CDIO FRAMEWORK AND SKILLSFUTURE: REDESIGN OF CHEMICAL ENGINEERING CURRICULUM AFTER 10 YEARS OF IMPLEMENTING CDIO

Sin-Moh Cheah, Katerina Yang

School of Chemical & Life Sciences, Singapore Polytechnic

ABSTRACT

This paper shares the experience of the Diploma in Chemical Engineering (DCHE) Course Management Team in using the CDIO Framework to help formulate its approach to redesign its DCHE curriculum to align it to the requirements of the SkillsFuture Initiative. The SkillsFuture Initiative was launched by the Singapore Government in 2015 and aimed at helping Singapore manufacturers improve their operations to remain competitive in the global marketplace, promoting lifelong learning by providing workers with avenues to deepen their existing skills and acquire new ones, so that they can stay relevant amid ever-changing workplace demands. It is the country's response to the challenge of Industry 4.0. Two key elements of SkillsFuture of relevance to education are the Skills Framework and Enhanced Internship. This paper first explains Chemicals 4.0 – the chemical industry's equivalent of Industry 4.0, and briefly summarises its implications for the chemical industry in general, and chemical engineering education in particular. Next, the paper shares how the CDIO approach is used to guide the curriculum review process, i.e. in addressing the questions of what knowledge, skills and attitudes are required for Chemicals 4.0. The outcome of the process is to establish a course structure that is able to meet the needs of learners in term of pre-employment training (i.e. students) as well as continuing education and training (i.e. adult learners). The paper then provides a summary of the authors' review of pertinent literatures to specifically address the need of the DCHE curriculum, narrowing the focus into the following knowledge areas: predictive asset management, process management and control, energy management, safety management, and production simulation. As for the skills and attitudes, the paper argues that most of the skills needed are already addressed in our "CDIO-enabled" curriculum. However, with the emphasis on Chemicals 4.0, some skills now take on greater importance, such as sense-making, data analysis, resource management and virtual collaboration. The paper then provides a summary of our revamp effort over the past 4 years since the last self-evaluation exercise in 2012 (i.e. from 2013-2016), and the plan for the next 4 years (2017-2020) to implement a new course structure based on a spiral curriculum. The paper concludes with a brief explanation on why a spiral curriculum is suitable for DCHE, and provides an approach to transition the existing curriculum to the spiral one.

KEYWORDS

Chemicals 4.0, Chemical Engineering, Spiral Curriculum, CDIO Standard 12

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called "courses". A teaching academic is known as a "lecturer", which is often referred to a as "faculty" in the universities.

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) from Singapore Polytechnic had adopted CDIO as the basis for revamping its curriculum since 2007 and its "CDIO-enabled" curriculum was introduced for the first time in April 2008 for students for the Academic Year 2008/2009 cohort. Since then, the course had been revised several times in response to changing socio-economic developments in Singapore affecting the educational sector. The details described in this paper, which arise as a result of the Singapore Government's SkillsFuture Initiative, is by far the single largest change we have made since 2008. The SkillsFuture Initiative is a response to the increasing VUCA (volatile, uncertain, complex, ambiguous) world, accelerated by the advent of Industry 4.0. In terms of educational outcome this means meeting the requirements for technical and generic competencies (knowledge, skills, attitudes) as detailed in the Skills Framework (SF) for the industry sector the program is serving. It also means we need to have a course structure that is able to meet the needs of both existing students (in terms of Pre-Employment Training, or PET in short) and adult learners (in terms of Continuing Education and Training, or CET in short). This paper focuses on the effort by the DCHE Course Management Team in responding to these challenges. The sector DCHE is serving is the Energy & Chemicals (E&C) Sector, comprising companies producing bulk and commodity chemicals, specialty chemicals, gas and utilities, etc. Our students also found employment in the pharmaceutical industries. Our students typically found employment as Engineering Executives, Process Technicians, Process Analysts, etc.

CHEMICALS 4.0 – THE CHEMCIAL INDUSTRY'S RESPONSE TO INDUSTRY 4.0

The chemical industry's equivalent of Industry 4.0 is often referred to as Chemicals 4.0. The chemical industry is typically characterized by continuous production as opposed to discrete production in other non-process industries. Another key feature is the industry's significant asset intensity as well as logistics and energy cost (De Leeuw, 2017; Wehberg, 2015). Despite the different nature of the chemical industry's production, Industry 4.0 is just as relevant. However, as argued by Wehberg (2015), the chemical industry's specific characteristics need to be taken into account. The chemical industry operates in a global environment with a high degree of uncertainty and volatility, and faced the following challenges (GE, 2016):

- Coping with low oil prices without jeopardizing future performance
- Increasing technical complexity of asset mix that oil and gas companies are developing and operating
- Aging and turnover of industry's workforce
- Regulatory concerns around health, safety and the environment

Chemicals 4.0 can potentially transform the chemical industry by promoting strategic growth and streamlining operations, across the entire value chain. There are opportunities for all stages of operations from upstream (e.g. oil exploration and production forecasting), to midstream (e.g. refining, conversion) and downstream (e.g. demand forecasting, facility integrity, commodity trading risk management and customer intelligence) (ATOS, 2016; SAS, 2014). All these are taking place because of the convergence brought about by Industry 4.0, e.g. in the areas of cloud computing, inexpensive sensors, progressive network availability, and big data analytics (IIC, 2015). With such convergence, many chemical companies can develop holistic solutions that integrate silos of information from suppliers, plant floor, sales and marketing, laboratory information management systems and third parties. Through advanced analytical techniques, companies can raise their productivity, manufacturers can increase efficiency and enhance product quality (Kaestner, 2016). Given the developments in

Chemicals 4.0, the question for chemical manufacturers is not whether to enter into the fray by adopting Industry 4.0 connectivity and "smart" manufacturing technologies, but rather where to start (Elsevier, 2017). Chemicals 4.0 not only transforms how the chemical industry operates, it also reshapes the nature of the workforce and the skills and competencies required (Accenture, 2015). The next section explores the impact on chemical engineering education.

REDESIGNING THE DIPLOMA IN CHEMICAL ENGINEERING: FOCUS AREAS

As mentioned earlier, revision to the course structure is necessary to achieve a form of "blurring" between PET and CET; to accommodate both students (PET) and adult learners (CET) to equip them with the competencies needed in a Chemicals 4.0 world. The first author had demonstrated elsewhere that the CDIO Framework is compatible with the requirements of SkillsFuture (Cheah, 2018). Therefore, in reviewing and redesigning our DCHE curriculum, we use the tried-and-tested 'standard' CDIO approach, by focusing on the following key questions:

1. Need: What is the professional role and practical context of the profession?
2. Learning outcomes: What knowledge, skills and attitudes should students (and adult learners) possess as they graduate from our programs?
3. Curriculum, workspace, teaching, learning and assessment: How can we do better at ensuring that students and adult learners learn these skills?

Questions 1 and 2 can be addressed by referencing the E&C SF. It provides program owners, curriculum designers, etc with a comprehensive set of reference documents to review and plan their curriculum. Among these documents are the sector and employment information, career map and job roles, technical and generic skills and competencies. Detailed study of the E&C SF showed that while our 3-year program covered many of the required technical skills and competencies (TSCs) and generic skills and competencies (GSCs), there are certainly gaps in our curriculum. This is not entirely surprising, as the E&C Sector is very broad; and the advent of Chemicals 4.0 did introduce new knowledge, skills and competencies that chemical engineering graduates needed, in particular Internet of Things and data analytics. Specifically, 2 TSCs are included for the job role of employees in the E&C sector include the following: (1) Internet of Things (IoT) Management, and (2) Robotic and Automation Technology Application.

What are the new or enhanced knowledge needed?

It is obviously not possible for a 3-year program to address all the needs and changes in Chemical 4.0 presented earlier. After reviewing the relevant literatures, and consulting with our industry partners, we narrowed down our focus areas to the following:

<u>Predictive Asset Management</u> (Deloitte, 2016; Frost & Sullivan, 2016; SAS, 2014)

Using the continuous feed of data collected from sensors on critical equipment such as turbines, compressors, and extruders, advanced analytics tools can identify patterns to predict when a piece of equipment is likely to experience a specific failure and diagnose possible breakdowns. In doing so, smart equipment can send messages to plant operators about any required maintenance, potential breakdowns, and parts ordering and delivery schedules. By integrating data from a variety of process sources with knowledge and experience databases, operations can boost uptime, performance and productivity while lowering maintenance costs and downtime. This can enable manufacturers to evolve from scheduled or reactive repairs to predictive maintenance. This is also known as Asset Performance Management (GE, 2016).

Process Management and Control (Deloitte, 2016)

Process variability results from a variety of factors, starting from the quality of raw materials to variations in internal processes such as raw material dosing, temperature control, residence times, system fouling, and aging catalysts. Similar to predictive asset management, process management and control involves collecting structured and unstructured data via sensors from various sources such as the lab, alarms, and process equipment to help to identify patterns and deviations in chemical processes before they occur, as well as helping in operation optimizations, thus helping to maintain production stability.

Energy Management (Deloitte, 2016, Frost & Sullivan, 2016; GE, 2016, Guertzgen, 2016)

Energy costs contribute significantly to a chemical plant's production costs. A typical plant involves multiple activities and their interactions, and it is difficult for operators to select optimal operating conditions. The chemicals industry has a high degree of automation, and most plants monitor standard variables such as temperature, flows, tank levels, and pressures to derive optimal plant working conditions. Industry 4.0 technologies can augment these data points with additional information and enable control of non-standard process variables to improve energy efficiency.

Safety Management (Accenture, 2017b; Uktem, et al, 2013)

Big data from all the process measurements and alarms can be analysed and processed rapidly to extract crucial risk information, thus creating leading indicators of potential performance issues, such as shutdowns, accidents, incidents, and operational problems, hence provide indicators of the process risks. For example, frontline supervisors can make data-driven decisions to identify risks and respond quickly to problems.

Production Simulation (Deloitte, 2016; Lozowski, 2017)

Chemical companies are increasingly using 3D visualization e.g. augmented reality (AR) and/or virtual reality (VR) for training operators and maintenance staff. Trainees can "walk" across a simulated plant, "work" with the equipment and instruments, and "handle" safety situations. They can also collaborate with their peers, and individual and collective performances can be monitored by instructors. In addition to operator training and prognostics, AR/VR also helps operators prepare before the plant operations begin.

What are the new or enhanced skills needed?

Cheah & Leong (2018) had reviewed the relevance of the CIDO Syllabus in addressing the competencies needed in Industry 4.0. However, with the emphasis on Chemicals 4.0, especially with regards to IoT and data analytics in the key focus areas identified above, some skills now take on greater importance, such as sense-making, data analysis, resource management and virtual collaboration (Accenture 2017a, SSG, 2017). Table 1 shows a summary of the present status of our curriculum with regards to the coverage of knowledge and skills needed, along with very broad identification of the gaps.

Lastly, to address Question 3, we use the CDIO self-evaluation process to identify specific action items to guide the redesign effort. Table 2 shows the concise summary of work done in the last 4 years since the last self-evaluation exercise in 2012 (i.e. 2013-2016), and suggested plans for the next 4 years (i.e. 2017-2020).

Table 1. Chemicals 4.0 – Focus area for Diploma in Chemical Engineering

Description	Existing Coverage in 3-year DCHE Curriculum	New/Enhanced Skills & Competencies	Gap in Coverage
Predictive asset management	Not covered	Internet of Things applications, data analysis, sense-making, resource management	HIGH
Process management and control	Focus on process instrumentation and control, limited coverage on optimization		LOW
Energy management	Limited to heat integration		HIGH
Safety management	Focus on inherently safer design and plant safety system, limited coverage on occupational safety & health	As above, but also include virtual collaboration in AR/VR environment	MEDIUM
Production simulation	Focus on steady-state modelling for chemical process plant design.		MEDIUM

KEY CHANGES IN DCHE COURSE STRUCTURE: NEW SPIRAL CURRICULUM WITH ENHANCED INTERNSHIP

Cheah (2018) had earlier shared some ideas of how the CDIO Standards can be used to review and redesign an engineering curriculum vis-à-vis the needs of SkillsFuture. In this paper, we apply these ideas to the DCHE curriculum. The results of the self-evaluation exercise identified key areas in the curriculum that the Course Management Team can focus the redesign effort on. The 2 key outcomes are: a new course structure termed the spiral curriculum, and enhanced internship that will strengthen students' learning experiences. We first discuss enhanced internship here but only briefly. The remaining sections of this paper provide more information about spiral curriculum.

Enhanced Internship

Enhanced Internship (EI) is a key feature under SkillsFuture. It is "enhanced" in that it required longer duration (1 semester to a year), with structured learning plan, defined learning outcomes and mentoring by industry partners. DCHE introduced its EI in Semester 1, Academic Year 2015 as part of institution-wide initiative to embrace SkillsFuture. Specifically, we rationalized our modules and introduced a "5+1" course structure whereby students spend 5 semesters studying in campus, and 1 semester on EI. This was done ahead of the curriculum review and redesign, and our effort is focused on securing sufficient EI places with relevant companies in the E&C Sector for our students. Details of our EI implementation will be shared in separate paper at a later date. Suffice to note that EI is now part of the newly designed course structure termed spiral curriculum which is discussed next.

What is Spiral Curriculum?

Spiral curriculum is a concept first proposed by Bruner (1960). It is an approach to education that introduces key concepts to students at a young age and covers these concepts repeatedly, with increasing degrees of complexity. This approach is also known as a "spaced" or "distributed" approach. It contrasts with "blocked" or "massed" curricula, which do not introduce difficult concepts until the student has reached a higher level of education.

Table 2. Outcome of DCHE CDIO Self-Evaluation vs SkillsFuture

<table>
<tr><td>CDIO Standard 1 – The Context</td><td colspan="3">Adoption of the principle that product, process, and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 5</td><td>2016: 5</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Maintain existing efforts to communicate CDIO to new students</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To extend the CDIO context for engineering education to workplace learning via Enhanced Internship (EI) at supporting companies. More elaboration of EI is provided in the text.</td></tr>
<tr><td>CDIO Standard 2 – Learning Outcomes</td><td colspan="3">Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
More modules now have learning outcomes included at activity/task levels, e.g. in lab manuals.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To integrate newly identified knowledge and skills needed (Table 1) into suitable modules (Standard 3) with existing/new activities (Standards, 7 and 8), as well as into EI as appropriate.</td></tr>
<tr><td>CDIO Standard 3 – Integrated Curriculum</td><td colspan="3">A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Switched to sequential diploma structure since AY13/14. Problem-based learning piloted as assignment in Environmental Engineering in AY13. Introduced integrated laboratory, integrated assignment & integrated mid-semester test for Year 2. EI (22 weeks) introduced in Semester 1, Academic Year (AY) 2015. To-date, 2 runs of EI had been completed. See also Standard 5.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To redesign the DCHE course structure to align to career map in the E&C SF, via a spiral curriculum, and closing gaps (Table 1) identified. To review EI for greater integration with the rest of DCHE curriculum. See also Standards 3 and 7 and discussion in main body of paper on approach taken.</td></tr>
<tr><td>CDIO Standard 4 – Introduction to Engineering</td><td colspan="3">An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 5</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Introduced activity on to promote greater awareness of career pathways, roles and responsibilities.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To include introduction to Internet of Things, with activities focusing on importance of sense-making and data analysis. These will be enhanced in other activities (see Standards 7, 8) as well.</td></tr>
</table>

Table 2. (cont'd)

<table>
<tr><td>CDIO Standard 5 – Design-Implement Experiences</td><td colspan="3">A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
EI, introduced in AY2015 requires that students complete company project(s). Strengthened teaching of chemical product design, with emphasis on sustainable development.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To retain existing chemical product design pathway as 3 modules running from Year 1 to Year 3 for the spiral curriculum, leading to the capstone final year project in Year 3 as part of integrated curriculum. To review coverage of process simulation leading to Plant Design Project in existing core modules, as the topics may be re-distributed to new modules. See also Standard 7.
To strengthen workplace learning during EI, especially via company project(s) by align learning outcomes from EI with E&C SF (Standard 2).</td></tr>
<tr><td>CDIO Standard 6 – Engineering Workspaces</td><td colspan="3">Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 3</td><td>2016: 3</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Budget secured in AY16 to renovate W318, preliminary concept and floor plan done for a new Energy & Chemicals Training Centre. Already went ahead with renovation work, and procurement of new integrated pilot plant.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To follow-up on work done as noted above and redesign new learning activities to align with TSCs and GSCs for E&C SF. In addition, to explore use of AR/VR and EI to leverage on company factory floor or laboratory to complement in-campus facilities. Together with Standard 7, the former is especially desirable in the development of identified skills and competencies (see Table 1).</td></tr>
<tr><td>CDIO Standard 7 – Integrated Learning Experiences</td><td colspan="3">Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Introduced Integrate Laboratories for Year 2. Introduced virtual collaboration in Year 3 module Plant Safety & Loss Prevention, taught using flipped learning format. Students work collaboratively in class and also during home-based learning (simulated campus closure for 1 week) on case studies and other class activities using Google Doc or Google Slide.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To review activities under existing modules and redistributed as appropriate to new modules in the spiral curriculum (see Standard 3). Where suitable, to also integrate new topics in Table 1 to close the gaps. Also, to introduce activities in virtual learning environment (VLE) using AR/VR (Schuster, et al, 2015) in suitable modules. See also Standard 8.</td></tr>
</table>

Table 2. (cont'd)

<table>
<tr><td>CDIO Standard 8 – Active Learning</td><td colspan="3">Teaching and learning based on active experiential learning methods</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Flipped classroom introduced for selected modules. Increased use of EdTech tools such as Socrative, Kahoot, Padlet, etc to enhance student participation in class.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To continue encouraging more adoption of flipped classroom in the spiral curriculum, especially on topics related to understanding factual information; to continue with more usage of EdTech tools. Also, to introduce activities on IoT and using AR/VR (see also Standards 6, 7).</td></tr>
<tr><td>CDIO Standard 9 – Enhancement of Faculty Competence</td><td colspan="3">Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 5</td></tr>
<tr><td>CDIO Standard 10 – Enhancement of Faculty Teaching Competence</td><td colspan="3">Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Introduced Academic Mentor Scheme where appointed lecturers serve as mentors to assist Course Chair in curriculum review, as well as fellow lecturers in adopting new pedagogy, module re-design (e.g. using CDIO) and/or use of EdTech tools.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To identity training opportunities for lecturers to develop facilitation skills in learning of GSCs such as sense-making, transdisciplinary thinking, etc. Training also needed on technological competencies in order to interact with students in VLE. This includes not only design of VLE but also experience in digital coaching and joint problem solving in virtual worlds, which is becoming a mode of teaching to tutor and moderate groups of students in VLEs (Richert, et al, 2015)</td></tr>
<tr><td>CDIO Standard 11 – Learning Assessment</td><td colspan="3">Assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 2</td><td>2012: 3</td><td>2016: 3</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Use of survey instrument not started. Assessment of knowledge and skill transfer via Integrated Assignment (see work on Standard 3)</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
At this moment, we are using a standard template for assessment on EI. We will continue to review execution of EI for the AY17 cohort whose EI will end in February 2018; and customize the EI to DCHE needs, especially in relation to the TSCs and GSCs for the E&C SF.</td></tr>
</table>

Table 2. (cont'd)

CDIO Standard 12 – Program Evaluation	*A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement*		
Rating from Self-Evaluation	2008: 2	2012: 3	2016: 4
Brief Summary of Selected Efforts (from 2013 to 2016) Integrated the CDIO self-evaluation process into AQMS (Academic Quality Management System) to help with course-level review, and cascaded the review down to module level. Diploma was successfully re-accreditation by IChemE UK in May 2017.			
Action Plans for Next 4 Years (2017 – 2020) To obtain management approval for new spiral curriculum, to share with External Examiner, and to update IChemE UK on the changes made. To explore obtaining additional external validation of the revised curriculum, in relation to meeting E&C SF requirements.			

Why Spiral Curriculum and How to Design One?

Spiral curriculum had been implemented in several chemical engineering programs, for example, see DiBiasio, et al (1999), Gomes et al (2006). This curriculum model is adopted because we believe it is best able to deliver the outcome desired from the redesign effort in good alignment with the E&C SF: a course structure that can accommodate the learning needs of both adult learners and students. The general approach we had taken in transitioning the existing curriculum into a spiral one is shown schematically in Figure 1. Note that the changes are made only to selected core modules, i.e. those directly mapped to the TSCs of the E&C SF. The colour rectangles on the left represent existing core modules in DCHE, while the white rectangles on the right represent the new curriculum, based on the concept of modular certificates (MCs). Each MC represents a collection of related modules, usually based on a set of core competencies. MC1 for example, consists of 3 modules MC1-1, MC1-2 and MC1-3. The MCs are arranged ("stacked") in a sequence of learning progression with increasing difficulty from MC 1 to MC5. MC6 is unique in the sense that it represents a single Enhanced Internship that students undertake, as briefly explained earlier.

Each module in the MC system is derived by combining related topics from existing modules (i.e. the colour rectangles). An example of this is shown in Figure 2, whereby an existing Year 2 Core Module 3 is firstly decomposed into its various topics represented by small squares. Similar approach is taken for other existing core modules. Squares of similar nature, but from different modules are then combined to form a new module in the MC system. This is best illustrated with an example from DCHE using a Year 2 core module entitled *Heat Transfer and Equipment*. In the existing structure, the module covered the all topics related to heat transfer: such as fundamentals, mechanisms, types of equipment, design and sizing calculations, modelling and simulation, operation and troubleshooting. Likewise, another core module entitled *Rotating Equipment* similarly covered all topics related to rotating equipment. For the new course structure, all topics from existing core modules related to, say design and sizing calculations, will be grouped under a new module in the MC.

Also shown on the right-most side of Figure 1, are labels such as E&C SF TSC L2, L3, etc. These represent the proficiency levels, based on the E&C SF, to be progressively developed over the 3-year duration of study.

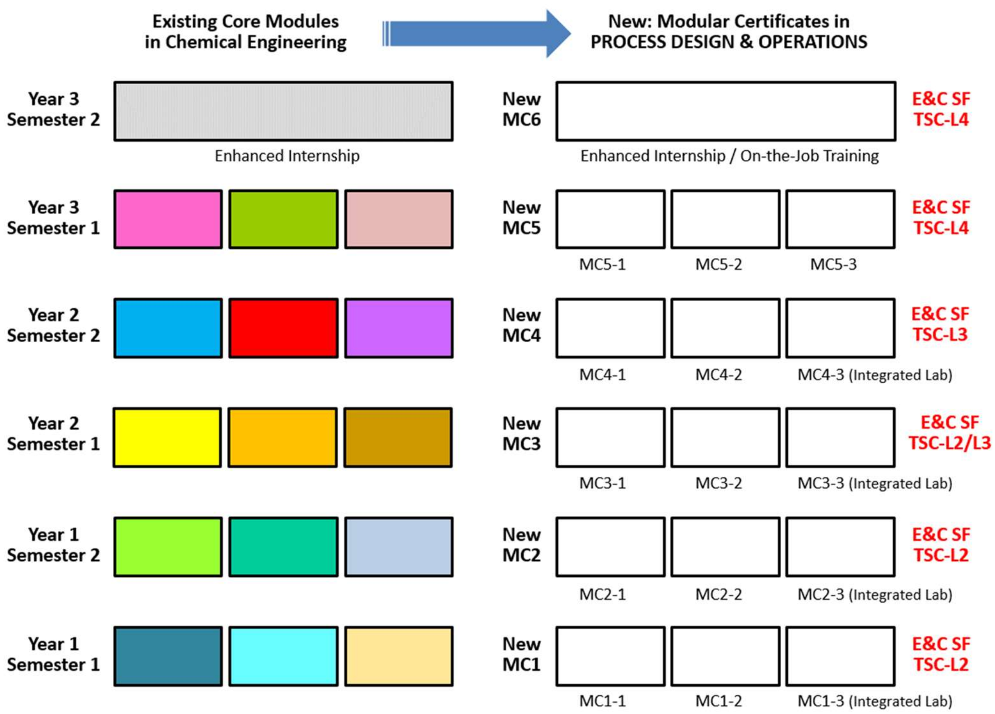

Figure 1. Modules in Existing Course Structure (left – coloured boxes) and New Modules in Proposed Spiral Curriculum Course Structure (right – white boxes)

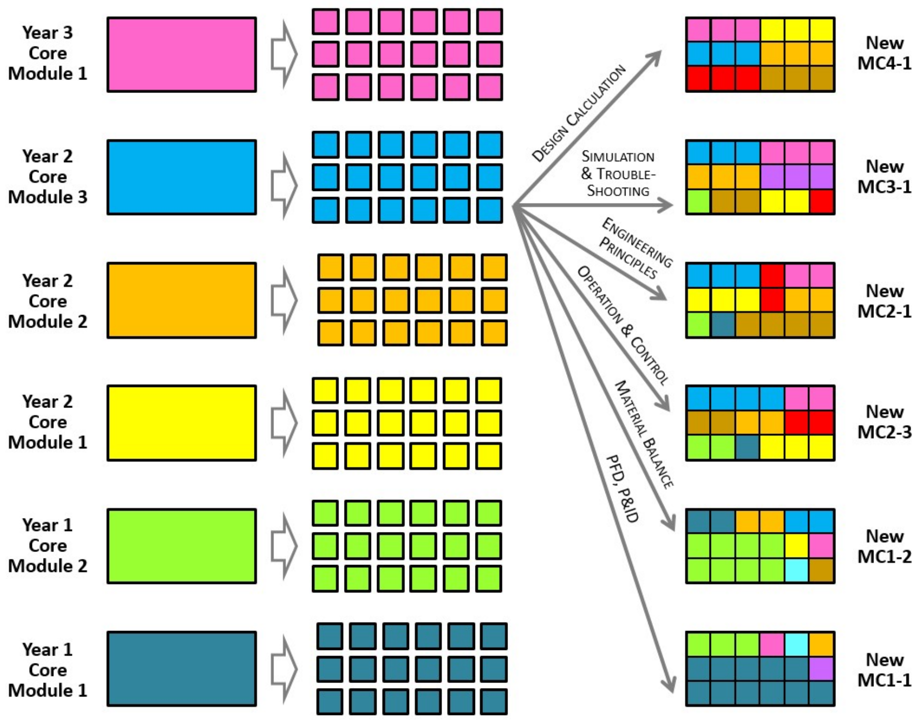

Figure 2. Approach to Redistribution of Topics in Existing Modules to New Modules

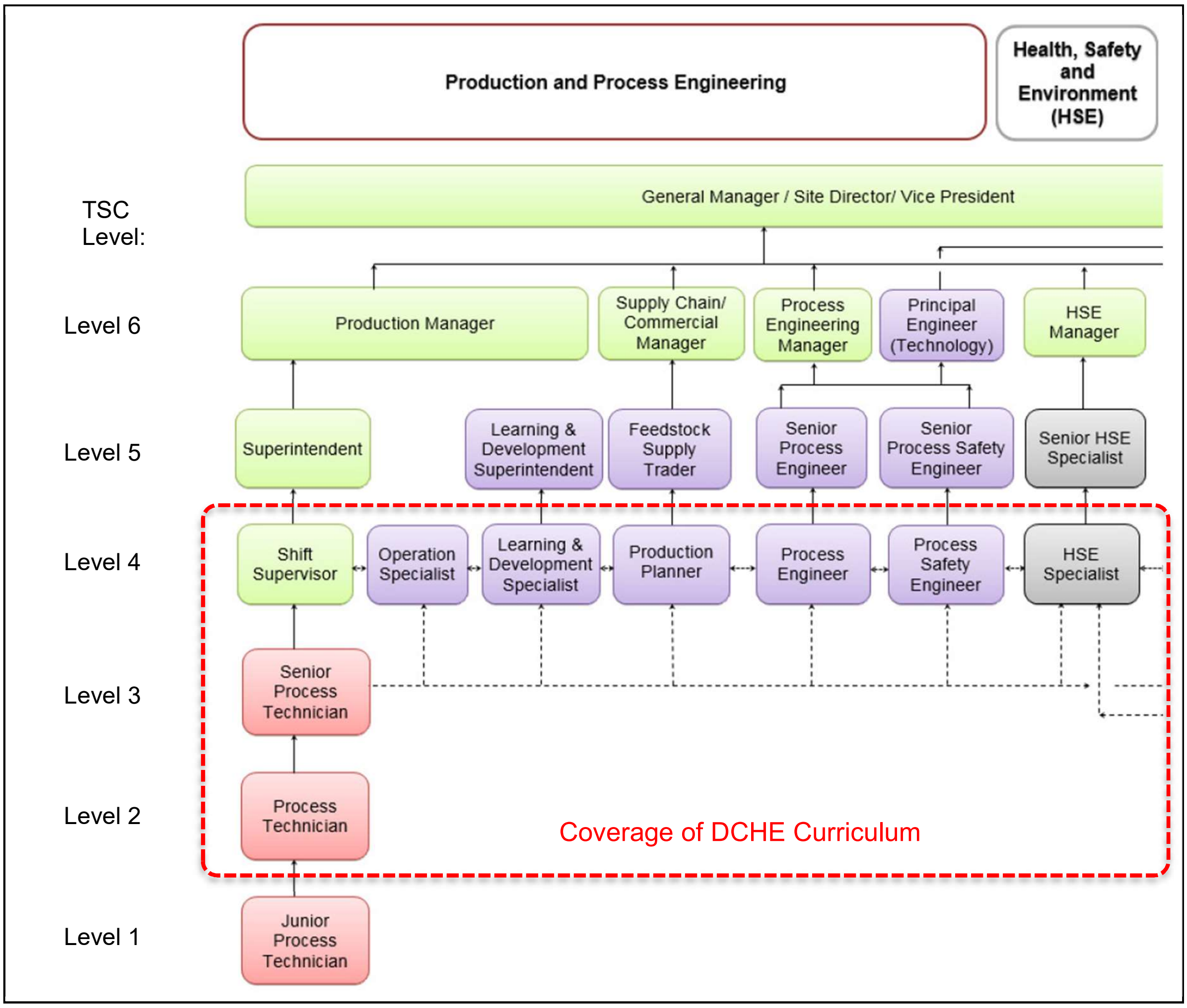

Figure 3. Partial Career Map for Energy & Chemicals Sector

These levels broadly correspond to the Job Roles and possible career pathways in the E&C industry. A partial career map for the E&C sector is shown in Figure 3, with 2 of several tracks in the E&C Industry, namely Production and Process Engineering; and Health, Safety & Environment (HSE). Also shown in Figure 3 is the focus of our curriculum design, where we attempt to map the new modules in the spiral curriculum according to the needs of a person to progress vertically from Process Technician up to Shift Supervisor; and from there horizontally to various positions such as Operation Specialist and Process Engineer to Process Safety Engineer and HSE Specialist.

The revised course structure is shown in Figure 4 as “House within a House”. With this we would be able to accommodate the learning needs of both adult learners and students under the SkillsFuture Initiative. Full-time (PET) students will take the full suite of modules covered by the big house, whereas adult (CET) learners can choose to pursue one or more MCs within the small house, depending on their career upgrading requirements, as shown earlier in Figure 3. The model also allows the “blurring” between PET and CET where adult learners may join the full-time students in classroom learning in so far as the MC-based modules are concerned.

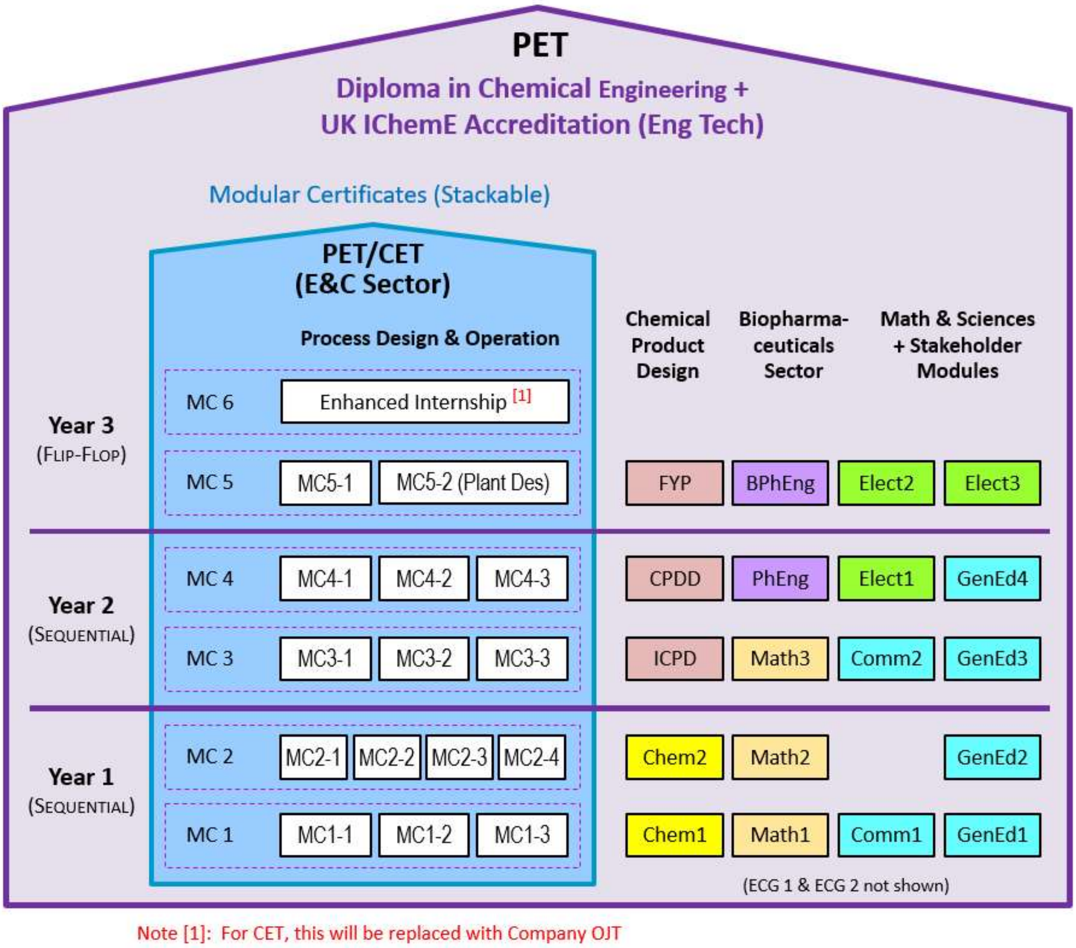

Figure 4. Revised Spiral Curriculum for DCHE

To provide a focal point of all core modules in the re-design effort, a typical chemical process plant is chosen to serve as "anchor" upon which the teaching of all chemical engineering related topics will make reference to the chosen chemical plant. This is to provide a consistent "sign post" in an integrated curriculum when building up the students' technical know-how from MC 1 all the way to MC 5 in a progressive manner. The typical chemical plant must be one that is commonly used in the chemical industry, utilises most of the unit operations needed in the DCHE curriculum, and technologically not too complicated.

All lecturers in DCHE are now in the midst of redesigning their respective modules in line with the abovementioned approach. The target roll-out date for the new spiral curriculum is April 2018. To meet the aggressive timeline, a series of meetings were planned, where the concept of spiral curriculum was explained, doubts clarified and the approach presented. Every Wednesdays were blocked for all lecturers to get together to discuss how best to "slice up" his/her respective module and reconstitute the components into a new module in the stated MC. The Year Coordinators (3 of them, one for each year of study) within the Course Management Team (CMT) takes the lead to guide the development work, supported by the Course Chair and Academic Mentors. Each year coordinator will mobilise the module coordinators and the team members on an as-needed basis to work on new modules under each MC.

Since every lecturer is a module coordinator of one or more modules, and at the same time a team member of other modules, such an approach ensures that each lecturer is made aware of the development work undertaken by everyone else. A master Excel file was created using Google Sheets so that at the end of each meeting, every module coordinator can enter the changes to be made, which can be referenced by everyone else. The Year Coordinator focused on the technical details of each module, especially the inclusion of all necessary content (i.e. the small coloured boxes in Figure 2); while the Course Chair assisted by the Academic Mentor reviewed the proposed new modules and ensure that the required integration and progressive learning are in place. Where omissions or shortfalls are detected, the Academic Mentor work with each module coordinator directly to improve the design of the said module.

At the time of this writing, all Year 1 modules (MC1-1, MC1-2, MC1-3, MC2-1, MC2-2. MC2-3 and MC2-4) are within different stages of receiving approval from the school management to implement the changes made.

CONCLUSION

This paper presented the journey undertaken by the Diploma in Chemical Engineering to re-design its curriculum after 10 years of implementing CDIO. The outcome showed that the CDIO Framework remained useful and relevant to guide the re-design process to handle the challenges posed by Chemicals 4.0. The self-evaluation process using the CDIO Standards proved most useful in guiding the team in the staged development of technical skills and competencies and generic skills and competencies as detailed in the Energy and Chemicals Skills Framework using the spiral curriculum approach.

REFERENCES

Accenture (2015). *The Future of Work in the Oil and Gas Industry*, Accenture Consulting

Accenture (2017a). *Manning the Mission for Advanced Manufacturing – New Demands on Talent in Singapore's Energy, Chemicals and Utilities Industries*, Accenture Consulting

Accenture (2017b). *Safety Culture in Chemicals*, Accenture Consulting

ATOS (2016). *Driving Digital Transformation in Oil and Gas*, ATOS SE

Bruner, J.S. (1960). *The Process of Education*, Cambridge MA, Harvard University Press

Cheah, S.M. (2018). A Comparison between CDIO Framework and SkillsFuture for the Redesigning of Engineering Curriculum, paper prepared for the Journal of Teaching Practice, Singapore Polytechnic

Cheah, S.M. & Leong, H. (2018). Relevance of CDIO to Industry 4.0 – Proposal for 2 New Standards, paper prepared for the *14th International CDIO Conference,* Kanazawa Institute of Technology, Jun 28 – Jul 2; Kanazawa, Japan

De Leeuw, V. (2017). Industrie 4.0 in the Chemical Industry, *ARC Insights*, May, ARC Advisory Group

Deloitte (2016). *Industry 4.0 and the Chemicals Industry: Catalyzing Transformation through Operations Improvement and Business Growth*, Deloitte University Press

DiBiasio, D., Clark, W.M., & Dixon, A.G. (1999). Evaluation of a Spiral Curriculum for Engineering, *29th ASEE/IEEE Frontiers in Education Conference*, November 10-13; San Juan, Puerto Rico

Elsevier (2017). *Industry 4.0: How Chemical Manufacturers Can Rise to the Challenges*, Elsevier R&D Solutions

Frost & Sullivan (2016). *Data-Driven Outcomes: How the Internet of Things is Driving Digital Transformation in the Chemicals Industry*, Frost & Sullivan

GE (2016). *Digital Future of Oil & Gas & Energy*, General Electric Company

Gomes, V.G., Barton, G.W., Petrie, J.G., Romagnoli, J., Holt, P., Abbas, A., Cohen, B., Harris, A.T., Haynes, B.S., Langrish, A.G., Orellana, J., See, H.T., Valix, M., & White, D. (2006). Chemical Engineering Curriculum Renewal, *Education for Chemical Engineers*, Vol 1(1), pp.116-125

Guertzgen, S. (2016). *Chemical Industry: 4 Opportunities Provided By Internet of Things*, Internet of Things Institute

IIC (2015). *Beyond Digitization: The Convergence of Big Data, Analytics and Intelligent Systems in Oil & Gas*, Industrial Internet Consortium

Kaestner, M. (2016). Big Data means Big Opportunities for Chemical Companies, *REACTION – Chemicals Magazine*, Twentieth Edition, KPMG Global Chemicals Institute

Lozowski, D. (2017). The Digital Transformation in the CPI, accessed on 18 August 2017, available from http://www.chemengonline.com/digital-transformation-cpi/?printmode=1

Richert, A., Plumanns, L., Gross, K., Schuster, K., & Jeschke, S. (2015). Learning 4.0: Virtual Immersive Engineering Education, *Digital Universities: International Best Practices & Applications,* Vol.2, pp.51-66

SAS (2014). *Analytic Innovations Address New Challenges in the Oil and Gas Industry*, White Paper by The SAS Institute Inc.

Schuster, K., Groß, K., Vossen, R., Richert A., & Jeschke, S. (2015). Preparing for Industry 4.0 – Collaborative Virtual Learning Environments in Engineering Education, *International Conference on E-Learning in the Workplace*, June 10-12; New York, NY

SSG (2017). Skills Framework for the Singapore Energy & Chemicals Sector, available from http://www.skillsfuture.sg/skills-framework

Uktem, U., Pariyani, A., & Grubbe, D.L. (2013). *Using Big Data to Predict Process Risks: White Paper*, Near-Miss Management LLC

Wehberg, G.G. (2015). *Chemicals 4.0 – Industry Digitization from a Business-strategic Angle*, Deloitte Consulting GmbH

BIOGRAPHICAL INFORMATION

Sin-Moh Cheah is the Senior Academic Mentor in the School of Chemical and Life Sciences, Singapore Polytechnic; as well as the Head of the school's Teaching & Learning Unit. He spearheads the adoption of CDIO in the Diploma in Chemical Engineering curriculum. His academic interests include curriculum revamp, academic coaching and mentoring, and using ICT in education.

Katerina Yang is the Course Chair for the Diploma in Chemical Engineering, School of Chemical and Life Sciences, Singapore Polytechnic. She leads the curriculum review for the diploma program to adopt the spiral curriculum model.

Corresponding author

Mr. Sin-Moh Cheah
School of Chemical & Life Sciences,
Singapore Polytechnic
500 Dover Road, Singapore 139651
smcheah@sp.edu.sg