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Article

Enriching Process Control Distance Learning: A Paradigm Shift to Modelling and Simulation Integrated Laboratory

Irene Lock Sow Mei [1] & Serene Lock Sow Mun[2*]

[1]*PETRONAS Group Technical Solutions Sdn Bhd, Tower 3, Petronas Tower, Kuala Lumpur City Centre, 50088 Kuala Lumpur, Wilayah Persekutuan Kuala Lumpur, Malaysia*

[2]*CO_2 Research Center (CO2RES), Department of Chemical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750, Tronoh, Perak, Malaysia.*

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Corresponding: sowmun.lock@utp.edu.my

Abstract: The global COVID-19 pandemic has crudely forced an unprecedented transition from conventional classroom settings to remote learning. The seismic movement in educational landscape revealed the importance of digital technology as panacea to enable on-going teaching and learning amid the crisis. The pandemic also magnified the urgency to reform existing education system, whereby adoption of technologies should no longer be viewed as sophistication, but rather as formidable tools to tackle the aftermath of COVID-19. Nevertheless, debates pertaining the dilution of process control learning through virtual learning arise as laboratory classes, which are seen as cornerstones to reinforce theoretical understanding via hands-on experiences cannot be conducted. Although the application of computer aided tools to supplement laboratory activities is gaining momentum, the actual application in Malaysia is rather low. As digital learning is metamorphosed into long-lasting reforms, it is important to integrate computational simulations into the existing laboratory education framework. This study proposes a novel solution by the integration of numerical modelling, computational simulation, and traditional laboratory experiments to facilitate digital learning experiences for chemical engineering undergraduates amid COVID-19. To evaluate the effectiveness of the integrated laboratory as prominent replacement for hands-on setup, 200 undergraduates in a local university were taught process control by applying different course module: the first batch using conventional laboratory setting while the second batch using the integrated simulation laboratory. The performance and learning satisfaction of the students were then benchmarked and evaluated to advocate the better module. Findings from the study suggested that students who completed the process control course with the integration of process modelling and simulation elements outperformed their peers who underwent the same course using conventional hands-on laboratory. Nonetheless, some students demonstrated poorer learning behavior due to lack of confidence and competencies in manipulating the computational simulators. This issue needs to be tackled to support the students' in attaining higher level of interest and inquisitiveness in the learning process.

Keywords: Distance learning; Laboratory; Modelling; Process control; Simulations.

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1. Introduction

The global COVID-19 pandemic, caused by a recently discovered and highly contagious coronavirus, has shined a harsh light on the vulnerabilities, intricacies, and ambivalence of the education system. While the development of a possible remedy is still far from inception, Malaysia's government has implemented a movement control order (MCO) to break the chain of the coronavirus. The pandemic has also crudely forced an unprecedented and seismic transition from conventional classroom settings with physical interactions to remote learning due to closure of public schools and higher learning institutions (Ismail, Abu Bakar, & Syed Saadun Tarek Wafa, 2020).

In concert with the government's initiative to flatten COVID-19 curve, universities, colleges, and schools had taken rapid action to deploy digital and online learning. The radical movement in educational landscape revealed the importance of technology as panacea to enable on-going teaching and learning experience amid the global crisis (Verma, Campbell, Melville, & Byong-Yeol, 2020; Gamage, et al., 2020; Tanveer, Bhaumik, Hassan, & Ul Haq, 2020). The pandemic has also magnified the urgency to reform existing education system, whereby adoption of technologies should no longer be viewed as sophistication, but rather as formidable tools to tackle the aftermath of COVID crisis.

However, debates pertaining the dilution of science education through online learning arise as laboratory classes, which are seen to be the cornerstone to reinforce theoretical understanding via hands-on experiences had to be sacrificed (Babinčáková & Bernard, 2020; Hofstein, 2017). As digital learning is metamorphosed into long-lasting reforms, it is concerned that scientific concepts, that are to be acquired through practical experiences will be poorly understood and appreciated by students. The asynchronous approach could also undermine the students' cognition abilities, problem solving competencies and collaborative learning experiences (Verma, Campbell, Melville, & Byong-Yeol, 2020; Chadwick & Mcloughlin, 2020; Harsha & Thara, 2020; Gamage, et al., 2020).

In reshaping the future of education towards digitalization and distance learning, computer simulations should be considered as prominent solutions to educate and deliver the content of hands-on laboratory. The application of computers, visual aiding facilities and technologies to improve, or even to replace certain laboratory exercises has gained momentum over the years (Bhargava, Antonakakis , Cunningham, & T. Zehnder, 2006). Besides eliminating the need for laboratory apparatus and space, virtual laboratories and simulations were reported to be beneficial to stimulate critical thinking and promote better learning. Pyatt and Sims (2007) concurred that simulated laboratories are more effective, foster higher-level thinking, and can generate more meaningful data. Some of the studies also highlighted that traditional laboratory setting often generates an enormous amount of peripheral information, which can be eradicated through well-designed and pedagogically sound virtual laboratories. The application of computer simulation is reported to be helpful in reducing the cognitive loads for students and offered them a more conducive learning environment to work at their own pace (Wieman & Perkins, 2005).

Nevertheless, there has been skepticism pertaining the application of computer simulations as a legitimate alternative and its advantages over the hands-on equivalent, particularly in process control course for Chemical Engineering student. In Malaysia, although there has been gradual transition to using computer aided laboratory to provide more relevant learning experience to students, majorities of the process control laboratories implemented in higher institution are still focusing on implementation of hands-on practical works. Process control course is described to be very mathematical and abstract, and practical laboratory experiences is important to reinforce the students' understanding by analyzing a physical system (Astrom & Lundh, 1992). Applying real experimental setups in laboratory for process control course enables the teachers to demonstrate critical components related with process control, such as calibration, sensors, digital input/output and real-time programs (Auer, 2018).

It has also been highlighted in these literatures that hands-on laboratory experience is necessary in process control courses to allow students to come into contact with a physical plant, relate theory and practice, and understand how control systems actually behave (Sharma, Martin, Valo, Kaluz, & Fikar, 2016; Sebastian, 2004). The resistivity of students and old-timers on the paradigm transition towards virtual laboratory is has also been well-mentioned in literature, stating that students perceive computational simulation to be difficult and tend to demonstrate poorer learning behavior at the initial transition phase due to lack of motivation and interest (Deslauriers, McCarty, Miller, Callaghan , & Kestin, 2019).

Despite having continuous effort to compare hands-on laboratory and the online equivalents, most of the attempts are stymied as the research studies focuses on different scopes, areas and objectives, making it challenging to deduce which module is more effective in promoting student's learning interest, critical thinking skills and assessment performance. To address this area of ambivalence, a novel solution (*Process Control Simulation Laboratory*) is developed by integrating numerical modelling, computational simulation, and traditional laboratory experiments to facilitate digital learning experience for chemical engineering undergraduates' process control course amid COVID-19 pandemic. The hybrid module is orchestrated to trigger the students in achieving higher level of Bloom's Taxonomy as they can enjoy the domain of simulation with interactive and engaging apprenticeship via computational simulation experiences, while ascertain the sensorimotor nature of laboratory settings. Furthermore, the amalgam of both traditional and virtual approaches assists to develop students' critical thinking by comparing psychological differences between hands-on laboratories and computational simulations.

To evaluate the effectiveness of the *Process Control Simulation* Laboratory as prominent replacement for hands-on setup in existing Chemical Engineering module, 100 Chemical Engineering undergraduates in Universiti Teknologi Petronas were taught process control by applying the new method within 12 weeks. The students were given post implementation survey and final test, whereby questions related to both process simulation and laboratory instructions are included in the assessment to gauge their conceptual understanding satisfaction in learning outcomes. The same set of data was collected for 100 students who had enrolled for the same course, presented in standard and practical laboratory settings. The performance of the students is then benchmarked and evaluated by using the students' final grade and feedback to advocate the better module.

2. Methodology

2.1 Intervention: *Process Control Simulation Laboratory*

CDB3062 Chemical Engineering Lab III has been conventionally designed to enable Chemical Engineering undergraduate students to apply appropriate sensors, instrumentation and/or digital tools to measure physical quantities through hands-on experience. Nonetheless, it is lacking the process simulation and computational integration aspect, which are highly required for the application and transition towards distance learning and online laboratory. The Process Control Simulation Laboratory is developed by incorporating the strategies of the "Five Es Inquiry-Based Learning" approach, that is engagement, exploration, explanation, elaboration, and evaluation (Duran & Duran, 2004).

The integration of computational simulation into the conventional laboratory module were performed following a strategized and planned sequence, focusing of improving laboratory contents, selection of the most easily comprehended and accessible process simulation software, technology integration and formative assessment.

The development of the *Process Control Simulation Laboratory* is performed by 3 main phases: pre-implementation, during implementation and post-implementation phases to ensure smooth and seamless execution of the new laboratory module. The activities have been categorized to the different phases based on their relevancy. This is to enable prioritization and implementation of the project activities within stimulated timeframe according to chronological order. The flow chart of the process activities is depicted in Figure 1.

In addition, mapping of course learning outcome (CLO) and program outcome (PO) of CDB3062 Chemical Engineering Lab III has been reviewed to ensure the new laboratory module is consistent with the course objectives. The review and mapping exercise is required to assess attainment of student's learning outcome based on the implemented innovation. It is found that the new laboratory framework is consistent with the three main elements required for effective teaching and learning for process control: industry needs, pedagogy, and application of technology (Rampazzo, Cervato, & Beghi, 2017).

A well-diverse team comprising of academia and industry advisory members have been formed to ensure the innovative teaching curriculum that

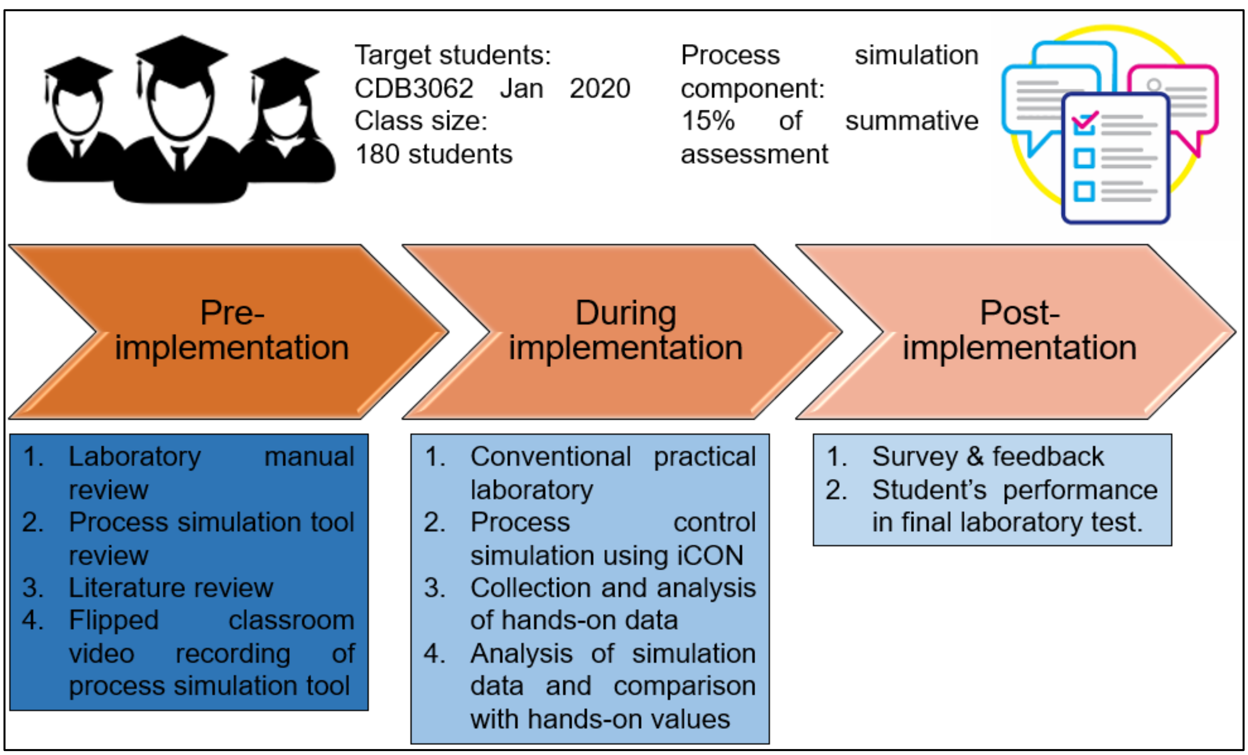


Figure 1: Flow chart of project activities for development of Process Control Simulation Laboratory

esigns conventional physical laboratory activities to accommodate in-line computer simulation work can be implemented effectively.

Inputs from engineers working at industry is required since working practitioners often perform simulation of the control system prior to alteration in set points or change-out plan to ensure efficient, safe, and economical operation. Therefore, the involvement enables existing gaps in the module with actual industrial needs to be identified. This collaboration demonstrates symbiotic expertise sharing between industry and academia, whereby the good adaptation contributes to learning curriculum that aim to produce future workers that are equipped with the Industrial Revolution 4.0 (I.R. 4.0) skills (Shahroom & Hussian, 2018). Continuous review and challenge sessions were conducted within the project team to improve the final version of the laboratory framework. Each laboratory is then designed with general background information, theoretical knowledge, objectives, pre-lab questions, a list of equipment and apparatus required to perform the practical experiments, video clips demonstrating the overview of the hands-on works and physical laboratory settings, post-lab assignments and projects, and viva voce evaluations.

During implementation, the curriculum of the *Process Control Simulation Laboratory* consists of both components of computation simulation and conventional laboratory, as shown in Figure 2.

The main components of the process control laboratory are the hands-on simulations of process units and laboratory equipment alongside with data gathering and analysis, that will enable the students to conduct the experiment online by applying the process simulator. Video demonstrations accompany each of the process simulation laboratories and feature students using the physical system to perform the experiment.

The students are also required to report the findings from both the simulation and practical laboratories. This exercise is to train the students to acquire critical thinking skills to analyze, evaluate, relate, and discuss the collected real time data from experimental observation and simulation work. They

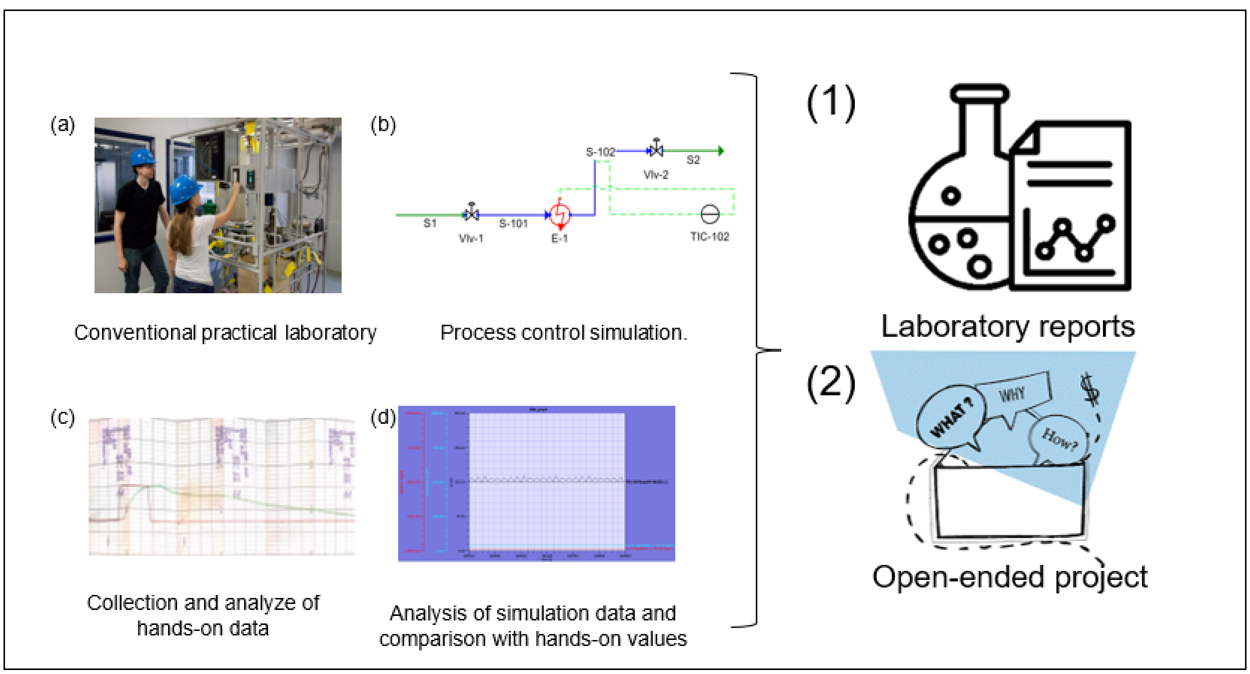


Figure 2: Curriculum of Process Control Simulation Laboratory consists of both the computation simulation and conventional laboratory.

are also required to simulate an open-ended project, which involves a daily encountered control system so that students understand its importance, find its reliability, and perceive simulation as an interactive and interesting task.

2.2 Participants

Two different sets of participants were engaged for this study. The first set of participants included 100 students from Universiti Teknologi Petronas, who enrolled in CDB3062 Chemical Engineering Lab III in September 2019, while the second set of participants included 100 students who had enrolled in the same course in January 2020. The first set of participants were taught the process control by practicing the standard and hands-on laboratory settings, while the other set of participants were taught the same by applying the newly implemented *Process Control Simulation Laboratory* module.

2.3 Data Collection and Analysis

The following were the instruments used to collect the data for this study:

- Student's final grade: The students' final grade for the CDB3062 Chemical Engineering Lab III score, which is a total summation of student lab report, post laboratory vice voce assessment and laboratory tests. The grading rubric to assess the students' understanding on the process control course is summarized in Table 1.

- Feedback and response from students: The perception of students regarding the new implementation of Process Control Simulation Laboratory in CDB3062 Chemical Engineering Lab III via the students' final evaluation of the course.

3. Results and Discussion

The overall performance of the students in laboratory test has been improved via implementation of the newly introduced *Process Control Simulation Laboratory* as shown in Figure 3. The performance of students in laboratory test has been compared to previous semesters from 2016. It is seen that student's performance in 2020 after implementation of the IR 4.0 oriented syllabus that incorporates both simulation and practical laboratory experience has been improved by demonstrating better grades (e.g., higher number of A and median) and exhibiting least number of failures.

Table 1: CDB3062 Chemical Engineering Lab III Grading Rubric.

Marks	Grade
85 – 100	A
80 – 84.9	A-
75 – 79.9	B+
65 – 74.9	B
55 – 64.9	C+
50 – 54.9	C
45 – 49.9	D+
40 – 44.9	D
0 – 39.9	F

Student's attainment of course learning outcome has also been improved by demonstrating 30% increment in students who score good grades of Bs and As, as depicted in Figure 4.

This demonstrates the effectiveness of enhancing students learning experience via incorporation of process simulation elements that are relatable to the practical laboratory. Exercises from both process simulation and hands-on experience can assist the students to understand the theory of process control more vividly given the deep learning thinking skills required to set up the simulation. Besides that, students are also given the real insights of the differences between the results generated from process simulation and hands-on laboratory, which enables them to achieve better and sound understanding of the physical system.

The perception of students regarding the new implementation in CDB3062 has been collected via students' final evaluation of the course, as illustrated in Figure 5.

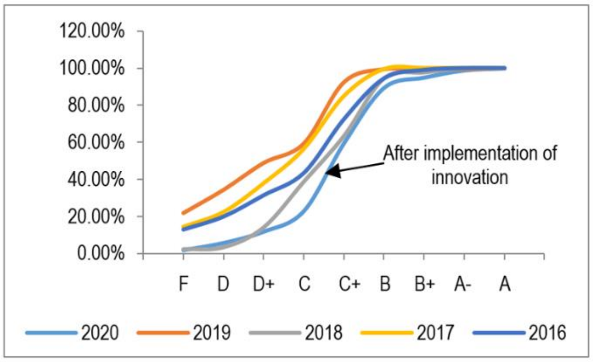


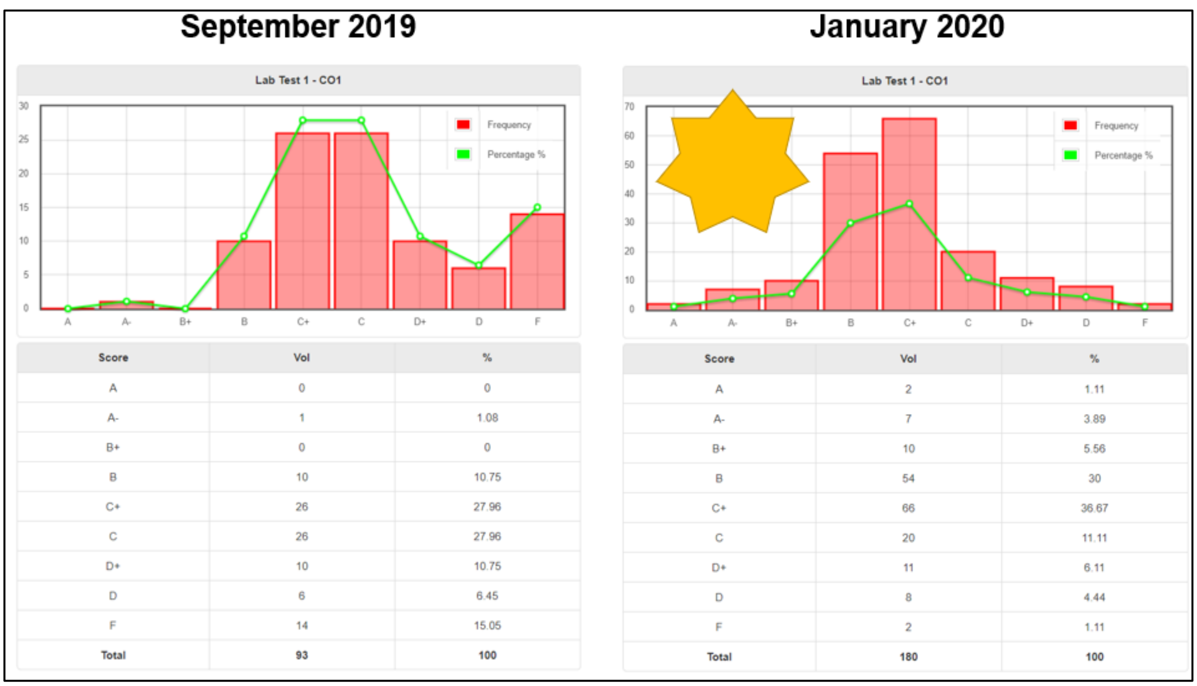
Figure 3: Cumulative frequency distribution of students' performance in CDB3062 laboratory test.

Majority of the students acknowledged that the incorporation of process simulation into CDB3062 Chemical Engineering Lab III was helpful to solidify and to reinforce their understanding on process control theories and applications. Students also responded that the newly developed laboratory module allows them to develop the intuition for how a given process should behave through repeated testing and trial & error on the process parameters, which cannot be achieved through the conventional laboratory settings as this can impose safety concern to the students. The integration of process simulations is also perceived positively by the students in the evaluation form, stating that the process simulators enable them to enhance their understanding of the different form of controllers, by comparing their responsive characteristics, the effect of noise and uncontrolled disturbance to process control loop.

Nonetheless, some of the students still find it challenging to fully grasp the key concepts of the process simulators, which emphasizes the importance to psychologically prepare the students in the coming offerings so that they can perceive process simulation positively and be fully engaged in the learning process.

4. Conclusion

The global COVID-19 pandemic has forced a dramatic shift in our education landscape from learning and teaching in conventional classroom set-



September 2019

Score	Vol	%
A	0	0
A-	1	1.08
B+	0	0
B	10	10.75
C+	26	27.96
C	26	27.96
D+	10	10.75
D	6	6.45
F	14	15.05
Total	93	100

January 2020

Score	Vol	%
A	2	1.11
A-	7	3.89
B+	10	5.56
B	54	30
C+	66	36.67
C	20	11.11
D+	11	6.11
D	8	4.44
F	2	1.11
Total	180	100

Figure 4: Comparison between student's attainment of course learning outcome in CDB3062 laboratory test with comparable level of difficulty and question variability

tings into online and distance learning.

Since hands-on laboratory experiences are viewed as the cornerstone for process control course, there is an urgent need to reform the education framework to enable continuous learning and teaching amid COVID-19. Although the application of computer aided tools to supplement laboratory activities is slowly gaining momentum in Malaysia, skepticism remains, regarding the use of computer simulations as viable option to replace conventional laboratory setting for process control course. The course is described to be abstract, complex, and students' exposure to a real physical system via hands-on activities are required to reinforce their understanding.

In this study, we evaluated a set of newly developed solution, (*Process Control Simulation Laboratory*), which is developed by integrating numerical modelling, computational simulation, and traditional laboratory settings. The objective of this research was to investigate the use of the newly developed laboratory module as a long-term reform to the conventional hands-on laboratory settings. The research was conducted with 200 Chemical Engineering undergraduates from Universiti Teknologi Petronas: the first group of students were taught process control by practicing the conventional laboratory settings, while the second group of students were taught the same course by using the newly developed *Process Control Simulation Laboratory*. The performance of the students is then benchmarked and evaluated by using the students' final grade and feedback to advocate the better module.

The analyses of the final data for both group of students suggested that the second batch of students, who underwent process control course with enhanced integration of computational simulations and numerical calculations, demonstrated better grades and outperformed their peers who completed the same course through conventional ways. Based on students' final evaluation of the course, several distinct advantages of the Process Control Simulation Laboratory were highlighted: it is effective to achieve higher level of understanding through curriculum augmentation; students are more confident to conduct experiments as the process simulation environment offers a safe and controlled environment with lesser hazards; and the process simulators enable them to visualize the effect of noises and disturbances to process control characteristics, which cannot be achieved through conventional laboratory settings.

Nonetheless, some students still perceive that modelling and running computational simulations was challenging due to the lack of exposure to process simulation exercises and poor understanding of how the process simulators work. Early exposure of students to computational simulation is therefore essential to enhance their co-

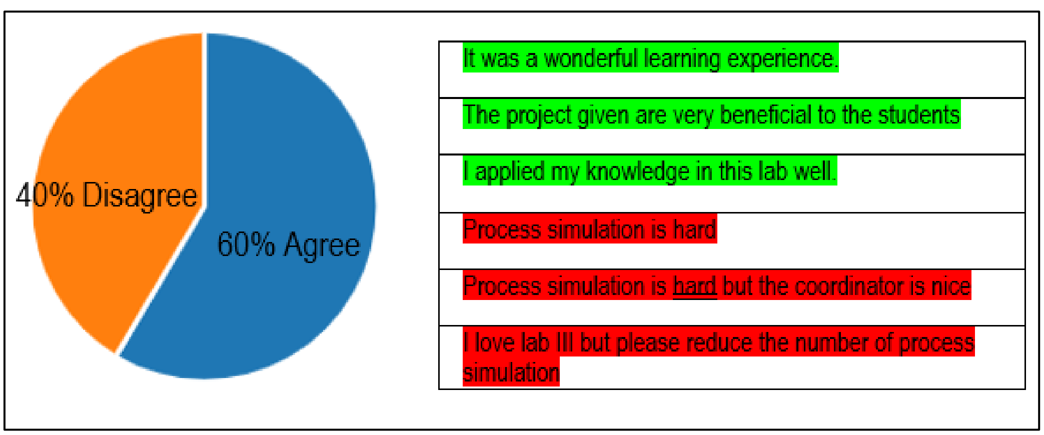


Figure 5: Feedback from students regarding implementation of Process Control Simulation Laboratory.

mpetencies, skills, and technical knowledge in manipulating the process simulators. This is important to ensure that they can perceive the immersive of process simulation positively and be fully engaged in the learning process.

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