Keynote Address

Engineering Education for Future World: The CDIO Approach (*Conceive*, *Design*, *Implement*, *Operate*)

Prepared on behalf of

إتحاد المهندسين العرب
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by

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1. Introduction

In his book The World is Flat, Thomas Friedman illustrates how around the year of 2000, the world entered a whole new era of globalization, one that is governed by the power of individuals to compete and collaborate globally. Technology has made the world flatter by removing barriers to information and trade, which means that countries need to get moving if they want to keep up in this global economy. Therefore, globalization should be the drive for developed and developing Arab countries to devise strategies that will advance their economies and societies.

Technology and knowledge are the basis for founding economic development. With globalization accelerating the pace of change and the fact that success in knowledge-based economies lies within the capacity of individuals, it becomes imperative to acquire problem-solvers who are able to build the technical infrastructure required for sustainable change and advancement. We believe and are confident that engineers are the ideal problem-solvers and the key knowledge workers for capacity building and sustainable economic growth particularly in emerging economies. It follows, then, that to effectively compete in a knowledge-based economy, the Arab countries must invest in producing a large enough pool of highly qualified and accredited engineering graduates to actively engage in technical capacity building in our countries.

2. Reforming Engineering Education

Reforming the engineering education, with all its challenges, is imperative for creating a knowledge-based economy. Engineering education must not only respond to the national challenges but also to the challenges faced in the Arab Region and to the global opportunities. To innovate and reform engineering education, stakeholders need to understand the requirements of an engineer, and what skills, competencies, and attributes she/he must possess. Their education and professional development is not only limited to knowledge but also encompasses skills, values, and competencies to address problems and opportunities. Therefore, engineering education, in particular, should play a central role in our increasingly technology-based societies. The education of engineers must prepare them for the multi-dimensional nature of the issues they will face.

In the Arab Region, there is a vital and undeniable need to reform engineering education. Many prestigious organizations such as the engineering syndicates and the global industries and services have reported on the growing need for change in engineering education in its shape, contents, objectives, outcomes, and its socio-economical pertinence and impact. It is evident to stakeholders that the world is paying more attention to the quality of engineering education given the increasingly important role of engineers in the society and the economy. We notice an evident gap between the needs of stakeholders (employers, including industry, business, government structures, parents, students ...) and the quality of education in the field of engineering and technology.

3. The CDIO Initiative

In an era of technology, information and innovative economies, specific emphasis is placed on the education of engineers to enable them to create new technics and technologies. The CDIO International Standards guide towards a complex approach for the formation of such specialists who are able to handle the complete lifecycle of a product, system, service or process. The framework stresses on engineering fundamentals which are set in the context of Conceiving, Designing, Implementing, and Operating engineering activities. The four phases are the abbreviation in the word **CDIO.**

It is essential for any engineer to have a comprehensive understanding of all stages of the lifecycle of new technics and technologies.

In order to play a pivotal role and contribute to building knowledge-based economies, engineering educational institutions in the Arab Region must adopt the CDIO initiative. Currently, the CDIO initiative has been adopted by more than 120 renowned universities from all over the world but none in the Arab Region apart from the Australian College of Kuwait, which has recently adopted the model and a university in Tunisia

The founders of the CDIO framework are professors from world-class institutes; namely, Chalmers University of Technology, KTH Royal Institute of Technology, Linkoping University in Sweden and spearheaded by Massachusetts Institute of Technology (MIT) in the USA since 2000. The CDIO initiative was developed with input from academics, industry, engineers, and students and was specifically designed as a template that can be adapted and adopted by any university engineering school. Because CDIO is an open architecture model, it is available to all university engineering programs to adapt to their specific needs.

The CDIO initiative is based on four phases namely:

- ✓ **Conceive phase**: Defining customer needs; considering technology, enterprise strategy, and regulations; developing concepts, techniques and business plans.
- ✓ **Design phase**: Creating the design; plans, drawings, and algorithms that describe what will be implemented.
- ✓ **Implement phase**: Transforming the design into the product, including manufacturing, coding, testing and validation.
- ✓ **Operate phase**: Using the implemented product to deliver the intended value, including maintaining, evolving and retiring the system.

3.1 CDIO Vision

The CDIO initiative envisions an education that stresses the fundamentals set in the context of Conceiving- Designing-Implementing-Operating products, processes, and systems. The salient features of the CDIO vision are:

- A curriculum organized around mutually supporting courses, but with CDIO activities highly interwoven
- Rich with student design-build-test projects
- Integrating learning of professional skills such as teamwork and communication
- Featuring active and experiential learning
- Constantly improving through quality assurance process with higher aims than accreditation.

This keynote address will discuss the essentials of the CDIO initiative in details which is based on:

3.2 CDIO Standards

The CDIO International Standards which define the distinguishing features of a CDIO program and cover:

- Program philosophy
- Curriculum development
- Design-build experiences and workspaces
- Teaching and learning methods
- Faculty developments
- Learning outcomes
- Assessments and evaluation

In particular, CDIO standards include:

- Adoption of the principle that product, process, and system lifecycle development and deployment are the context for engineering education.
- specific, detailed learning outcomes for personal and interpersonal skills, professional competencies consistent with program goals and validated by program stakeholders;
- a curriculum designed to integrate personal and interpersonal skills, and product, process, and system building skills;
- an introductory course that provides the framework for engineering practice as part of the curriculum;
- participation of students in two or more design-implement experiences at various levels;
- workspaces and other learning environments that support hands-on learning are fundamental resources for learning to design, implement, and operate products, processes, and systems;
- an environment for integrated nature of the learning process (training, real practice);
- teaching and learning based on active experiential learning methods;
- enhancement of faculty competence in CDIO implementation;
- Students' assessment system focusing not only on acquisition of disciplinary knowledge, but also on evaluation of their ability to create new products, processes, and systems.

An Appendix is attached showing the detailed CDIO Standards including the description, the rational and the rubric (CDIO Standards v2.0 (Appendix B).

3.3 CDIO Syllabus

The first tangible outcome of the CDIO initiative is the CDIO syllabus which is a codification of contemporary engineering knowledge, skills, and attitudes [1], [2], [3]. The objectives of the syllabus are to create clear, complete, and consistent set of goals for engineering education in sufficient detail that they could be understood and implemented by engineering faculty [2].

The strength of the CDIO syllabus is that is adaptable across all engineering schools. The level of detail provided in the syllabus creates the basis for curricular and assessment planning in engineering education.

Most importantly, the CDIO syllabus is used as a reference to derive specific learning outcomes in engineering education and classifies learning outcomes into four high level categories [2], [3]:

Level one: Disciplinary knowledge and reasoning
Level two: Personal and professional skills and attributes
Level three: Interpersonal skills
Level four: Conceive, design, implement, and operate systems.

The four levels in the syllabus represent the competencies that are expected to be achieved upon graduation from the educational program. The content of level one 'Disciplinary knowledge and reasoning' varies widely from one specialization to another; this is the reason why this item is placed at the beginning of the syllabus because the development of deep knowledge of technical fundamentals is the main objective of undergraduate engineering education [1], [2], [3]. The second, third, and forth levels are more common across all education fields [4]. The second level of the syllabus focuses on students' cognitive skills such as critical and system thinking. The third level focuses on individual and team level based interactions, and the fourth level presents a view of how a product or system development moves through four metaphases: conceive, design, implement, and operate [4].

In addition, the CDIO syllabus is linked with the UNESCO Four Pillars of Learning with which it is aligned at a high level [2] as follow:

- The first level Disciplinary Knowledge and Reasoning is linked with UNESCO's Learning to Know;
- The second level Personal and Professional Skills and Attributes is linked with UNESCO's Learning to Be;
- The third level Interpersonal Skills is linked with UNESCO's Learning to Work Together; and
- The fourth level Conceive, Design, Implement, and Operate Systems is linked with UNESCO's Working to Do.

It is important to note that since the CDIO syllabus was written and released in 2001, it has undergone an extensive review process and missing skills were added. As a result, the extended CDIO syllabus version 2.0 was released in 2011 to include an extension on engineering leadership and entrepreneurship. In addition, modifications on innovation, invention, internationalization, and sustainability were incorporated into the revised version.

Furthermore, in order to translate the syllabus into learning objectives for the program, a specific process, based on stakeholder input, is formulated to determine the required proficiencies expected from the graduates at each level of the syllabus. This process includes administering well-constructed surveys to stakeholders and analyzing the results. Based on the feedback received from the stakeholders and consensus, the levels of proficiencies are determined.

An appendix is attached to show the CDIO Syllabus v2.0 (Appendix A)

4. Pedagogical Foundation

The CDIO approach provides the context and not the content for engineering education. Engineering content should be taught within the CDIO framework. This framework requires a specific pedagogical foundation, discussed in this section, to support the realization of its vision.

Adopting the CDIO model implies an eminent shift in engineering education to a more integrated curriculum. This requires change in the curricular structure and to benchmark the existing curriculum from the perspective of the CDIO syllabus. The CDIO's essential feature is that it creates dual impact learning experiences through the usage of modern pedagogical approaches, new learning experiences and innovative teaching methods. Therefore, learning becomes imparted in personal and interpersonal skills, product, process, and system building skills [1].

As stated earlier, engineers require a comprehensive set of skills to enable them to thrive within their domains. A necessary and required skill for every engineer is the systems thinking skill. The strength of the CDIO model is that it uses the systems thinking approach.

Systems thinking skill revolves around four basic ideas: complexity, interrelationships, context and emergence: the complexity of a system to solve/operate, the interrelationships between its components, the context at which the system operates, and the emergence of the solution/operation [5]. Therefore, the importance of this skill is that it allows engineers to solve complex engineering designs and avoid problems which could be caused by a lack of understanding of subsystem interactions or a lack of problem exploration [5], [6].

Furthermore, engineering students possess little concrete experience upon which to base engineering theories. The lack of practical experience in engineering education affects the student's ability to learn abstract theory which is the basis of engineering fundamentals and hinders their ability to comprehend the practical usefulness of these theories. The relevance of this model is that it is based on the experiential learning theory which is defined as active learning where students learn by constructing their own knowledge; therefore, the role of the faculty becomes a facilitator and a mentor for processing new information and supporting the construct of meaningful connections [2].

Active learning is a student-centered instruction approach with emphasis on collaboration and a balance between individual and teamwork. Through active learning, students engage in critical thinking, problem solving, and decision making and are able to consolidate skills and ideas through reflection and feedback. The active application of knowledge facilitates the process of learning and retention through promoting deep learning of technical fundamentals and of practical skills. One method of active learning is Project Based Learning (PBL). PBL allows the students to develop technical and generic competencies which are extremely valued in the professional field. By using PBL to develop CDIO skills, students are prepared for real life in meaningful and purposeful environments. Adopting the PBL methodology enhances students learning and improves not only their confidence about their technical skills, but also transversal skills increasingly in demand in the business world, that classical methods do not develop [7], [8], [9].

Currently, assessments for many educational objectives are vague and immeasurable to a certain extent. The CDIO model offers comprehensive practices which are based on widely accepted educational taxonomies, guaranteeing clear and measurable assessment statements of each educational objectives [10]. This model adopts assessment tools that embrace creativity, design, and entrepreneurship such as portfolios, critiques, and design reviews [10]. Assessments allow students to take autonomy of their learning; making them the drivers of their own learning. Along their educational journey, their skills and attitudinal changes are continuously assessed. In addition, it is important to note that assessments designed using the CDIO approach are based around five levels of proficiency: exposure, participate, understand, skilled practice, and innovate. The expected proficiency is then mapped to learning objectives expressed in several educational taxonomies [4].

5. Conclusion

The CDIO initiative is becoming increasingly popular and is developing graduates ready for the workforce with the capability to validate their skills and competencies throughout the phases of developing engineering products, services, processes, or systems. Furthermore, the competencies gained through CDIO based programs equip graduates with the ability to easily adapt to the changing needs of future developments and requirements. Higher education institutions offering engineering education are encouraged to learn more about this model, examine its suitability, and adapt it as applicable. In addition, many world renowned universities are establishing CDIO networks to provide educators with a platform to exchange best practices.

It should be noted that faculty members and program leaders are playing a fundamental role in the success of this initiative. Faculty are instrumental in the execution of this model. Therefore, it is pivotal that universities find ways to strengthen the collective skills of their faculty by re-tasking existing resources while largely using existing resources [1]. The allocation of resources is necessary to aid and assist faculty in developing their active and experiential learning teaching methods.

Many universities that adopted this model have established an associated faculty development program to enhance and strengthen their faculty's competence skills and support them in the processes of designing and implementing the teaching, learning, course evaluation techniques, and assessment methods best suited for the CDIO model.

Finally, on a separate but similar note, many universities that adopted the CDIO model have established a CDIO academy which gives students the opportunity to showcase their projects, meet fellow peers from engineering programs around the world, participate in workshops, and attend sessions presented by leaders in engineering education [11].

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