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# A Perspective on Integrating Process Dynamics Simulation into Process Control Education at Undergraduate Level

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Process dynamics simulation is the next logical step after process design and integration tasks have been performed. Dynamics simulation is a highly sought-after yet niche skill that is extremely valuable in the industry to date. This paper reflects on the integration of dynamics simulation into undergraduate process control education, particularly focusing on its implementation in CEE30007 Process Control & Measurements unit at Swinburne University of Technology Sarawak Campus. Dynamics simulation was seamlessly integrated into the current curriculum without altering the existing learning outcomes. These changes include a comprehensive project-based assessment where students develop and evaluate dynamic control strategies of a distillation system. The integration of simulation-based learning not only provided hands-on experience and improved the problem-solving skills of the students but also and prepared them to analyse dynamics in the chemical engineering industry. A detailed survey was conducted to assess the effectiveness of these changes and to attain feedback for further curriculum refinement. Implemented over three cohorts, 96 % of surveyed students reported improved understanding of dynamic behaviours and better connection between theory and application.

## 1. Introduction

Process dynamics simulation serves as a pivotal way to replicate real-world processes within a controlled environment. It is commonly used to study the performance of time-dependent chemical processes in transient states. This is an essential skill that process engineers must have to quickly build dynamic models to study operability and design control strategies for a given process (Cox et al. 2006). Given its importance, there is a notable need for more professionals with experience in process dynamics simulation. Hence, mastering process dynamics simulation is a highly sought-after yet niche skill that is extremely valuable in the industry today. Process dynamics simulation has been taught in chemical engineering curriculums over the years, typically in units that focus on teaching process control. The earliest record of implementing dynamics simulation in chemical engineering was by Henson and Zhang (2000). Henson and Zhang (2000) have effectively implemented simulation software such as HYSYS.Plant (i.e. into process control learning at the undergraduate level). Henson and Zhang (2000) presented an example problem using HYSYS.Plant to simulate the production of ethylene glycol. More recently, the established form of process dynamics simulation teachings in most university curriculums involve the use of MATLAB/Simulink. MATLAB/Simulink-based courses rely on the developing specific process, mass, momentum, and heat transfer models prior to their application to ensure accurate and rigorous calculations that can be compared to real systems. This tends to be time-intensive and pose challenges when complex processes are involved (Moodley 2020). Simulation has also gained traction across engineering education as a valuable tool for facilitating inquiry-based, low-risk learning environments. Negahban et al. (2024) emphasised that simulation not only serves as a systems analysis tool but also supports immersive, experiential learning.

Having been established as a key component in most process control curriculums, it is important to ask if the students are using the simulations or are they creating them? Clough (2000) emphasises the difference between “the students using simulations” and “the students creating simulations”, reinforcing the need for careful

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consideration to ensure that process dynamics simulations are implemented to enhance the understanding of the students rather than serving as a mere crutch allowing surface-level problem solving without a deeper comprehension of the process model. This is because of the primary design of dynamics simulations, which focuses on practical application and problem-solving rather than explicitly guiding the students through the theoretical understanding of underlying concepts. While several studies have demonstrated the use of dynamic simulation tools such as MATLAB/Simulink or Aspen HYSYS in chemical engineering education, few have described how these tools are pedagogically integrated to align with learning outcomes in a process control unit. This paper addresses this gap by presenting a structured framework that incorporates process dynamics simulation into an undergraduate-level process control unit at Swinburne University of Technology Sarawak Campus (SUTS), called CEE30007 Process Control & Measurements.

## 2. Course Design

The following subsections outline the existing curriculum of the unit, the proposed changes for integrating dynamics simulation, bridging activities and resources required for such changes.

### 2.1 Existing Curriculum and Proposed Changes

The CEE30007 unit at SUTS consists of the topics listed in Figure 1. This is accompanied by assessments such as the MATLAB assignment, class tests, laboratory activities, and the final examination. The unit learning outcomes of CEE30007 are as follows:

1. Identify variables and signals to be measured and/or controlled in a typical system.
2. Explain basic principles of modelling for process control applications and analyse control systems in Laplace and time domain.
3. Analyse stability of control systems.
4. Apply controller tuning techniques through laboratory projects.
5. Develop block diagrams for control systems using standard graphical symbols.

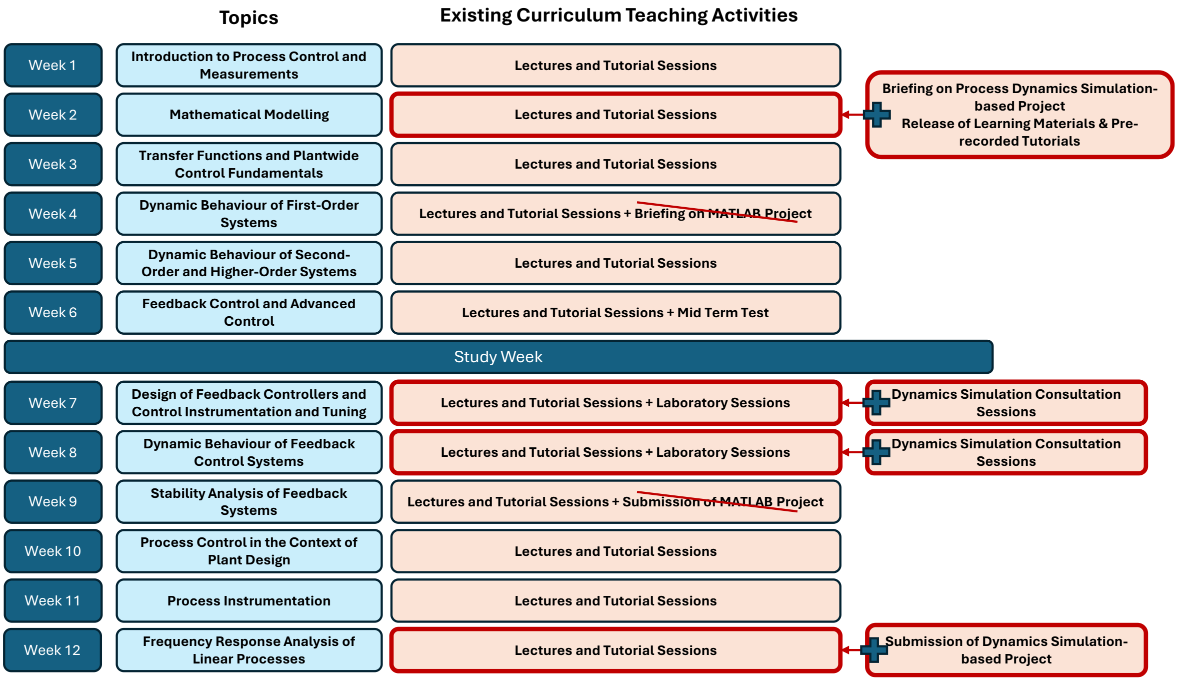


*Figure 1: Weekly topics delivered, existing teaching activities and changes introduced in CEE30007 unit at SUTS*

### 2.2 Learning Materials and Required Software

The learning materials required for the proposed change above include a set of lecture notes and pre-recorded video tutorials, which are given at the start of the semester (more details in Section 2.3). The dynamics simulation software package used in this unit is Aspen Plus Dynamics, the dynamics simulator offered by Aspen Tech. This is because SUTS is already subscribed to Aspen Tech's simulation software packages. Therefore, the use of Aspen Plus Dynamics is a seamless and cost-effective transition to dynamics simulation learning and teaching activities in the unit. However, the framework proposed here can be applied using any simulation package that offers the ability to analyse process dynamics.

### 2.3 Bridging Activities

As mentioned earlier, the bridging activities included in this unit are dynamics simulation-based project briefing, providing topic-specific learning materials (i.e. pre-recorded video tutorials and lecture notes) and consultation sessions. The briefing is delivered at the initial stage of the semester. In the briefing, the instructor explains the requirements of dynamics simulation-based project and release it for the students to begin their work. The reason for this early release is to provide the students sufficient time to begin reviewing the unit content throughout the semester while simultaneously completing the project. The lecture notes provide step-by-step procedures for developing a process dynamics simulation in Aspen Plus Dynamics, and the pre-recorded video tutorials demonstrate those mentioned procedures. These pre-recorded tutorials give the students the flexibility to review step-by-step tutorials on how to develop a dynamics simulation file at any time. The purpose of these materials is to cater for the students with different learning styles. Consultation sessions essentially replace some sessions previously occupied by tutorial sessions. The consultation sessions are sessions where the students can drop in to discuss and clarify their doubts with the tutors and the unit convener. This session also allows the instructors to provide feedback on the overall direction of the students' work.

## 3. Project Brief / Problem Sheet

All bridging activities culminate with the process dynamics simulation-based project. The students were assessed through a project accounting for 30 % of their overall unit assessment. The assessment is mapped to the third unit learning outcome, which is on analysing stability of control systems. This simulation-based project was designed as a group project, allowing a maximum of four members per group to encourage collaboration among the students and shared learning experiences. The students are required to work on the project based on the project brief given at the start of the semester. The project brief enumerates a series of project tasks focusing on implementing and evaluating of dynamic control strategies. The students were also provided with a ready-configured base case simulation file alongside the project brief. A sample of this brief and the base case simulation file can be seen in Figure 2.

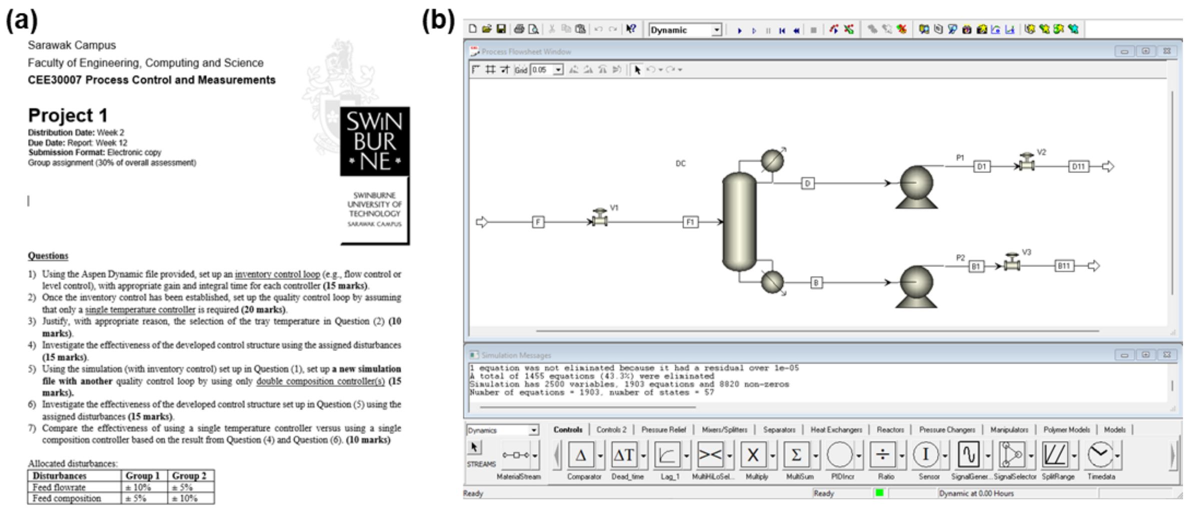


*Figure 2: (a) Sample project brief and (b) base case simulation file*

The project brief had the following detailed project tasks:

### 3.1 Project Task 1: Inventory control loop

The first project task required students to establish an inventory control loop within the Aspen Plus Dynamics file. This includes setting up both flow and level control while determining the appropriate gain and integral time for each controller. This project task aims to assess the students' knowledge and skills on the fundamentals of a control loop, with a specific focus on inventory control.

### 3.2 Project Task 2: Quality control loop with single temperature controller

Following the implementation of the inventory control loop, the second project task for the students was to set up a quality control loop. In this project task, the students had to establish a single temperature controller and configure it effectively to meet required product requirements. This project task is designed to examine the students' ability to set up a quality control loop, particularly by utilising a single temperature controller, to ensure product quality.

### 3.3 Project Task 3: Justification of tray temperature selection

In this project task, the students had to justify their choice of tray temperature for the quality control loop. They had to provide proper reasoning to explain why a specific tray stage is being selected. This project task challenges the students to articulate the reasoning behind their choice of tray temperature in the quality control loop, linking their theoretical understanding to practical decision-making.

### 3.4 Project Task 4: Alternative temperature controller

The students had to suggest an alternative controller to replace the temperature controller in Task 2. Besides, they discussed the reasons for the replacement, outlining both the advantages and disadvantages of the suggested alternative. The objective of this task was to stimulate creative problem-solving skills among the students, offering them a platform to deepen their understanding of quality control loop selection.

### 3.5 Project Task 5: Evaluation of control structure

For this project task, the students explored the effectiveness of the developed control structure with a single temperature controller under assigned disturbances. This project task allowed students to apply their knowledge, focusing on evaluating the robustness and stability of the constructed control structure. Through this project task, the students can gain valuable experience in analysing the effectiveness of their control system in response to various disturbances.

### 3.6 Project Task 6: Quality control loop with dual temperature controller

To challenge the ability of the student in handling a more complex control structure, Task 6 involved the students in setting up a dual temperature controller using the file with inventory control loops previously set up after Task 1. Additionally, the students were required to analyse the effectiveness of the new control structure and compare it with the single temperature controller using the assigned disturbance. This aims to facilitate the learning process of the students not only in configuring a dual temperature controller but also in challenging them to conduct a comprehensive analysis of the advantages and challenges associated with dual temperature control.

### 3.7 Project Task 7: Justification of tray temperature selection

As with Project Task 3, this task examined the students' ability in selecting the appropriate tray for both temperature controllers. The proposed project task not only requires the students to justify their choice of tray temperature for both temperature controllers but also to provide appropriate reasons for their selection.

### 3.8 Project Task 8: Alternative control structure

The final project task instructed the students to enhance the performance of the single temperature controller instead of relying on the dual temperature controller. This task is designed to encourage the students to explore alternative strategies for improving control system efficiency while fostering innovation and critical thinking in process control.

The consultation sessions shown in Figure 1 are included to support their progress. These sessions are intended for the tutors to be available to the students and to address/troubleshoot any challenge, such as simulation errors, that the students might encounter during their project. The submission deadline for the project was set at the end of the semester, specifically by week 12. This timeframe, spanning a total of 10 weeks, is anticipated to provide the students with sufficient time to complete their project successfully. By the end of week 12, each group of students submitted an Aspen Plus Dynamics file containing the completed control structure, accompanied by an electronic copy of the final report outlining the justifications for the implemented control structure and the results obtained.

## 4. Feedback from Students

A 7-item questionnaire was designed and utilised to determine the student's perception and reception towards this change. A sample of the questionnaire is shown in Table 1. Items 1 to 4 in the questionnaire used a 2-point Likert scale that included responses “agree” and “disagree”, and responses were analysed quantitatively using frequency and percentage distribution. Items 5 to 7 were open-ended and analysed thematically. The questionnaire was distributed to students by the last tuition week i.e. week 12 and received anonymous responses from students. The proposed changes shown in Sections 2 and 3 were rolled out for three cohorts with total sum of 28 students. From that total, 22 students responded to the questionnaire.

*Table 1: 7-Item questionnaire designed to gather student feedback on integration of dynamics simulation*

| Item | Description |
|---|---|
| 1 | The use of Aspen Plus Dynamics improves my understanding of dynamic behaviour in chemical processes. |
| 2 | Aspen Plus Dynamics helps me connect theoretical concepts of process control and measurements to real-world applications. |
| 3 | The hands-on experience with Aspen Plus Dynamics enhances my problem-solving skills in process control and measurements. |
| 4 | Aspen Plus Dynamics provides a practical perspective on the importance of process dynamics in chemical engineering |
| 5 | Were there any specific topics or concepts in process control and measurements that you found particularly well-explained or clarified using Aspen Plus Dynamics? Please provide examples. |
| 6 | Were there any challenges or difficulties you faced when working with Aspen Plus Dynamics? How can those challenges be addressed or mitigated in future lessons? |
| 7 | What suggestions do you have for improving the integration of Aspen Plus Dynamics into the Process Control and Measurements unit? This can include specific features, examples, or exercises |

From the questionnaire, the feedback from the students were gathered and evaluated. The result from the questionnaire suggests that 96 % of students agree that the use of dynamics simulation improved their understanding of dynamic behaviour in chemical processes. Similarly, 96 % found that dynamics simulation helped to connect theoretical concepts of the unit to real-world applications. 60 % noted that the hands-on experience with dynamics simulation enhanced their problem-solving skills in the unit while 96 % stated that it provides a practical perspective on the importance of process dynamics in chemical engineering. No substantial variation was observed in feedback across the three cohorts, indicating consistency in delivery and student experience. These findings are consistent with a recent report that highlights the educational value of commercial process simulators in undergraduate process control and dynamics courses (Udugama et al. (2023)). For example, Suthar and Joshipura (2023) emphasised that simulators not only support process design and optimisation but also enhance control loop understanding and operator training, especially when integrated through active learning strategies. These studies corroborate the effectiveness of embedding simulation tools in coursework to boost engagement and conceptual understanding, which is an outcome reflected in this study's student feedback. The qualitative feedback from Items 5 to 7 shared by the students pointed out a growing interest in the unit and several areas for further improvement. Some notable feedback was as follows:

*Table 2: Notable Feedback Provided for Items 5 to 7 in Questionnaire*

| Item | Feedback |
|---|---|
| 5 | "Yes, the concept of control strategies and the controller actions (e.g. reverse acting or direct acting) as well as the P, PI and PID controller characteristics were clearer"<br>"Yes, the part where control signals were connected to equipment in Aspen Plus Dynamics made me easily understand and differentiate terms such as process variable and set point." |
| 6 | "Materials on how to analyse the generated response graphs would be helpful"<br>"Learning materials can benefit from adding reasons on why certain steps are required for the simulation" |
| 7 | "More examples can be provided for the students to attempt."<br>"None, the assignment and the practicality of the unit can be used in the industry, as well as the purpose of learning the unit is clear." |

The feedback shown in Table 2 indicates that positive response to integration of process dynamics simulation into the unit. For Item 5, students highlighted that the dynamic simulation environment enhanced their understanding of key control concepts, particularly controller action types (e.g. reverse acting or direct acting) and PID controller characteristics. This indicates that visual and interactive elements of dynamics simulation helped to clarify abstract concepts which are often challenging when taught through lectures alone. One student explicitly stated that the process of connecting control signals to equipment made it easier to differentiate between process variables and set points, suggesting that simulation promotes intuitive comprehension through hands-on application. For Item 6, students pointed out a lack of support materials for interpreting response graphs, which are essential in evaluating control system behaviour. Another useful suggestion was to include explanations for each simulation step, to improve understanding of not just how, but why certain configurations are made. These responses indicate the need to expand support materials beyond procedural guides to include analytical tools and conceptual explanations, thereby reinforcing critical thinking. As for Item 7, some students requested the inclusion of additional worked examples and practice cases, particularly for trying different control strategies. This feedback points toward student interest in applying simulation tools beyond the assessed project, which reflects positively on the perceived relevance of the simulation approach. On the other hand, one student noted that the assignment was already very practical and relevant to industry, implying that the current structure is effective but can benefit from optional enrichment materials for advanced learners.

Generally, students were able to share some useful feedback on how the learning materials can be improved further for the next delivery of the unit. To support continuous enhancement of the unit, future work will be directed towards expanding the collection of student feedback in upcoming unit deliveries. This ongoing feedback cycle will facilitate a more comprehensive evaluation of the pedagogical impact and support the refinement of instructional materials and teaching strategies.

## 5. Conclusions

This paper presented a framework on the integration of process dynamics simulation into process control curricula at SUTS, where it helped students to bridge theoretical concepts with real-world applications and significantly improved their problem-solving skills as well as practical knowledge. The framework outlines several changes made to the unit, to teach undergraduate chemical engineering students not only on how to apply process dynamics simulation, but also on how the fundamentals of process control are linked to its usage. These proposed changes complement the current structure of the unit without altering its learning outcomes, emphasising the practical component of dynamics simulation that can be easily integrated into the existing curriculum. Moving forward, it is essential to continuously gather and analyse the student feedback to refine and optimise the curriculum, ensuring that it remains relevant and beneficial in developing proficient process control engineers. In addition, the self-reported nature of the feedback may not directly measure learning gains. Thus, future work will include objective measures such as assessing performance in exams to triangulate the impact of the proposed changes on overall student performance.

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