An Integrated Engineering Education Alignment Model towards Industry 4.0

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Abstract

This paper describes an integrated alignment model towards Industry 4.0 for undergraduate engineering education. This integrated alignment model nurtures synergy among engineering education activities such as applied learning, applied research, and continuous education training (CET) programs to share a common Industry 4.0 vision. The stakeholders of this model include students, faculty, industry partners, and recipients of CET programs. This model applies Singapore Smart Industry Readiness Index (SIRI) as a guideline to align the various engineering activities. It advocates effective collaborations with industry partners, thus improve the quality of applied learning and applied research. Meanwhile, industry partners can benefit from receiving the state-of-the-art concepts and knowledge of Industry 4.0. The proposed integrated model provides practical guidelines to align the undergraduate engineering education towards Industry 4.0 vision. The case study presented in this paper shows that multifaceted results can be obtained from applying this model.

Keywords

Integrated Alignment Model, Applied Learning, Engineering Education, Applied Research, Industry 4.0

1. Introduction

Many countries have begun with adapting their infrastructure, including the education system, to meet the Industry 4.0 requirements since the first definition of Industry 4.0 was published in 2011 (Drath and Horch, 2014). The phenomena of Industry 4.0 as the next wave of the industrial revolution are widely embraced and accepted by the Singapore government, academic institutions, and industries.

In 2017, the first Industry Transformation Asia-Pacific (ITAP) was held in Singapore. It is the world's leading trade fair for industrial technology and the Asian edition of Hannover Messe. The year 2020 was the third year Singapore hosting ITAP, which returned as a three-day virtual event with physical bolt-on activities due to the Covid-19 crisis. In this event, a few initiatives were announced focusing on manufacturing by leveraging Industry 4.0 and upskilling the workforce. An industry-led national program, Advanced Manufacturing Training Academy, was launched to lead the foresight of emerging skills and knowledge required for Industry 4.0 (Baharudin, 2020).

Singapore Smart Industry Readiness Index (SIRI) was initially launched in 2017 by the Economic Development Board (EDB) of Singapore in partnership with a network of leading technology companies, consultancy firms, and industry and academic experts. SIRI was designed to be a comprehensive tool to help industrial companies harness the potential of Industry 4.0 (EDB, 2017). After that, an extension of SIRI, the Prioritization Matrix, has been further developed to further assist industries in developing action plans and implementations of Industry 4.0 (EDB, 2019). Singapore is also partnering with the World Economic Forum to drive the global adoption of the Smart Industry Readiness Index (SIRI) (EDB, 2020).

A big challenge of the Industry 4.0 development lies in the timely upgrading of the existing workforce and preparing the next generation talents. It is critical to adapt and align the higher engineering education to Industry 4.0 vision. It requires a holistic system review and meticulously alignment of existing higher engineering education systems according to emerging Industry 4.0 requirements.

With the disruption of the pandemic of Covid-19, universities sense the urgency and need of acting more aggressively by shifting to online teaching and aligning engineering education towards Industry 4.0. As Covid-19 pushes learning institutes to transform, Singapore universities must disrupt themselves to transform or be forced to do so (Ang, 2021).

Many research works have been published regarding the development of new courses, setting up new learning labs, or learning factories to catch up with the emerging technologies related to Industry 4.0. However, less research work is found at the higher engineering education system level to explore the alignment of various existing engineering education activities from an Industry 4.0 perspective.

1.1 Objectives

The research objectives of this paper are listed below:

1.1.1 Conduct a literature review of the related works: related research works on engineering education and Industry 4.0;
1.1.2 Describe the proposed integrated alignment model: the key pillars of the alignment model;
1.1.3 Demonstrate a case study for the application of the model: how the different pillars are aligned to Industry 4.0 through CET, applied research, and applied learning;
1.1.4 Future works: further enhancement of curriculum, greater coverage of CET, and further strengthening industry collaborations.

2. Literature Review

The rapid development of Industry 4.0 worldwide across industries triggered a surge in demand for Industry 4.0 ready talents. The undergraduate engineering education system is facing both challenges and pressure of creating a next-generation talent pool to support the Industry 4.0 revolution. With the emerging of Industry 4.0, recent years have seen growing number of research work on the subject of the engineering education system in the context of Industry 4.0.

A major group of works focused directly on the emerging technology areas involved in Industry 4.0. These works focused on the educational needs of certain key technologies, which should be added into the curriculum, such as artificial intelligence, IoT, cloud computing, etc. (Dopico et al., 2016).

It has been a hot spot for many universities to set up new lab concepts in recent years to steer engineering education towards the Industry 4.0 vision (Zarte and Agnes, 2017). It is hoped the new lab platforms could enable students to work in Industry 4.0 environments. Faller and Feldmüller (2015) described one example of a learning factory designed and implemented as their lab concept. The learning factory was built with processes at the shop floor level and integrated with a high-level ERP system. Such a learning factory tried to address the problems faced by SMEs of lacking skills and skilled talents.

Some research works focused on the technical support of engineering education. For instance, novel digital education technologies such as mixed-reality systems and virtual teaching and learning systems are evaluated and applied in higher education (Guo, 2015). The merging of the real and virtual world with mixed-reality technologies enable users to experience reality-based interaction. It enhanced the digital E-learning experience with virtual physical experiences. The engineering education system should be the pioneer to employ advanced digital education technologies, such as intelligent learning systems, big data support systems, AR/VR systems, and innovative learning environments like mixed-reality, simulation, augmented reality, and remote laboratories (Jacob et al., 2008).

At the university level, a framework of Industry 4.0 engineering education at Turkish German University is presented by Coskun et al. (2019). This framework covers three main stages of university engineering education, i.e., curriculum, laboratory, and student club. The curriculum incorporating Industry 4.0 vision and knowledge enables students to obtain a basic knowledge of Industry 4.0. At the lab stage, interactive learning tools were applied for students learning, such as visualization software tools, Lego Mindstorms systems, rapid prototyping, etc. The third stage is an interesting student club, which involves students on the application of the Industry 4.0 scenarios to the production models at a Lego-lab.

Another group of works concentrates on the new qualification requirements in the Industry 4.0 revolution. Some of the new requirements include interdisciplinary thinking, decision, and problem-solving, cultural and intercultural competency, and lifelong learning. For the university-level education system, the increasing need for flexibility in terms of interdisciplinary collaboration and soft skills, in-depth university and industry collaboration, and open learning systems were highlight by Huba and Kozák (2016).

Few works were found to examine the university curriculum from the industry standard. Götting et al. (2017) presented a study related to curriculum development, which proposed a methodology using the Industry 4.0 Reference Architecture Model to evaluate study programs. Two study programs of the Faculty of Technology of the University of Applied Sciences Emden/Leer are assessed based on their methodology.

It can be seen that most of the literature works focused on curriculum-related engineering education activities within the campus, such as new courses, new learning lab, or learning factories. These works addressed the importance for universities to create an Industry 4.0 learning environment within the campus.

However, other than curriculum development and new lab concepts, more can be done to explore the alignment of the engineering education activities at the university level. This paper presents an integrated alignment model towards Industry 4.0 vision by nurturing synergy among engineering education activities, with a case study to show multifaceted results achieved from the application of this model.

3. Integrated Alignment Model

This section describes an integrated engineering education alignment model to align the university engineering education towards Industry 4.0. As applied learning and applied research-focused university, SIT actively encourages and supports faculty to work with industry partners to use the practical industry problem statements for applied learning purposes, and address the latest practical industry-specific challenges through applied research.

To embrace the challenges from Industry 4.0, new courses are created, and existing courses are revamped to accommodate increasing demands for Industry 4.0 related technological areas. New learning labs are also established to provide students with Industry 4.0 related learning environment.

Besides, it requires collaborative efforts from both industry and academic in transforming the engineering education system to be aligned with Industry 4.0 vision. In SIT, it is planned in the curriculum for students to take an eight-month to one-year industry work and study program (IWSP). This IWSP aims to equip students with industrial knowledge by bringing them out of campus and being involved directly in real-world projects.

Applied learning, applied research, and continuous education training (CET) are three important engineering education pillars at SIT. These three pillars are running in parallel and managed by different departments. Applied learning mainly focuses on how to bring the latest industry requirements and knowledge into students learning. Applied research is to encourage academic faculty to develop industry engagement and collaborations to address industry-related real-world problems. Continuous education training is referred to the industry-specific training provided to companies, working adults, and student alumnus.

This paper discusses an integrated alignment model of SIT that intends to nurture the synergy among these different engineering education activities. As shown in Fig.1, this model consists of the three pillars of engineering education and intends to nurture the synergy among the three. With this model, it is expected the Industry 4.0 vision alignment could be holistically managed across the three pillars of engineering education.

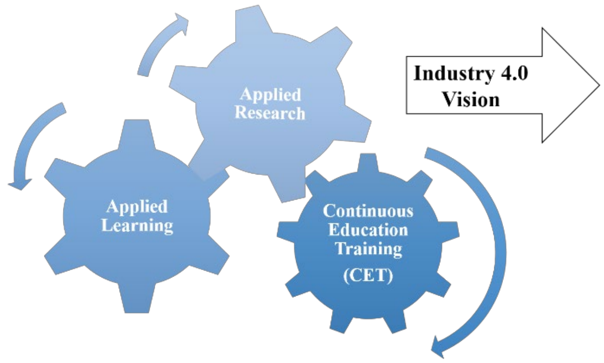


Fig.1. Concept of Integrated Engineering Education Alignment Model

The CET programs are managed by SIT SITLearn Professional Development (SITLearn PD), which is the lifelong learning division of SIT. The CET programs are catered for working adults who are keen to upgrade and gain new skill sets needed in their workplace. While SITLearn PD is taking care of the applied learning activities for industry training, it also plays an important role in synergizing the applied learning activities between the CET programs for working adults and those for Undergraduate/Postgraduate students.

The applied research requires close collaboration between SIT faculty and industry companies. With applied research projects, faculty has exposure to seeking practical applications of new concepts and technologies by working together with industry partners. Through applied research projects, proof-of-concept prototypes can be developed and subsequently implemented in companies. The applied research results could also be used for CET programs to propagate the newly generated concepts, knowledge, and skillsets to broader industries.

Once the applied learning materials for CET are verified and finetuned with feedbacks from the industry, they can be used for applied learning for Undergraduate/Postgraduate students. They could also be conducted in parallel with the newly developed materials, thus the process of transferring the industry knowledge for applied learning can be expedited.

4. Case Study

This section describes a case study on the application of the integrated alignment model. The case study covers examples of applications of the model in CET programs, applied research, and applied learning respectively.

4.1. CET Programs

The CET programs play an important role for faculty to engage with industry and propagate academic and applied research knowledge to industries. In the meantime, through interactions with industry participants, SIT faculty could have a better understanding of industry problems and industry requirements. Besides, the feedback from the CET programs and lessons learned are valuable to enhance the applied learning and applied research.

The concept of Industry 4.0 could be new to many industries, especially SMEs. The mission of CET programs is to convey the concepts, vision, and knowledge of Industry 4.0 to industries. Existing and new proposed CET programs need to be reviewed to ensure they incorporate the latest development of Industry 4.0.

The recommended tool to review the CET programs is the Singapore Smart Industry Readiness Index (SIRI). SIRI was designed as an effective evaluation tool to help industrial companies to explore the potential opportunities towards Industry 4.0 (Lin et al. 2019), it can be also used to evaluate CET programs to understand the width and depth of the contents in terms of Industry 4.0 coverage.

Fig.2 shows the three layers of SIRI with the top layer consisting of the three fundamental Industry 4.0 building blocks: i.e., Process, Technology, and Organization. The second layer lists eight key pillars, i.e., operations, supply chain, product lifecycle, automation, connectivity, intelligence, talent readiness, structure and management. At the third layer, the eight pillars are mapped into 16 dimensions.

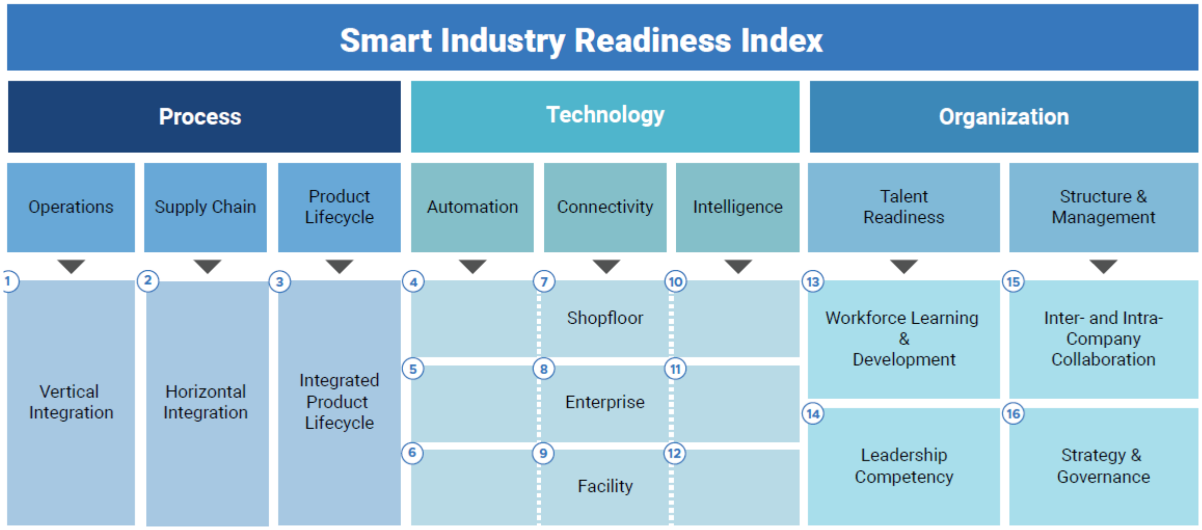


Fig.2 Three layers and sixteen dimensions of SIRI

As part of the integrated model, the selected CET programs are evaluated according to the SIRI to identify their relevance to Industry 4.0. Table 1 shows a few examples of CET program courses being evaluated. For example, Courses 1, 2, and 3 are all related to Dimension 4 (shop floor automation), Course 4 is related to Dimension 7 (shop floor connectivity), and Course 5 is related to multiple dimensions 10, 11, and 12 (intelligence).

Such a mapping helps to review and evaluate existing or new proposed CET programs with SIRI as a reference to align the CET programs to Industry 4.0 vision. SIRI also encapsulates a LEAD framework with four steps of a process, i.e. Learn, Evaluate, Architect, and Deliver. As learning is the first step for companies to understand the key concepts of Industry 4.0, followed by evaluating the current status, architect the future desired Industry 4.0 company structure, and finally develop the roadmap of transformation to deliver the outcomes.

In a CET program course for industry, i.e. System Operations, an assignment was tasked for the participants from industry to apply the LEAD framework for their workplace applications. Fig.3 shows an example submitted by a group of participants from a company. They adopted the four steps plan to work towards Industry 4.0.

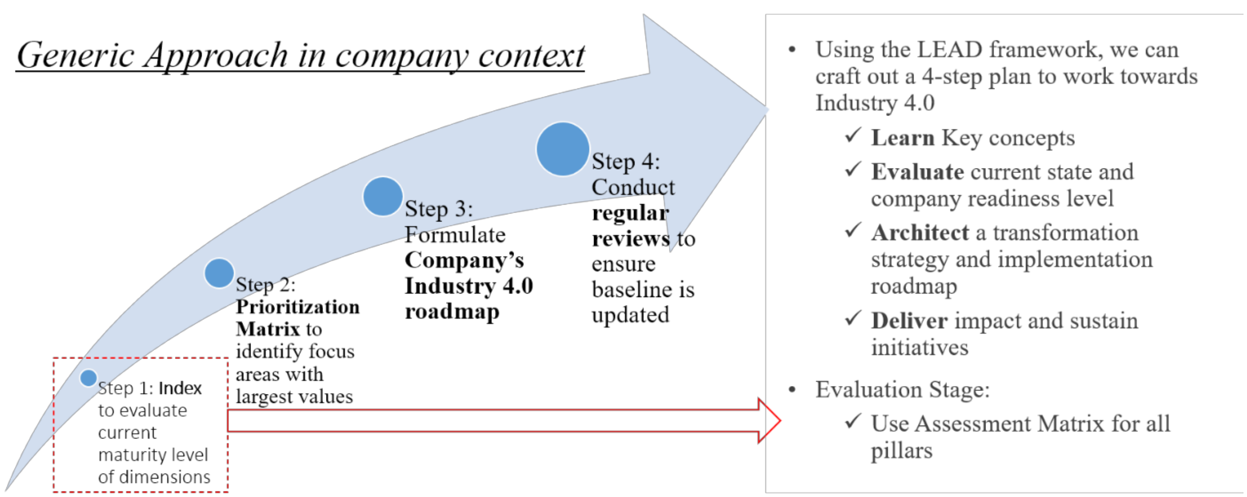


Fig.3. Application of SIRI LEAD framework for Industry 4.0

Table 1. Classification of CET programs according to SIRI

Mapping of CET courses to Smart Industry Readiness Index			
S/N	**Course Title**	**Course Synopsis**	**Potential Relevance to SIRI Dimensions**
1	Introduction to Robotics Fundamentals	This workshop will introduce participants to this exciting world of robotics. It aims to equip participants with the fundamental knowledge in robotics such as the anatomy of robots, characteristics of robots, modelling of robots as well as selection of the right robots for the right tasks.	Dimension 4 - Shop Floor Automation
2	Introduction to Robotic Modeling	This workshop will equip participants with the theories of robotics and related mathematical tools for robotic modelling. Topics will include forward & inverse kinematics, Denavit-Hartenberg representation, Jacobian and trajectory planning. There will be hands-on exercises which allow participants to apply the knowledge of robot kinematics. These knowledge will allow the participants to gain a quantitative understanding of robotic system commonly employed in the industries.	Dimension 4 - Shop Floor Automation
3	Introduction to Robotic Programming	The workshop will equip participants the basics of Robot Studio software and RAPID, a high-level robot programming language. The second half of the workshop will be a hands-on session to perform offline robot programming of the robotic arm for a specified pick-and-place task. Subsequently, the program will be loaded into the actual robotic work cell to execute the task.	Dimension 4 - Shop Floor Automation
4	Internet of Things (IoT)	This beginner-level 2-day workshop is aimed at introducing participants to gain an appreciation of Internet of Things (IoT) and the building blocks for such a solution.	Dimension 7 - Shopfloor Connectivity
5	Machine Learning II: ML Fundamentals and Supervised Learning	This course focuses on establishing the math and programming foundations for machine learning (ML) as well as introducing supervised learning techniques, a class of ML techniques based on learning by examples. This course is recommended to be taken as a continuation from Machine Learning I or as a standalone for attendees with the recommended foundation.	Dimension 10 - Shop Floor Intelligence Dimension 11 - Enterprise Intelligence Dimension 12 - Facility Intelligence

4.2. Applied Research

Applied research is to encourage academic faculty to develop industry engagement and collaborations with industry partners to explore the opportunities to transfer the latest academic concepts and technologies into industrial applications and address industry-related real-world problems. It has always been a requirement for university faculty and students to conduct applied research at the premises of industry partners for faculty to acquire the latest industry knowledge and state-of-the-art skill sets.

One alternative method is to set up an in-house learning lab or learning factory. However, it is often very costly to maintain and upgrade these in-house built facilities because the industry is undergoing rapid development, most technologies are quickly changing and evolving. New technologies and new processes keep emerging with fierce market competition. There are limitations to only rely on learning labs or learning factories inside the campus, for the assets are static, and costly to maintain their further expansion or development. Therefore, real workshops and factories are preferred for applied research work.

SIRI can be used as a technology road-mapping tool to engage industry partners for exploring the opportunities of collaborations. Rather than work with a company on ad hoc projects, it desires to work with an industry partner by co-conducting the technology road-mapping through evaluating current processes and systems and working out the future Industry 4.0 development plan. After the evaluation and road-mapping exercises, a few major work areas and opportunities can be identified to collaborate with the industry partner. These areas normally fall into the process and technology building blocks of SIRI for engineering education.

Fig.4 illustrates the results from the technology road-mapping exercise collaborated with an industry partner. A portfolio of project opportunities related to Industry 4.0 is planned out in phases according to the applied research plan. Four key pillars are covered by the planned portfolio of applied research project topics, i.e. connectivity, automation, operation, and intelligence. All these project opportunities are mapped into different phases with a timeline of about two years.

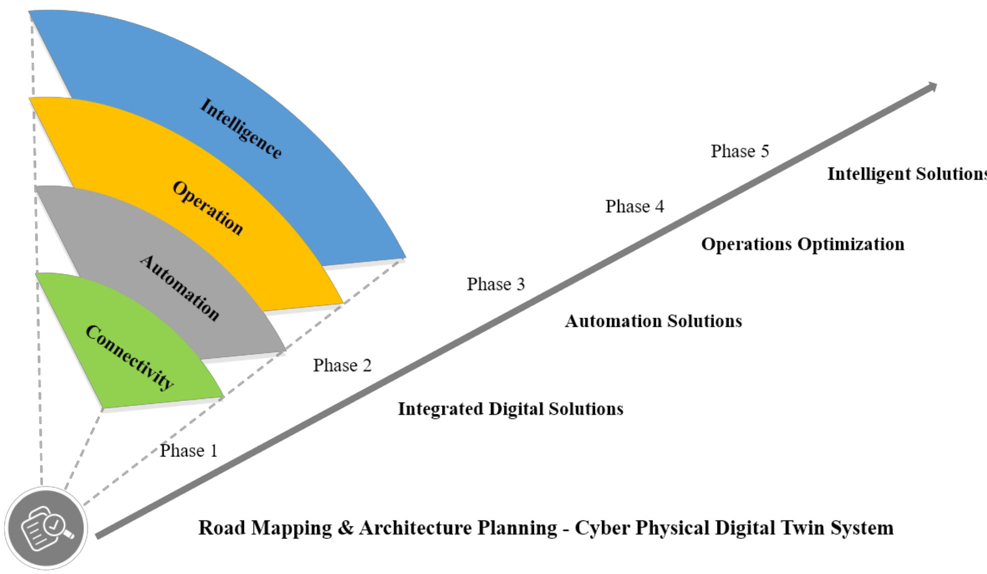


Fig.4 The results from the evaluation and road-mapping exercise

Based on the evaluation and technology road-mapping exercise, an applied research project, an Industry 4.0 Cyber-Physical Digital Twin for manufacturing is defined as a key applied research project. This applied research project plays an important role in setting up an Industry 4.0 testbed and platform for experimenting with different scenarios of Industry 4.0 factory configurations, various IoT technologies, and intelligent decision-making systems, including potential machine learning and autonomous optimizations.

4.3. Applied Learning

With the applied research project as an anchor point, a pipeline of student projects are defined according to the technology road-mapping exercise as subsequent following activities associated with the applied research project. Most of these projects are aligned and related to the road-mapping plan shown in Fig.4.

These student projects are published as potential capstone and final year project (FYP) projects in the students' portal. Students need to express and register their interests on those they are willing to participate in. Some of the projects with wider project scope are for a group of students to work as a capstone project, and the rest projects are for an individual student to take as an FYP project. Since most of these projects are derived from the evaluation and technology road-mapping exercises, the projects' scopes are in line with the company's requirements and students' learning outcomes.

Table 2 lists the project title of the applied research and some example capstone and FYP projects. It can be seen that with the integrated alignment model, it is very productive to define students' projects related to the applied research project. Because this integrated model addressed real industry requirements related to the applied research project, the context of the applied learning is highly relevant to problem statements demanded from the industry. Faculty and students are therefore strongly motivated to work on these practical industry problems.

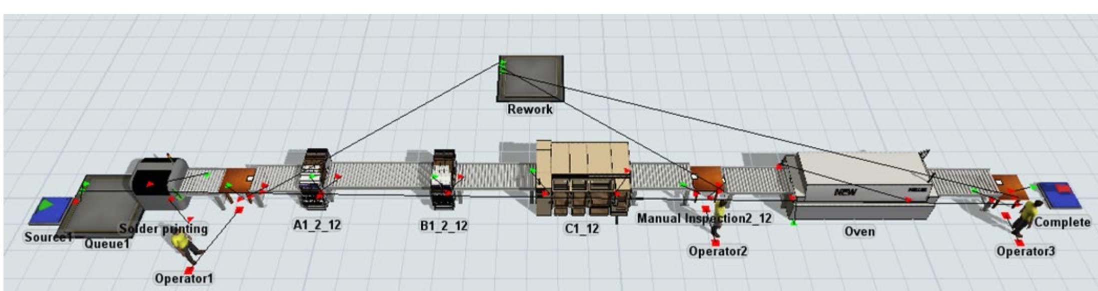
Table 2. Applied research project and related students projects

	Applied Research Project and students projects
AR Project	Applied research project on A Cyber-Physical Digital Twin System for Manufacturing
Capstone Project	Manufacturing Digital Twin System
FYP	Manufacturing Monitoring and Controlling System
FYP	Concept and Implementation of Digital Twin System for Manufacturing
FYP	Manufacturing Inventory Control System
FYP	Manufacturing E-Scheduler System
FYP	An Integrated Dashboard for Digital Twin
FYP	LED Guiding Tool for Manufacturing
FYP	Simulation-Based Robot Design for Manufacturing
FYP	Universal Poka-Yoke Controller for Production Line
FYP	Using OptQuest for Simulation Optimization of Production Schedule

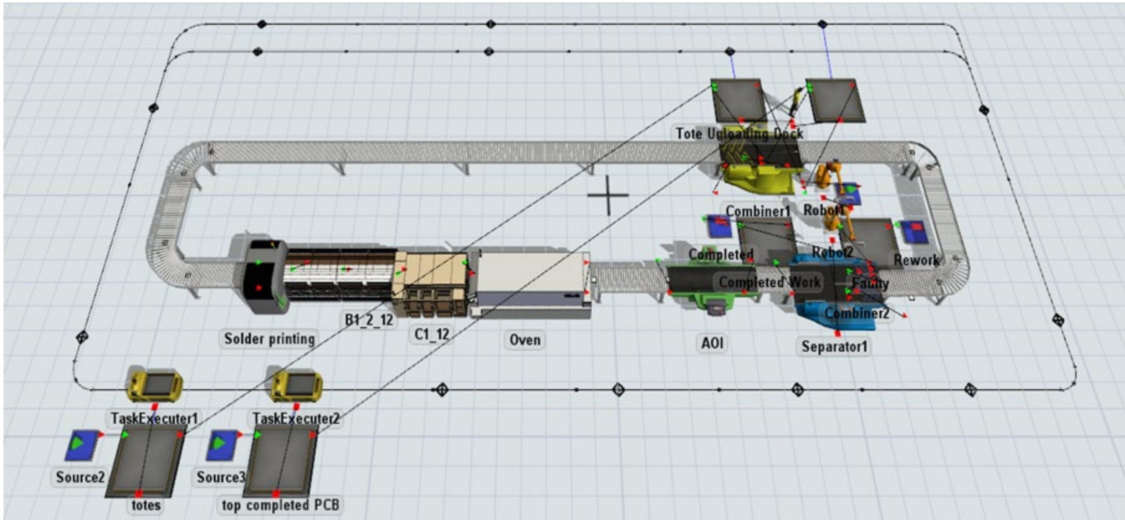
With such an integrated alignment model, the state-of-art industrial knowledge can be brought into the applied learning activities promptly. The students are also well prepared and motivated to capture the latest industrial requirements for Industry 4.0. With a research collaboration agreement endorsed by the management of both SIT and industry partners, it makes the time invested by both faculty, students, and companies more effective and productive. The continuity of the collaborations with companies is further enhanced because most of the capstone and FYP projects are defined according to the evaluation and technology road-mapping exercise.

During the Covid-19 circuit-breaker period, students were not able to physically visit the shop floors of the industry partner. To help students to understand the industrial processes better, 3D simulation models were used to explain and demonstrate the industrial problems. These 3D simulation models can be accessed through a web-server.

Fig.5 illustrates an example of a production line built in Flexsim®. Through the simulation model, students can understand the details of the production processes, and conduct simulation study and analyze the industry problem under study. This simulation project not only helps students acquire industry knowledge through simulation modeling but also enables them to analyze the current systems and experiment with new Industry 4.0 technologies for process improvements in terms of efficiency, throughput, and cost reduction.



(a) Current Production Line Layout



(b) Proposed Production Line Layout

Fig.5 Applied learning through simulation modeling of manufacturing production lines

5. Conclusion

This paper conducted a literature review of related research works on engineering education and Industry 4.0. Then it described an integrated engineering education alignment model towards Industry 4.0 vision. Through a case study, it discussed the applications of this model on how a series of synergized engineering education activities can be defined and planned to leverage industry standard, i.e. SIRI. The involved engineering education activities include applied research projects, students' capstone and FYP projects, and CET programs. Through this model, both faculty and students are exposed to opportunities to address the practical technological challenges of Industry 4.0. It also enhanced the strategic partnership between university and industry partners. By and large, this integrated alignment model could help to align the engineering education to be more industry-oriented and support the Industry 4.0 vision.

The success of the case study depends on many factors, such as the applied research topics, the support from industry partners, the involvement of faculty and students, etc. The use of Industry 4.0 standard SIRI for technology road-mapping is more suitable at the corporate level. It is ideal for the alignment to be dialogued at the university level with industry partners.

The future works include firstly the further enhancement of the curriculums with more relevance with Industry 4.0 vision, especially new proposed programs with a greater breadth and more interdisciplinary and cross-domain knowledge. Secondly, the greater coverage of CET programs on Industry 4.0 topics, which are in surging demand to upskilling the existing workforce with Industry 4.0 knowledge. Thirdly, the further strengthening of the strategic relationship between academics and industries. After all, ROI is the fundamental concern for companies to collaborate with universities on applied research, it is important to plan in phases for companies obtaining the business benefits along the journey.

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