An Outcome-Based Curricular Framework and Design Templates for Engineering Programmes

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ABSTRACT

This paper aims to illustrate how the engineering programmes are transformed into an outcome-based education (OBE). The OBE requires higher education institutions (HEIs) to demonstrate that their graduates have met the programme learning outcomes (PLOs). This requires all curriculum, teaching, and assessment decisions to be made based on the goals of accomplishing those PLOs. It was identified that the biggest challenge for the programmes is to classify their learning outcomes at programme and course levels and to link the programme components to formulate appropriate assessment models. In Vietnam, OBE implementation has been initiated at the national level, however, it remains a challenge for HEIs to develop a curricular framework to establish and ensure the sustainable implementation of an OBE system at the institutional level. Vietnam National University-Ho Chi Minh City (VNU-HCM) proposed a solution that involved using CDIO (Conceive - Design - Implement - Operate) approach to plan and assess engineering curriculum based on learning outcomes, as the basis to build a model framework to help accelerate the nation's efforts in OBE implementation. Based on the CDIO approach, this paper presents an Outcome-Based Curricular Framework and a set of Design Templates that would help engineering programmes plan and assess their curriculum to achieve respective graduate attributes.

Keywords: *outcome-based education, engineering programme, outcome-based curricular framework, curriculum design template.*

INTRODUCTION AND BACKGROUND

The OBE requires HEIs to demonstrate that their graduates have met the PLOs. Several international accords on engineering qualifications and professional competence provide for mutual recognition of signatories' accredited engineering programme graduates. The Washington Accord (WA) provides for recognition of programmes accredited for engineer track. Since 2001, the signatories to the WA have recognized the need to describe graduates' attributes. Thence, the Graduate Attributes were developed, the Version 1 was adopted in June 2005, and the Version 2 that form a set of individually assessable learning outcomes was approved in June 2009 (IEA, 2009). As the WA Graduate Attributes have been improved over the years in assisting members' development of outcome-based accreditation criteria, the OBE implementation has increasingly expanded among signatories and provisional members. In several countries, establishment of an OBE system in all HEIs offering engineering programmes is required, supported, and monitored by their organizations which foresee the quality of engineering programmes (ACBET, 2012) (Aravind, & Rajparthiban, 2011) (EAC Malaysia, 2012). The OBE requires all programme curriculum, teaching, and assessment decisions to be made based on the goals of accomplishing PLOs. It was identified that the biggest challenge for the programmes is to classify the learning outcomes at programme and course levels and to link the programme components to formulate appropriate assessment models.

In Vietnam, at the national level, OBE implementation has been initiated through the mandates of Ministry of Education and Training that all HEIs develop and publicly declare their PLOs (Phan et al., 2010). While these changes have served as a catalyst to facilitate the transition efforts, it remains a challenge for HEIs in Vietnam to develop a curricular framework to establish and ensure the sustainable implementation of an OBE system at the institutional level. VNU-HCM proposed a solution that involved using a creative education approach called CDIO (Crawley et al., 2007), which provides the CDIO Syllabus--a comprehensive and well-structured list of learning outcomes--to formulate PLOs, and the CDIO Standards to plan and assess engineering programmes based on learning outcomes, as the basis to build a model framework to help accelerate the nation's efforts in OBE implementation through widespread implementation of CDIO in Vietnam (Phan et al., 2010).

VNU-HCM has implemented that model framework since 2010. The implementation has focused on the adaptation of CDIO Syllabus and implementation of CDIO Standards to systematically reform the curricula of our strategic university departments, to use the pilot implementation as a means to develop generalizable solutions that can be exported and replicated at universities within VNU-HCM and at other HEIs throughout Vietnam, and to nucleate the pilot implementation at our model CDIO-based university departments to widespread implementation at other HEIs in Vietnam, and, thereby, have broad impact in contributing to accelerating the nation's efforts in OBE implementation. The key components of OBE systems that support engineering education transformation were identified. The common frameworks and model templates generalized from the CDIO implementation have been developed (Nguyen et al., 2012). Based on the CDIO approach, this paper presents an Outcome-Based Curricular Framework and a set of Design Templates for engineering programmes that would help plan and assess their curriculum to achieve respective graduate attributes.

THE ADAPTATION OF CDIO SYLLABUS AND IMLEMENTATION OF CDIO STANDARDS AT VNU-HCM

The crux of CDIO is its integrated framework including Syllabus, a statement of undergraduate engineering education goals, and a set of 12 Standards designed to help achieve the goals.

Adaptation of the CDIO Syllabus as a Framework for PLOs Classification and Formulation

The CDIO Syllabus is a list of knowledge, skills, and attitudes (KSA) that is formulated based on the norms of contemporary engineering practice, and reviewed by experts in many fields, thereby comprehensive of all known skills lists. The content and structure of the Syllabus which were motivated, in part, by an understanding of how it will be used, lays the foundation for curriculum planning and integration, teaching and learning practice, and outcome-based assessment (Crawley et al., 2007).

The CDIO Syllabus v.2 (Crawley et al., 2011) classified learning outcomes into four high-level (x-level) categories or sections: disciplinary knowledge and reasoning; personal and professional skills and attributes; interpersonal skills, and other professional skills specific to the engineering profession reflecting graduates' high-level expectations. The content of each section was expanded in the CDIO Syllabus to a second level (x.x-level), to a third level (x.x.x-level), and to a fourth level (x.x.x.x-level) of detail.

The principal value of the Syllabus is that it can be applied across a variety of programmes and can serve as a model for all programmes to derive specific learning outcomes at both programme and course levels:

1. The Syllabus at x-level of detail addressed programme educational objectives, e.g. ABET Criterion 2 – Educational Objectives.
2. The Syllabus at x.x-level of detail consists of topics that are roughly at the level of detail of national standards and accreditation criteria, e.g. ABET Criterion 3 - Educational Outcomes, WA Graduate Attributes and Professional Competences.
3. The Syllabus at third and fourth levels of detail are necessary to transform high-level goals to teachable and assessable learning outcomes. Specifically, the Syllabus at x.x.x-level consists of topics that are at the level of detail of learning outcomes at programme level; and the Syllabus at x.x.x.x-level consists of topics that are at the level of detail of learning outcomes at course level.

Our strategic university departments have begun adapting the CDIO Syllabus to derive PLOs that are contemporary and reflective of the KSA needed by the industry (Nguyen et al., 2012). Specifically we have customized the CDIO Syllabus and conducted surveys, focused group discussions, document research, workshops, and peer review sessions to understand the needs of industry partners and how well our programmes are meeting these needs. This process has helped modify at the detailed level of the Syllabus, but it has also elucidated an important problem in defining a consensus on both the current and future need of industry for specific disciplines, especially those in the high-tech sectors. This problem originates from the fact that the maturity of the industry in Vietnam and the recent investment of international investment in Vietnam are still at an early stage, thus, Vietnamese-based companies and international companies can have very different requirements in terms of the needed KSA. We have taken an approach to balance the different views and strive to leverage the comprehensive CDIO Syllabus to derive PLOs that meet highest international standards while still satisfying the specialized requirements of the industry in Vietnam.

Implementation of CDIO Standards as a Framework for Outcome-Based Curriculum Planning and Assessment

The CDIO approach provides a set of 12 Standards designed to help engineering programmes achieve their goals. The CDIO Standards address programme philosophy and educational objectives (Standard 1), programme learning outcomes (Standard 2), integrated curriculum development (Standards 3-4), design-build experiences and workspaces (Standards 5-6), new methods of teaching and learning (Standards 7-8), faculty development (Standards 9-10), and assessment and evaluation (Standards 11-12). As designed, the Syllabus provides the answer to the question of what KSA engineering graduates should possess, while the 12 Standards provide the answer to the question of how we can do better to ensure that our graduates achieve those KSA. Providing answers to the "what" and "how" questions in a systematic and un-prescriptive way makes it viable for the programmes to adopt and adapt CDIO according to their needs and unique conditions (Crawley, et al., 2007) (Crawley, et al., 2011) (Nguyen, et al., 2012).

Based on CDIO Syllabus and the standards for curriculum design, the curricular frameworks that enable classifying learning outcomes at programme and course levels and linking the programme components to make sure that overall programme educational objectives (PEOs) are met through individual courses and assessment methods, were developed and implemented for CDIO-based and non-CDIO-based new curricula, and renewed curricula (Malmqvist, et al., 2006) (Berglund, & Malmqvist, 2007) (Hermon, et al., 2010) (Nguyen, et al., 2012).

To ensure that PLOs will be met, our implementation was guided by the 12 CDIO Standards (Nguyen et al., 2012). We intended to integrate all CDIO standards into our programme evaluation process at the department levels to evaluate the extent to which a department curriculum has implemented CDIO, and more importantly, to differentiate our programmes from other programmes that want to promote their own interests by calling themselves CDIO-compliant.

AN OUTCOME-BASED CURRICULAR FRAMEWORK

In OBE, the relationship between the intended learning outcomes, teaching and learning activities, and assessment of student learning were referred as constructive alignment (Biggs, & Tang, 2011), or backward design (Wiggins, & McTighe, 2005). All these models of OBE design highlight the centrality of learning outcomes and the importance of the alignment of curriculum, teaching, and assessment. Based on the curricular frameworks derived from adaptation of CDIO Syllabus and implementation of CDIO Standards for various programmes, mentioned above, a common Outcome-Based Curricular Framework for engineering programmes was proposed with the key components (Figure 1) classified into four categories:

1. Programme goals: programme educational objectives (PEOs), programme learning outcomes (PLOs).
2. Curriculum: curriculum structure, curriculum matrix (matrix of courses and PLOs).
3. Teaching and learning: course syllabi with course learning outcomes (CLOs), CLOs assessment model.
4. Curriculum assessment: PLOs assessment model.

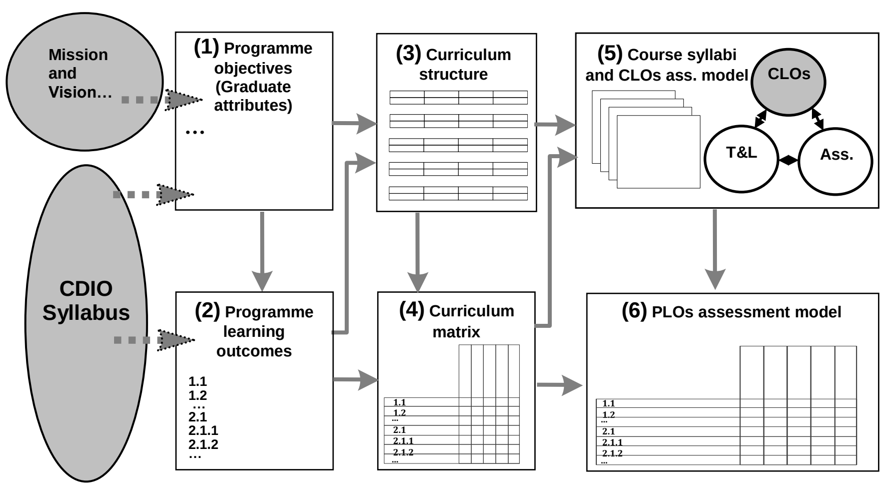

Figure 1: An Outcome-Based Curricular Framework

CURRICULUM DESIGN TEMPLATES

Outcome-Based Curriculum Design and Implementation

An Outcome-Based Curricular Framework describes the goals, content and structure of an educational programme, as well as how these components are connected. Figure 1 indicates that the CDIO Syllabus is used as a starting point for defining the learning outcomes. The programme graduate attributes are predefined as the PEOs. PLOs are then defined in line with the PEOs. Next, curriculum structure and matrix are defined in line with the PLOs; the CLOs of each course are formulated to cover the PLOs. Finally, course syllabi are designed to align with the CLOs, teaching and learning, and assessment. The PEOs are assessed at various point of the learner's progress. The curricular framework proposed in this paper adapted the course assessment model (Gray, 2012), the PLOs and CLOs correlation achievement model (Aravind, & Rajparthiban, 2011), and the PLOs assessment model (Doan, et al., 2012). Both the first and the third models used the CDIO Syllabus structure to specify and correlate CLOs and PLOs.

The Curriculum Design Templates

We have applied that Outcome-Based Curricular Framework for various programmes. In order to assist the programmes to plan and assess their curriculum systematically accordingly to the proposed curricular framework, a set of curriculum design templates was developed. The content of each template was defined based on the adaptation of the CDIO Syllabus and implementation of the related standards, as described above.

As refer to the Table 1 and Table 2, the templates for PEOs and PLOs formulation are proposed in accordance with the CDIO Syllabus structure at x-level, x.x-level, and x.x.x-level of detail. The formulation of PLOs at x.x-level of detail is intended for accreditation or public declaration purpose; at x.x.x-level of detail is intended curriculum structure design.

Table 1: The template for PEOs formulation

CDIO Syllabus (x-level)	PEOs
***1.** Disciplinary knowledge and reasoning*	1. Develop a working knowledge of technical fundamentals
***2.** Personal and professional skills and attributes*	2. Develop a refined ability to discover knowledge, solve problems, think about systems, and master other personal and professional attributes
***3.** Interpersonal skills: teamwork and communication*	3. Develop an advanced ability to communicate and work in multidisciplinary teams
***4.** CDIO skills*	4. Develop skills to conceive, design, implement, and operate systems in an enterprise and societal context

Samples source: (MIT AeroAstro)

The templates for curriculum structure (Table 3) and curriculum matrix (Table 4) are proposed based on the CDIO Standard 3-Integrated Curriculum, which requires the curriculum to allow the disciplinary courses (specified in the Syllabus section 1) to be mutually supporting; and the personal skills (specified in the Syllabus section 2), the interpersonal skills (specified in the Syllabus section 3), and other skills specific to the engineering profession (specified in the Syllabus section 4) to be interwoven in the engineering curriculum. The template for curriculum structure allows specifying course areas that are then developed into sequences of courses and projects to cover entire required PLOs.

Table 2: The template for PLOs formulation

Syllabus (x.x.x)	PLOs (x.x)	PLOs (x.x.x)
1. Disciplinary knowledge and reasoning		
1.1 Knowledge of underlying mathematics and sciences	1.1 Demonstrate a capacity to use the principles of the underlying sciences of mathematics, physics, chemistry, and biology	1.1.1 Mathematics 1.1.2 Physics 1.1.3 Chemistry 1.1.4 Biology
…		
2. Personal and professional skills and attributes		
2.1 Analytical reasoning and problem solving	2.1 Analyze and solve engineering problems	…
…		
3. Interpersonal skills: teamwork and communication		
3.1 Teamwork	3.1 Lead and work in teams	…
…		
4. Competences for professional practice/ Applying knowledge to benefit society		
4.1 External, societal, and environmental context	4.1 Recognize the importance of the societal context in engineering practice.	…
…		

Samples source: (MIT AeroAstro).

Table 3: The template for curriculum structure
(4-year curriculum, min. 32-credits/ year)

Subject Areas	**Mathematics & Basic Sciences**				**Engineering Sciences & Engineering Design**			**Other**	
Course Group	Math	Bio	Chem	Phy	Core eng. funda-mental courses, & Projects	Advanced eng. fundamental knowledge, methods and tools courses, & Projects	Intern, Capstones/ Final project	Social Sciences & Human.	Other
100%	Sample: 25%/ min 32 credits (1)				Sample: 37.5%/ min 48 credits (2)		…		
Credits	…								

Sample: (1): one year of a combination of college level mathematics and basic sciences (biological, chemical, and physical sciences, some with experimental experience). (2): one and one-half years engineering topics consisting of engineering sciences and engineering design (ABET, 2013).

For the teaching and learning design, a model template for course syllabus is proposed to ensure an alignment between CLOs (the learning outcomes topics at x.x.x.x-level with Bloom's verbs), teaching and learning, and assessment methods as shown in Table 5. A model template for course assessment based on CLOs is proposed as shown in Table 6. The course grades are computed using the assessment evidences, criteria for evaluation, guidelines (e.g. rubrics and answer keys), and standards used to judge the learning outcomes evidences (Gray, 2012).

Table 4: The template for curriculum matrix

Sem.	**No.**	**Courses/ Projects**	**PLOs (x.x.x)**									
			2.1					**2.2**	**...**	**4.6**		
			2.1.1	2.1.2	2.1.3	2.2.4	2.1.5	2.2.1	...	4.6.4	4.6.5	4.6.6
1.	1.	Course 1	2	2	2							
	2.	Course 2						2				
	...											
2.	...											

Proficiency level (MIT AeroAstro):

0. Do not know or understand
1. To have experienced or been exposed to
2. To be able to participate in and contribute to
3. To be able to understand and explain
4. To be skilled in the practice or implementation of
5. To be able to lead or innovate in

Table 5: The template for course syllabus (After Gray, 2012)

Course Title			…	
Brief Description (where this course fits in the curriculum and its major purpose(s)):			…	
Course Goals (major topics at the X.X level):			…	
Course Outline (week by week schedule)				
Time Frames (weeks/days)	**Teaching Content**	**CLOs** (x.x.x-topics &x.x.x.x-topics with Bloom's verbs)	**Teaching and Learning Activities** Instructor/Students; In-class/out-of-class	**Assessment Evidences**
…				

Table 6: The template for course assessment

Ass. Evidences	**Compo-nents**	**Ass. Criteria**	**Guide-lines**	**Ass. Standards**	**Weights** (%)
Assessment 1 e.g. Exams (multiple choice questions)	***Assessment 1.1***	E.g. Students are able to recognize, recall, identify facts covered in lectures and reading.	E.g. Answer keys	E.g. 75% of the answers are correct	E.g. 10%
	Assessment 1.2	…			
…					

To assess an achievement of the PLOs, a template is proposed based on PLOs and CLOs correlation achievement model (Aravind, & Rajparthiban, 2011), and PLOs assessment model (Doan et al., 2012) as presented in Table 7. This assessment template shows the overall quantitative achievement of PLOs through the CLOs specified in course syllabi (Table 5), and course assessment model (Table 6).

CONCLUSION

Based on the common frameworks and design templates that have been generalized from the adaptation of CDIO Syllabus and implementation of CDIO Standards at VNU-HCM, the Outcome-Based Curricular Framework and a set of

Design Templates for transforming engineering programmes into OBE are proposed. These provide HEIs in Vietnam with the framework to establish and ensure the sustainable implementation of an OBE system at their institutional level, and, therefore help accelerate the nation's efforts in OBE implementation.

Table 7: The template for PLOs assessment

After (Aravind, & Rajparthiban, 2011) (Doan et al., 2012)

CLOs		**PLOs**									
		2.1					**2.2**	**...**	**4.6**		
		2.1.1	2.1.2	2.1.3	2.2.4	2.1.5	2.2.1	...	4.6.4	4.6.5	4.6.6
Course 1	x.x.x.x										
	x.x.x.x										
	x.x.x.x										
	x.x.x.x										
Course 2	x.x.x.x										
	x.x.x.x										
	x.x.x.x										
	x.x.x.x										
Course "n"	x.x.x.x										
	x.x.x.x										
	x.x.x.x										
	x.x.x.x										

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