CDIO- The Framework for Outcome-based Engineering Education for Accreditation: A Case Study of Thai Industrial Engineering Program

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*Sirichai Torsakul, Anin Memon, Surat Triwanapong and Natha Kuptasthien**
Department of Industrial Engineering, Faculty of Engineering, Rajamangala University of Technology Thanyaburi, Pathumthani 12110, Thailand
**natha.k@en.rmutt.ac.th*

Abstract
The recent movement of Thai engineering education and accreditation is a shift from content- to outcome-based. With the aim to achieve an accreditation by the Thailand Accreditation Body of Engineering Education (TABEE) and an international recognition, the objective of this paper is to share how the industrial engineering (IE) program of Thailand's Rajamangala University of Technology Thanyaburi (RMUTT) has applied the Conceive-Design-Implement-Operate (CDIO) framework to transitioning from the content- to outcome-based curriculum. For the methodology, the learning outcomes in the CDIO Syllabus were mapped to the Thailand Qualification Framework (TQF)'s engineering curriculum requirements and to TABEE Criterion 3 (learning outcomes and assessment). The mapping was to portray their complementary nature. To this end, the CDIO implementation in accordance with the 12 CDIO Standards was undertaken and the details elaborated. The rubric-based CDIO and TABEE self-evaluations were carried out and the results translated into actions for continuous improvement. The 4-5 rubric scores from 2013-2018 suggesting that the successful CDIO implementation contributes to the concurrent fulfillment of the TQF and TABEE learning outcomes.

Keywords: CDIO, TABEE, outcome-based accreditation, curriculum design, industrial engineering

Introduction

The CDIO (Conceive-Design-Implement-Operate) initiative is an educational framework emphasizing the engineering fundamentals in the context of conceiving, designing, implementing and operating real-world systems and products. Increasingly, the CDIO initiative members (i.e. CDIO collaborators) across the globe have adopted CDIO as the framework of the curricular planning and outcome-based assessment. In other words, CDIO is becoming the educational framework for producing the next generation of engineers (Crawley et al., 2011). Malmqvist et al. (2015) studied 47 institutions in 22 countries for the effect of implementing CDIO and its effect on educational quality. The study revealed that the main motives for choosing to adapt CDIO are; ambitions to make engineering education more authentic; the need for a systematic methodology for educational design; and the desire to include more design and innovation in curricula. The implementation of CDIO results in the achievement the learning goals and external recognition of educational quality.

The CDIO framework consists of a CDIO Syllabus and 12 CDIO Standards. The CDIO Syllabus offers rational, complete, universal and generalizable goals for undergraduate engineering education and is the cornerstone of CDIO (Crawley, 2001), while the 12 CDIO Standards serve as guidelines for educational program reform and evaluation, create benchmarks and goals with worldwide application, and provide a framework for continuous improvement (Bennedsen et al., 2016).

In Thailand, CDIO was first introduced to faculty members of Rajamangala University of Technology Thanyaburi (RMUTT) and those of the Faculty of Engineering of Chulalongkorn University in 2013 (Kuptasthien et al., 2014). The project was funded by Singapore's Temasek Foundation and lasted 21-day intensive training with 2-year implementation and follow-up. Upon completion, the participants were instructed to apply the CDIO concept to their respective study programs. For RMUTT, the CDIO framework has been adopted and fully implemented by the industrial engineering (IE) department to transform itself into a CDIO-based IE program. To that end, the IE program transformation involves the adoption of CDIO as the context for engineering education (CDIO Standard 1), the integrated curriculum development (CDIO Standards 2-5), the innovative teaching and learning methods and assessment (CDIO Standards 7, 8, 11), the workspace renovation (CDIO Standard 6), the faculty competency enhancement (CDIO Standards 9 and 10) and the program evaluation (CDIO Standard 12). In 2014, RMUTT was the first Thai university appointed as a CDIO Initiative member. As of 2018, there are 154 institutions worldwide and 44 of them are in Asian Region (CDIO worldwide initiatives, 2018)

According to Choo et al. (2015), CDIO played a key role in meeting the US's Accreditation Board for Engineering and Technology (ABET) criteria. In addition, CDIO was the most relevant educational framework to prepare Vietnamese universities and colleges for international accreditation (Nguyen, 2012). Moreover, Burbano (2016) effectively utilized the ABET student outcomes (Criterion 3) and the CDIO framework as part of the curriculum review process for continuous improvement.

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In North America, the Accreditation Board for Engineering and Technology (ABET) in the United States and the Canadian Engineering Accreditation Board (CEAB) are responsible for the accreditation of their respective engineering programs (Karapetrovic et al., 1998). In Europe, the accredited engineering programs are awarded the European Accredited Engineer (EUR-ACE) Label (Augusti, 2007). Meanwhile, in Asia, different countries have established their own accreditation bodies, e.g. the Accreditation Body of Engineering Education Korea (ABEEK) (Joo et al., 2019), the Japan Accreditation Body for Engineering Education (JABEE) (Bevrani, 2012) and Chinese Engineering Education Accreditation Association (CEEAA) (Zhu et al., 2012).

Interestingly, the current accreditation of Thai engineering programs emphasizes the documentary review, content-based emphasis curriculum, and an institution visit (Council of Engineers, 2015). The practice however contributes to the lack of international recognition of Thai engineering education, given that the universally acceptable accreditation system is that of *outcome-based* emphasis. Moreover, the content-based engineering graduates lack the distinguishing features regardless of educational institutions.

To meet the international standards and promote the transition from the content- to outcome-based emphasis of Thai engineering education, Thailand's Council of Engineers (COE) has thus established the Thailand Accreditation Body for Engineering Education (TABEE) in 2016 (Council of Engineers, 2017). One of TABEE's goals is to have a certain number of Thai engineering programs accredited by 2017 so that the COE could apply for a provisional signatory status to the Washington Accord in 2018. The achievement will lead to the international recognition of Thai engineering education.

Specifically, this academic paper aims to presents the application of the CDIO Syllabus and the 12 CDIO Standards to the industrial engineering (IE) program of RMUTT, with the goal to transition from the content- to outcome-based curriculum and the subsequent TABEE accreditation and an international recognition. In the study, the learning outcomes in the CDIO Syllabus were mapped to the Thailand Qualification Framework (TQF)'s engineering curriculum requirements (i.e. the six learning domains) and to TABEE Criterion 3 (learning outcomes and assessment). The mapping was to illustrate the linkages between the three "benchmarks" and their complementary nature. That is, the successful CDIO implementation contributes to the concurrent fulfillment of the TQF and TABEE learning outcomes. In this research, the CDIO implementation according to the 12 CDIO Standards was also detailed. Moreover, the rubric-based CDIO and TABEE self-evaluations were carried out and the results translated into actions for continuous improvement.

Theoretical Discussion

CDIO Syllabus

The CDIO Syllabus offers rational, complete, universal and generalizable goals for undergraduate engineering education. In other words, the knowledge, skills, and attitudes intended as a result of engineering education (i.e. the learning outcomes) are codified in the CDIO Syllabus. These learning outcomes detail what engineering graduates should know and be able to do upon the completion of their engineering programs; and are categorized into four categories in the first-level: (1) technical disciplinary knowledge and reasoning; (2) personal and professional skills and attributes, including engineering reasoning and problem solving, experimentation and knowledge discovery, system thinking, creative thinking, critical thinking, and professional ethics; (3) interpersonal skills, including teamwork, leadership, and communication; and (4) product and system building skills which focus on conceiving, designing, implementing, and operating systems in enterprise, societal and environmental contexts (Crawley et al., 2011). The knowledge and skillsets in CDIO Syllabus are detailed into second-level (x.x) and third-level (x.x.x). Table 1 shows an example of CDIO Syllabus and first, second and third level content.

Table 1: An Example of First, Second, and Third Level Content

Level	Content
First	2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES
Second	2.1 ENGINEERING REASONING AND PROBLEM SOLVING
Third	2.1.1 Problem Identification and Formulation 2.1.2 Modeling 2.1.3 Estimation and Qualitative Analysis 2.1.4 Analysis with Uncertainty 2.1.5 Solution and Recommendation

TQF Learning Domains

Under the TQF of Thailand's Office of the Higher Education Commission (OHEC), the engineering curriculum is required to cover the six following learning domains (OHEC, 2010): Domain 1: Ethical and moral development, consisting of five sub-domains (1.1–1.5); Domain 2: Knowledge (sub-domains 2.1–2.5); Domain 3: Intellectual (sub-domains 3.1–3.5); Domain 4: Interpersonal skills and responsibility (sub-domains 4.1–4.5); Domain 5: Analytical, communication and information technology (IT) skills (sub-domains 5.1–5.5); and Domain 6: Practical skills (sub-domains 6.1–6.3).

Table 2 tabulates the mapping of the TQF learning sub-domains (phrase-by-phrase breakdown) to the third-level CDIO Syllabus learning outcomes (i.e. x.x.x). The mapping identifies their linkages, suggesting that implementing the CDIO framework also fulfills the TQF engineering learning outcomes. Meanwhile, Table 3 presents the TQF-CDIO syllabus mapping outcomes, where the black dot (●) represents the linkage between a particular CDIO syllabus learning outcome and a given TQF learning sub-domain. The mapping indicates the complementary nature of both frameworks (i.e. the CDIO and TQF frameworks).

Table 2: The Mapping of the TQF Learning Domains to the CDIO Syllabus

TQF Domain	Phrase-by-phrase Breakdown	CDIO Syllabus	Description
1	**Ethics**		
1.1	Appreciation of Thai culture	4.1.4	The Historical and Cultural Context
	Ethics awareness		
	Loyalty	2.5.6	Trust and Loyalty
1.2	Punctuality	2.4.7	Time and Resource Management
	Self- and social- responsibilities	2.5.1	Ethics, Integrity and Social Responsibility
	Respect for rules and regulations of organizations and society		
1.3	Ability to be a leader and a follower	3.1.4	Team Leadership
	Teamwork	3.1.2	Team Operation
	Conflict solving based on prioritization	3.2.8	Negotiation, Compromise and Conflict Resolution
	Respect for others' rights and ideas, human value and dignity		
1.4	Evaluate the impact of engineering on human, organization, society and the environment	4.1.2	The Impact of Engineering on Society and the Environment
1.5	Academic and professional ethics	2.5.1	Ethics, Integrity and Social Responsibility
	Professional responsibility		
	Societal roles of engineering profession from past to present	4.1.4	Roles and Responsibility of Engineer
2	**Knowledge**		
2.1	Knowledge of fundamental mathematics,	1.1	Knowledge of Underlying Mathematics and Sciences
	Basic engineering	1.2	Core Engineering Fundamental Knowledge
	and Economics	4.2.7	Engineering Project Finance and Economics
	Applicability to engineering, innovation and technology	4.7.8	Innovation – the Conception, Design and Introduction of New Goods and Services
2.2	Knowledge of the theoretical and practical principles of specific engineering fields	1.3	Advanced Engineering Fundamental Knowledge, Methods and Tools
2.3	Integrate knowledge	2.4.5	Self-awareness, Metacognition and Knowledge Integration
2.4	Analyze and solve problem with appropriate methods and tools such as computer programing	2.1	Analytical Reasoning and Problem Solving
2.5	Apply disciplinary knowledge and skills to real-world problems	2.1	Analytical Reasoning and Problem Solving
3	**Intellectual**		
3.1	Good judgment		
3.2	Identify the problem and needs	4.3.1	Understanding Needs and Setting Goals
3.3	Think, analyze and solve engineering problem systematically	2.1	Analytical Reasoning and Problem Solving
	Ability to deploy information for decision-making efficiently	2.3	System Thinking
3.4	Imagination	2.4.3	Creative Thinking
	Apply knowledge to develop innovation	4.7.4	Creating New Solution Concepts
3.5	Conduct informational search and forming lifelong learning habits to keep abreast of new technology	2.4.6	Lifelong Learning and Educating
4	**Interpersonal Skills and Responsibility**		
4.1	Communicate in Thai	3.3.2	Communications in Languages of Regional Nations
	Communicate in foreign languages	3.3.1	Communications in English

	Ability to articulate and communicate disciplinary knowledge to general public	3.2.1	Communications Strategy
4.2	Creative problem solving		
4.3	Develop a continuous self-direct learning in engineering profession	2.4.6	Lifelong Learning and Educating
4.4	Roles and responsibilities as a team leader and team follower	4.1.1	Roles and Responsibility of Engineers
4.5	Workplace safety awareness		
	Environmental conservation	4.1.2	The Impact of Engineering on Society and the Environment
5	**Numerical, Communication and IT Literacy**		
5.1	Use computer for disciplinary work	3.2.4	Electronics/Multimedia Communication
5.2	Analyze the data mathematically or statistically	2.1.3 2.2.4	Estimation and Qualitative Analysis Hypothesis Test and Defense
5.3	Apply ICT and communicate effectively	3.2	Communications
5.4	Ability to speak, write and communicate with symbols	3.2.6 3.2.3 3.2.5	Oral Presentation Written Communication Graphical Communication
5.5	Use calculation and engineering tools for engineering practice		
6	**Skills**		
6.1	Use equipment and engineering basic tools correctly and safely	1.3	Advanced Engineering Fundamental Knowledge, Methods and Tools
6.2	Develop and modify equipment, tools for specific problem-solving	4.5 4.6	Implementing Operating
6.3	Carry out engineering drawing works	3.2.5	Graphical communication

Table 3: The TQF-CDIO syllabus mapping

TQF Domain	CDIO Syllabus																	
	1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	4.1	4.2	4.3	4.4.	4.5	4.6	4.7	4.8
1.1												●							
1.2							●												
1.3									●	●								●	
1.4												●							
1.5								●				●							
2.1	●	●											●					●	
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5.5			●																
6.1			●																
6.2																●	●		
6.3															●				

TABEE Criterion 3—Learning Outcomes and Assessment

In 2015, Thailand's Council of Engineers (COE) established the Thailand Accreditation Body of Engineering Education (TABEE), with the aim to transform the country's current engineering program accreditation of content-based emphasis to that of internationally recognized outcome-based emphasis. There are seven TABEE general criteria for engineering program accreditation, including Criterion 1 (Students), Criterion 2 (Program Educational Objectives), Criterion 3 (Learning Outcomes and Assessment), Criterion 4 (Curriculum), Criterion 5 (Faculty), Criterion 6 (Facilities) and Criterion 7 (Institutional Support).

Of particular interest is TABEE Criterion 3, which describes what engineering graduates should know and be able to do at the conclusion of their engineering program (i.e. the graduate attributes), which in turn largely corresponds to the learning outcomes of the CDIO syllabus. In fact, TABEE Criterion 3 is closely modelled on ABET Criterion 3 (Student Outcomes). While the ABET student outcomes are listed (a) through (k), the ABET-inspired TABEE graduate outcomes are listed numerically from (1) to (11).

Given the close resemblance between the ABET and TABEE graduate outcomes (Criterion 3), the mapping follows that of Crawley (2001) and is presented in Table 4. In the table, the black (●) and white (❍) dots respectively represent a strong and a good linkage between a specific CDIO Syllabus learning outcome and a given ABET-inspired TABEE graduate outcome. The mapping indicates the compatibility of the CDIO Syllabus and the TABEE graduate outcomes. Table 5 shows the description of ABET and TABEE Criterion 3.

Table 4: The mapping of the CDIO Syllabus to TABEE Criterion 3

ABET Criterion 3	a	e	c	b	k	d	g	h	f	j	i
TABEE Criterion 3	1	2	3	4	5	6	7	8	9	10	11
CDIO Syllabus											
1.1. Knowledge of Underlying Sciences	●										
1.2. Core Engineering Fundamental Knowledge	●										
1.3. Advanced Engineering Fundamental Knowledge, Methods and Tools	❍				●						
2.1. Analytical Reasoning & Problem Solving		●			❍						
2.2. Experimentation, Investigation & Knowledge Discovery				●							
2.3 System Thinking			❍								
2.4. Attitudes, Thought and Learning											●
2.5. Ethics, Equity and Other Responsibility									●		
3.1. Teamwork						●					
3.2. Communications							●				
3.3. Communication In Foreign languages											
4.1. External, Societal and Environmental Context			●					●		●	
4.2. Enterprise and Business Context			●					●		●	
4.3. Conceiving, Systems Engineering and Management			●								
4.4. Designing			●								
4.5. Implementing			❍								
4.6. Operating			❍								
4.7 Leading Engineering Endeavour											
4.8 Entrepreneurship											

● Strong Correlation ❍ Good Correlation

Table 5: The description of ABET and TABEE Criterion 3

ABET	Description	TABEE	Description
a	an ability to apply knowledge of mathematics, science and engineering	1	an ability to apply knowledge of mathematics, science and engineering to identify concept, model or definition and implement methods, process and engineering system into real-life work
e	an ability to identify, formulate, and solve engineering problems	2	an ability to identify, formulate, search and solve complex engineering problems to get preliminary conclusion by using mathematics, science and engineering concepts and analytical tools
c	an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	3	an ability to solve complex engineering problems, design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
b	an ability to design and conduct experiments, as well as to analyze and interpret data	4	an ability to inspect, investigate, evaluate work and complex engineering problems, design and conduct experiments, as well as to analyze and interpret data for reasoning conclusion
k	an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	5	an ability to build, select, and use the techniques, resources, information technology and modern engineering tools according to their requirements and limitations
d	an ability to function on multidisciplinary teams	6	an ability to function on multidisciplinary teams effectively as a leader and a member
g	an ability to communicate effectively	7	an ability to communicate effectively in engineering and other disciplines with verbal, writing report, presentation, engineering drawing, directing and receiving directions
h	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	8	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, societal context and sustatinable development
f	an understanding of professional and ethical responsibility	9	an understanding of professional and ethical responsibility
j	a knowledge of contemporary issues	10	a knowledge of economy, investment, engineering management concerning risks and changes.
i	a recognition of the need for, and an ability to engage in life-long learning	11	a recognition of the need for, and an ability to engage in life-long learning

Implementing the CDIO Standards

Curriculum Design and Improvement (CDIO Standards 1 -5)

The revision and improvement of the industrial engineering (IE) curriculum of RMUTT to integrate the CDIO framework (outcome-based emphasis) into the already existing curriculum (content-based emphasis) was commenced in 2013. Figure 1 illustrates the CDIO-focused IE curriculum revision and improvement process, which is in accordance with CDIO Standards 1 (CDIO as Context), 2 (CDIO Syllabus Outcomes) and 3 (Integrated Curriculum).

In the figure, the stakeholders survey was first conducted to identify the crucial learning outcomes (i.e. graduate attributes) that the graduates should possess at the conclusion of their engineering program. The stakeholders were industrial partners, IE faculty, alumni, and students of 2013, and the survey was carried out according to Kuptasthien et al (2014). The survey results were then mapped to the COE's TABEE Criterion 3 (learning outcomes and assessment), the TQF's learning domains and the CDIO Syllabus for the common denominators (i.e. the common learning outcomes). The common learning outcomes were subsequently used to formulate the IE program objectives and to design the integrated outcome-based curriculum.

The mapping of the learning outcomes revealed three common graduate attributes that the IE students are expected to possess upon the program completion: multidisciplinary teamwork skills, critical thinking skills and communication skills. These learning outcomes were translated into study or co-curricular courses and integrated into the already existing curriculum, as shown in Figure 2. Specifically, the IE students advance these skills (i.e. teamwork, communication and critical thinking skills) through a series of courses from the first to final year where faculty act as a coach and a role model in applying these skills in the industrial engineering context. For instance, the acquisition of the multidisciplinary teamwork skills is realized by enrolling in the IE Design & Building course in the second year of study, Productivity Management and Pre-project in the third year, and then the Cooperative Education and Project courses in the final year.

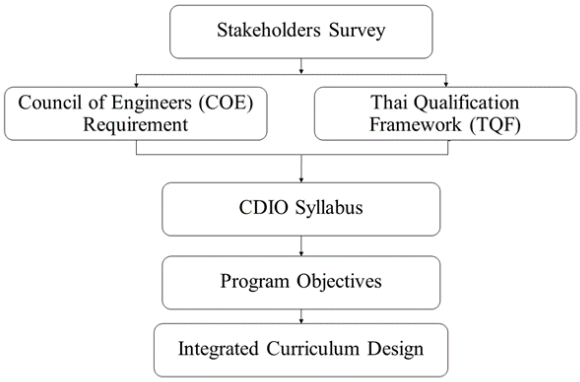

Figure 1: The CDIO-based industrial engineering curriculum design process.

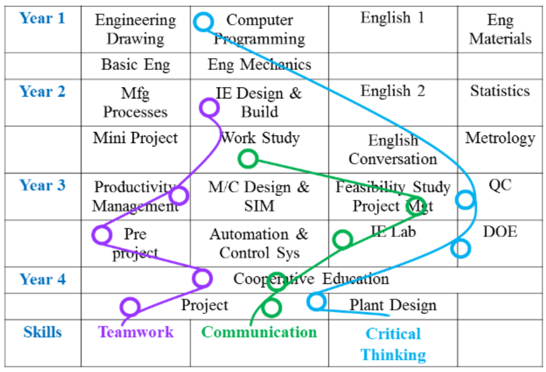

Figure 2: The CDIO-based, stakeholders-focused IE integrated curriculum.

As part of the already existing curriculum, Basic Engineering is a 1st-year prerequisite that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills, which is in accordance with CDIO Standard 4 (Introduction to Engineering).

To enable the IE students to develop product and system building skills and to promote early success in engineering practice, the reformed IE curriculum has added four new design-build experiences-oriented courses into the already existing curriculum: Engineering Workshop, IE Design and Build, IE Mini-project and Machine Design and Simulation (Figure 3). Formerly, the IE students (pre-CDIO adoption) were required to take Basic Engineering in the first year, then IE Pre-project in the third year and Plant Design and IE project in their final year. The scheme had contributed the design-build experiences "deficit" and the subsequent students' failing grades in the final year's IE Project course. The four new design-build experiences-oriented subjects have been thus introduced to address the issue, which is in accordance with CDIO Standard 5 (Design-Build Experiences).

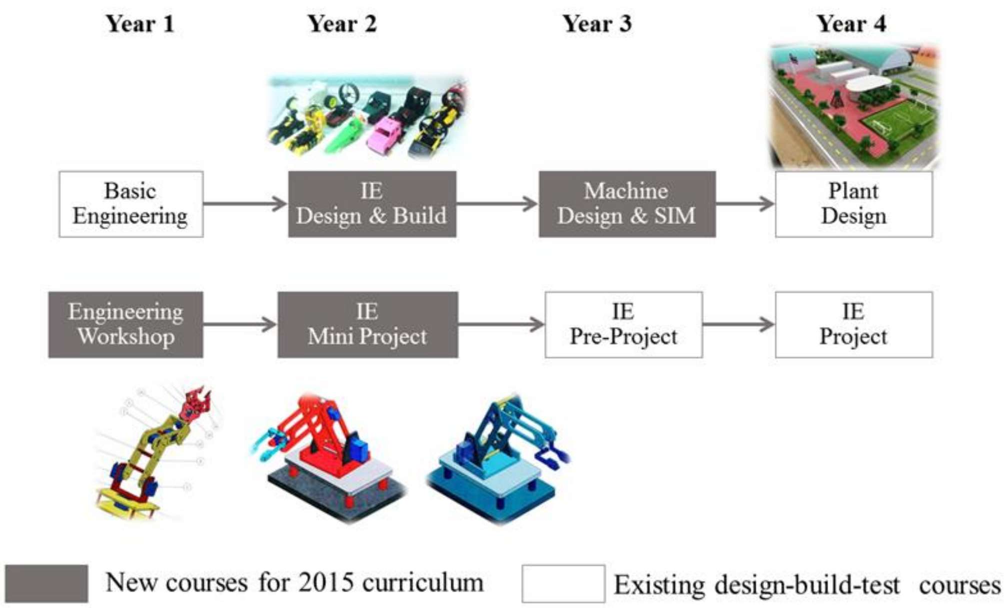

Figure 3: The Design-Build Experiences Courses of the Reformed IE Program from Years 1 – 4.

In Figure 3, the Engineering Workshop subject is open in the second semester of the first year of study, whereby the students are exposed to engineering activities and practices of the other engineering departments at the university (10 departments in all). This course enriches the students with more understanding of the engineering professions and is beneficial to the students when choosing their major by the end of the first year.

Under the reformed curriculum, the 2nd-year

IE students are required to enroll in IE Design and Build and IE Mini Project. In the IE Design and Build course, the students are taught the Design Thinking concept to innovate products, services, processes and systems in a team-based setting. Meanwhile, IE Mini Project focuses on project-based learning where the student team up to design, draw, select materials, fabricate parts, assemble, and integrate hardware and software to build robot arms to perform a specific task.

In the Machine Design and Simulation and IE Pre-project courses, the 3rd-year IE students are required to perform advanced team-based tasks using the design and build skills acquired in preceding courses as well as hone their communication and presentation skills. The design-build experiences course end with the Plant Design and the IE Project courses in the final year.

Workspace Renovation (CDIO Standard 6)

To fulfill CDIO Standard 6 in which workspaces and laboratories support and encourage hands-on learning of product and system building, disciplinary knowledge and social learning, the traditional learning spaces and classrooms were upgraded to smart learning spaces where the furniture can be arranged to suit the collaborative learning activities. In addition, a newly constructed fabrication laboratory provides more workspaces for hands-on, design-build experiences-oriented learning as shown in Figure 4. Moreover, the campus-wide single sign-in internet connection is deployed to facilitate instructor-learner communications and encourage learning.

Figure 4: Fabrication Laboratory and Hands-On Workspace

Innovative Teaching and Learning and Student Assessment (CDIO Standards 7, 8, 11)

Howards and Campbell (2013) noted that a number of faculty members are unable to differentiate learning outcomes from tasks, giving rise to challenges in the transition from the content- to outcome-based education; and thus recommended that the engineering educators align the outcome-based curriculum with the accreditation guidelines. The constructive alignment is an essential starting point for outcome-based education, which involves the learning outcomes, teaching and learning activities and student outcomes assessment.

A faculty development workshop on the theory of constructive alignment was thus organized for the IE faculty and staff. According to Biggs (2003), the constructive alignment involves four steps: (1) Defining the intended learning outcomes (ILOs); (2) Choosing teaching/learning activities likely to lead to the ILOs; (3) Assessing students' actual learning outcomes to see how well they match what was intended; and (4) Arriving at a final grade.

In fact, since the inception of the CDIO scheme at RMUTT in 2013, the IE faculty have transitioned from the traditional lecture-based teaching, which emphasizes the passive transmission of information, to the active learning methods that engage students in manipulating, applying, analyzing and evaluating ideas. Specifically, the flipped classroom pedagogical model, where the typical lecture and homework elements are reversed, has been implemented in certain courses. Figure 5 depicts the students' feedback on the benefits of the innovative teaching and flipped classroom format in 2016. There were 206 students participated in the new learning environment.

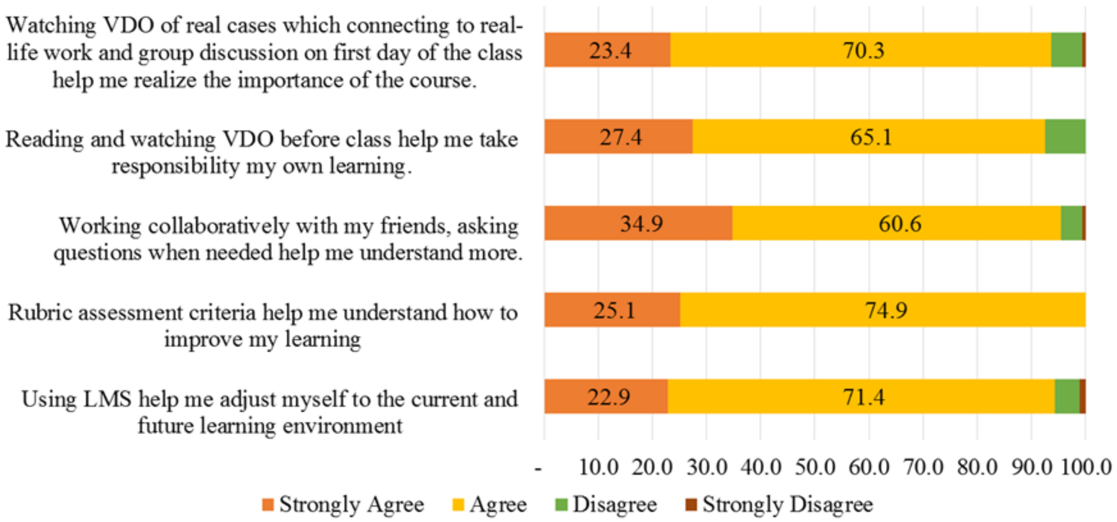

Figure 5. Students' feedback on the benefits of the flipped classroom format

The 23.4 percent of students strongly agreed, 70.3 percent of the students agreed that they realized the importance of the course when the teacher connected real cases to real-life work using videos and group discussion. For flipping the classroom, 27.4 percent of students strongly agreed, and 65.1 percent of students agreed that they were able to take full responsibility of their own learning when reading books and watching video before coming to class. The 34.9 percent of students strongly agreed, 60.6 percent of the students agreed that collaborative group work help them understand more. Lastly, with the current technology of learning management system, 22.9 percent of students strongly agreed, 71.4 percent of the students agreed that they can adjust to the current and future learning environment.

Faculty Competency Enhancement (CDIO Standards 9 and 10)

To facilitate and accelerate the successful CDIO implementation, the university (i.e. RMUTT) has appointed 15 master trainers from the pool of faculty members to lead the CDIO implementation. In addition, the five-day in-house CDIO training program has been offered twice a year to the university faculty and staff. The training program includes: Introduction to CDIO and Design Thinking (day 1), Design-Build-Test (day 2), Integrated Curriculum (day 3), Active and Experiential Learning (day 4), and Program Evaluation (day 5).

The introduction to CDIO covers the framework fundamentals, CDIO Syllabus and CDIO Standards along with examples of the CDIO implementation from various institutions. In the design-build-test session, the design thinking concept is introduced along with multidisciplinary team-based activities. A team competition at the end of the day provides the participants the excitement along with the achievement. It raises the awareness of how the students' behavior changes when the design-build-test learning activities are part of their learning process. In the integrated curriculum session (day 3), CDIO Standards 2 – 5 are explained in detail coupled with activities to design the integrated curriculum within the participants' discipline and program. This allows the participants to identify what is still lacking under the current curriculum or otherwise required for the design of the CDIO-based integrated curriculum. The active and experiential learning (day 4) deals with the constructive alignment theory where the participants are asked to re-plan their responsible courses with transition from traditional lecture-based teaching to active and experiential learning. The program evaluation (day 5) concludes with the self-evaluation rubrics with action plans for continuous improvement.

In the actual CDIO implementation, four working groups of the IE faculty members have been appointed and are responsible for different educational dimensions, as shown in Figure 6. The IE department head and the IE department administrators are responsible for engineering education reform and faculty development programs (CDIO Standards 1, 9, 10). The program administrators are tasked with the curriculum and quality assurance (CDIO Standards 2, 3, 4, 5, 12). The CDIO master trainers contribute as peer-mentors to colleagues for implementing new pedagogy, active and experiential learning techniques (CDIO Standards 7, 8, 11). Meanwhile, the section heads of the IE department are responsible for the readiness and improvement plans for facilities, including learning space, workspaces and laboratories.

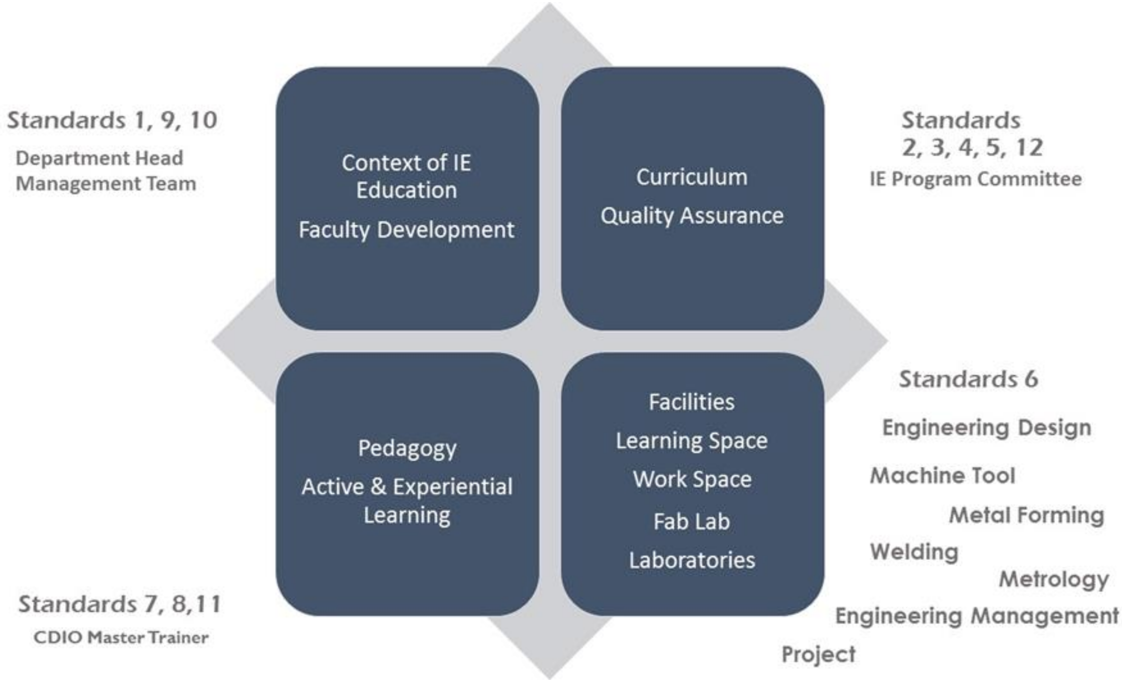

Figure 6: The IE Working Groups by CDIO Standards for Continuous Improvement

Program Self-evaluation for Continuous Improvement (CDIO Standard 12)

Cheah (2012) documented that the CDIO Standards and the self-evaluation process have been used to provide the foundation for meeting accreditation expectations. Brodeur and Crawley (2005) viewed the CDIO Standards as an internal program self-evaluation tool as well as for external quality assurance purposes. Choo et al. (2015) used the 12 CDIO Standards as guidelines for program evaluation and a framework for academic design and continuous improvement in the areas of curriculum, workspaces and teaching-learning-assessment practices.

Thus, the CDIO-based IE program of RMUTT has been evaluated relative to the CDIO Standards. Evidence of overall program value is collected with course evaluations, instructor reflections and follow-up studies with graduates and employers. In addition, the evidence is reported back to instructors, students, program administrators, alumni, and other key stakeholders. The feedback forms the basis of decisions about the program and its plans for continuous improvement.

Specifically, the IE program administers have evaluated the CDIO-based IE program relative to the 12 CDIO Standards using a six-point-scale rubric, where 0 denotes no documented plan or activity related to the CDIO standard; 1 = there is an awareness of need to adopt the standard and a process is in place to address it; 2 = there is a plan in place to address the standard; 3 = implementation of the plan to address the standard is underway across the program components and constituents; 4 = there is documented evidence of the full implementation and impact of the standard across program components and constituents; and 5 = evidence related to the standard is regularly reviewed and used to make improvements.

Figure 7 illustrates the six-year self-evaluation of the CDIO-based IE program in relation to the 12 CDIO Standards from the years 2013 (the inception of the CDIO implementation) to 2018 (most recent year). More importantly, the evaluation results have been reported back to the working groups for future actions about the program and for continuous improvement. In the figure, the rubric scores associated with the 12 standards at the inception year (i.e. 2013) were 1, indicating an awareness of need to adopt the CDIO standard and a process is in place to address it. The program self-evaluation showed the steady improvement on every CDIO standard as the feedback of preceding years was utilized for the continuous improvement of the IE program. The most recent rubric scores (i.e. the year 2018) were in the range of 4 – 5, indicating that either the CDIO implementation is underway across the program or there exists the documented evidence of the full implementation and impact of CDIO across program components.

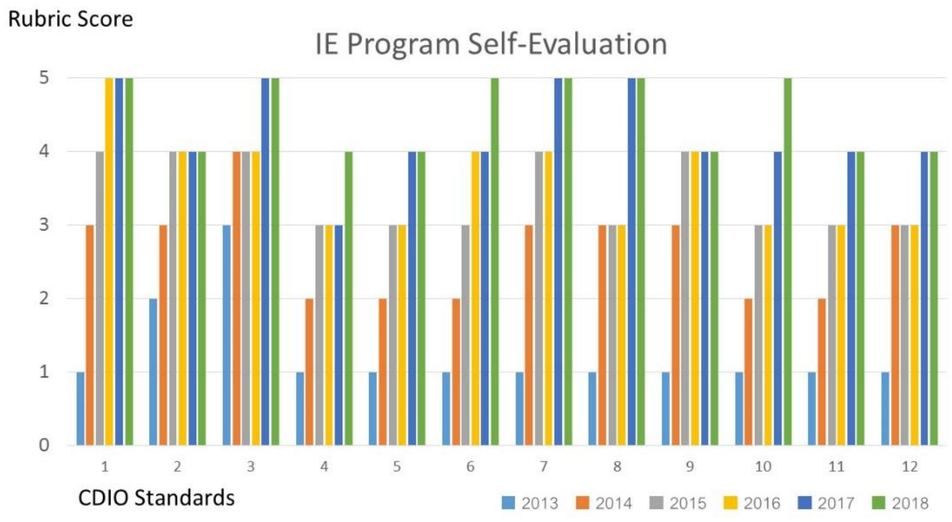

Figure 7: The Self-Evaluation of The CDIO-Based IE Program Relating to 12 CDIO Standards

TABEE Accreditation

The application for an accreditation by the Thailand Accreditation Body for Engineering Education (TABEE) requires the applicants to perform a self-evaluation using a six-point-scale rubric on the seven TABEE criteria. The six-point-scale rubric scores include 0 for no work system or no actions; 1 for the work system or procedures being developed; 2 for starting to implement a work system or procedures; 3 for implementation of the work system and procedures; 4 for follow-up for improvement of the work system or procedures; and 5 for the work system or procedures being reviewed and used to make improvement at least one PDCA cycle (Plan-Do-Check-Act).

The seven TABEE criteria for engineering program accreditation include Criterion 1 (Students), Criterion 2 (Program Educational Objectives), Criterion 3 (Learning Outcomes and Assessment), Criterion 4 (Curriculum), Criterion 5 (Faculty), Criterion 6 (Facilities) and Criterion 7 (Institutional Support). Each TABEE criterion has a list of topics for self-evaluation, with the average rubric score associated with the criterion calculated at the end of the list or the last row of the table. Table 6 shows average scores according to each criterion, where table 7 shows an example of the TABEE self-evaluation list associated with TABEE Criterion 3 (Learning Outcomes and Assessment).

Table 6: TABEE's Self-Evaluation Average Rubric Scores

Criterion	TABEE Criteria	Average Rubric Scores
1	Student	4.0
2	Program Educational objective	4.1
3	Learning outcome and assessment	4.0
4	Curriculum	4.2
5	Faculty	4.2
6	Facilities	4.0
7	Institutional Supports	4.0

Table 7: An example of TABEE Criterion 3 self-evaluation list.

Criterion 3 - Learning Outcomes and Assessment		
No.	**Description**	**Rubric**
3.1	The program has a procedure to link between program objectives and program outcomes, work system, assessment methods and frequency. There is a review of the work system for better learning outcome.	4
3.2	Program provides a system to assess students outcome systematically with different assessment methods and appropriate to the outcomes.	4
3.3	Program provide a system or mechanism to link classroom teaching and learning activities to achieve the program outcome.	4
3.4	Students can use the system to track their progress of learning outcomes for self-improvement.	3
3.5	Graduates achieve the learning outcomes, can practice the engineering profession as stated in the program objective.	5
	Average Score	4.0

Furthermore, the linkages between the CDIO standards to the ABET (Costa et al., 2012) and TABEE criteria were mapped and tabulated in Table 8. Meanwhile, Table 9 compares between the six-point-scale TABEE and CDIO rubric scores. The TABEE rubric emphasizes the work system and procedures while the CDIO rubric focuses on the impact of the standards. However, each level of the score shows similarities, 0 means there are neither working system no evidence in assuring the quality of engineering education. The maximum score of 5 focuses on the continuous improvement.

Table 8: The mapping of the CDIO Standards to the ABET and TABEE criteria.

CDIO Standards	ABET Critera	TABEE Criteria
11 (partial)	Student	Student
1	Program educational objective	Program educational objective
2, 5	Student outcome	Learning outcome and assessment
12	Continuous Improvement	-
3, 4, 7	Curriculum	Curriculum
8, 9, 10	Faculty	Faculty

Table 9: Comparison between the Six-Point-Scale TABEE and CDIO Rubrics

CDIO Rubrics	Criteria	TABEE Rubrics	Criteria
5	Evidence related to the standard is regularly reviewed and used to make improvements.	5	The work system or procedures are reviewed and used to make improvement at least 1 PDCA cycle (Plan-Do-Check-Act)
4	There is documented evidence of the full implementation and impact of the standard across program components and constituents.	4	Follow-up for improvement of the work system or procedures
3	Implementation of the plan to address the standard is underway across the program components and constituents.	3	Implementation of the work system and procedures.
2	There is a plan in place to address the standard.	2	Start to implement a work system or procedures
1	There is an awareness of need to adopt the standard and a process is in place to address it.	1	The work system or procedures are being developed
0	There is no documented plan or activity related to the standard.	0	There is no work system or no actions.

Specific to the IE program of RMUTT, Table 10 compares the average TABEE self-evaluation rubric scores along the seven TABEE criteria with those of the most recent year (2016) of CDIO along the CDIO Standards. The findings revealed the close resemblance between their self-evaluation rubric scores, indicating the complementary nature of both frameworks. In some countries where the outcome-based accreditation system exists, various institutions adopt CDIO framework with the goal to get the program accredited. For IE program, the CDIO concept was adopted with strong believe in excelling the quality of the education. At the time of the establishment of TABEE, many institutions faced a big challenge to meet with all the criteria and requirements. However, three pioneers CDIO-based programs in Thailand; namely, Mechanical Engineering (Chulalongkorn University), Chemical Engineering (Chulalongkorn University) and Industrial Engineering (RMUTT) have smooth transitions and succeeded in submitting the TABEE self-evaluation reports and went through the TABEE accreditation process in a year of 2018. There were the first 3 programs with outcome-based accreditation in the history of Thai engineering education.

Table 10: Comparison between the TABEE and CDIO Self-Evaluation Rubric Scores

CDIO Standards	Rubric Scores Year 2018	TABEE Criteria	Average Rubric Scores
Standard 11 (partial)	4	Student	4.0
Standard 1	5	Program Educational objective	4.1
Standard 2 Standard 5	4 4	Learning outcome and assessment	4.0
Standard 3 Standard 4 Standard 7	5 4 5	Curriculum	4.2
Standard 8 Standard 9 Standard 10	5 4 5	Faculty	4.2
Standard 6 (partial)	5	Facilities	4.0
-	-	Institutional Supports	4.0

Conclusion

Armstrong et al (2006) argued that the accreditation criteria beget the "meet a minimum standard" mindset. On the other hand, the CDIO framework encourages the engineering educators to strive for excellence through continuous improvement. In fact, both are complementary, as evidenced by the research findings. Specifically, this academic paper has presented the successful application of the CDIO Syllabus by integrating the CDIO knowledge and skillsets into the industrial engineering (IE) program. In addition, the self-assessment rubric scores of 4-5 showed a continuous improvement attempts regarding the 12 CDIO Standards. With the aim to transition from the content- to outcome-based curriculum and the subsequent accreditation by the Thailand Accreditation Body for Engineering Education (TABEE) and an international recognition, the findings revealed that the successful CDIO implementation has laid a solid foundation and prepared the IE department for external evaluation and accreditation. Such would benefit future engineering graduates who are highly competent and contribute to the greater competitiveness of Thai industries.

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