DESIGN THINKING FOR CDIO CURRICULUM DEVELOPMENT

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ABSTRACT

Design Thinking (DT) is a human-centric approach to designing product, process, system and services. This paper aims to show how DT methodology and principles can assist curriculum developers empathise and gain deep understanding of their students. Insights on students' deep needs and learning behaviours can inspire curriculum development and teaching approaches that better engage students in active learning. The thematic Advancing CDIO curriculum development approach involves 4 themes, namely Mapping, Enhancing, Innovating, and Sustaining. For mapping the focus is on ensuring the continuous relevance of the curriculum. This involves conducting environmental scanning to better understand what are the emerging trends and the arising opportunities and challenges. Insights on the forces driving the changes for future of work help to determine and define the future skills expected of graduates. For enhancing CDIO skills, it is set in the context of Conceive-Design-Implement-Operate (CDIO) real-world systems and products. The emphasis is on enhancing students learning experience in a multi-disciplinary environment where students learn to work and collaborate with students from different disciplines to develop a project. The third Advancing CDIO theme on innovating teaching and learning approaches as well as learning space design explores how pedagogy and space design could be integrated to create conducive learning space that supports learning. Lastly, the sustaining phase describes how to determine the requisite resources and capabilities to consistently deliver quality CDIO programmes. The paper also shares the experiences gained from implementing engineering and non-engineering programmes through applying the design-led approaches in developing CDIO curriculum.

KEYWORDS

Design thinking, curriculum development, mapping CDIO skillsets, multi-disciplinary project, innovating CDIO learning and space, standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

INTRODUCTION

As the CDIO regional centre in Asia, Singapore Polytechnic (SP) showcases a model for transforming engineering education that other Institutions of Higher Learning (IHLs) in Asia can draw insights, learn and adapt. SP is keen and willing to share its CDIO experience and to assist other universities implement the CDIO framework. SP has shared its CDIO experiences with many IHLs in Asia and these CDIO capability development programmes that have been implemented were supported and funded by Temasek Foundation International (TFI). With the introduction of CDIO, these participating institutions shared common experiences of higher motivation and engagement of students. They also encountered

challenges such as understanding of the CDIO framework, implementation of the framework, buy-in from faculty members and workspace availabilities. (Lee et al., 2015)

Rajamangala University of Technology Thanyaburi (RMUTT), as the first CDIO collaborator in Thailand, has started introducing and applying the Conceive, Design, Implement, and Operate (CDIO) Framework for Re-Thinking Engineering Education since 2013 through a collaboration with SP that was supported by TFI. The institution is fully committed to the adoption and implementation of CDIO framework. RMUTT has established the quality management framework with CDIO as a foundation to produce hands-on professional graduates. Currently, 12 programmes from 5 faculties: Engineering, Business Administration, Mass Communication Technology, Architecture and Thai Traditional Medicine College, have fully adopted the CDIO framework. Industrial Engineering was the pioneer programme to adopt CDIO. (Kuptasthien et al., 2014).

In recent years, SP has developed expertise in Design Thinking (DT) human-centred approach to problem solving that drives creativity and innovation. The key to this process is empathising with the users' needs to generating innovative solutions. SP has already incorporated DT in the CDIO framework to enhance the "Conceive & Design" processes. Here, SP experimented with applying DT methodology and principles to strengthen curriculum development as a way to "Advancing CDIO" implementation. For simplicity this approach is called "Advancing CDIO". SP also shared this approach with the network of Rajamangala University of Technology (RMUTs) with the support of TFI.

This paper aims to:

1) Show how DT can assist the curriculum developers gain deep understanding of their students. Insights on students' deep needs and learning behaviours inspire curriculum development and teaching approaches that better engage students in active learning.
2) Highlight how the Advancing CDIO approach with its four themes, namely Mapping; Enhancing; Innovating; and Sustaining serve as a guide for effective curriculum development.
3) Demonstrate with examples from both engineering and non-engineering programmes, how this Advancing CDIO approach guides curriculum development.

LITERATURE REVIEW

Design Thinking (DT) is a human-centred approach to designing product, process, system and services. Many authors around the world have applied DT methodology in their teaching and learning practices as it promotes collaborative teamwork and communication along with critical and creative thinking skills. Some literatures are listed below:

A self-directed human-centric software engineering capstone course at Lappeenranta University of Technology, Finland, has effectively supported students with more hands-on and minds-on for the problem-based curriculum. (Palacin-Silva et al., 2017)

Computer Science and Software Engineering courses at a Federal University of Amazonas in Brazil implemented DT as an analytical and creative process to prepare students for the software development industry. The experience showed that DT encouraged students to come up with innovative and creative features for the application and improved the interaction among team members. (Valentim et al., 2017)

Multidisciplinary teams of students from engineering, design and art faculties at Shenka College of Engineering and Design in Israel have experienced using DT for product design practices. (Levy, 2017)

Darrin and Devereux (2017) at John Hopkins College of Applied Physics, USA has explored the incorporation of DT and Agile Manifesto in generic system engineering steps for system development life-cycle. The benefits of these new techniques will help systems engineering stay relevant and keep up with rapidly advancing technologies and intense competition environment.

The United States Air Force Academy, USA has adopted project-based learning and DT to achieve their educational outcomes. Their goal is to produce future digital-age military officers and government thinkers who can drive innovation with human-centric design approach. (Collins & Chiaramonte, 2017)

Suzuki (2016) investigated a novel approach of entrepreneurship education based on design thinking. Connections of design thinking courses with technology commercialization programme will benefit in the creation of a new key industry.

DT has been variously implemented by the CDIO community. At SP, DT has been infused into the CDIO framework in the Design-Built-Test concept and capstone-design projects. Here, the students have the opportunities to practice teamwork and communication skills along with creative and critical thinking (Fai, 2011). Yew et al (2016) showed the application of DT in conceive and design phases in Engineering Design and Business Project at SP. Kanazawa Technical College in Japan teaches DT in the curriculum with design methods, engineering management and graduation research. Learning Express[1] programme and mini-hydro power generation contest for extracurricular projects (Ito et al., 2015). CDIO framework and Design Thinking help raise the intrinsic motivation of the student to be innovative and try new ideas and challenges. (Leong, 2016).

Literatures showcase several applications and implementation of DT in teaching and learning, product design, capstone project, extra curriculum activities. However, to the authors' knowledge, there are very few literatures showing application of DT in curriculum development. McKilligan et al. (2017) used DT as a catalyst for changing teaching and learning. Faculty members redesigned courses and pedagogical approaches. One of the few literatures is a paper written by Kemp and Klaassen (2016) to envision engineering education 2030 for TU Deft. DT method explored questions regarding what future engineers should learn in higher engineering education in 2030. SWOT analysis was conducted to identify boundary conditions. The ideation stage revealed four future engineering students profiles: the Specialist, the System Integrator, the Front-end Innovator and the Contextual Engineer. An engineering and research environment called the Hubs encourage interdisciplinary learning. Last point of the findings is that common languages for future engineers consist of Mathematics, Digital literacy (data analytics, programming), Design skills, Academic communication, Engineering ethics and Collaborative and interdisciplinary teamwork.

[1]Learning Express (LeX) programme is an international Social Innovation Programme by Singapore Polytechnic that provides students with the opportunity to experience the natural world, learn new skills, make meaningful new friendships and rediscover yourselves through out-of-classroom learning.

DESIGN THINKING

This paper aims to show how DT can assist the curriculum developers gain deep understanding of their students. Insights on students' deep needs and learning behaviours inspire curriculum development and teaching approaches that better engage students in active learning. DT begins with empathizing with students' needs and challenges. This involves conducting observations and **Deep User Interviews** to uncover students' deep needs, motivations and pain-points. The open-ended interview questions were used to ask about their hopes, frustrations, needs, feelings, and desires, all of which will inspire ideas that improve student learning experience (including learning space design). Figure 1 shows an interview session of a student from the Tourism and Hotel Management programme. The next step, in **Needs Finding,** is to transform the observation and interview data into meaningful insights to uncover deep user needs. The interview transcripts were deconstructed into key information, quotes, and further clustered to identify common themes as shown in Figure 2. To help the programme committee focus on their students' needs, motivations, and challenges, **Student Persona** was developed to humanise the target users. Persona is a fictional character developed from interview outcomes that can help represents the student group.

Figure 1. Deep user interview (Tourism and Hotel Management Programme)

Figure 2. Deconstruct interviews into key information

ADVANCING CDIO CURRICULUM DEVELOPMENT

The Advancing CDIO curriculum development approach comprises 4 themes: Mapping; Enhancing; Innovating; and Sustaining. These 4 themes can be used to guide the institutions to enhance and strengthen CDIO implementation in addressing these 4 education concerns,

namely: ensuring continuous relevance of curriculum, meeting the professional standards of graduates, innovating teaching and learning approaches, and strengthening the quality of education. This thematic approach challenges institutions to explore and innovate guided by the four principles of Future-Focused, Purpose-Driven, Design-Led and Quality-Minded.

Mapping

Mapping focuses on ensuring curriculum relevance in the face of rapidly changing environment. It highlights the importance of gaining insights on the future landscape so as to achieve a better understanding of the emerging trends and the arising opportunities and challenges. The goal is to gain broad and deep background knowledge of the forces driving the changes that influence the future of work and future skills expected of graduates. Figure 3 shows the Mapping process which includes STEEP analysis, identifying new competencies, determining graduate attributes and CDIO skillsets mapping.

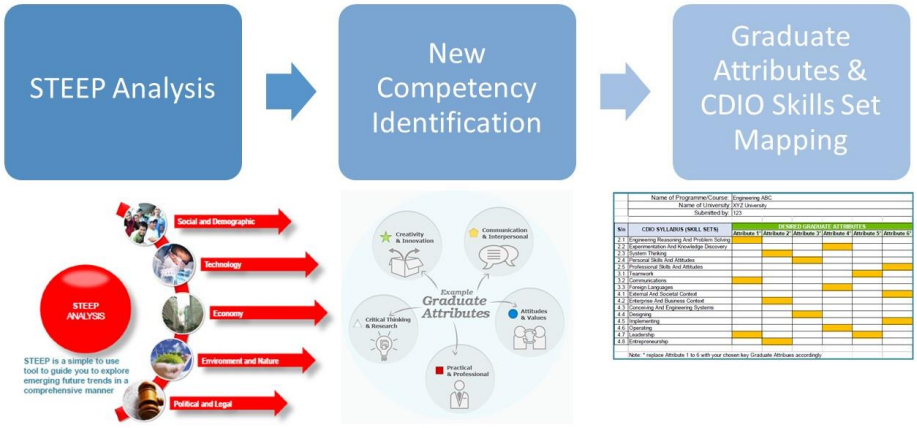

Figure 3. Mapping Phase

STEEP Trends Analysis

STEEP Analysis tool is a well-known framework used to explore future trends and their implications. Emerging mega trends are explored through these 5 categories: Social & Demographic, Technology, Economic, Environment & Nature, Political & Legal. The programme committee applied the STEEP framework to research and analyse the future trends for their industries.

Define the Future Graduate Attributes

Anchored in future trends, the programme committee analysed the opportunities and challenges as well as the future of works the students will encounter in this future reality. Insights on this future reality help to determine what are the desired future graduate attributes, which include attitudes, mindsets, skills and knowledge, may be needed to meet the future opportunities, challenges and future of works.

Mapping CDIO Skillsets with Future Graduate Attributes

The CDIO Syllabus is then mapped with the desired future-ready graduate attributes to determine which CDIO skillsets to emphasise and strengthen. The identified CDIO skillsets are then purposefully integrated into the programme curriculum and incorporated into the learning outcomes.

Enhancing

For enhancing CDIO skills, it is set in the context of Conceive-Design-Implement-Operate (CDIO) real-world systems and products. In line with DT principles which advocate multidisciplinary teamwork, the emphasis is on enhancing students learning experience in a multi-disciplinary environment where students learn and collaborate with students from different disciplines to develop a project. The enhancement of CDIO skillsets focuses on developing personal and interpersonal skills through cross-functional, multi-disciplinary projects (MDP) to foster resourceful professional graduates. The MDP is a student-project prepared by the teaching team. The students received a project brief before the commencement of the project. In addition, the process of completing a project provides opportunities for students to develop interpersonal skills and the opportunity to network with professionals who support them in the projects. Figure 4 shows 5 steps for planning MDP.

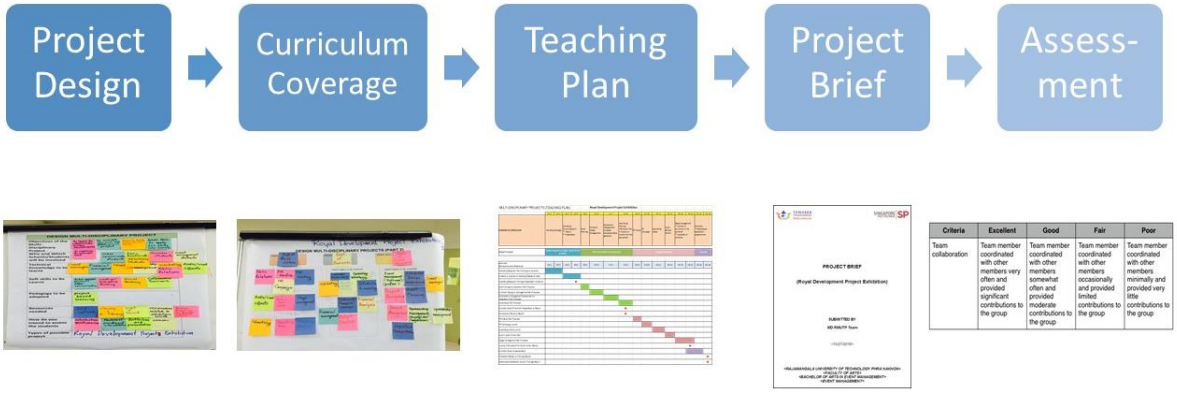

Figure 4 shows 5 steps for planning MDP.

The process begins with *Project Design* emphasizing on the development and design of MDP projects based on industry needs relevant to the programme. Grounded on solving real-world problems, MDP facilitate students to apply and acquire the range of requisite skills including personal and interpersonal skills. This is followed by *Curriculum Coverage* by identifying the range of topics and skills from each discipline involved in the project to allow the faculty member in-charge of MDP to map out the topics and skills that students need to learn from each discipline. This process ensures the MDP project curriculum covers all the requisite knowledge, skills and experiences that students are expected to gain. A weekly MDP *Teaching Plan* is then plotted with key milestones and activities. With that both students and MDP teaching staff can monitor and evaluate their progress. A MDP *Project Brief* is then prepared by lecturer that clearly spells out the project objectives, desired learning outcomes, the scope of the project, the different phases of the project, and the stakeholders relevant to the MDP project .This project brief serves as a guide for the entire project, from defining user requirements to completion ,Finally .MDP teaching staff design appropriate *assessments* given the nature of MDP projects and supported by assessment rubrics to ensure student performance is fairly evaluated across the disciplines involved.

Innovating

The third Advancing CDIO theme on innovating teaching and learning approaches as well as learning space design explores how pedagogy and space design could be integrated to create conducive learning space that supports learning. This design-led process encourages teaching faculty to explore and design effective teaching and learning experience drawing insights and inspiration from the student persona to better understand current student's needs, challenges and aspirations. Figure 5 represents components of innovating process with teaching and learning approach and learning space design.

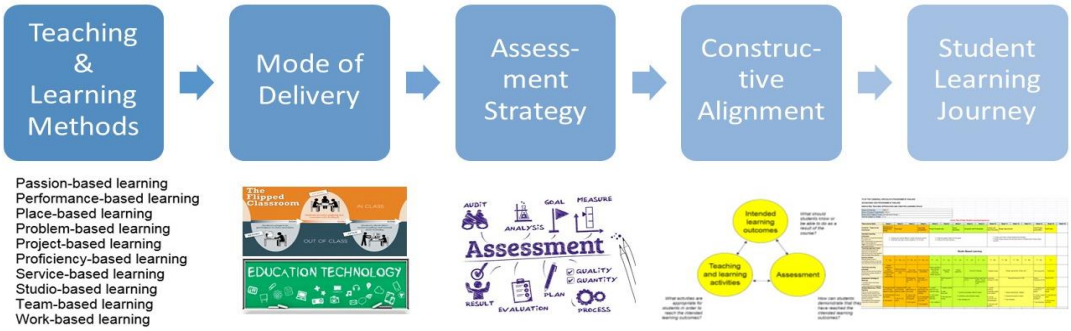

Figure 5. Innovating Phase

Here, the CDIO incorporated learning outcomes are first clearly defined on what the students will be able to do and what they should become. Then appropriate teaching approaches with relevant assessment methods are developed to address students' achievement of the desired learning outcomes and standards.

Create Conducive Learning Space

This design-led process to creating conducive learning space involves 5 steps, each supported by specific tools and techniques as shown in Figure 6.

Figure 6. Steps and techniques for Learning Space Design

Step 1: Visual Mapping is an effective way to illustrate the desired spatial atmosphere for the learning space. To stimulate creativity and idea generation, a visual "mood" board with a large quantity and variety of pictures is used. Faculty members select those visuals that best articulate the spatial atmosphere they envision the space to provide.

Step 2: Concept Development is defined by using Metaphors or Themes. This process involves identifying and defining the central themes or metaphors that best illustrate the overall concept of the learning space where the planned learning activities and student learning experience would take place.

Step 3: Ideal User Journey is illustrated by using Storyboarding. This step requires sketching images that illustrate students' learning experience in the learning space. The storyboard can explain the atmosphere of learning space one by one. Every perspective can show details of the functions and the relationship between the students and the learning activities.

Step 4: Space Plotting aims to visually zone the relevant physical space where the different planned learning activities may take place within the learning space. One approach is to use "bubble diagram" to zone or delineate where a particular learning activity would take place.

Step 5: Prototyping the Desired Learning Space is to transform the sketches into tangible, physical prototypes of the space. Prototyping allows the developing and testing of the space ideas at an early stage before large-scale resources are committed to build the learning space.

Sustaining

The sustaining phase focuses on the supportive and sustaining strategies needed to instil quality–mindset and culture amongst academic staff and across the entire institution. This may include a commitment to professional development of teaching staff and providing the requisite resources essential for advancing CDIO initiatives in the institution. Another contributing factor to sustaining CDIO initiative is to promote positive relationships and activities that engage teaching staff to collaborate with one another, as well as with peer mentors and academic mentors. The community of practice can lead to sustaining the change. It involves a group of educators/lecturers who meet regularly, shares expertise, and works collaboratively to improve teaching skills and the academic performance of students. Specific activities and goals of learning community may vary from institution to institution.

Example of Engineering Program: Industrial Engineering (IE)

Mapping: The program committee conducted STEEP Analysis and defined IE program outcomes and graduate attributes to align with Thailand 4.0 scheme (responding to the Global Industrial 4.0). Enhancing: Deep Users' interviews were conducted to better understand students' learning behaviors and their needs in order to help the program committee developed a Learner Centered curriculum. The students are assessed not only on their technical knowledge, but also communication and teamwork skills in the MDP. Innovating: The IE department explores how pedagogy and space design could be integrated to create conducive learning space that supports learning. Fab Lab as an innovative workspace to all students was developed after this exercise. Sustaining: Faculty development plan is developed annually to improve professional and teaching skills. The faculty members were encouraged to collaborate with industries. IE program was accredited by Thailand Accreditation Board of Engineering Education (TABEE) on 13-15 December 2017. It will be recognized as the 1st IE programme with outcome-based accreditation in Thailand. The Council of Engineers (Thailand) wish to submit to be a member of the Washington Accord in 2018. CDIO implementation since 2013 has facilitated the department in ensuring a smooth preparation for the programme accreditation.

Example of Non-Engineering Program: Tourism and Hotel Management

The Advancing CDIO thematic approach of Mapping, Enhancing, Innovating and Sustaining was adapted and applied to the "Tourism and Hotel Management" programme curriculum in inspiring the programme committee to rethink, develop and enhance its programme curriculum. Consequently, several courses have been developed for CDIO implementation this current academic year. The Innovating CDIO in teaching and learning has been integrated with Thai Qualification Framework (TQF) for planning the course. The team has observed a gradual positive change of their colleagues' attitudes towards CDIO. They found that CDIO concept is very beneficial for both of teachers and students. From the teachers' perspective, they can apply the CDIO framework and methodology in their classes, including designing the curriculum. In addition, students are more motivated and better engaged through the applied, hands-on active experiential learning.

CONCLUSION

This paper proposes a thematic Advancing CDIO approach to enhancing and strengthening CDIO implementation. This approach incorporates DT methodology and principles in

understanding and empathising with students' needs and challenges. With the future reality in view, the future graduate attributes help determine which CDIO skillsets need further emphasis. For enhancing CDIO skillsets, MDP can deepen student learning experience and strengthen students learn and develop requisite skills including personal and interpersonal skills. Active teaching and learning along with learning space innovation can increase intrinsic motivation and support students' learning in the Innovating process. For sustaining CDIO initiatives, it is important for the institution to encourage the community of practice in sharing and exchanging CDIO implementation experiences. Future work can focus on comparative studies among engineering and non-engineering programmes in the network of RMUTs regarding areas of improvement, challenges of the implementation and learning points.

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BIOGRAPHICAL INFORMATION

Chong Hwa, Lee (chonghwa.spi@gmail.com) is currently a Principal Consultant in Design Thinking and Education with Singapore Polytechnic International (SPI). He has over 30 years of career experience with a good track record in designing innovative educational models, quality courses and successful programme implementation. As a certified Design Thinking practitioner by Rotman DesignWorks, University of Toronto, he is a pioneer in infusing Design Thinking in business education. He has consulted, led and facilitated many Design Thinking and Education projects and workshops in Singapore and overseas. Chong Hwa graduated with a Bachelor of Social Sciences (Hons) from the National University of Singapore and a Master in International Business (President's Hons) from the Institute Surperieur de Gestion (ISG), France.

Linda Lee (lindalee.spi@gmail.com) is currently a Principal Consultant with Singapore Polytechnic. Since 2012, Linda has conducted many CDIO and other educational capability development programmes in countries including Mongolia, Malaysia, Indonesia, Vietnam, Thailand, Philippines, Korea and China. Prior to this, she was the Deputy Director from the School of Mechanical and Aeronautical Engineering and has been involved in the implementation of CDIO in Singapore Polytechnic since 2006. Linda graduated with a Bachelor of Science (1st Class Hons) and PhD in Information Technology in Machining from Loughborough University, United Kingdom.

Natha Kuptasthien is currently as assistant to president for International Relations and an associate professor at the industrial engineering department, faculty of engineering, RMUTT. She led a full CDIO implementation at RMUTT since 2013. She has conducted a number of CDIO introductory workshops for engineering and non-engineering programs, which expanded the CDIO network to 8 RMUTs and universities in Asia. Natha graduated with a Bachelor of Engineering in Industrial Engineering from Chulalongkorn University, Master of Science and PhD in Engineering Management from University of Missouri-Rolla, USA.

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