Research Article

Design of a Process Control Laboratory Curriculum Incorporating Simulation Modules and Hands-On Training for Enhanced Learning Experience

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Abstract: *Integrating Industry 4.0 principles into laboratory programs is essential for mastering modern process control. However, many existing curricula rely heavily on direct instrument use, which may not fully prepare students for Industry 4.0 requirements. In response, Universiti Teknologi PETRONAS has introduced an updated, simulation-focused curriculum, starting with the CEB3032 Chemical Engineering Laboratory III course for the January and May 2021 cohorts, which included 207 and 162 students, respectively. These cohorts faced limited hands-on training opportunities due to COVID-19, underscoring the need for enhanced practical skill development through simulation. To prepare, the university carefully selected suitable experiments for process simulation, modeling them using dynamic simulation tools. Students were exposed to methodologies such as Euler's, Runge-Kutta, and Gear methods for lumped parameter systems, and finite difference methods for distributed systems, to understand the calculation basis underlying the dynamic system. Within this curriculum, students participated in simulation creation, experimentation, results documentation, and comparison with conventional laboratory results. Advanced Bloom's Taxonomy and the Five Es Inquiry-Based Learning model were key components, allowing students to design their own labs and explore foundational control principles. Feedback and performance metrics highlighted the program's success, with improved student performance indicators, including higher rates of top grades (e.g., A's) and a rise in median scores. Approximately 30% more students earned grades from B to A, and many reported that process simulation had significantly strengthened their ability to apply theoretical knowledge in laboratory settings. This approach's success points to its potential for broader academic adoption, offering a scalable, cost-effective model adaptable to various engineering curricula using existing simulation resources.*

Keywords: Computation simulation; Practical experience; Process control laboratory; IR 4.0 education.

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1. INTRODUCTION

Malaysia's higher education system is increasingly emphasizing Industrial Revolution (IR) 4.0 principles to equip future professionals with essential skills in emerging technologies (Rawi, Isa, Ismail, Sajak, & Sulaiman, 2022). This is particularly relevant for process control courses, where automation and computational tools play a critical role in real-world applications.

A review of current literature shows a gradual shift toward computer-aided laboratories for enhancing student learning (Potkonjak et al., 2016), yet many process control laboratories in Malaysian institutions still focus primarily on hands-on practical work, supplemented by digital control and automation features. The integration of process simulation software into laboratory modules is relatively uncommon. Furthermore, most laboratory designs are limited to single-process units or simplified transfer functions within a computerized environment. This does not fully replicate the complexity of actual industrial processes, which rely on multiple interconnected units to meet unified control objectives.

Moreover, computerization in these laboratories often centers on basic visualizations of changes in input variables without capturing the dynamic interconnections and dependencies essential for design and optimization, which are key elements of industrial automation requiring advanced cognitive skills. Current setups tend to rely exclusively on either hands-on or virtual simulation experiences, yet both are necessary to create a comprehensive learning environment in line with IR 4.0 educational goals. Integrating both approaches would better reflect the complexity of industrial automation and enhance student learning by fostering higher-level critical thinking.

2. METHOD & MATERIAL

This work is defined by its seamless integration of computational simulation with hands-on training in the process control laboratory. The traditionally design-oriented Aspen Tech process simulation software is now embedded into the lab curriculum. To model the behaviour of lumped parameter systems, such as heaters, coolers, and continuously stirred tank reactors, numerical methods like Euler's, Runge-Kutta, and Gear are utilized. For distributed parameter systems, including heat exchangers and plug flow reactors, the finite difference method is applied. Figure 1 provides a summary of the mathematical components used to analyse the dynamic behaviour of the experimental setup.

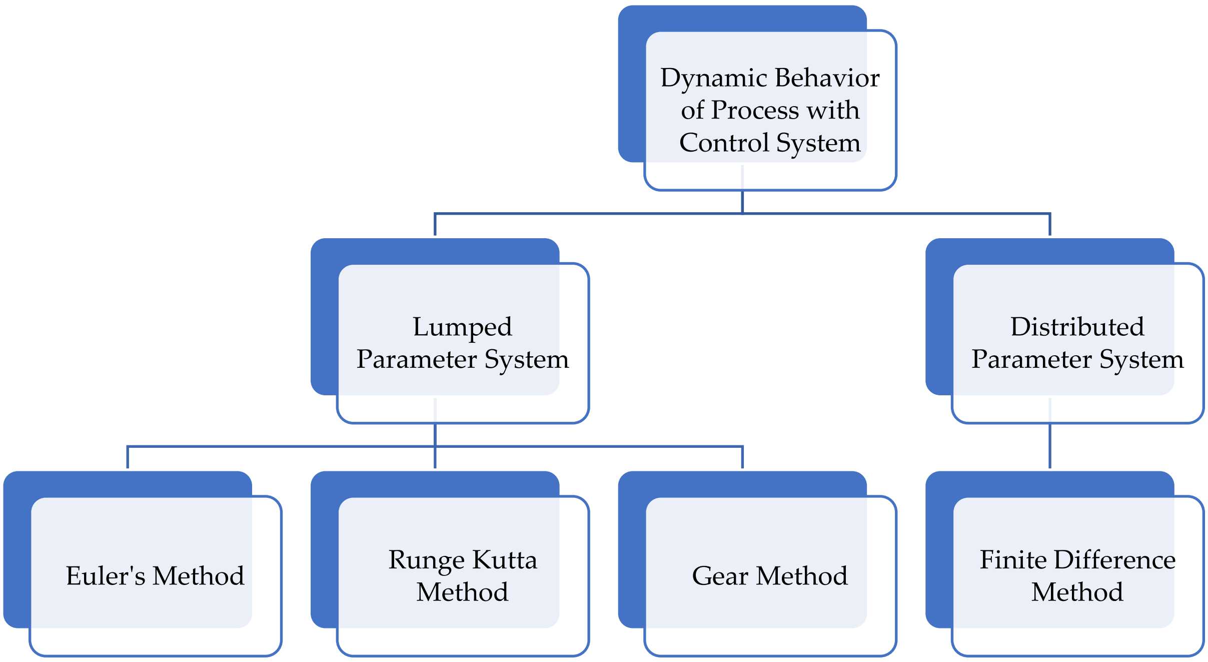

Figure 1. Mathematical elements involved in novel innovation of IR 4.0 oriented design for process control laboratory courses

The innovative combination of computational simulation and hands-on practice has been implemented in the CEB3062 chemical engineering lab iii course for the January and May 2021 semesters, involving

207 and 162 students, respectively. The blended laboratory curriculum highlights the design process for an effective integration of simulation and practical learning experiences.

In the preliminary phase, a comprehensive review of existing laboratory manuals was conducted to identify experiments compatible with the process simulation curriculum. Experiments involving heat exchangers, temperature control, and cascade control were selected for simulation. An evaluation of different process simulation tools determined Aspen Tech as the preferred choice due to its widespread application in engineering education. A literature review was also undertaken to identify pertinent studies and to understand challenges in implementing simulation modules within hands-on laboratory settings. To prepare students for this transition, pre-recorded videos explaining the role of simulation in process control, accompanied by practical examples, were created and presented at the start of the semester.

During implementation, the curriculum integrated simulation laboratories where students emulated control systems using process simulators alongside traditional hands-on exercises. After watching pre-recorded videos on conventional experiments, students performed these simulations as part of their summative assessments. They then compared their simulation results with data obtained from hands-on laboratories practice, fostering critical thinking skills by analyzing, evaluating, and correlating real-time experimental observations with simulated outcomes. Additionally, students engaged in an open-ended project to simulate a commonly used control system, emphasizing the system’s importance, assessing its reliability, and presenting simulation as an engaging and insightful learning experience.

The effectiveness of the innovation had been validated through post-implementation surveys, student feedback, and an analysis of performance in summative assessments. To further assess the impact of this implementation, questions related to process control simulation were included in the laboratory evaluation. This evaluation and alignment exercise is crucial for assessing the extent to which students achieve their learning outcomes in relation to the newly implemented innovation. The analysis revealed that the innovation was in alignment with Course Learning Outcome 1 (CLO1), which focused on the application of relevant sensors, instrumentation, and computational tools to measure the physical properties of process variables effectively, but via an integrated simulation and practical experience in the revised curriculum.

3. FINDINGS

3.1 Students’ Performance in Summative Assessment

Students’ performance in laboratory tests had improved significantly since the introduction of the industry 4.0-aligned laboratory design, as shown in Figure 2.

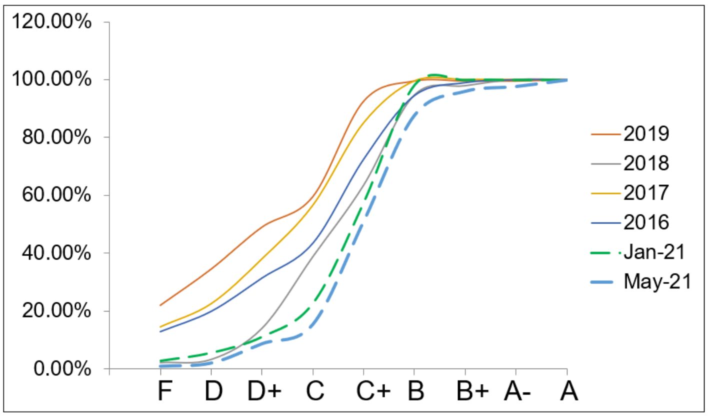

Figure 2. Cumulative frequency distribution of laboratory test

When comparing laboratory test results with data from semesters since 2016, it was evident that the January and May 2021 semesters, following the implementation of the industry 4.0-aligned curriculum that integrated both simulation and hands-on experiences, demonstrated enhanced student outcomes. This was evidenced by a more favourable grade distribution, including an increase in the number of A grades, a higher median score, and a reduction in failure rates.

3.2 Students' Attainment of Course Learning Outcome

Additionally, there was observed to be an approximate 30% increase in the number of students earning commendable grades of B and A with respect to CLO1, as shown in Figure 3.

(a) (b)

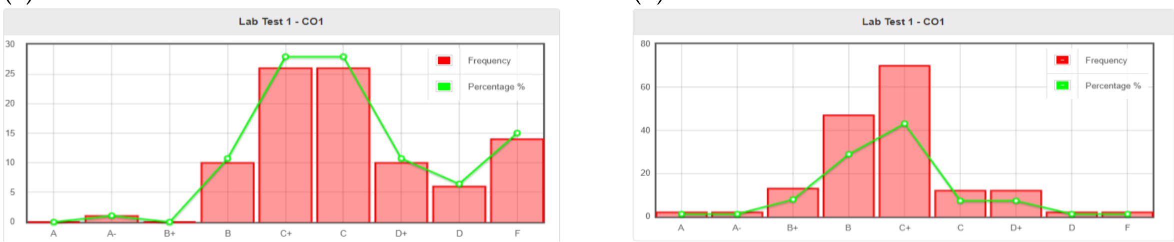

Figure 3. Comparison between student's attainment of course learning outcome for (a) January 2019 before implementation of innovation and (b) May 2021 after implementation of innovation

3.2 Students' Feedback

More, feedback had been collected from students to gauge their level of acceptance on the updated curriculum. Within this feedback, 70% expressed that the incorporation of process simulation in CEB3032 had significantly enhanced their application of knowledge within the process control laboratories.

4. DISCUSSION

In the context of Malaysia's higher education, most process control laboratories emphasize hands-on practical work, augmented by digitalization and computerization for control and automation. Clearly, there has been a limited integration of process control via simulation software in these laboratory modules. To our understanding, the study stands as the inaugural effort in Malaysia's higher institutions to merge computational simulation with traditional hands-on lab infrastructure, including digitalized instrumentation, aligning with the industry 4.0 framework. The efficacy of the coupled curriculum highlights the importance of enhancing student learning through the integration of process simulation components with hands-on laboratory work. By engaging in both simulation and practical exercises, students gain a clearer understanding of the complexities of process control, particularly given the advanced cognitive skills required to configure and operate the simulations. This dual approach not only reinforces theoretical concepts but also fosters critical thinking and problem-solving abilities essential for success in the field. The innovation does not require additional resources (Goodwin, Medioli, Sher, Vlacic, & Welsh, 2011), as it effectively integrates existing learning tools to create a novel IR 4.0 educational experience. Given its cost-effectiveness and the numerous benefits it offers to students' learning outcomes, it is recommended that higher education institutions consider adopting this approach. This strategy not only enhances the learning experience but also prepares students to meet the demands of modern industry. In addition, although majority of the students provide positive feedbacks towards the update curriculum, remaining of them still perceive the experience to be challenging, which substantiate further improvement in this realm since students' attitude towards computer and their preference of using engineering simulation software has been realized to be one of the key factors in governing success of the implementation in previous study (Balamuralithara & Woods, 2012).

5. CONCLUSION

An innovative integration of computational simulation using process simulation software and hands-on experience has been implemented in the process control laboratory course at Universiti Teknologi PETRONAS. A well-designed curriculum has shown to enhance students' understanding of course materials and learning outcomes, as evidenced by improved grades in summative assessments. This approach equips students with the essential skills required in the IR 4.0 environment. The innovation is recommended for adoption across all higher education institutions in Malaysia to align with IR 4.0 educational standards. However, some students still find the material challenging, highlighting the need for effective psychological preparation in future offerings to ensure that students view this innovation positively and remain fully engaged in the learning process.

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