CDIO APPROACH IN DEVELOPING SOLUTION MINDED LEARNERS

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ABSTRACT

From its early days as the first polytechnic in Singapore, Singapore Polytechnic (SP) has been working closely with the government to train and arm the workforce with the skills needed for the country's economic growth. As the pace of globalisation accelerated in the 80s to 90s, the strategic policy was implemented to strengthen and drive towards becoming an innovation economy. This strategy led to the setting up of research and innovation centres in the local Institutes of Higher Learning (IHL) such as SP. In SP, the Civil Engineering course is one of the first engineering courses that offers a broad-based engineering discipline. The School of Architecture and the Built Environment (ABE) is the first school to offer built environment related courses, including the civil engineering course, before being a coordinator of training for the Building and Construction sector among the five local polytechnics. As an applied learning institution, ABE Civil Engineering has adopted the CDIO approach allowing staff and students to engage in real-life and industry relevant research projects to enable the application of knowledge and the use of CDIO skills to conceptualize, design and develop industry relevant solutions. Such engagement in real-life and industry research project settings enable students in their final year projects (FYP) to directly contribute to real-life such industry projects, while building their proficiency to become solution-minded learners who are both innovative and have a curious mindset.This paper describes the integrated learning process of how the adoption of CDIO approach can be realised with staff in close collaboration with the industry to pursue industry relevant solutions. This integrated learning experience (CDIO Standard 7) can foster the learning of disciplinary knowledge simultaneously with solution-minded strategies.This collaboration with the industry explores the journey that ABE has taken from concept, design to development of its green masterplan, to its evolution and establishment of focus on green technology research that expose students to such research areas through their (FYP) involvement. Two research projects of recycling of palm frond into bioplastic, and also of incinerator ash to aerogel materials, will be utilised to show how these FYP student activities help students to be solution-minded in their approaches. Feedbacks were collected through face-to-face interviews with the two groups of students to identify challenges and propose improvements to facilitate the integrated learning experiences. This paper represents the work of the current CDIO implementation and the initial development of a new module.

KEYWORDS

Solution minded, green technology, industry projects, curious mindset, innovative, Standards: 2, 3, 7

INTRODUCTION

Circular Economy has become an economic imperative more than ever, compounded with many pressing factors such as game-changing and world-changing phenomena that have changed the industrial landscape. Among these factors, Industry 4.0 revolution, environmental/resource impact, social and regulatory pressures (Lopes de Sousa Jabbour *et al*., 2018). There is only so much of resources at human's disposal in the current stage, making

a paradigm shift from linear to circular the sustainable way to reconcile with the nature (Michelinia, 2017). This far-reaching trend has resulted in many countries, including Singapore, setting zero-waste masterplan as one of its key priorities (NEA, 2020). This paper explores the green journey that the institution, Singapore Polytechnic, has taken from concept, design to development of its green masterplan to its evolution and establishment of focus on the development of the civil engineering education with green technology infusion.

BACKGROUND: EVOLUTION IN SUSTAINABLE RESEARCH INITIATIVE

Singapore Polytechnic have had a deep root of green concept from early days of the establishment. It has been embodied in the institution's green pledge and exemplified in its campus in a garden philosophy (Singapore Polytechnic, 2014). The culture had permeated to its teaching, learning and research with the key green technologies development activities taking place in its various schools, such as the waste recycling process technology developed jointly by the School of Architecture and the Built Environment (ABE) and the department for technology, innovation and enterprise (TIE).

From its early days as the first polytechnic in Singapore, it has been working closely with the government to train and arm the workforce with the skills needed for the country's economic growth. As the pace of globalisation accelerated in the 80s to 90s, the strategic policy was implemented to strengthen and drive towards becoming an innovation economy (Strait Times, 2017). It was with this strategy that led to the setting up of research and innovation centres in the local Institutes of Higher Learning (IHL) such as Singapore Polytechnic.

With the launch of the government's zero-waste nation vision and setting the year 2019 as the Year towards Zero Waste, the momentum was accelerated for the institution to consolidate the green technologies and charting its course for specific thematic technology research to build up its technological edge.

Building Platforms for Research Scale-up

School of Architecture and the Built Environment (ABE) was the one of the oldest schools in the institution that at one point offered degree courses in 1965, before the decision to transfer the faculties of architecture and engineering to the University of Singapore in 1968. It was of no coincidence that the ABE as the first school to offer BE related course (Singapore Polytechnic, 2018) was appointed as the sector coordinator for Building and Construction among the local polytechnics (MOE, 2016).

Apart from its extensive lesson-based pedagogy, as an applied learning institution, ABE has been through its practical learning platform allowing staff and students to engage in real-life and industry relevant research projects to enable the application of knowledge and the use of skills to conceptualise, design and develop industry relevant solutions. These efforts have paid off well with its projects winning awards for several years in the Greenwave competitions (Sembcorp, 2015). Imbued with passions to pursue industry relevant solutions for augmenting academic excellence, the ABE school's close collaboration with the AMTC transformed the research ecosystem in the institution into a powerful twin-engine, which allows both the industry-relevant applied pedagogy and the applied scientific research's calibrated integration for allowing the development of an innovative and curious mindset in its solution-minded graduates (Singapore Polytechnic, 2015). Such kind of industry-research-infused methodology plays an instrumental role, among other strategic initiatives in achieving its mission of "Life-ready, Work-ready and World-ready".

With a school and TIE coming together, working on a calibrated approach, such collaborative platform allows for the systematic way of training of both staff and students through a structured framework that encompasses different work packages designed for supporting the industry. The work package's themes are aggregated from the industry, representing the problem statements that requires innovative solutions to either to increase the productivity or the development of specific capability to uplift the industry. In this way, not only does the industry benefit through the skilled and entrepreneurial workforce, such kind of industry engagement with companies offers them the opportunity to transform their business with solutions designed to increase their competitiveness. The application of aerogel to multiple areas in BE materials was achieved for the waste to aerogel project through such platform (Strait Times, 2019).

Manifesting People- Private- Public Partneship Spirit

In Singapore, the relationship is manifested in a People-Private-Public (3Ps) Partnership as first defined by the Singapore 21 Committee (1999). The 3P partnership elevates the scale of collaboration allowing for a multiplier effect on the technology solutions developed by the institution to be proliferated at a quicker pace and to a broader range of target audience. In the waste to aerogel project for example, the partnership with the waste recycling association has yielded successful training and industry projects (Teo, 2018). To close the waste loop, the cooperation and interwoven working network of the waste producer and waste recycler is critical for the business case to work in the circular economy. As such, identifying the right partner to work with from the proof of concept to proof of value and ultimately an industry pilot scale-up is important. Therefore, through the institution's technology development strategy of a "Seed", "Grow" and "Scale" phase of staging technology development projects, there is always an industrial collaborator involvement. While the seeding phase sees primarily laboratory experimental type of projects, most industrial collaborators will generally be more willing to take part in the "Grow" and "Scale" phase where the project is of a certain level of technology readiness level and the commercial potential is more apparent.

CDIO Approach In Developing Solution Minder Learners

Problem solving skill is the most in demand in the workplace. This is reported in an Economist Intelligence Unit report (2015): Preparing students for the future, sponsored by Google for Education. We believe that solution minded is a mindset that focus on solutions and is an essential driver of problem solving. Jenkins and Germaine (2018) have shown that solution-oriented learning helps students to stay positive. It is important to understand that being focused on solutions does not mean that we are denying the existence of a problem but rather it is by identifying a problem or a challenge that leads our step to move forward to the solution.

To support students to become a solution minded learner, the kind of mental activities that leads to this mindset thinking has to be made visible in their learning process. CDIO approach is adopted to make this thinking visible.

CDIO emphasizes on an approach to strengthen the learning of the fundamentals and at the same time improves the learning of personal, interpersonal skills and product, process and system building skills through experiential learning set in the context of conceiving-designing-implementing-operating (CDIO) team-based environment (Crawley *et al*., 2007). An integrated syllabus is also crucial in building a structure so that a student can easily grasp it, also supported by Bruner (1965) who has a significant impact on education and on the understanding of the learning process (Donaldson, 1978).

Civil Engineering (CE) course, a 3-year programme in ABE, is a broad-based engineering discipline, which focuses on developing students' competencies in solving problems in the society while maintaining positive attitude in learning. In recent years, there is an increase need for civil engineering diploma graduates who have an open mindset and interest in involvement in tackling sustainability issues.

The Integrated Learning Process

To equip students with solution minded thinking skills, various problem-solving tools or approaches were contextualized into the CDIO stages. Table 1 outlines tools and approaches integrated into CDIO stages in the CE course 3 years' programme.

Disciplinary subjects are mutually supporting when they make explicit connections among related and supporting content and learning outcomes. An explicit plan identifies ways in which the integration of CDIO skills and multidisciplinary connections are to be made.

Figure 1 shows a diagram illustrating a CBL project spine with some supporting modules in the DCEB course and finally a final year project with all supporting modules in year 1, 2 and 3.

Table 1. Problem Solving Tools or Approaches Contextualized into CDIO

CDIO Stages				**CE Course**	**Problem Solving Tools / Approaches**			
					Strategies for Question Generating and CBL	Problem solving tools (e.g. Ishikawa Diagram and Scamper)	Design Thinking	Self-Directed Learning (SDL) Strategies
C	D	I	O					
√		√		Year 1	√		√	√
√	√			Year 2		√	√	√
√	√	√	√	Year 3*				√

** Students in CE course do their FYP and Internship in year 3*

Details of the project spine in DCEB course described as follows:

- Year 1- Introduction to Civil Engineering module. A project of making a high-rise framework using wooden sticks in line with learning basic structure theory.
- Year 2- Water Technology module. Use of CDIO approach to design HDB rooftop rainwater harvesting system in a mini project. A checklist is provided as guiding questions.

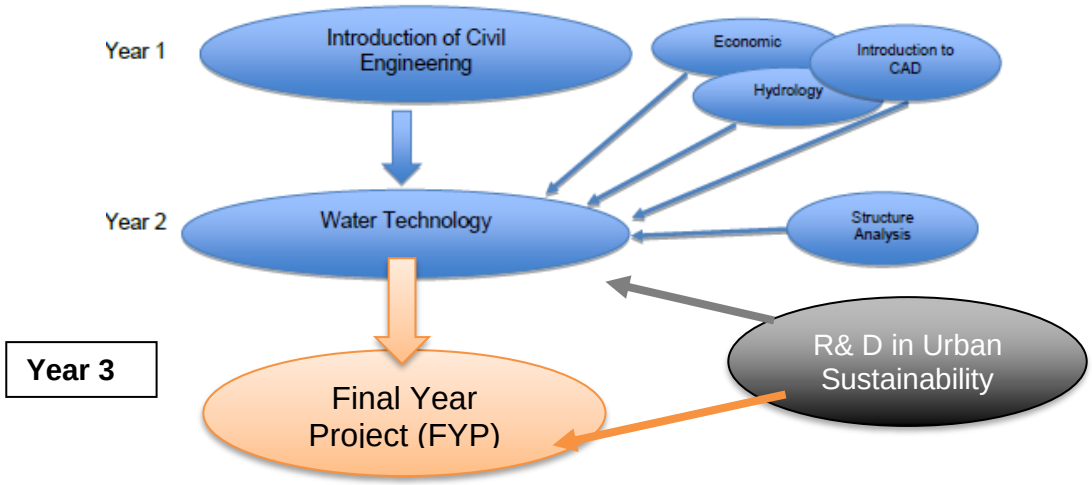

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Figure 1. CBL implementation into DCEB

In the 2nd Year, a mini project that incorporates some 1st year modules such as Introduction to Civil Engineering, CAD design, Hydraulics & Hydrology and Economic was developed. In this particular study, a 2nd Year module entitled Water Technology was selected as one of DCEB course modules, environmental engineering sub-discipline. The module covered a mini CBL project with a theme of HDB rainwater harvesting project.

In a nutshell, a Challenge- Based- Learning (CBL) project is adopted to provide students with a collaborative learning experience working to solve real-world workplace issues, particularly in Singapore context. Results analysis and feedback of this implementation were presented at the Proceedings of the CDIO Asian Regional Meeting, Mongolian University of Science and Technology, Ulaanbaatar, Mongolia September 22 – 25, 2020 (Djati Utomo, 2020).

In the 3rd Year, problem solving tools, Challenge Based Learning (CBL) reinforced with industry sponsorships is adopted to provide students with a collaborative learning experience working to solve real-world workplace issues. Through deliberated practices guided by the SDL strategies throughout their 3 years of learning as shown in Figure 2, students were also expected to apply their learning across different contexts in their FYP and to further develop soft skills in the area of self-directed learning, teamwork, creativity, project management and global mindset.

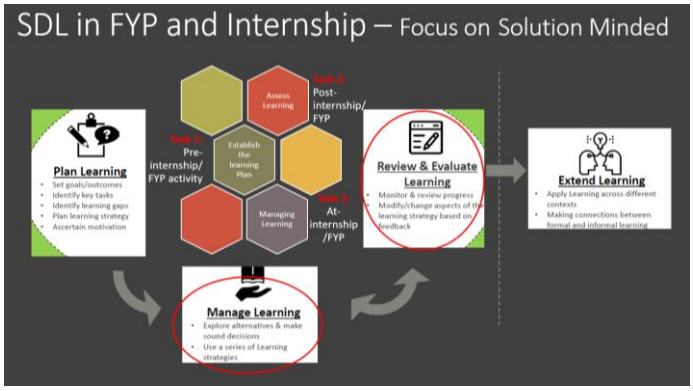


Figure 2. SDL – Focus on Solution Minded

Two FYP industry sponsored research group of recycling of palm frond into bioplastic, and another group of incinerator ash to aerogel materials were selected to continue the solution-minded journey with a teaching staff in close collaboration with the industry to pursue industry relevant solutions. Such engagement in real-life and industry research project settings has provided students the best learning environment leading them to be solution minded.

One of the FYP group has proven their contribution in a competition and awarded double prizes of SWIM (Sembcorp Innovation Medal) and the 1st runner up in SG Junior Water Prize Competition. As a result, attracted a small medium enterprise (SME) to sponsor their FYP in 2020.

STUDENTS FEEDBACK

To identify challenges and propose improvements to facilitate the integrated learning experiences, group instructional feedback technique was employed to collect feedback through face-to-face interviews with the two groups of students (8 students in total but 1 absent with apologies). Interviewees from these 2 FYP groups are students have done well in their 3 years' coursework with GPA above average.

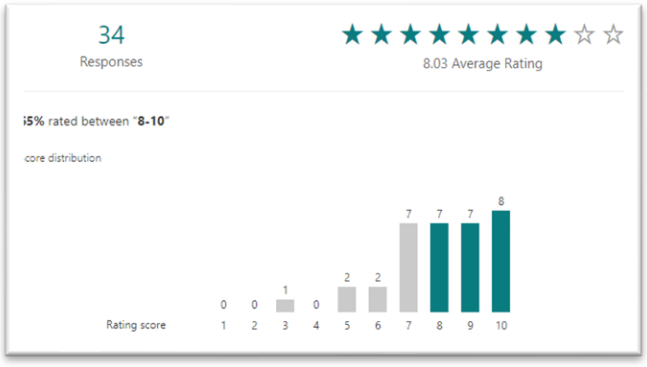
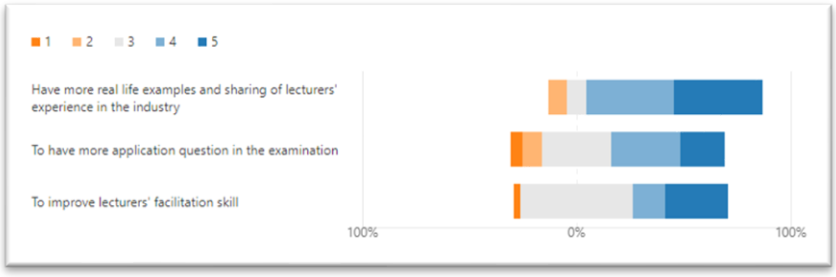
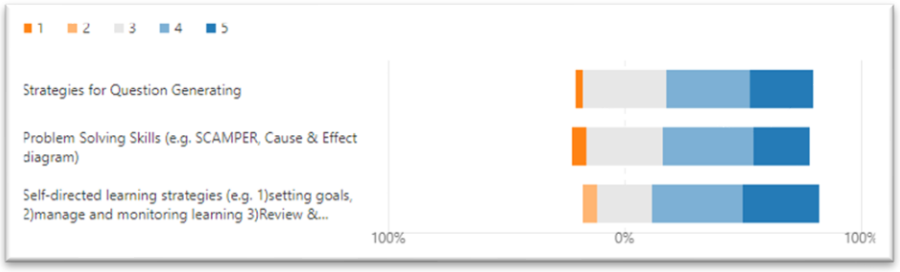
Interview was conducted at the end of their FYP. As students were not explicitly told that they were on a solution-minded learning journey during their course, proper facilitation is necessary before the interview. They were briefed on the definition of solution minded and to reflect on their learning journey leading them to be a solution minded learner in their 3 years course of study. They were then asked to fill out the following questionnaires and their responses are summarized in Table 2.

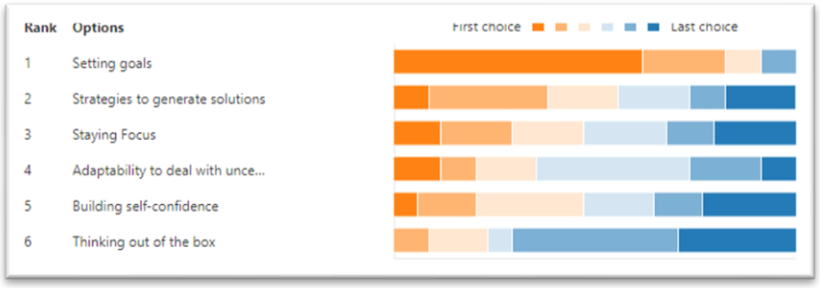
Table 2. Group Instructional Feedback from 2 FYP Research Groups

Interview Questionnaires	Summarized Response
1. What does the lecturer(s) do that help with your learning to be a solution-minded learner?	Lecturers are generally approachable and activities designed are appropriate with deliberate practices leading them to be solution minded learner.
2. What changes/improvements to the course would promote your learning to be a solution-minded learner?	Request for: • more real-life examples and sharing of lecturers' experiences in the industry. • more application question in examination • to improve lecturers' facilitation skill
3. What do you do that facilitates your learning to be a solution-minded learner?	Many Students have exhibited self-directed learners' dispositions. However, not able to articulate well specific problem-solving tools or strategies.
4. What might you do to improve your learning to be a solution-minded learner?	
5. What is the hardest thing to learn in the journey of a solution-minded learner?	Following key words are identified as the hardest : • Setting goals • Adaptability to deal with uncertainties • Strategies to generate solutions • Staying Focus • Thinking out of the box • Building self-confidence

Peers' ratings of questionnaire formulated based on the input from the F2F interview responses listed in Table 3 is used to collect data to quantify the identified challenges and improvements. 34 final year students participated. Survey was facilitated by first to brief them on the definition of solution minded and to reflect on their solution-minded learning in their 3 years course of study. They were then asked to complete the survey before their responses summarized in Table 3 below.

Table 3. Group Instructional Feedback from 2 FYP Research Groups

	Questionnaire	Results
1	Generally, lecturers are approachable and learning activities designed are appropriate to lead me to solution-minded.	(Rating are indicated by number of stars where maximum of 10 stars represent lecturers are approachable and learning activities are well designed. More than 65% has rated between 8-10 stars. 
2	Rate the following changes/improvements that would promote your learning to be a solution-minded learner. • Have more real-life examples and sharing of lecturers' experience in the industry • To have more application question in the examination • To improve lecturers' facilitation skill	(Rating scale : 1-Disagree 2- Slightly disagree 3-Neutral 4-Slightly Agree 5-Agree) 82% wanted to hear more real-life examples from lecturers 53% agree that by having more application question would help 44% agree that an improvement in facilitation skills would help 
3	Rate the following dispositions/skillsets that will facilitate/ improve your learning to be solution-minded. • Strategies for Question Generating • Problem Solving Skills (e.g., SCAMPER, Cause & Effect diagram) • Self-directed learning strategies (e.g., 1)setting goals, 2)manage and monitoring learning 3)Review & evaluate learning)	(Rating scale : 1-Disagree 2- Slightly disagree 3-Neutral 4-Slightly Agree 5-Agree) 60% rated 4-5 believed that these dispositions and skillets is important in leading them to be solution minded learners. 
4	Rate the following dispositions/skillsets from the Easiest to the Hardest to achieve. • Setting goals	(Rating scale : 1- Easiest to 5 - Hardest)

	• Strategies to generate solutions. • Staying Focus • Adaptability to deal with uncertainties. • Staying Focus • Thinking out of the box • Building self-confidence	Majority have rated Adaptability to deal with uncertainity (65%) and Thinking out of the box (70%) as the most difficult to achieve. 

NEXT STEP: DEVELOPMENT INTO A CURRICULUM

A CDIO curriculum includes learning experiences that lead to the acquisition of personal, interpersonal, and product and system building skills, integrated with the learning of disciplinary content. Disciplinary subjects are mutually supporting when they make explicit connections among related and supporting content and learning outcomes. An explicit plan identifies ways in which the integration of CDIO skills and multidisciplinary connections are to be made.

Feedback in Table 2 & 3 showed that students have gained personal, interpersonal and appropriate disciplinary content and skills through the curriculum but lack of the connection to extended learning as seen in their response to the last questionnaire in Table 2. This is quantified by 34 participants' feedback and narrowed down to improve 2 important disposition/skillsets. To address this, ABE is planning to develop a module called R& D in Urban Sustainability the AY2021. The module aims to introduce students the basic research design principles and various data collection and analysis methods commonly used in science and engineering, and to equip students the knowledge of innovative and sustainable building materials and latest civil engineering (CE) technologies as well as giving them opportunities to practice thinking out of the box. The module will reinforce their solution-minded journey and to prepare them for the final year project and working in R&D related companies or lab testing companies. It will also develop students' competency in thinking skills, problem solving skills and interpersonal skills like teamwork and communications.

This module is conducted through a combination of lectures, tutorials and practical. Lab testing skills of advanced materials in civil engineering will be covered in the module. Students are expected to participate in workshops, seminars and technical conferences as part of the module requirements. Guest research scientists/ lecturers may be invited to present talks on the latest development in civil engineering. Students will be introduced to a wide range of literatures and case studies will be discussed in the module.

The students formed teams and worked together to define learning goals as well as negotiate within team members to set project timelines. The lecturer shall play the role as an advisor to guide students in managing and monitoring their learning progress.

CONCLUSION

An integrated curriculum in a CDIO approach has allowed staff and students to engage in real-life and industry relevant research projects to enable the application of knowledge and the use

of CDIO skills to conceptualize, design and develop industry relevant solutions. Such engagement in real-life and industry research project settings enable students in their final year projects (FYP) to directly contribute to real-life such industry projects, while building their proficiency to become solution-minded learners who are both innovative and have a curious mindset.

This integrated learning process can be further realized with staff in close collaboration with the industry to pursue industry relevant solutions. This integrated learning experience (CDIO Standard 7) can foster the learning of disciplinary knowledge simultaneously with solution-minded strategies. This is clearly seen in the 2 FYP groups working on industry project facilitated by the teaching staff in close collaboration with the industry partner. The 2 FYP groups' feedback, together with 34 other students have allowed us to identify challenges faced by learners in the solution-minded learning journey.

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BIOGRAPHICAL INFORMATION

Handojo Djati Utomo is currently as a Civil Engineering Lecturer, R& D Unit of Civil Engineering, School of Architecture and The Built Environment (ABE) at Singapore Polytechnic, Singapore. He received a PhD in Environmental Chemistry and a MSc (Eng) in Environmental Civil Engineering from University of Otago, Dunedin, New Zealand and University of Liverpool, Liverpool, United Kingdom respectively. His current focus is on the development of FYP- internship with industrial research collaboration in the area of water technology and waste recycling technology. He also served as Scientific Committee member in Challenges in Environmental Science and Engineering, Australia since 2015, Member of International Water Association (IWA, UK) since 2010 and member of MOE Science Judge since 2017.

Soo-Ng Geok Ling passion for teaching and technology can be traced back to my early-professional days with her first job in supporting the transforming construction industry to use IT solutions in engineering projects. The reason? She likes getting people excited about how technology can help them to be efficient. She is now a senior lecturer in the School of Architecture and the Built Environment at the Singapore Polytechnic. She is committed to education through improving students' learning and mentor teaching staff through effective professional development. Also, check out her recent project in leading the School of ABE into a holistic integrated approach to foster self-directed learning in 6 diploma courses: https://rise.articulate.com/share/i-biu-PMFt1iwSHqCjJXIYvyMDvQBN7I.

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