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CDIO Initiative: A Guarantee for Successful Accreditation of Engineering Programmes

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A B S T R A C T

The accreditation bodies and engineering councils set a number of qualifying requirements and accreditation criteria to ensure the quality of engineering graduates and programmes. One of these requirements is the engineering curriculum. Some institutions using the traditional engineering curriculum often face difficulties and burden to meet the accreditation minimum academic requirements as their curriculum lacks the innovation and the integration of graduate attributes such as personal, interpersonal, teamwork, entrepreneurship, development of life skills and emotional wellbeing, among many. This eventually leads to deferred or even declined accreditation. To overcome these difficulties, the CDIO initiative is an ideal tool for successful accreditation. The CDIO standards, syllabus, engineering curriculum, and learning outcomes are not only meeting what accreditation bodies require, but they offer innovative curriculum more on high-level cognitive skills set in the context of the product-system lifecycle; Conceiving-Designing-Operating-Implementing metaphases. This paper shares a successful engineering education experience of the School of Engineering/Taylor's University and how the CDIO initiative contributed not only to a successful accreditation but also to have a new innovative engineering curriculum. The adopted new curriculum is innovative, hands-on and project-based in order to achieve integrated learning where acquiring discipline-specific knowledge and CDIO skills take place simultaneously.

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1. INTRODUCTION

The accreditation bodies and engineering councils worldwide set a number of qualifying requirements and accreditation criteria for the Institutions of Higher Learning (IHLs) to meet to ensure the quality of engineering graduates and programmes. Whether in Malaysia or elsewhere, the core requirements and criteria are almost similar but probably differently expressed and practiced. The Board of Engineers Malaysia (BEM) has been a full signatory in the Washington Accord since June 2009. Therefore, Engineering Accreditation Council (EAC) has the role to ensure the implementation of Outcome-based Education (OBE) in all engineering degree programmes offered in Malaysia as a requirement for accreditation.

Based on EAC manual in 2017 (EAC, 2017), one of the objectives of accreditation is to ensure that graduates of the accredited engineering programmes meet the minimum academic requirements for registration as a graduate engineer with the BEM. For Malaysian IHLs to meet these requirements, EAC set a number of evaluation criteria, among them for example, are Programme Educational Objectives (PEOs), Programme Outcomes (POs) and Academic Curriculum. In addition to that, 8 components of the qualifying requirements any engineering programme must have, such as, Outcome-based Education (OBE) implementation, Integrated design project, Final year project, Industrial training, etc.

1.1. Outcome-Based Education (OBE)

In its manual, EAC provides guidelines on what are the required skills the graduate engineers should possess. This requires the IHL to adopt an educational framework through the implementation of OBE and build a culture of Continual Quality Improvement (CQI).

Based on (Spady & Marshall, 1991), OBE is a transitional approach in the educational system primarily concerned with the students' capabilities upon graduation and focuses curriculum and assessments design around higher-order exit outcomes. However, there are critics of OBE reported in a number of literatures. (Brady, 1996) claims that OBE may not be suitable for certain educational systems. Brady supports the view of (Glatthorn, 1993) that OBE is not the panacea (Spady & Marshall, 1991) believes it to be. Neither is it a pernicious movement to turn schools into factories, as its critics suggest. (Eldeeb & Shatakumari, 2013) reviewed the advantages and disadvantages of OBE. They mentioned among the disadvantages that the shift to OBE has attracted lots of opposition. Opponents believed that, education should be an open ended and should not be constrained by outcomes and that education should be valued for its own sake, not because it leads to some outcomes. (McKernan, 1993) found that OBE reduces education to a rather mechanical process resulting in limiting the enquiry and speculation of students because of the development of very specific programme outcomes.

Despite those perceived shortcomings, OBE is gaining grounds progressively as a reliable educational framework (Al-Atabi *et al.,* 2013). As Malaysia is a full member of the Washington Accord, it is required to embrace the OBE for the engineering degrees accredited under its jurisdiction (Aziz *et al.,* 2005). Besides grading system, IHLs are required to balance accreditation requirements by providing specific and measurable programme outcomes while maintaining sufficient openness for students to realise and celebrate their individualism, for example, the use of OBE with project-based learning (Hashim & Din, 2009).

1.2. Academic curriculum

Academic curriculum is one of the most important and challenging criteria. For this criterion, EAC does not limit the IHLs with a specific academic curriculum to adopt and use. In fact, it opens the door for IHLs

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provided they follow the manual guidelines which provide essential elements and features of an academic curriculum which produces and eventually renders an engineering programme acceptable for accreditation by EAC.

Among the essentials elements, here come the teaching-learning (delivery) and assessment methods, a balance between the core and electives modules, and most importantly the integration of theory with practical activities through laboratory work and professional engineering practice. So, as for the academic curriculum, the big challenge is how to design an academic curriculum which is innovative and ensure the integration of graduate attributes such as personal, interpersonal, teamwork, entrepreneurship, development of life skills and emotional wellbeing.

Thus, the question or the challenge to address is: How an IHL meets the accreditation requirements to guarantee the successful accreditation of its engineering programmes?

1.3. CDIO and OBE

To ensure a successful accreditation, IHLs are required to design and use an academic curriculum to ascertain the OBE implementation and the attainment of PEOs and POs in engineering programmes through the submission of documents that provide accurate information and sufficient evidence for the purpose of evaluation.

The engineering accreditation criteria that advocate Outcome-based Education (OBE) and the calls from industry (Lang *et al.,* 1999) that require employment-ready graduates are driving the engineering curriculum to adopt more non-traditional approaches. One of the non-traditional approaches is CDIO Initiative.

The main motivation why to adopt CDIO Initiative is the ability of this educational framework to address the gap between industry needs and the quality of engineering graduates being produced. Students are instilled with engineering fundamentals in the context of the whole product life cycle (Conceiving-Designing-Implementing-Operating), and are able to master a deeper working knowledge of the technical fundamentals, lead in the creation and operation of new products and systems, and understand the importance and strategic value of research work (Crawley *et al.,* 2007).

There is an increasing number of world universities that have already used CDIO educational framework for the proficiency development (Bankel *et al.,* 2002; Hermon *et al.,* 2010) and also for accreditation (Gray, 2012; Wah *et al.,* 2015). (Abdul Halim & Buniyamin, 2016) presented an overview and comparative study of engineering education learning outcomes stated by CDIO and EAC to prepare the engineering graduates for the industry. They mapped EAC manual 2012 POs against the CDIO syllabus version 2.0 and concluded that CDIO Syllabus offers encompassing view of engineering learning outcomes than EAC's by considering the complete phase from knowledge development to the implementation phase.

This paper shares a successful engineering education experience of the School of Engineering/Taylor's University, Malaysia and how the CDIO initiative along with Project-based learning have contributed not only for a successful accreditation but also for a new innovative engineering curriculum.

2. Taylor's school of engineering, OBE and CDIO

Taylor's School of Engineering (SOE) is established in 1996 and had its own engineering programmes in 2009. SOE joined CDIO in 2009 and became the first engineering school in Southeast Asia to adopt the CDIO Initiative.

Being a member of the CDIO initiative, the head of school and his team believed that CDIO Syllabus represents important design criterion for the implementation of OBE to

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establish the school PEOs, define the POs, and design new academic curriculum for engineering educational programmes offered at the school.

The following sections share the steps on how the SOE implemented OBE as required by EAC for accreditation through the implementation of CDIO initiative and adoption of Project-based learning to design and use an innovative academic curriculum which eventually led to a successful accreditation.

3. PEOs, POs and CDIO

As the first step to design the academic curriculum, the Programme Educational Objectives (PEO) must be established. PEOs must be consistent with the mission and vision of the IHL and describe the expected achievements of graduates in their career and professional life a few (3 to 5) years after graduation (EAC, 2017).

In 2009, Taylor's University core purpose and mission stated as follows: to educate the youth of the world to take their productive place as leaders in the global community and Top Employers' Top Choice University by 2016. Based on EAC, the PEOs must be considered in the design and review of curriculum in a top down approach. Accordingly, SOE aligned OBE concept in running degree programmes as modelled in **Figure 1** (Gamboa & Namasivayam, 2012).

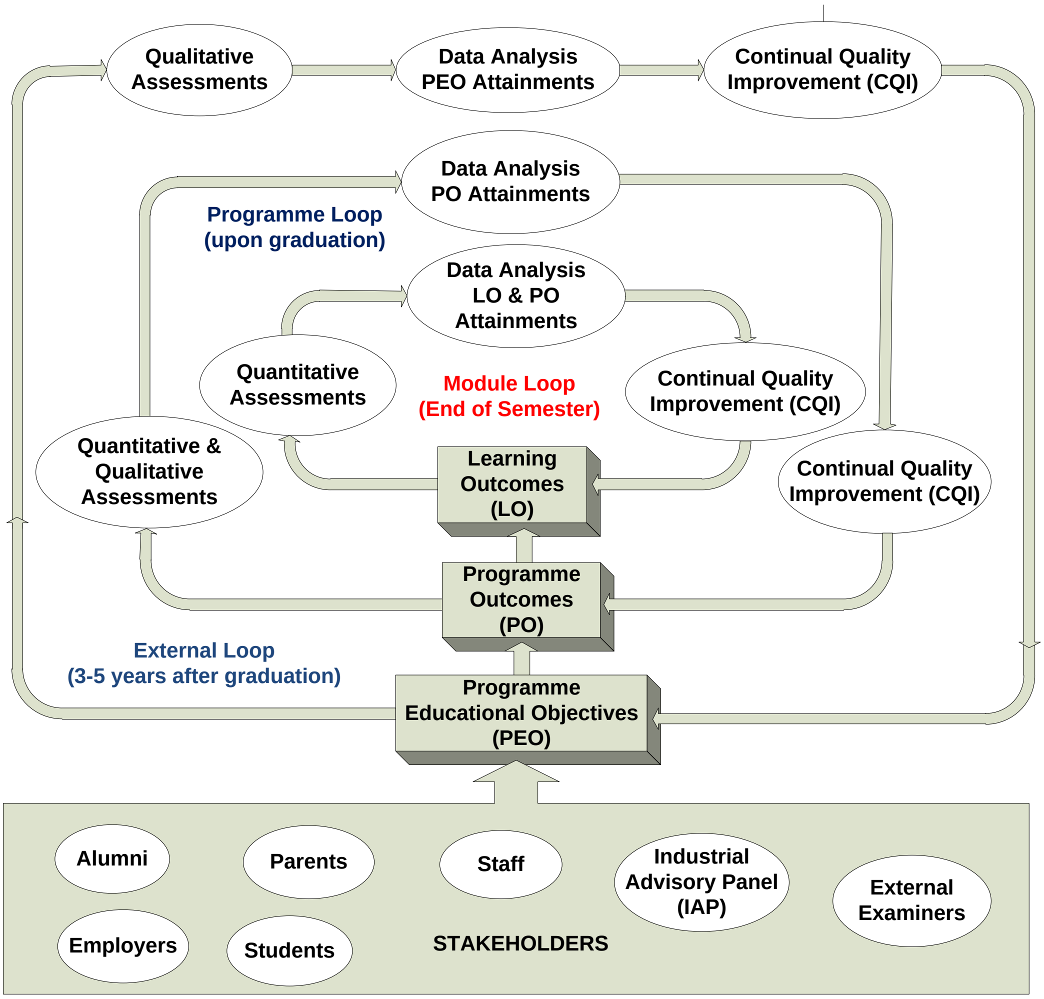

Figure 1. The OBE model adopted by Taylor's SOE (Gamboa & Namasivayam, 2012)

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With the alignment with CDIO initiative the following four PEOs were established for Mechanical Engineering Programme:

- Achieve a high level of technical expertise and excel in positions in Mechanical Engineering practice, research or other fields they choose to pursue.
- Conceive, design, implement and operate Mechanical Engineering systems, processes and products that consider functionality, safety, cost effectiveness and sustainability using sound principles.
- Assume and aspire to leadership positions at both multinational companies and enterprises.
- Pursue lifelong learning, such as graduate studies and other continuous professional development activities.

As can be seen, the second PEO is directly related to the implementation of CDIO engineering educational framework.

The second step is to define the Programme Outcomes (POs). POs describe what students are expected to know and be able to perform or attain by the time of graduation. These relate to the skills, knowledge, and behaviour that students acquire through the programme (EAC, 2017). **Table 1** shows the 12 EAC generic POs the students of an engineering programme are expected to attain.

To meet the EAC requirements for accreditation in this regard, the school team decided to map SOE's POs directly with the EAC's POs one by one with modifying PO #3 to meet the requirement of CDIO implementation. This resulted in the following Taylor's SOE POs as outlined in **Table 2**.

4. IMPLEMENTATION OF CDIO INITIATIVE IN SOE ACADEMIC CURRICULUM

POs is the starting point for any academic curriculum design. To design the academic curriculum, CDIO was considered since it aims directly towards what the accreditation bodies, for instant EAC, require. This aimed at achieving and developing a learning experience that mirrors the lifecycle of a product (Al-Atabi *et al.,* 2013). The school team made a substantial change in the mode of delivery based on the latest CDIO syllabus version 2.0. This syllabus is divided into four categories (Crawley *et al.,* 2011):

i. Disciplinary Knowledge and Reasoning
ii. Personal and Professional Skills and Attributes
iii. Interpersonal Skills, Teamwork and Communication
iv. Conceiving, Designing, Implementing and Operating Systems in the Enterprise, Societal and Environmental Context

To design the new academic curriculum, Taylor's POs are mapped against the CDIO syllabus version 2. This mapping is shown in **Table 3**.

Based on EAC manual (EAC, 2017), the academic curriculum and curricular design shall strongly reflect the philosophy and approach adopted in the programme structure, and the choice of the teaching-learning (delivery) and assessment methods. Following the new established PEOs and POs with the mapping of CDIO syllabus, the academic curricula for all engineering programmes at Taylor's SOE have been designed not only to meet the EAC criteria for curricular design but also to meet the implementation of CDIO initiative via CDIO syllabus.

Below is a summary of some initiatives adopted by the school team which ended with an innovative academic curriculum which integrated the graduate attributes such as personal, interpersonal, teamwork, entrepreneurship, development of life skills and emotional wellbeing and eventually renders an acceptable programme for the school accreditation by EAC.

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4.1. Adoption of Project-Based learning (PBL) framework

Adoption of Project-Based learning (PBL) framework which is successfully known as a means to apply engineering principles and interpersonal skill through the projects to develop competent graduates. PBL address particularly PO #3 in EAC manual which is modified in the view of CDIO initiative, as mentioned earlier.

Table 1. EAC generic programme outcomes (EAC, 2017)

PO #	PO Title	Description
1	**Engineering Knowledge**	Apply knowledge of mathematics, natural science, engineering fundamentals and an engineering specialisation as specified in WK1* to WK4 respectively to the solution of complex engineering problems
2	**Problem Analysis**	Identify, formulate, conduct research literature and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences (WK1 to WK4)
3	**Design/Development of Solutions**	Design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations (WK5);
4	**Investigation**	Conduct investigation of complex engineering problems using research-based knowledge (WK8) and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions;
5	**Modern Tool Usage**	Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering problems, with an understanding of the limitations (WK6);
6	**The Engineer and Society**	Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems (WK7);
7	**Environment and Sustainability**	Understand and evaluate the sustainability and impact of professional engineering work in the solutions of complex engineering problems in societal and environmental contexts. (WK7);
8	**Ethics**	Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice (WK7)
9	**Individual and Teamwork**	Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings
10	**Communication**	Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions;
11	**Project Management and Finance**	Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, to manage projects in multidisciplinary environments;
12	**Lifelong Learning**	Recognise the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

* WK refers to the knowledge profile (EAC, 2017).

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Table 2. Tylor's University SOE Programme Outcomes (POs)

PO #	PO Title	Description
1	**Engineering Knowledge**	Apply the knowledge of mathematics, science, engineering practices, innovation techniques, entrepreneurship and human factors to provide value-adding solutions to complex Mechanical Engineering challenges.
2	**Problem Analysis**	Identify, formulate, analyse and document complex engineering challenges to arrive at viable solutions and substantiated conclusions.
3	**Design/Development of Solutions**	Conceive, Design, Implement and Operate solutions for complex engineering challenges that meet specified requirements with appropriate consideration for public health and safety, cultural, societal, environmental and economical considerations.
4	**Investigation**	Conduct research and investigation into complex challenges using methods which include experiment design, analysis of data and synthesis of information to provide valid conclusions.
5	**Modern Tool Usage**	Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering activities, with an awareness of the accompanying assumptions and limitations.
6	**The Engineer and Society**	Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal, economical and cultural issues and the consequent responsibilities relevant to professional engineering practice.
7	**Environment and Sustainability**	Explain the global impact of professional engineering solutions in societal, economical and environmental contexts and demonstrate knowledge of and need for sustainable development.
8	**Ethics**	Apply professional and ethical responsibilities of engineering practice.
9	**Communication**	Effectively communicate complex engineering activities, both orally and in a written form, in both technical and non-technical contexts.
10	**Individual and Teamwork**	Function effectively as an individual and in multidisciplinary settings with the capacity to be a leader.
11	**Lifelong Learning**	Recognise the importance of lifelong learning and engaging in continuous professional development activities in accordance with technological change.
12	**Project Management and Finance**	Effectively manage projects in multidisciplinary environments and apply project management tools and techniques to one's own work, as a member and leader in a team to satisfy stakeholders requirements.

Based on this, Taylor's SOE embraces the PBL philosophy and delivers it through a series of project-based design modules from semester 1 to semester 8. These modules are offered to all engineering students as core modules. **Table 4** shows a brief description of each module offered in all 8 semesters for Mechanical Engineering programme. (Al-Atabi *et al.,* 2013) detailed the learning outcomes of these modules.

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Table 3. The mapping of SOE POs against the CDIO syllabus

CDIO Syllabus Categories	Programme Outcomes (POs)											
	1	2	3	4	5	6	7	8	9	10	11	12
Disciplinary Knowledge and Reasoning	√	√		√	√							
Personal and Professional Skills and Attributes						√		√			√	
Interpersonal Skills, Teamwork and Communication									√	√		
Conceiving, Designing, Implementing and Operating Systems in the Enterprise, Societal and Environmental Context				√		√	√					√

Table 4. Project-based Modules offered in SOE engineering Programme in view of CDIO initiative (Al-Atabi *et al*., 2013)

Semester	Module Name	Description
1	**Engineering Design and Communication**	aims to introduce the basics of engineering design principles and its related skills. Also, to provide technical communication skills such as reporting, sketching and drafting
2	**Engineering Design and Ergonomics**	to equip students with the knowledge and skills related to human factor engineering. Students are required to apply these skills working on a major team design project that involves human-machine interaction
3	**Multidisciplinary Engineering Design**	to familiarize students with real-life work environments where engineers from different disciplines and backgrounds work together to realise a given task
4	**Engineering Design and Innovation**	aims to introduce design thinking as part of the engineering design process and the process of commercialising a product
5	**Managing Projects for Success**	allows students to apply and evaluate project management tools and techniques in managing their Engineering Design and Innovation project to reach its goals and targets
6 and 7	**Group Project 1 and 2**	Group Project 1 and 2 modules represent opportunities for students from different programmes to work on a fairly complex disciplinary specific project with peers from their respective programme. This is necessary to allow specialisation and disciplinary skills to develop
7 and 8	**Final Year Project 1 and 2**	These modules represent the climax of the project-based experience where a student will individually work on a major, research-based engineering project. Working closely with a project supervisor, these two modules represent an opportunity for the students to develop high-level research and analytical skill. Students need to have work of a publishable standard.

4.2. Integrated PBL framework

The successful implementation of PBL through offering the projects mentioned above at the institutional level faced some challenges and has deterred many. One of the major challenges is the number of projects needed to sustain such an implementation. As a means to overcome this, an integrated PBL framework was proposed. This framework is based on proposing major projects by different research groups at the school. These projects can have different groups of students working on different parts of the projects simultaneously (Al-Atabi *et al.,* 2013). It was found that the integrated project-based model offers complex engineering projects, whose solutions can be addressed through a variety of modules. This, in fact, is one of the most important feature EAC through the accreditation wants to see and how it is implemented. Integrated project-based model is further enhanced through the schools ability to track the Los attainment of students as they progress throughout each module and provide an avenue for the school to further enhance its delivery, ensuring the learning experience of the students continues to progress and evolve (Bankel *et al.,* 2002; Hermon *et al.,* 2010).

4.3. Research-led teaching engineering

The research conducted at universities and institutions of higher learning is supposed to have some support and positive impact on the teaching quality. However, the research is less impactful on teaching and therefore a number of recommendations to create a positive correlation between teaching and research are proposed. This issue is identified by Taylor's SOE and addressed it by applying a teaching framework that utilises the Grand Challenges for Engineering and CDIO initiative to create a clear link between teaching and research. Ensuring that students' projects and other CDIO activities are derived from the academic staff research interests helped in creating a learning environment in which research and teaching are integrated (Al-Atabi *et al.,* 2013).

4.4. Eureca Conference

The final year project is a compulsory requirement mandated by Engineering Accreditation bodies. SOE adopted a new approach to include a participation in a conference. Engineering Undergraduate Research Catalyst Conference (or EURECA in short) is a unique approach to assess final year project. It aims to expose the students to a real environment of a conference to gain further skills. Participation in a peer reviewed conference, assessment by external reviewers, oral defence of thesis, and anonymous assessment coupled with prompt feedback to students are some of the approaches implemented to deliver the learning outcomes (Al-Obaidi *et al*., 2014).

5. ACCREDITATION PROCESS AND RESULTS

EAC panel made a visit in April 2013, for the accreditation of the programmes following the submission of Self-Assessment Report (SAR) by Taylor's University/School of Engineering. In September 2009 SOE has offered three new programmes; B.Eng. (Hons.) in Chemical Engineering, Electrical and Electronic Engineering, Mechanical Engineering. **Table 5** shows some parts quoted from the Evaluation Panel Report which clearly show how the implementation of CDIO and Project-Based learning framework positively impacted the panel and eventually contributed in a successful accreditation of all programmes. Finally, the summary of EAC report stated there is no weakness and the school strength is CDIO initiatives and Project-based learning embedded in the curriculum. As a result, the accreditation process was successful, the panel was satisfactory, and the programmes have been accorded a 3-year accreditation by the Engineering Accreditation Council (EAC) for graduates of 2013, 2014 and 2015.

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Table 5. Some results from Evaluation Panel report of SOE accreditation in 2013 (EAC Evaluation Panel Report (2013)

Item evaluated	Results
Qualifying requirements	All the 8 qualifying requirements were met
Programme Educational Objectives (PEOs)	• There is a process in place to establish and review the PEOs. The first set of PEO statements for the programme was developed in 2009 and reviewed in 2012. The PEOs were reviewed to align with the change in Taylor's vision and mission, and to accommodate CDIO (Conceive, Design, Implement, Operate) initiative.
Programme Outcomes (POs)	• The process in the formulation of POs is clearly established with the existence of adequate processes at the school and at the programme level. Course outcome/learning outcome and programme outcome matrix has also been established.
Curriculum	• The school practices CDIO (Conceive, Design, Implement, Operate) curriculum and is accepted as an official member of the CDIO international initiative. In general, the curriculum structure of the engineering subjects is balanced. • The programme delivery is satisfactory. The school has implemented a good mixture of delivery modes of lectures, tutorials, laboratory work, integrated projects, design project, final year project and industrial training. Project based learning which is part of the CDIO is implemented in the programme delivery. • The assessment of the FYP2 report is moderated by second examiners. The assessment breakdown of marks is as follows; weekly log (15%), conference paper (10%), conference presentation (25%) (*EURECA* conference) and final project report (50%).
Students and Student Involvement	• During the interview session with first- and second-year students, they mentioned that they chose TU because of the CDIO (project-based learning) implementation in the programme. Similarly, for the final year students who said that project-based learning is their preferred element in the programme. • Students have participated in engineering competitions such as shell eco-marathon, UTem Formula Varsity racing competition, Engineering Fair, CDIO conferences, Malaysia Technology Expo (MTE) and EURECA 2012. • Nearly all the interviewed students chose TU because of CDIO implementation/project-based learning as a central of the curriculum practiced by the school of engineering.

6. CONCLUSION

Accreditation of Engineering programmes has been always a challenge for IHLs. Successful accreditation requires IHLs to meet the evaluation criteria and the qualifying requirements set by the accreditation bodies. The implementation of CDIO educational framework and Project-based learning proved to be a key role in module planning, designing, implementation, and eventually in meeting the EAC criteria and requirements.

It is important for any IHL to have a systematic approach to design the academic curriculum based on PEOs and POs of the engineering programmes. The use of the new academic curriculum under CDIO initiative should be continuously practiced, evaluated, and improved through the continual quality

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improvement (CQI). This requires building the culture of CDIO among the school teaching staff through trainings and workshops to produce professional staff having a can-do spirit and ability to successfully implement the CDIO initiative and Project-based learning in all engineering modules and research as well.

Last-minute preparation for accreditation will always lead to a failure. In contrast, the systematic preparation, proper documentation with clear evidence, closing the loop of the CQI cycle will ensure the successful accreditation. It will also help the IHL to ensure and improve the quality of engineering graduates and programmes and as a result improve its reputation and ranking.

Finally, it is important to point out here, that all information shared in this paper, is for the period from 2009 to 2013. Currently, the SOE further developed and is developing its programmes and curriculum by adopting more innovative methods of teaching and learning to face the new era of industry and engineering challenges. This includes, Grand Challenges Scholars Program (GCSP), Engineering Undergraduate for Industrial Adoption (EUFORIA), Taylor's Curriculum Framework, and SHINE program, just to mention few.

7. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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