.3 **System Thinking**		0.5		0.5	0.25				0.5		0.25	
2.4 **Attitudes, Thought and Learning**		1	1	1	1	0.5			0.25		0.25	1
2.5 **Ethics, Responsibility, Equity, and Core Values**						0.25		1	0.25	1		0.5
3.1 **Teamwork**						1						
3.2 **Communications**						0.25	1					0.25
3.3 **Communications in a Foreign Language**							0.25					
4.1 **External, Societal, Economic and Envir. Context**								1	1	0.5		0.25
4.2 **Enterprise and Business Context**				0.25	0.5						1	
4.3 **Conceiving, Systems Eng. and Management**				1	0.25				0.5		0.5	
4.4 **Designing**				1	0.25				0.5		0.25	
4.5 **Implementing**				0.5	0.5				0.5		0.5	
4.6 **Operating**				0.5	0.5	0.25			0.5		0.25	

6 Data Fusion

Data enter the model from multiple different sources with differing degrees of reliability and completeness. The fusion process depends on the target outcome. Information may be readily integrated and aggregated under the coarse divisions of the 12 attributes to demonstrate the attainment of CEAB requirements. On the other hand, considerable judgement is required to interpret the employer and graduate feedback combined with the more detailed internal control measures to address refinements in individual program elements to improve outcomes.

Data fusion is enabled in part by a mapping of CDIO topics onto the 12 attributes of CEAB. Although an order-two summary of this correlation is presented in Table 2 for illustration, its application requires the details of order-three and the insight available in the original paper (see [10]).

7 Status of Implementation

As with many changes and innovations, a number of aspects need to progress in parallel; because of the change of paradigm, and also the interactions between the various aspects that help raise relevant issues more efficiently than would a sequential approach.

7.1 Needs of Stakeholders

Survey methods and tools are well developed. Instructions and forms are readily available from the CDIO-org site on the web, should an institution decide to use the topics of the CDIO Syllabus. The CDIO survey is available in both Canadian official languages, as well as a number of other languages.

7.2 Tools for Data Capture

The original kernel of the XML-based tool has matured at *École des Hautes Études Commerciales* (HEC). Recent developments at the *Maison des technologies de formation et d'apprentissage Roland-Giguère* (MATI) covered descriptors compatible with the CEAB norm. Collaborations with MIT and Chalmers are broadening its application to the European Qualification Framework (EQF) [13]. Most technical challenges have been overcome. A prototype is under test on a focus group.

7.3 External Assessment Tools

Assessment tools for industrial supervisors have been reviewed by a number of P.Engs on many of the advisory committees at ÉPM. A group of 27 industrial partners are currently testing a static form. A prototype

is being assessed internally on Moodle. External trials await comments from this focus group.

7.4 Empowerment by Faculty and Workgroups

The Department of Mechanical Engineering at ÉPM has recently instituted workgroups of faculty to revise learning objectives in the context of the CEAB attributes. From the correlation between the CDIO Syllabus and the CEAB attributes, only five workgroups are thought to be required, each targeting a single CEAB attribute: by choosing the right five attributes, the CDIO topics relating to nearly all 12 are covered. Selected faculty are also involved in the validation of the XML OpenSyllabus prototype.

7.5 Challenges

A number of challenges remain, not the least being agreement on a common interpretation of the details of the new requirements.

7.5.1 Complex problems, activities or concepts

The CEAB norm requires graduates to cope with complexity: "complex" qualifies *problems*, *activities* or *concepts* in nearly half a dozen rubrics. Expressions like "complex problems" and "complex activities" are defined by the IEA (see tables 4.1 and 4.2 in [2]). From table 4.1, complex problems would bear "some or all" of eight characteristics, the rest being shared between "broadly" and "well-defined" problems. This leaves over 200 combinations of the characteristics of the "complex" class, and roughly 5000 ways of creating *complex problems* from all three classes. Some first impressions might have been that the CEAB norm would result in rigid constraints and uniformity for all programs. The issue is rather to identify, select and foster distinctive strengths and foci through such a vast solution space, and share it consistently amongst faculty members.

7.5.2 Control module passed according to usual grading rules, attribute not necessarily attained

Programs that maintain their usual scoring system, and assess outcomes for the set of control modules only could see some students pass the module based on scores, but fail the attainment of the related CEAB attributes. Such a two-tier assessment system may be less costly to establish, but will confuse and anger students over misunderstandings of how they could "pass" but not be finished with a module. It is essential to have a mechanism that allows students to either revise until a satisfactory outcome is reached, or repeat the entire activity. This may conflict with institutional

practices by which there is no opportunity to make up an incomplete element of a course at the end of term.

More fundamentally, many of the (complex) outcomes may well resist "measurement", and reliability in the *subjective perception* of results by markers may only come at the cost of the validity of a simplified assignment that would be used, thus evaluating something other than the original intent.

7.5.3 Data and information fusion

Although we have a correlation matrix to relate the CEAB attributes and CDIO topics, there is still no basis for managing the uncertainties associated with range in the quality of data and the reliability of observers. This process requires that the data be collected and assessed for inconsistencies. It would be unwise to hypothesise in advance of that data.

7.5.4 Global and long term involvement of faculty

Faculty traditionally share their time between research, teaching, and administration. Depending on the culture of the institution and the requirements of tenure, involvement in a continuous improvement effort may not appear worthwhile. The recognition and credit to personnel for their involvement in the continuous improvement process is essential to ensure long-term success of the process.

8 Conclusion

Canadian engineering programs face a new accreditation standard. A theoretical model with the appropriate characteristics was presented.

The needs of stakeholders help set final proficiency levels against CDIO topics. A correlation maps these onto CEAB attributes. Learning objectives of modules and internal assessment in key modules refer to the CDIO topics. External assessment uses the global CEAB attributes. Supervisors of interns help define intermediate levels, and act as advisors for the design of the curriculum. Alumni provide feedback with minimum lag as to the current form of the curriculum.

Maintaining a common understanding of attributes and proficiency levels was addressed, with ways of renewing participating advisors and stakeholders. A meta-process to reduce variation is thus encouraged.

Challenges were outlined, a major one being the long term empowerment and involvement of faculty members. The fusion of data and devising meaningful improvements remain complex activities. Successful implementation will require the CEAB Standard to be used as an opportunity. This more detailed approach, although producing higher value, will come at a cost.

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