

# **CASE STUDY ON INTEGRATED CURRICULUM USING SPIRAL CURRICULUM MODEL FOR CHEMICAL ENGINEERING**

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## **ABSTRACT**

This paper shares the experience of the Diploma in Chemical Engineering (DCHE) offered by Singapore Polytechnic (SP) in using the CDIO Framework to guide the design and implementation of the integrated curriculum for chemical engineering students through a spiral curriculum model. An anchor chemical plant, namely Amine Treating Unit (ATU) is used to introduce simple concepts to the students first, which are then revisited and re-constructed in a more in-depth and elaborated manner throughout the three-year course. The CDIO learning outcomes are intertwined into the context of learning to support the levelling up of knowledge and skills from one semester to another, from one module to another, while integrating critical thinking skills with disciplinary knowledge to provide a more holistic approach to engineering education for our students. The paper first introduces spiral curriculum for chemical engineering and explains how the modules are sequenced within the three-year course based on the complexity of concepts, context of learning as well as opportunities for application and integration of knowledge. Then, it describes the use of ATU chemical process plant as a case study to deliver the spiral curriculum where knowledge and skill competencies are levelled up via a series of modules offered within the 3-year diploma course. Learning opportunities are created for students to revisit knowledge and content at different stages of the curriculum, activate prior knowledge and integrate knowledge and skills. Surveys were carried out to evaluate the effectiveness of student learning. It was found that when the same case study is used, students are familiar with the case and are more receptive to building new knowledge, hence making connections between prior knowledge and new knowledge. Faculty teaching staff make deliberate efforts to point out how the concepts are related and connected, how the concepts are levelled up from one level to the next so that students make personal meaning of knowledge and see how it is used in real world applications and problem-solving. In the last section of the paper, it outlines the broad areas where the delivery of the spiral curriculum can be further improved and enhanced to better support student learning.

## **KEYWORDS**

Chemical Engineering, Spiral Curriculum, Anchor Case Study, CDIO Standard: 3

**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 as "faculty" in the universities.

## INTRODUCTION

The Diploma in Chemical Engineering (DCHE) course offered by Singapore Polytechnic (SP) 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 in the Academic Year (AY) 2008/2009 cohort (Cheah, 2009). There was a need to shift the curriculum model, which was largely content driven and taught in silos with little connectivity between modules, to one focusing on key concepts fundamental to understanding and in a more integrated format [Standard 3 – Integrated Curriculum]. In addition to integration of discipline-specific knowledge in the curriculum, various generic skills such as teamwork, communication and critical thinking were integrated into carefully designed learning activities in laboratory sessions or assignments to core chemical engineering modules.

Since then, a national initiative named Singapore Skills Framework took off which led to further review of the course to re-design and deliver appropriate learning content to meet both existing and emerging skills required for the changing industry needs and work roles. The redesign of the chemical engineering curriculum and its CDIO experiences after years of implementation were documented in various earlier papers, e.g. Cheah, Phua & Ng (2013) and Cheah & Yang (2018).

As part of a continual improvement over past efforts, the most recent revamp of the DCHE course took place in 2017 which led to the adoption of the spiral curriculum model for its course structure for students in the AY2018/2019, in response to providing a more systematic structure to build up student competencies using the CDIO approach while ensuring the curriculum retains its integrated form.

The process undertaken by the Course Management Team to carry out the transition had been described by Cheah & Yang (2018). The DCHE curriculum model shown in Figure 1 illustrates the progressive development of key competencies over the diploma’s 3-year duration.

Yang, Cheah & Phua (2021) carried out the first evaluation on the spiral curriculum in DCHE and found that spiral curriculum model benefitted student learning where key concepts and principles are revisited over time to further clarify and extend the knowledge base in terms of adding new related knowledge, enhancing integration and further refining until students make sense of the knowledge and apply them purposefully and meaningfully.

## SPIRAL CURRICULUM MODEL

In a spiral curriculum, the key concepts and principles are revisited throughout the instructional process. New related knowledge are added over time to extend the knowledge base, enhance integration of concepts and principles across related topics and further refine until the student’s mental schemata comprises of most accurate and appropriate mental representation of the concepts and principles.

Through the spiral curriculum model, the DCHE course aims to enable students to build knowledge and skills progressively and in an integrative manner from one semester to another so that students can apply knowledge and skills purposefully and demonstrate competence in both technical and non-technical skills during their internship programme.

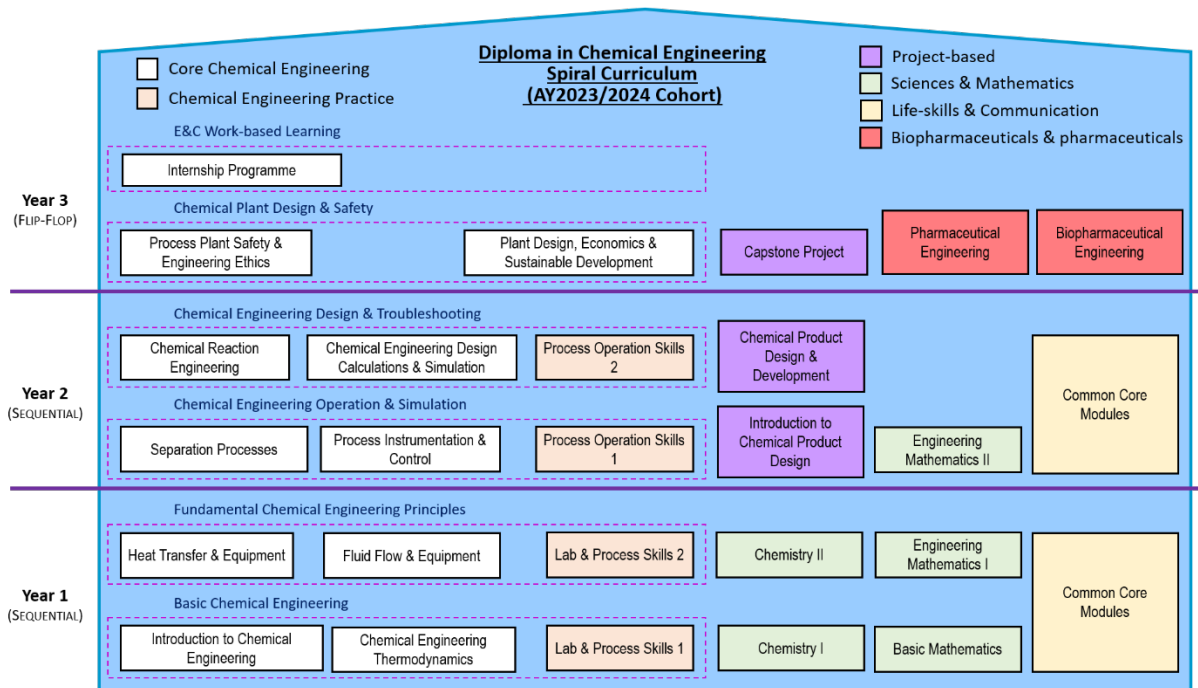


Figure 1. The DCHE Spiral Curriculum Model

Spiral curriculum is a concept widely attributed to Bruner (1960), who refers it as a curriculum design in which key concepts are presented repeatedly throughout the curriculum, but with deepening layers of complexity, or in different applications. Bruner (1960) believes that “any subject can be taught in some honest form and a curriculum would be structured around the great issues, principles and values that a society deems worthy of the continual concern of its members”. Bruner (1960) also asserted that “we begin with the hypothesis that any subject can be taught effectively in some intellectually honest form to any child at any age of development.”

It is through the systematic teaching of key concepts, and varying degrees of complexity and elaboration, over the duration of the curriculum that were most fundamental to the approach. Indeed, within the field of cognitive neuroscience, there is much validation to Bruner’s (1960) conceptions. The importance of teaching key concepts that are fundamental to understanding, and the need for spaced and deliberate practice over time to ensure that knowledge and skills are encoded and cemented in long-term memory is well validated by Brown, Roediger, & McDaniel (2014).

Since then, a number of implementations at academic institutions in different countries have adopted the spiral curriculum model, such as those in medicine (Brauer & Ferguson, 2015; Harden & Stamper, 1999), mathematics curriculum for primary education in Singapore (Ministry of Education, 2007), online learning courses (Masters & Gibbs, 2007), undergraduate chemical engineering degree courses (Gomes, Barton, Petrie, Romagnoli, Holt, Abbas, Cohen, Harris, Haynes, Langrish, Orellana, See, Valix, & White, 2006; Gupta, Joseph, Alcantar, Toomey, & Sunol, 2008), and chemical engineering master degree program (Neumann, Neumann, & Lewis, 2017).

Gomes et. al. (2006) and Gupta et. al. (2008) believe that spiral curriculum is a superior learning approach because it allows students to “master each increment of subject in

hierarchical sequence before going on to the next” (Gupta et. al., 2008). In fact, Gomes et. al. (2006)’s study reveals that there is significant increase in student engagement within the broader learning process. Masters & Gibbs (2007) finds the spiral curriculum to be very effective for online learning if the practice is used consistently.

### INTEGRATED CURRICULUM USING SPIRAL CURRICULUM MODEL WITH AMINE TREATING UNIT (ATU) AS ANCHOR CASE STUDY

Chemical Engineering is a broad discipline where the knowledge, concepts and skills taught can be applied to different processes, such as chemical, pharmaceutical and biological. Amine, being very effective in removing carbon dioxide ( $\text{CO}_2$ ) and hydrogen sulfide ( $\text{H}_2\text{S}$ ), is commonly used in refinery and petrochemical plants to remove acid gases. Thus, it is chosen as an anchor case study for the DCHE course. The Amine Treating Unit (ATU) is selected as an anchor case study to support the integrated curriculum using the spiral curriculum model through the three years of studies in DCHE. An anchor case study serves to provide students with a single process to develop deep familiarity with, and use it to build increasingly more complex concepts and extend the knowledge learnt. Students will not need to spend time understanding new processes before being able to apply concepts taught. The presence of the familiar case study will aid students in learning new concepts (Reder, Liu, Keinath, & Popov, 2016). When incorporating this ATU case study into the various modules in the course, existing content and learning outcome in the curriculum remain unchanged. The ATU case study merely replaces the scenarios used to teach the concepts that were already there.

There are two main steps in ATU as shown in Figure 2:

- 1<sup>st</sup> Stage: Amine Absorber whereby acid gases are brought in contact with amine and the gases are absorbed in the liquid amine.
- 2<sup>nd</sup> Stage: Amine Stripper whereby the acid gases are stripped away from the liquid (amine). This is to regenerate lean amine solution and recirculate it to the amine absorber.

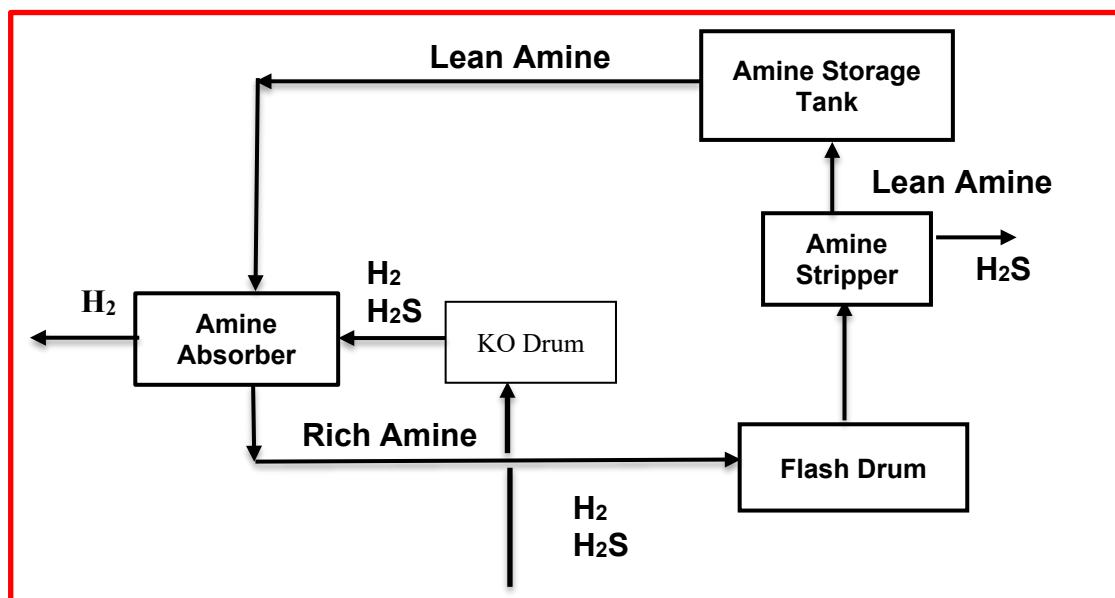


Figure 2: Amine Absorber and Amine Stripper in ATU

### ***Amine Treating Unit (ATU) as Anchor Case Study for Year 1***

In this integrated curriculum effort, students in their Year 1 studies are provided appropriate scaffold to guide their learning when using the ATU. As the context becomes more complex in Year 2, the learning scaffold is gradually removed so that students learn to become more self-directed and develop resilience to solve more complex problems using the ATU. Finally in Year 3, students are expected to apply concepts and principles without explicit instructions where it is hoped that the spiral curriculum model in the DCHE course has enabled them to develop some form of mastery, think in-depth and have the confidence to solve real-world problems.

ATU is used as a group assignment in the first core module for Year 1 students in a Semester 1 module, named *Introduction to Chemical Engineering*. In this module, students were first introduced to various unit operations (basic step in process) commonly used in the chemical industry. After which, the topic of Process Flow Diagram (PFD) is taught. A PFD is a diagram commonly used in chemical and process engineering to indicate the general flow of plant processes and equipment. In the assignment, the process description of ATU is provided. Students are required to construct a PFD for amine treating system using Microsoft Visio software by applying standard requirement of preparing PFD. Four unit operations, namely Amine Absorber, Rich Amine Flash Drum, Amine Stripper and Lean Amine Storage Tank are to be included together with process accessories such as control valves, pumps and heat exchangers where appropriate. A sample of the deliverable PFD is shown in Figure 3.

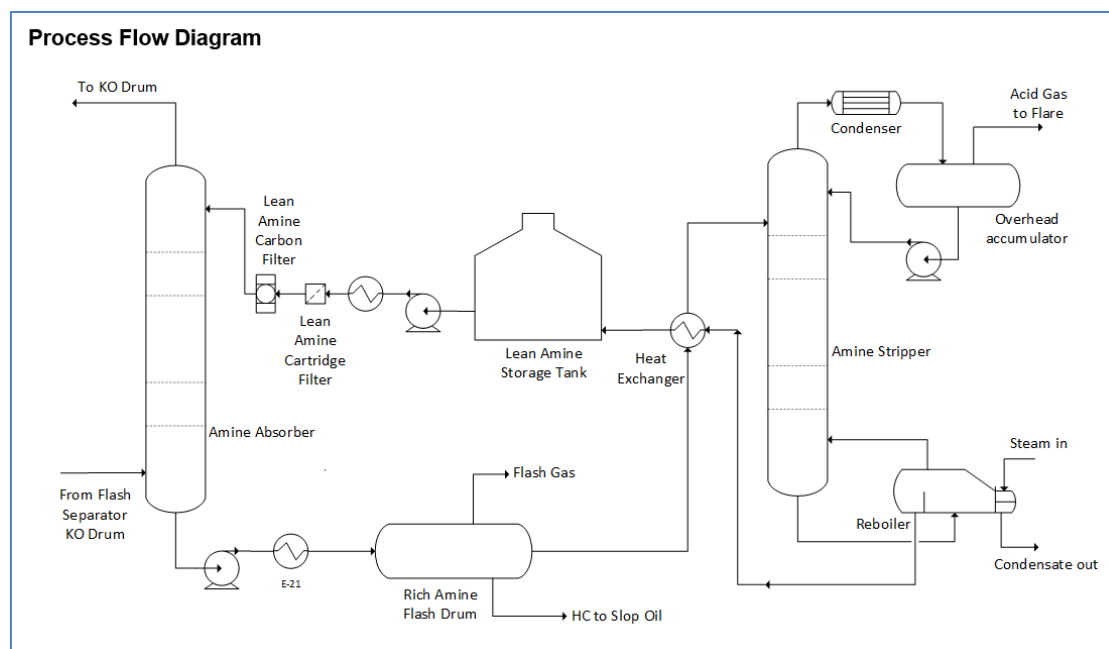


Figure 3: ATU PFD – A sample of deliverable of the group assignment for *Introduction to Chemical Engineering* module

In the second core module for Year 1 students, named *Chemical Engineering Thermodynamics*, the same ATU PFD is used in a group assignment as an extension to the assignment completed earlier. In this module, students were introduced to the fundamentals of 1<sup>st</sup> Law of Thermodynamics and were then taught how to apply it to various equipment such as pumps and heat exchangers commonly used in a chemical plant. In the group assignment,

students are required to apply 1<sup>st</sup> Law of Thermodynamics and perform engineering calculations on both the heat exchanger, E-101 and pump, P-201 as shown in Figure 4. Students are subsequently required to describe how changes in stream composition entering heat exchanger, E-101, have a direct impact to its outlet temperature. In order to describe the impact, they are required to have an understanding about feed composition and specific heat capacity. The knowledge of feed composition was covered in an earlier module (*Introduction to Chemical Engineering*). The students will have learnt about specific heat capacity in *Chemical Engineering Thermodynamics* module. So, in this assignment, the students demonstrate their ability to draw the connection between feed composition and specific heat capacity of the process fluid and how the relationship between these two knowledge can affect the heat exchanger operation. With this, students have the opportunity to revisit a concept and then add new related knowledge over time to extend their knowledge base and enhance integration.

In addition, the students were further challenged to predict how the changes in stream composition entering the heat exchanger eventually affect the heat exchanger duty and subsequently the downstream process after the heat exchanger. Students will derive the Bernoulli's equation from the 1<sup>st</sup> Law of Thermodynamics based on pump P-201 in Figure 4. This derivation is commonly applied in calculations involving pumps. This enables students to better understand the basis of the Bernoulli's equation which eases them into application in other context that are covered in a follow on module named *Fluid Flow and Equipment*. In the assignment, student will make use of the Bernoulli's equation to study the effect of liquid level in the Lean Amine Storage Tank on the pump power requirement for pump P-201.

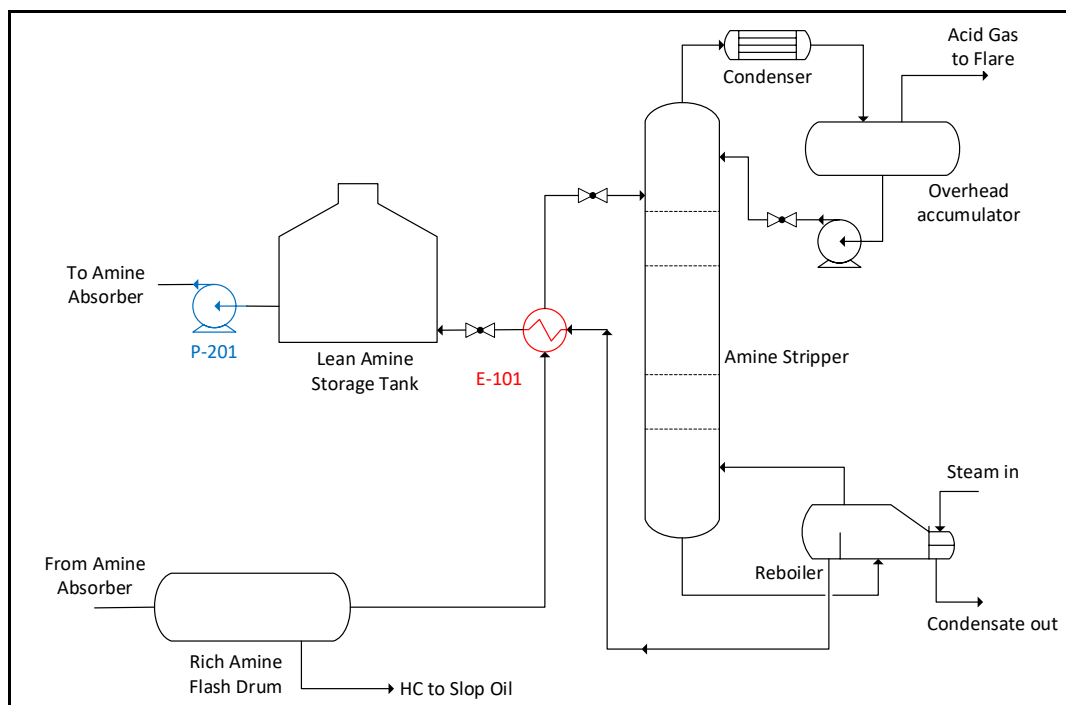


Figure 4: Selected equipment from ATU used in *Chemical Engineering Thermodynamics* assignment

In the third core module for Year 1 students, named *Heat Transfer & Equipment*, ATU is used for students to identify the type of heat exchangers from the Process Flow Diagram of ATU.

Based on the Process Flow Diagram, students are first required to identify the service type of the heat exchangers, i.e. either cooling or heating. Then based on the service type identified, the students are to make recommendations on the appropriate type of medium to match the service type. These tasks require students to leverage on their prior knowledge about unit operation.

Through a group assignment, students analyse the process parameters and derive the heat exchanger duty required in order to design a heat exchanger in the ATU to meet the process requirement. In addition, the concept of heat integration is introduced to create awareness in the effort of sustainability in chemical industry. Students have to compare the heat source required with and without the heat integration and evaluate the advantage of heat integration in chemical plant. This group assignment enables the students to work on more complex problems that mimic the chemical industry.

In the fourth core module for Year 1 students, named *Fluid Flow & Equipment*, a higher level of application of 1<sup>st</sup> Law of Thermodynamics is introduced. Students have to derive the Bernoulli's Equation to compute the pump power requirement for pump sizing, taking into consideration of various friction losses along the pipe line. Again, this demonstrates the increasing complexity and elaboration of the concepts and principles taught in the DCHE curriculum. This module is the concluding module in the Year 1 curriculum and wraps up the fundamental knowledge and concepts needed for Year 1 students to move on to their studies in Year 2.

In general, Year 1 modules provide fundamental concepts to prepare students to tackle and solve more complex engineering problems in later years in a course. In our work, we realised that there are many opportunities to inject levelling-up learning tasks for students even at Year 1 level. With the four Year 1 core modules providing the levelling-up experience for students, Year 2 core modules also follow suit and continue to use the ATU case study as the anchor plant to deliver the spiral curriculum.

### ***Amine Treating Unit (ATU) as Anchor Case Study for Year 2***

The ATU is first used to activate prior knowledge in the first core module for Year 2 students, named *Separation Processes & Simulation*. Students are shown Figure 5 and required to recall knowledge, such as unit operations, heat transfer and fluid flow concepts related to the ATU, and principles and types of heat exchangers, pumps, and valves, learnt in various modules in the previous year.

The ATU is next used to show the linkage of concepts that will be taught in the two core modules in Year 2, *Separation Processes & Simulation*, and *Process Instrumentation & Control*. In *Separation Processes & Simulation* module, students learn about the principles of two separation processes, namely flash drum, gas absorption / stripping that are present in the ATU. Students also had to compare and contrast gas absorption and stripping processes so that they do not merely know these processes but also understand the differences and similarities between these separation processes providing an opportunity for students to think in-depth. Once the students understand the separation processes concepts, the ATU can be used to extend learning through the application of process monitoring and appropriate control strategies for those processes in the second core module in Year 2 named *Process Instrumentation and Control* where students learn about process instrumentation, and basic and advanced process control concepts.



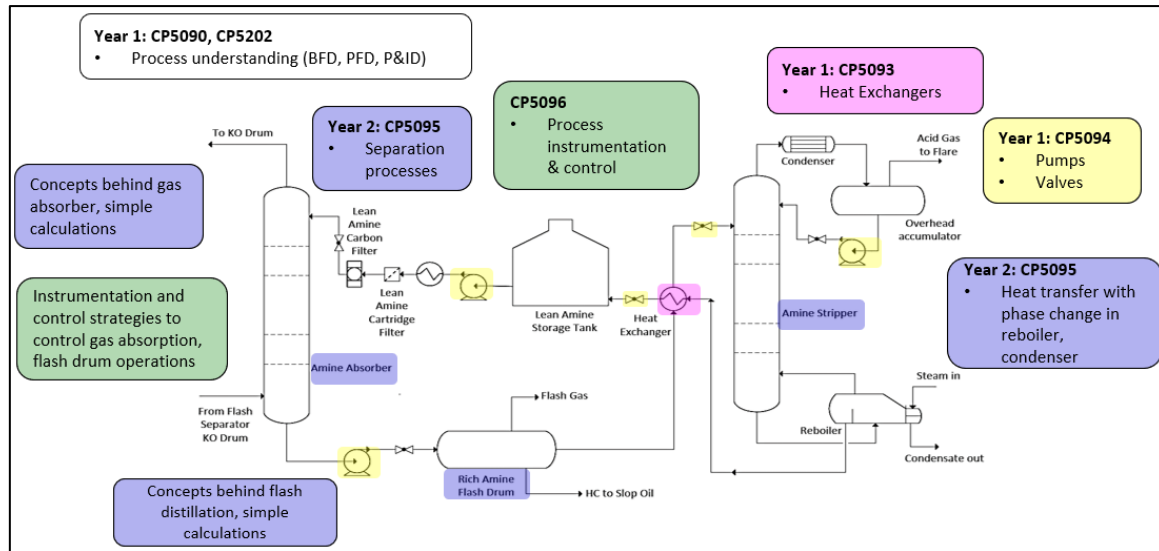


Figure 5: Process flow diagram of ATU used to activate prior knowledge and link concepts taught in *Separation Processes & Simulation* module

### Amine Treating Unit (ATU) As Anchor Case Study For Year 3

The final module in the DCHE curriculum that uses the ATU case study is in *Process Plant Safety and Engineering Ethics* module in Year 3. This module leverages on students prior knowledge on unit operations, heat transfer, fluid flow, separation processes, instrumentation and control to conduct a hazards operability study (HAZOP). A HAZOP study is a structured and systematic examination of a complex plan to identify and evaluate problems that present risks to personnel and/or equipment during operation. When the students conduct the HAZOP study using the ATU case study, it presents them an increasingly complex scenario where there are various dimensions to consider as opposed to the scenarios presented to them in Year 1 core modules. This certainly mirror a real engineering problem with many aspects for students to cogitate, understand and apply their competence that they have mastered through the 3 years of studies in DCHE.

### SURVEY RESULTS ON SPIRAL CURRICULUM

With the implementation of the spiral curriculum module, the Course Management Team is interested to understand its impact on student learning. Hence, a quantitative survey was conducted at the end of each semester. Specifically, students were asked to indicate on a 5-point Likert scale the extent to which they agree or disagree with the following statements with 1 being Strongly Disagree and 5 being Strongly Agree.

- Question 1: I was able to see connections between what was taught in different modules.  
 Question 2: I can understand the basic engineering concepts better.  
 Question 3: The spiral curriculum challenges me to think in depth (e.g. analyse, compare and contrast, evaluate)

Two cohorts of students were surveyed. The first cohort participated in the survey in AY2018/2019, when they were in Year 1, and again in AY2019/2020 when they progressed to Year 2. The second cohort was surveyed in AY2019/2020 when they were in Year 1, and again in AY2020/2021 when they moved to Year 2.



Figure 6 shows the response obtained from Year 1. Based on the responses obtained, 63% (AY2018/2019) and 80% (AY2019/2020) of the students agreed that they are able to “see the connections” among the modules where spiral curriculum enhances students’ ability to integrate knowledge learnt and strengthen their ability to solve problem of higher level of complexity. In another words, the integrated curriculum had enabled students to link the key concepts from one core module to other core modules.

60% (AY2018/2019) and 79% (AY2019/2020) of the students agreed that the spiral curriculum enables them to better understand the basic engineering concepts and 64% (AY2018/2019) and 73% (AY2019/2020) of the students agreed that the spiral curriculum challenges them to use higher order thinking skills such as compare, contrast and solve engineering problems. This enabled students to build on key concepts at the beginning of the semester and complex concepts are then developed more elaborately throughout the semester in different context whereby students develop critical thinking skills within the chemical engineering context.

Through a focus group discussion with students, they shared that the basic engineering concepts taught in *Introduction to Chemical Engineering* module laid the foundation needed for them to connect with the concepts taught on *Chemical Engineering Thermodynamics* module. In the DCHE course, the assignments challenge students to work in groups, analyse the problems and devise appropriate solutions by applying chemical engineering concepts taught in the modules.

Overall, there is a significant improvement in the students’ feedback from AY2018/2019 to AY2019/2020. This is primarily due to the continuous effort by the module team to improve the delivery of the flow of module contents.

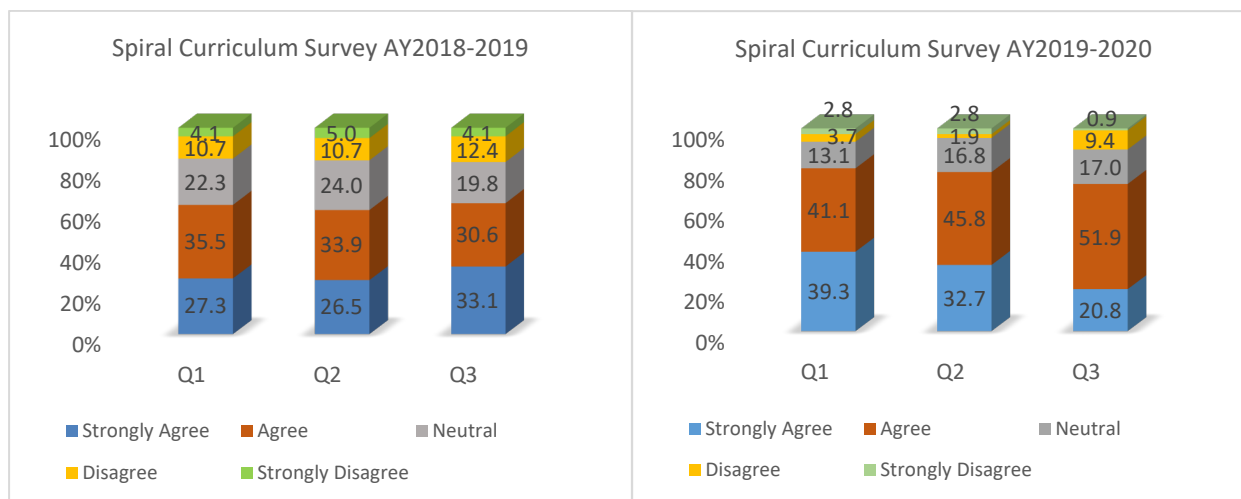


Figure 6. Students’ Responses on Spiral Curriculum in Academic Year (AY) 2018/2019 & 2019/2020 for Year 1 students

In summary, the quantitative survey result obtained was encouraging with majority of the students either “Agree” or “Strongly Agree”, indicating strong alignment to the intended outcome.

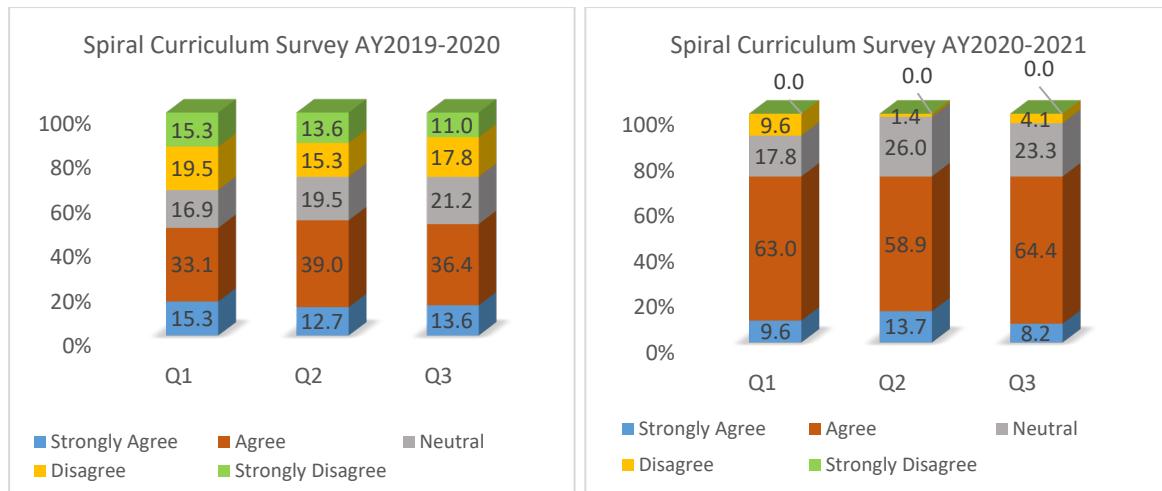


Figure 7. Students' Responses on Spiral Curriculum in Academic Year (AY) 2019/2020 & 2020/2021 for Year 2 students

Figure 7 shows the students' responses on spiral curriculum when they progressed to Year 2 in AY2019/2020, and AY2020/2021. When the students moved onto Year 2, 48% (AY2019/2020) and 73% (AY2020/2021) of students agreed that they are able to "see connections" among the two modules (*Separation Processes & Simulation*, and *Process Instrumentation & Control*) taught in that year. 52% (AY2019/2020) and 73% (AY2020/2021) of the students agreed that the spiral curriculum enables them to better understand basic engineering concepts. 50% (AY2019/2020) and 73% (AY2020/2021) of students agreed that the spiral curriculum challenges them to use higher order thinking skills. Similar to the survey outcome for Year 1 students, there is an improvement in the students' feedback from AY2019/2020 to AY2020/2021 for Year 2 students for the two different cohorts.

When the survey outcomes were compared within the same cohort of students, the percentages of students who agreed that they were able to "see connections" among modules (63% in Year 1 and 48% in Year 2), that the spiral curriculum enables them to better understand basic engineering concepts (60% in Year 1 and 52% in Year 2), and that the spiral curriculum challenges them to use higher order thinking skills (64% in Year 1 and 50% in Year 2) dropped for the first cohort of students when they progressed from Year 1 to Year 2. However, for the second cohort of students, comparable percentages of students agreed that they were able to "see connections" among modules (80% in Year 1 and 73% in Year 2), that the spiral curriculum enables them to better understand basic engineering concepts (79% in Year 1 and 73% in Year 2), and that the spiral curriculum challenges them to use higher order thinking skills (73% in Year 1 and 73% in Year 2) even when they moved from Year 1 to Year 2. This is primarily due to the Year 2 lecturers putting in deliberate efforts to strengthen linkages between and within the modules and improving the flow of module delivery, upon reflecting on the results from the first cohort of students.

## PLANS FOR MOVING FORWARD

This section discusses plans for moving forward such as opportunities to widen the use of ATU as the anchor case study, integration of other CDIO skills and incorporation of sustainability into the DCHE course.

Moving ahead, the connections between what was taught in different modules can definitely be strengthened in Year 2 using ATU. For instance, a learning task could be introduced in *Separation Processes & Simulation* module for students to explore the impact of changing solvent rate specially for the amine absorber. In *Process Instrumentation & Control* module, there are ample possibilities to incorporate applications in terms of control strategies to the separation processes in ATU such as the flash drum, and amine absorber / stripper. Furthermore, in Year 2, it can be assumed that students already have the knowledge of the principles, function and operation of every unit operation at this stage of study. Lesser learning scaffold can be provided to students so that they can inculcate more independent learning and allow them to be more self-directed. There are more opportunities for them to make inquiry and seek clarification so that they become more independent learners. So, when the students are given a separation process in the ATU to apply process control principles, they will have to analyse the given information themselves, can be tasked to sketch appropriate process control scheme to achieve desired control objective and suggest suitable instrument set points to attain specific safety objective.

Through the survey outcome, the delivery of technical content using the ATU case study and spiral curriculum model indeed enhanced student learning. There remain other opportunities for the Course Management Team to integrate other skills into the curriculum such as digital skills and development of resilience through learning from failure (Shepherd, 2004). The Course Management Team can also evaluate teamwork skills as part of the integration of skills and attitude in the spiral curriculum through the use of appropriate validated instrument like Comprehensive Assessment of Team Member Effectiveness (CATME) that assesses effective teamwork (Ohland, Loughry, Woehr, Bullard, Felder, Finelli, & Schmucker, 2012).

In 2022, Singapore Green Plan 2030 was launched as a national movement to advance Singapore's national agenda on sustainable development. This forms a mandate for educational institutions to include sustainability into its curriculum so that graduates who join the workforce in future will be able to propagate green practices into the industry and strive to build a sustainable future nationally and internationally. There is an opportunity to infuse sustainability using the ATU through alternative low energy technologies that could be used in place of ATU to remove acid gases, and let students perform a comparison between the two technologies, or to conduct literature research on alternative green solvents that can be used instead of amine.

## CONCLUSION

In conclusion, the use of ATU case study and spiral curriculum model have benefitted student learning where students revisit chemical engineering concepts and principles over several modules and across semesters. The complexity of the context increases with every revisit of the ATU case study. This provides opportunities for students to deliberately practice their understanding of the concept while extending the knowledge base in terms of adding new related knowledge, enhancing integration and further refining until students make sense of the knowledge and apply them purposefully and meaningfully.

Our study has shown that the use of a simple process, such as the ATU case study, when infused purposefully into selected modules in the DCHE course using the spiral curriculum model, enabled students with little chemical engineering knowledge to build familiarity with this process and progressively learn and apply core chemical engineering concepts and principles at various stages of the course.

The Course Management Team also identified opportune areas to further enhance the integration of other skills sets in the DCHE course, for example CDIO skills (teamwork and communication) as well as future skills (digital skills and versatility). Making connections with concepts taught in different modules can be strengthened to enhance student learning and ways to infuse sustainability concepts meaningfully into the course are areas for improvements.

## FINANCIAL SUPPORT ACKNOWLEDGEMENTS

*The author(s) received no financial support for this work.*

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