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AN ENGINEERING EDUCATION FRAMEWORK FOR FULFILLING THE OUTCOME-BASED EDUCATION REQUIREMENTS

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ABSTRACT

The recently revised Engineering Accreditation Council (EAC) Engineering Program Accreditation Manual (The Engineering Accreditation Council (EAC), 2012) requires all undergraduate engineering programs in Malaysia to demonstrate twelve new set of learning outcomes which are aligned with the Washington Accord graduate attributes. The attributes emphasized not only on the mastery of technical disciplines but also on the acquirement of soft skills such as communication, leadership and a range of creative and critical thinking skills. CDIO is an international initiative of engineering education framework which provides an integrated curriculum model with an aim to produce global engineers who are workplace ready. This paper highlights the significance of using CDIO engineering education framework in reviewing Malaysian engineering programs in order to fulfil the requirements of EAC and Outcome-Based Education (OBE) approach. Mapping of the relationships between CDIO Standards and OBE components and principles is also discussed.

Keywords: CDIO, OBE, Curriculum design, Integrated curriculum, Engineering accreditation, Engineering education.

1. INTRODUCTION

Engineers face an increasingly complex world, in which large issues such as rapid technology change, increase concern of the environment and economic crises merge with increased globalisation (National Academy of Engineering (NAE), 2004; 2005). Engineering graduates are expected to work in multidisciplinary, multicultural teams to both assess needs and co-create solutions with local and global communities. There are also suggestions for curriculum changes to accommodate the new knowledge such as biotechnology, nanotechnology, alternative energy,

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health informatics, sustainability, multi-scale analysis and systems approach to processes and engineering systems (National Academy of Engineering (NAE), 2004; 2005; Vest, 2008; Morell, 2010). These changes and requirements contribute to gaps between competencies developed during higher education and competencies required for engineering work.

Many authors have discussed the persistent gaps related to these competencies or generic skills (Bodmer *et al.*, 2002; World Chemical Engineering Council(WCEC), 2004; Ashman *et al.*, 2008; Johnston *et al.*, 2008; Nair *et al.*, 2009). Different terms have been used to describe these competencies such as “soft skills”, “generic attributes”, “employment skills”, “transferable skill”, and “generic competencies”. Among the skills which are rated most important in many studies are communication and teamwork (Connelly and Middleton, 1996; Meier *et al.*, 2000; Bodmer *et al.*, 2002; National Academy of Engineering (NAE), 2004; World Chemical Engineering Council(WCEC), 2004; Reio and Sutton, 2006; Nair *et al.*, 2009), integrity and commitment (Nguyen, 1998; Male *et al.*, 2009), problem solving (Nguyen, 1998; National Academy of Engineering (NAE), 2004; World Chemical Engineering Council(WCEC), 2004; Male *et al.*, 2009), ability to learn (Nguyen, 1998; National Academy of Engineering (NAE), 2004; World Chemical Engineering Council(WCEC), 2004), leadership (National Academy of Engineering (NAE), 2004) and an interdisciplinary approach (World Chemical Engineering Council(WCEC), 2004; Male *et al.*, 2009).

Responding to the needs of industries, leading engineering educational governing bodies in Australia, Europe, New Zealand, and the USA have carried out review of the engineering education outcomes which include the generic skills elements (Maillardet, 2004; Engineers Australia, 2005; European Network for Accreditation of Engineering Education, 2008; Engineering Council, 2009; Institution of Professional Engineers New Zealand, 2009; International Engineering Alliance (IEA), 2009; Quality Assurance Agency for Higher Education, 2010; Accreditation Board for Engineering and Technology (ABET), 2012). For example, The Washington Accord which is an international agreement among bodies responsible for accrediting engineering degree programs has listed 12 engineering program outcomes which include both the engineering and generic skills (International Engineering Alliance (IEA), 2009).

Engineering programs in Malaysia are required to be accredited by the Engineering Accreditation Council (EAC) of Malaysia. Being a Washington Accord member since 2009, EAC has adopted all the program outcomes specified by the Washington Accord in its latest manual (The Engineering Accreditation Council (EAC), 2012) as guides in developing new or reviewing existing undergraduate engineering program outcomes (The Engineering Accreditation Council (EAC), 2012). Although the new set of program outcomes has emphasized on the need to teach the generic skills of teamwork, lifelong learning, communication, etc., there still lacked of a solid framework on how this can be infused into the engineering curriculum. By complying with the (The Engineering Accreditation Council (EAC), 2012) program outcomes, engineering programs will only be emphasizing on “an ability”, “an understanding” or “demonstrate competency” without detailing the level of competency to be achieved. This leaves room for individual institutions to ascertain their own detail interpretation of the attributes, usually within a context of complex engineering problems and activities.

2. OUTCOME-BASED EDUCATION

An area of concern for all undergraduate engineering program designers is complying with the Outcome-Based Education (OBE) approach. Engineering programs in Malaysia since 2004 began to use an OBE approach in all aspects of academic processes such as restructuring of curriculum, teaching and learning activities, assessment and reporting practices. OBE is an approach to education in which the curriculum is designed based on the exit learning outcomes which should be displayed by students at the end of the course. OBE is defined as a "…comprehensive approach to organizing and operating an education system that is focused in and defined by the successful demonstrations of learning sought from each student" (Spady, 1994a). Spady (1994a) has also stated: "Outcome-Based Education means starting with a clear picture of what is important for students to be able to do, then organizing the curriculum, instruction, and assessment to make sure that this learning ultimately happens."

There are three elements that are important for an outcome-based approach to learning (Spady, 1994a):

- statement of exit learning outcomes which reflect expected student competencies and abilities which include the educational aims, purposes and values;
- the strategy or process to enable the intended learning outcomes to be achieved (via teaching, learning, assessment and support and guidance methods); and
- criteria for assessing learning which are aligned to the intended learning outcomes and teaching strategies.

The OBE approach has shifted the focus of teaching and learning from educator to learner that requires change within the educational system in order to facilitate learning. According to Spady (1994a) the basic principle of OBE is the *clarity of the focus*. This principle emphasizes that curriculum development, implementation and evaluation should be based on the intended learning outcomes expected of the students at the end of their study. Curriculum designers firstly, have to identify a clear focus on what they want learners to be able to demonstrate at the end of learning time. Once these outcomes have been identified, the second principle of *design down* suggests curriculum and instructional activities are then made to ensure these desired end results are achieved. The third principle of *high expectations* brings about high standards of performance in order to encourage students to engage deeply in what they are learning. Early success heightens self-confidence and provides motivation to learners. The fourth principle of *expanded opportunities* provides for a flexible approach in time and teaching methodologies matched against the needs of the learner allowing more than one opportunity to succeed (Killen, 2000).

Spady and Marshall (1991) have defined the implementation of OBE in a series of stages from traditional programs to transitional and, eventually, transformational models. Many engineering curriculum designers at the early stage were working with the transitional model of OBE. The focus is on addressing student higher level competencies such as critical thinking, effective communication, technological application and problem solving skills upon graduation and work on the curriculum and assessment design around these higher order exit outcomes. To be fully transformational, an institution needs to look at cross-curricula outcomes, teaching real world engineering problems, authentic assessments as well as measurement indicators from the "future graduates" competencies and abilities perspective.

In order to be fully accredited by the EAC, engineering programs are also required to prove and provide evidences that all these OBE components and principles are truly implemented and the Continual Quality Improvement (CQI) culture is being practiced by institutions (The Engineering Accreditation Council (EAC), 2012).

3. CDIO

CDIO is an innovative engineering education framework initiative pioneered by the Massachusetts Institute of Technology and three Swedish partners namely, Royal Institute of Technology (KTH), Linkoping University and Chalmers University of Technology for producing the next generation of engineers. The initiative provides a framework for engineering education stressing on engineering fundamentals in the context of Conceiving, Designing, Implementing and Operating (hence the acronym CDIO) real-world systems and products (Crawley *et al.*, 2007) . There are now over 90 institutions world-wide that are CDIO collaborators and had adopted CDIO as the framework for their curricular planning and outcome-based assessment.

The CDIO approach in improving the engineering education is based on two central questions as highlighted by Crawley *et al.* (2007):

- *"What is the full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university, and at what level of proficiency?"*
- *"How can we do better at ensuring that students learn these skills?"*

The first question is addressed by the CDIO syllabus which is a set of specific detailed learning outcomes. The syllabus is divided into four sections:

- technical knowledge and reasoning – focus on specific technical disciplinary knowledge.
- personal and professional skills and attributes – focus on individual student's cognitive and affective development such as reasoning and problem solving, experimentation and knowledge discovery, system thinking, creative thinking, critical thinking and professional ethics.
- interpersonal skills – focus on individual and group interactions such as teamwork, leadership and communication.
- product, process and system building skills – focus on conceiving, designing, implementing, and operating systems in the enterprise and societal context.

The CDIO syllabus is in full agreement with the UNESCO framework of education which states that curriculum as its core should be restructured or repacked around the four pillars of learning: learning to know, learning to do, learning to live together, and learning to be (UNESCO, 2004). The CDIO syllabus down to the second level details is shown in Table 1.

Table-1. CDIO Syllabus at the Second Level

1.0	**Technical Knowledge And Reasoning**	3.2	Communications
1.1	Knowledge of Underlying Mathematics, Science	3.3	Communication in Foreign Languages
1.2	Core Engineering Fundamental Knowledge		
1.3	Adv. Engr. Fundamental Knowledge, Methods, Tools	**4.0**	**Conceiving, Designing, Implementing, And Operating Systems In The Enterprise And Societal Context**
		4.1	External, Societal and Environmental Context
2.0	**Personal And Professional Skills And Attributes**	4.2	Enterprise and Business Context
2.1	Analytical Reasoning and Problem Solving	4.3	Conceiving, Systems Engineering and Management
2.2	Experimental Investigation and Knowledge Discovery	4.4	Designing
2.3	System Thinking	4.5	Implementing
2.4	Attitude, Thought and Learning	4.6	Operating
2.5	Ethics, Equity and Other Responsibilities	4.7	Leading Engineering Endeavours
		4.8	Entrepreneurship
3.0	**Interpersonal Skills: Teamwork And Communication**		
3.1	Teamwork		

Twelve standards have also been developed under the CDIO initiative which could be used as the guiding principles in designing and developing an engineering program. The standards provide an outline of the answer to the second question "*How can we do better at ensuring that students learn these skills?*" The standards were developed through feedbacks from program leaders, alumni, industrial partners as well as students of the respective first collaborators. These standards provide guidelines for engineering education reform, create benchmarks and goals as well as offers a framework for continuous improvement.

Table 2 lists the 12 CDIO Standards which emphasize on program philosophy (Standard 1), curriculum development (Standards 2, 3 and 4), design-implement experiences and workspaces (Standards 5 and 6), methods of teaching and learning (Standards 7 and 8), faculty development (Standards 9 and 10) and assessment and evaluation (Standards 11 and 12).

CDIO provides a general framework of approach to reform engineering education. The framework is not prescriptive in nature and the 12 Standards and the CDIO Syllabus have to be transformed to fit the context and conditions of each institution or engineering program. The institution could take whichever element of the standards or syllabus that would fit into the curriculum, transform it and give it a local flavour. The key success factor is local staff ownership and getting them involve early in the planning and implementation stages are crucial.

Table-2. The CDIO Standards (Crawley *et al.*, 2007)

1. CDIO as Context Adoption of the principle that product and system lifecycle development and deployment are the context for engineering education **2. CDIO Syllabus Outcomes** Specific, detailed learning outcomes for personal, interpersonal, and product and system building skills, consistent with program goals and validated by program stakeholders **3. Integrated Curriculum** A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills **4. Introduction to Engineering** An introductory course that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills **5. Design-Build Experiences** A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level **6. CDIO Workspaces** Workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning.	**7. Integrated Learning Experiences** Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills **8. Active Learning** Teaching and learning based on active experiential learning methods **9. Enhancement of Faculty CDIO Skills** Actions that enhance faculty competence in personal, interpersonal, and product and system building skills **10. Enhancement of Faculty Teaching Skills** Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning **11. CDIO Skills Assessment** Assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge **12. CDIO Program Evaluation** A system that evaluates programs against these 12 standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement

4. OBJECTIVES

Undergraduate engineering programs in Malaysia are required to use the OBE approach in all aspects of academic processes such as designing of curriculum, teaching and learning activities, assessment and reporting practices. Without any proper framework individual institution is struggling to develop their "own brand" of OBE in order to fulfil the requirements in the EAC 2012 Manual. Hence, the main objective of this paper is to show that CDIO Standards provide a framework that could guide the development or review of undergraduate engineering programs that are consistent with OBE main components and principles.

5. PROCESS

The analysis was carried out firstly, by looking for correlation between the 12 CDIO Standards and OBE components and principles. The mapping is done by putting a tick in the relevant boxes to show how the CDIO standards are very much consistent and complementing the OBE components and principles. The authors only considered a strong contribution of each standard to relevant OBE components and principles. Results of the mapping are shown in Table 3.

6. RESULTS

Table 3 provides a summary that clearly shows the significance of CDIO Standards in complying with the requirements of OBE approach. The first component of OBE approach is the development of learning outcomes. The important issue affecting the development of outcomes is the relevancy and significance of learning outcomes. In defining outcomes which are significance, Spady (1994b) wrote: "*Do the outcomes we expect students to demonstrate matter in the long run—in life after formal schooling?*" In formulating the program outcomes and designing the curriculum, Standard 1 provides a holistic perspective of "*What is the full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university.*" An effective engineering program should make product, process and system lifecycle development and deployment as the context of engineering education. By adopting Standard 1 the curriculum of any engineering program should be able to prepare engineering graduates for the wider perspective of engineering careers in conceiving, designing, implementing and operating product, process or system. Furthermore, the standard emphasizes on a framework that represents the professional role of engineers and settings to teach engineering and generic skills.

OBE approach requires explicit statement of learning outcomes which reflect educational aims, purposes and values and this is complemented well by Standard 2. The standard together with CDIO Syllabus provides detailed learning outcomes for disciplinary knowledge, skills and attitudes students should know and able to do at the end of their studies. Aspects of generic skills are covered under the personal and interpersonal skills of the syllabus. Curriculum and course designers could make the CDIO Syllabus as a reference in writing the program as well the course learning outcomes. Standard 3 gives emphasis on the explicit connections of disciplinary courses that are related in terms of contents and learning outcomes. Curriculum should also be planned in a way that personal and interpersonal skills together with the product, process and system building skills are integrated with the disciplinary courses. The advantage of an integrated curriculum could be argued from the practical and pedagogical reasons. From practical point of view, the currently packed engineering curriculum would not accommodate more content or time especially if the learning outcomes are beyond the disciplinary core content. Pedagogically, generic skills such as communication skills are generic to engineers, lawyers or doctors. But, at more concrete level, oral communication skills in a technical field depends on discipline specific aspects such examining problems at different levels of abstraction and explaining technical issue to different audiences. Students also need to be given opportunities to develop these skills during class activities.

The introductory course that provides the framework for the practice of engineering is emphasized in Standard 4. The standard encourages students to be engaged early in the practice of engineering through problem solving individually or in teams. Standard 5 guides curriculum designer to create a sequence of design implement experiences from basic to advanced levels. Therefore, in terms of OBE approach, the development of engineering curricula together with the program as well course learning outcomes would be more realistic and practical by considering Standards 1 to 5. The second important component of OBE approach is the instructional strategies that enable the intended outcomes to be achieved and demonstrated. The teaching of engineering in the context of conceiving- designing-implementing-operating requires a learning environment with adequate spaces and resources. Standard 6 gives emphasize on the workspace that support the learning of product, process and system building skills and at the same time supportive of the disciplinary knowledge. Standard 7 highlights on the importance of students learn and practice the personal and interpersonal skills and product, process and system building skills while learning disciplinary knowledge. This strategy conforms to the constructive alignment concept which represents an OBE model (Biggs and Tang, 2007). Active learning methods are known to engage students directly in thinking and experiencing the professional engineering practice (Woods *et al.*, 2000; Prince, 2004; Mo *et al.*, 2009; Andersson and Andersson, 2010). Subsequently, OBE approach encourages student-centered-learning approach which is the main theme of Standard 8.

With the OBE approach, academic staffs are expected to teach a curriculum that integrates disciplinary knowledge with personal and interpersonal skills and product, process and system building skills. So there is a great need for academic staffs to be competent in embedding those skills in their teachings. Standard 9 outlines the strategies for enhancing academic staff generic as well as CDIO skills competency while Standard 10 focuses on the enhancement of academic staff skills in teaching and assessing student learning. The third component of OBE approach addresses assessments of student learning which are aligned to the intended outcomes and instructions. Standard 11 emphasizes on the four phases of assessment of student learning namely, the specification of learning outcomes, the alignment of assessment methods with learning outcomes and teaching methods, the use of variety of assessment methods and the use of assessment results to improve teaching and learning. The standard also supports assessment culture that promotes learning from the perspective of learning-centered approach, a shift from the teaching-centered approach which is in line with the OBE approach. Standard 12 provides systematic and comprehensive approach to data collection and analysis in order to improve engineering program which is equivalent to the continual quality improvement (CQI) phase of OBE approach.

The OBE principles are fully complemented by CDIO Standards. The *clarity of focus* in terms of curriculum development, implementation and evaluation of engineering program that is based on the specific outcomes (Spady, 1994a) could be achieved if the institution or curriculum designer considers all the standards. For example, Standards 1 – 4 highlight the importance of designing engineering programs that prepare graduates for the life cycle of product, process and system building with great emphasis on the generic skills. Standards 5and 6 provide interesting insight of undergraduate engineering curricula by proposing extensive design-build experiences for the students. Standards 7 – 10 offer instructional methods as well as staff training required to achieve the prescribed outcomes. Standards 11 and 12 offer systematic assessment techniques for the courses as well as the overall engineering program. *Design down* principle which begins with identifying the exit outcomes followed by the “building blocks” of learning activities that enable students to achieve these outcomes is also supported by all the CDIO Standards. The standards recommend curriculum designers to use Standard 2 in determining the outcomes, Standards 3 – 5 and 7 for curriculum design, and Standards 6, 8 – 12 for planning the teaching and learning facilities and resources such as workspaces for design-build experiences, as well as enhancing lecturers teaching and assessment skills of generic skills besides the technical contents. The principle of *high expectations* emphasizes on raising the acceptable standard of “successful” or “finished” performance and eliminating success quotas by disregarding the bell curve grading (Spady, 1994a). These could be achieved if all the standards are considered when planning the program structure and curriculum as well as the resources. *Expanded opportunities* provide a flexible approach in time and teaching methodologies which is matched against the needs of the learner by allowing more than one opportunity to succeed. Spady (1994a) listed five dimensions of opportunity that need to be explored in OBE approach namely, teaching and learning time; teaching and learning styles; allowing teachers to apply the other three OBE principles consistently, systematically, creatively and simultaneously in their classrooms; applying same standards for all students and enforce no limits on how many students can achieve the given performance level; and opportunity for all to access essential learning experiences and resources. All these issues are addressed very well by all 12 CDIO Standards.

7. CONCLUSION

The main issue faced by curricula designers or program owners is to comply with the requirements of accreditation bodies such as EAC in Malaysia. This paper focused on the suitability of using CDIO framework in designing or reviewing undergraduate engineering programs. There have been some misconceptions among academic staffs that CDIO is just another model of engineering education which has different requirements from OBE approach. On the contrary, the mapping of CDIO and OBE has shown strong relationship between CDIO and OBE and it can be used to convince the proponent of OBE that CDIO is not only consistent but also compliment the components and principles of Transformational OBE. In conclusion, CDIO Standards provide good guide for developing or reviewing existing undergraduate engineering programs that would comply with the OBE requirements. Nevertheless, CDIO Standards act only as guiding principles and each institution could transform them to suit their needs.

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Table-3. Mapping of CDIO Standards with OBE Components and Principles

CDIO Standards	OBE COMPONENTS			OBE PRINCIPLES			
	Learning Outcomes	Instruction	Assessment	Clarity of Focus	Design Down	High Expectations	Expanded Opportunity
1 - CDIO as Context	✔	✔	✔	✔	✔	✔	✔
2 - CDIO Syllabus Outcomes	✔			✔	✔	✔	✔
3 - Integrated Curriculum	✔			✔	✔	✔	✔
4 - Introduction to Engineering	✔			✔	✔	✔	✔
5 - Design-Build Experiences	✔			✔	✔	✔	✔
6 - CDIO Workspaces		✔		✔	✔	✔	✔
7 - Integrated Learning Experiences		✔		✔	✔	✔	✔
8 - Active Learning		✔		✔	✔	✔	✔
9 - Enhancement of Faculty CDIO Skills		✔		✔	✔	✔	✔
10 - Enhancement of Faculty Teaching Skills		✔		✔	✔	✔	✔
11 - CDIO Skills Assessment			✔	✔	✔	✔	✔
12 - CDIO Program Evaluation			✔	✔	✔	✔	✔