ŌTAUTAHI CHRISTCHURCH AOTEAROA NEW ZEALAND
35TH AUSTRALASIAN ASSOCIATION FOR ENGINEERING EDUCATION ANNUAL CONFERENCE
8-11 DEC 2024
THE ENGINEER AND THE WORLD

Blended learning: Enhancing students' engagement using simulation-based learning

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ABSTRACT

CONTEXT

MATLAB, a widely used computational tool in engineering and scientific fields, offers students a dynamic platform to apply theoretical concepts practically. The utilization of MATLAB Live Scripts in teaching mathematical models in process dynamics and control courses is an emerging educational tool aimed at enhancing students' comprehension and analytical skills. By integrating Live Scripts into the curriculum, educators can provide interactive learning experiences that improve active engagement and deeper understanding of complex mathematical models and dynamic systems. While previous studies have demonstrated the effectiveness of incorporating MATLAB/Simulink into chemical engineering process control education (Li & Huang, 2017), further research is needed to specifically explore the tailored integration of Live Scripts into process dynamics concepts to effectively improve students' learning.

PURPOSE

Integrating mathematical concepts with simulation-based learning can be a promising approach to enhance students' understanding and increase their engagement. This study aims to bridge the gap in students' understanding of mathematical concepts of chemical process dynamics. By designing and implementing simulation-based examples as weekly post-class activities, this study aims to investigate the effectiveness of this implementation on students' achievement of the course learning outcomes.

METHODOLOGY

Using MATLAB Live Scripts, models with different dynamical characteristics and their responses to various input signals are simulated. The examples, aligned with weekly course content, are introduced to students as post-class activities. Students' engagement with the activities and their perceived usefulness were preliminarily investigated to understand the effectiveness of the intervention in improving student learning in the course.

OUTCOMES

The post-class activities are designed to improve interactive learning experiences for students by exploring the intricate dynamics inherent in chemical processes. These activities provide an additional platform for students to understand how systems with different process characteristics behave under varying input signals. Furthermore, these activities facilitate a comparative analysis between the output generated by process modeling and the results obtained through simulations. A preliminary analysis of students' engagement with the activities can estimate the effectiveness of integrating simulation-based learning into teaching practices. The observations suggest that integrating simulation-based learning into the course can enhance chemical engineering students' understanding of mathematical concepts and effectively supplement traditional teaching components.

CONCLUSIONS

The tailored integration of MATLAB Live Scripts in process dynamics and control courses presents an opportunity to enhance chemical engineering students' understanding of mathematical concepts. These observations align with existing literature that supports the efficacy of simulation-based methods in engineering education (Li & Huang, 2017) Therefore, integrating such practices into teaching can significantly contribute to improving students' learning and overall educational experience in this field.

KEYWORDS

Simulation-based learning, MATLAB Live Scripts, Process dynamics and control

Introduction

Blended learning, which combines traditional teaching methods with digital tools, has gained considerable attention in higher education. This approach offers a dynamic platform for students to engage with course content actively. By combining face-to-face instruction with online resources, blended learning facilitates active participation and provides a more interactive learning environment. The use of digital tools allows for personalized learning experiences, immediate feedback, and greater flexibility, which can lead to improved understanding (Rahman, & Ilic, 2018 and Low et al., 2021).

The use of simulation-based learning in engineering education has been extensively studied, revealing numerous benefits in enhancing students' understanding of complex concepts through interactive and visual representations (Botero et al., 2016 and Ramírez et al. 2020). For example, simulation-based platform is used to design a virtual laboratory for a chemical reaction engineering course. The virtual model simulates various engineering scenarios, such as petroleum refining and nanoparticle synthesis, that are often impractical to replicate in laboratories. It integrates economic and environmental analyses to address engineering problems. The integration of problem-solving with practical constraints received positive feedback, highlighting the effectiveness of virtual labs in bridging theoretical concepts with real-world applications (Ramírez et al. 2020).

Moreover, simulation-based practice is key to developing more effective online delivery methods, which, when combined with innovative assessment strategies, ensure learning outcomes are achieved despite limited physical interaction. This challenge is particularly critical in fields like chemical engineering, where acquiring practical skills is crucial. Virtual labs and simulations offer promising solutions, enabling students to understand concepts and operational procedures before engaging in physical experimentation (Botero et al., 2016 and Glassey & Magalhães, 2020). For example, a simulation-based platform integrates reactor engineering and process control concepts to design a system for remotely operating a chemical reactor. This approach allows students to apply theoretical concepts to real-time experimental observations, especially useful when access to physical plants is restricted (Botero et al., 2016).

MATLAB is a widely used computational tool that facilitates the practical application of theoretical concepts. Recent advancements in educational technology have introduced MATLAB Live Scripts, an interactive tool that can enhance students' comprehension and analytical skills (Durán et al., 2007). MATLAB Live Scripts enables an interactive and engaging learning experience by combining text, images, equations, and code. This approach allows students to experiment with code and parameters, receiving immediate feedback and improves students' understanding and engagement (Vicéns et al., 2016). The implementation of MATLAB Grader and Live Scripts in engineering education help student learning (Ni & Hekman, 2022). Using these tools provided immediate feedback, which helped students to better understand complex concepts. MATLAB Live Scripts allowed for an integrated learning environment where students could interact with code and visualizations in a single document, making the learning process more cohesive and efficient. The use of these tools improved students' performance and made the learning experience more engaging and enjoyable.

Previous studies have demonstrated the effectiveness of incorporating MATLAB into engineering education (Li & Huang, 2017 and Domínguez et al., 2023) with the aim at bridging the gap between traditional engineering education and modern computational requirements, ensuring that students are well-prepared for the complexities of the digital industry. For example, a platform using MATLAB was developed for chemical engineering students in both online and offline formats. This platform is used to model convection-diffusion-reaction processes and visualize the data through mathematical simulations. By integrating computational analysis with reaction kinetic data, students simultaneously learned advanced programming skills and created numerical models of chemical reactions. The capability to simulate complex chemical processes has practical applications in multidisciplinary fields of science and engineering. (Bezrukov & Sultanova, 2021). However, there is more need for further research to explore the tailored integration of Live Scripts into course material and their specific impact on enhancing students' understanding specific complex theoretical concepts of chemical engineering.

Process dynamics and control are fundamental topics in chemical engineering, involving the study of dynamic systems and their responses to various inputs. Understanding these concepts is crucial for students to design and control chemical processes effectively. Traditional teaching methods often find it challenging to convey the dynamic nature of these systems, leading to gaps in students' understanding. MATLAB facilitates an active learning environment, enabling students to apply theoretical knowledge to practical scenarios. The integration of digital tools, into the curriculum aligns with the principles of blended learning, providing students with a more interactive and engaging educational experience. Using MATLAB in conjunction with traditional lectures increased students' engagement and motivation to learn, emphasizing the tool's effectiveness in enhancing educational outcomes. For example, the implementation of a MATLAB/Simulink-based platform in a chemical process control course was observed to significantly improve students' understanding of process control concepts and their skills in programming to model ODEs in the Laplace domain, and to design and simulate PID controllers (Li & Huang, 2017).

While studies support the effectiveness of MATLAB and blended learning in engineering education, there is limited research on the specific use of MATLAB Live Scripts in process dynamics and control courses. The focus is mostly on traditional MATLAB applications or general simulation tools without exploring the unique benefits of Live Scripts. This study aims to fill this gap by investigating the impact of simulation-based learning, particularly through MATLAB Live Scripts, on students' engagement and understanding of process dynamics and control.

Methodology

The simulation-based activities were designed using MATLAB Live Scripts, focusing on process models with diverse dynamical characteristics and their responses to various input signals. These activities were aligned with weekly course content and introduced to students as post-class exercises. Each activity included a concise theoretical background of the process model, a step-by-step guide to simulate the model using MATLAB Live Scripts, interactive elements such as sliders and buttons to modify input parameters, output plots to observe real-time system responses and exercises to reinforce learned concepts. A graphical user interface using Simulink was also introduced to allow students to manipulate input parameters without requiring prior programming skills. The simulation-based activities include interactive exploration of: (i) first-order systems responding to different input signals including step, rectangular pulse, and impulse inputs, (ii) second-order systems responding to similar inputs, (iii) parallel operation of first-order process elements, (iv) dynamic responses of liquid levels in interacting and non-interacting tanks and (v) stability analysis of a closed-loop system with a proportional-only controller.

To assess the effectiveness of the simulation-based learning activities, we observed students' engagement with the activities during the course. We initially investigated if students' engagement with the activities and their perceived usefulness enhances their understanding of process dynamics and control. A preliminary analysis of the investigation was performed to estimate the impact of the simulation-based learning approach on students' educational experiences.

Outcomes

The post-class activities aim to provide interactive learning for students by investigating the complex dynamics of chemical processes. The activities are designed as an additional platform for students to observe how systems, characterized by different processes, respond to various input signals. Moreover, these activities enable students to compare the outputs from theoretical process models with those derived from simulations. This comparative approach supports students in connecting theoretical concepts with practical outcomes.

Dynamic behaviour of a first order system. Figure 1 illustrates an example workflow designed using MATLAB Live Script for educational purposes in a process dynamics and control course. The workflow is structured to facilitate an interactive learning environment that aids students in understanding the behavior and analysis of first-order systems. The workflow begins with the schematic definition of a first-order system (Figure 1a), represented by the transfer function $G(s) = K/(\tau s + 1)$. This standard form encapsulates the dynamics of the system, where K represents the system gain and τ the time constant, fundamental parameters that describe how the system responds over time. As the workflow progresses (Figure 1b – e), it further breaks down the process of setting up, analysing, and simulating the system's response to various input signals. The plant transfer function is defined for simulation (Figure 1b). An example of an input signal (Figure 1c), where the choice of input (e.g., step, delayed step, ramp, sinusoidal) significantly influences the system's output, is shown in the corresponding plots. This is critical in helping students visualize the effects of different inputs on system behavior. It demonstrates the open-loop analytic response of the system and emphasizes how the selected values of K and τ affect the output (Figure 1d). Additionally, the integration of both numerical methods and Simulink simulations (Figure 1e) further explores system responses. This approach supports theoretical concepts and enhances practical understanding through hands-on simulation and real-time parameter adjustments, offering a comprehensive educational tool that bridges theory with practical application.

The structured approach of the workflow beginning with the schematic definition of a system, followed by the simulation of different input signals and their corresponding system responses provides a compelling example of effective educational tool integration. The use of real-time simulations and parameter adjustments breaks down complex concepts into understandable segments, which is particularly beneficial in fields requiring a high level of abstract thinking. The use of dynamic simulation software in engineering education enables students to better understand the mathematical concepts of process dynamics and enhance their simulation skills using MATLAB (Li & Huang, 2017).

Moreover, the integration of this workflow into educational practice addresses common challenges, such as the difficulty students often face when attempting to relate mathematical models to real-world systems. By providing a clear, visual, and interactive representation of how changes in parameters affect system behavior, MATLAB Live Script helps overcome these obstacles, making abstract concepts more tangible. This connection between MATLAB Live Script's capabilities and educational effectiveness aligns with the broader academic discourse advocating for the increased use of simulation-based tools in engineering education to enhance learning outcomes.

Stability of a closed-loop system. Another example of a more sophisticated system is presented in Figure 2. The stability of a closed-loop control system is investigated using simulation. The system's block diagram and the closed-loop transfer function are schematically shown to help students understand the components of the system. This foundational understanding is important for analysing how the system behaves under feedback control. The Live Script also step-by-step explains different components of a closed-loop system and define the closed-loop transfer function relating input $U(s)$ to the output $Y(s)$ as:

$$\frac{Y(s)}{U(s)} = G(s) = \frac{G_c(s)G_v(s)G_p(s)}{1 + G_c(s)G_v(s)G_p(s)G_m(s)} = \frac{G_c(s)G_v(s)G_p(s)}{1 + G_{OL}(s)} \quad (1)$$

where the open loop transfer function is $G_{OL}(s) = G_c(s)G_v(s)G_p(s)G_m(s)$ and $G_c(s)$, $G_v(s)$, $G_p(s)$, and $G_m(s)$ are transfer functions describing the controller, the valve, the process and the measurement device, respectively. The stability of the closed-loop system is determined by the roots of the characteristic equation.

$$1 + G_{OL}(s) = 0 \quad (2)$$

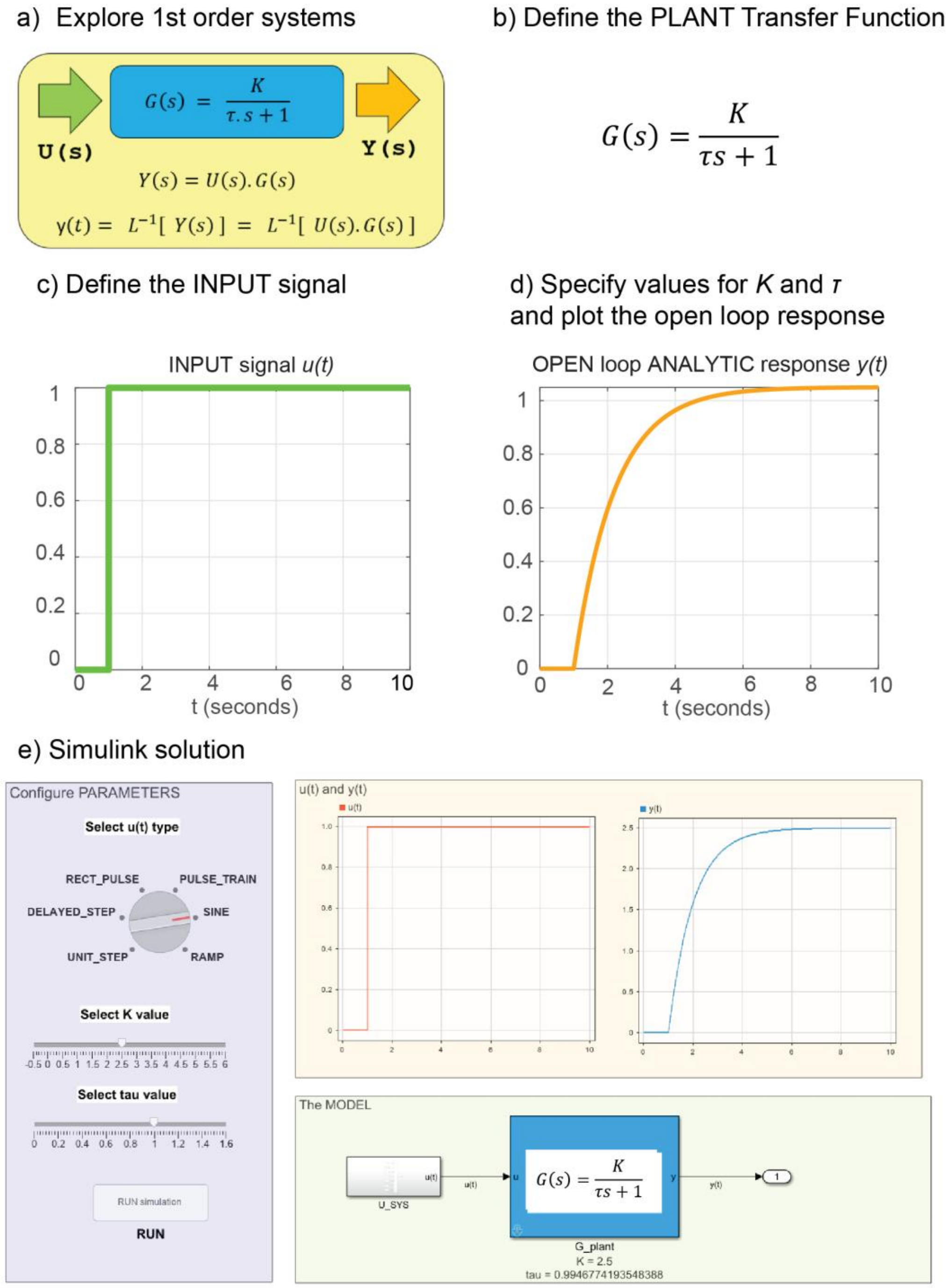

Figure 1: An example of the workflow in MATLAB LiveScript for designing an interactive learning environment for a first-order system in a process dynamics and control course. a) Schematic definition of a first-order problem, b) defining the plant transfer function, c) an example of the input signal based on the selected input signal type, d) the response of the system based on the values of parameters, e) Simulink exploration of the system.

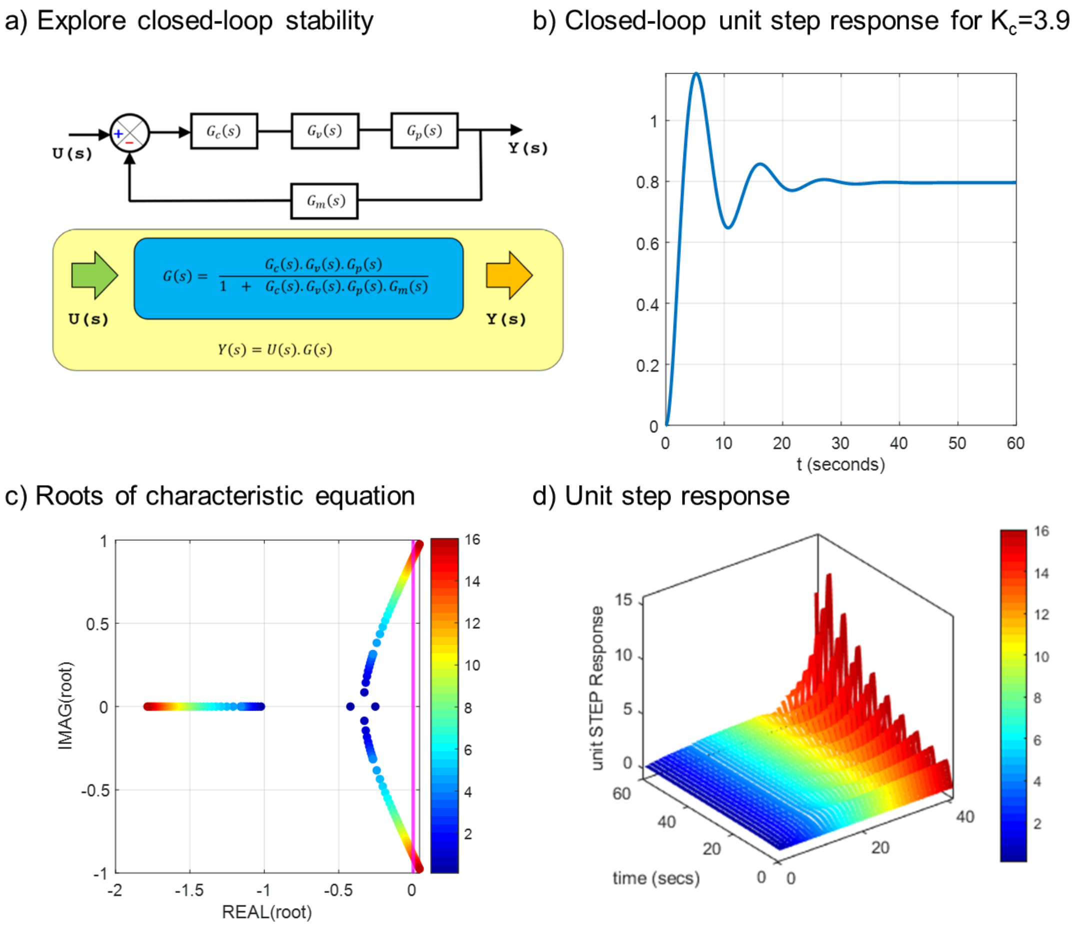

Figure 2: An example of the workflow in MATLAB Live Script for designing an interactive learning environment for understanding closed-loop stability. a) The schematic of a block diagram and transfer functions of a closed-loop system. b) The response of the closed-loop system to a specific value of controller gain ($K_c = 3.9$). c) Exploration of the impact of K_c on the roots of the characteristic equation. d) Visualisation of the unit step response at different values of K_c.

The script explains that a stable closed-loop system requires that all roots of the characteristic equation have negative real components. The simulation allows the student to use different values of controller gain K_c to observe the corresponding roots of the characteristic equation and the closed-loop unit step response (Figure 2b). In the next step, the process is automated by varying K_c and then plotting the locations of the roots of the characteristic equation (Figure 2c). The model emphasises that the characteristic equation is a third-order polynomial and generates three roots. As the value of K_c changes, the different roots are expected to trace out "branches" when plotted, called a "root locus" plot. To visualize the impact of K_c on closed-loop stability, the unit step response to different values of K_c is plotted over time. The 3D plot shows the closed-loop step response for a range of K_c values. The simulation explains that the step response starts to grow exponentially for $12 < K_c < 14$, consistent with the root locus plot. A value of $K_c \approx 12.6$ produces a marginally stable closed-loop system, and values greater than this cause some of the roots of the characteristic equation to become positive, resulting in an unstable closed-loop system (Figure 2d).

The use of simulations and interactive plots encourages active learning, where students engage directly with the theory. The step-by-step exploration of the system's response helps students connect theoretical knowledge with practical application. By visualizing the impact of different control settings, students can better understand how evaluating the roots of the characteristic equation contributes to the stability of a closed-loop system. The process of experimenting with different controller gains and analysing the resulting system behavior enhances students' problem-solving skills. It requires them to think critically about the effects of their adjustments and to understand the underlying principles governing the system's dynamics.

A preliminary observation of how students respond to the use of MATLAB Live Script examples for pre- and post-class activities in a process dynamics and control course and their effectiveness on learning was conducted. The majority of students found the examples helpful, indicating that these interactive tools enhance their learning experience by offering a practical, hands-on understanding of complex concepts. The real-time feedback provided by the Live Scripts helped students visualize the effects of different input parameters on the system's behavior, thereby deepening their comprehension. The observations suggest that integrating simulation-based learning into the curriculum can supplement traditional teaching methods and improve students' overall educational experience. This positive reception aligns with findings from prior studies, which have consistently highlighted the effectiveness of interactive and simulation-based learning environments in improving student engagement and comprehension in STEM education.

However, a portion of students were observed not to engage with the materials. This neutrality could suggest a lack of opportunity to explore these resources, possible hesitation about exploring a simulation-based environment, or a lack of assessment-based reinforcement. Previous research by Campos et al. (2020) suggested that while simulation tools are beneficial, their impact is maximized only when accompanied by supportive assessment strategies that reinforce the learning objectives.

Formal student survey will be gathered in the future to accurately assess the effectiveness of interactive educational tools and highlight areas for improvement, such as encouraging greater engagement and demonstrating the practical benefits of these examples to all students. Future initiatives could focus on integrating more guided tutorials and context-specific examples that directly tie into assessment tasks, enhancing both the perceived value and actual usability of the tools in educational settings.

Discussion

The integration of MATLAB Live Scripts into the process dynamics and control curriculum provides a valuable opportunity to enhance students' learning experiences. The interactive nature of Live Scripts allows students to engage with the material in a more hands-on and visual manner, facilitating a deeper understanding of complex concepts. This approach aligns with the Constructivist Learning Theory (Bada & Olusegun, 2015), which suggests that learners construct knowledge through active engagement and interaction with their environment. Our findings align with existing literature supporting the efficacy of simulation-based methods in engineering education (Li & Huang, 2017; Domínguez et al., 2023). By bridging the gap between theoretical knowledge and practical application, simulation-based learning can significantly contribute to improving students' learning outcomes and overall educational experience. The positive feedback from students regarding the usefulness and engagement of the simulation-based activities underscores the potential of this approach to enhance chemical engineering education.

However, the lack of engagement of some students might be attributed to the activities being optional and not contributing to their overall assessment in the course. This observation aligns with the principles of Motivational Theory (Gopalan et al., 2017) in education, which suggests that students are more likely to engage in learning activities that are perceived as relevant and are tied to their assessments. By incorporating these simulation-based exercises into the grading scheme or offering additional incentives, such as extra credit, students would be more motivated to participate actively.

Compared to previous studies, this research provides a more focused examination of the impact of MATLAB Live Scripts on a process dynamics and control course. While the general benefits of MATLAB in enhancing students' understanding and engagement were previously investigated (Li & Huang, 2017; Domínguez et al., 2023), our study highlights the specific advantages of Live Scripts, such as real-time interactivity and the ability to modify input parameters dynamically. This unique aspect of Live Scripts offers an enhanced learning experience that supports traditional

MATLAB applications. According to the Cognitive Load Theory (Sweller, 2011), providing interactive and immediate feedback helps reduce extraneous cognitive load, thereby allowing students to focus more on learning the core concepts. Using blended learning to combine digital tools with traditional instruction can improve educational outcomes. Integration of MATLAB Live Scripts into the curriculum enhances students' understanding of complex concepts and increases their engagement and motivation to learn. This synergy between blended learning and simulation-based activities creates a more effective and enjoyable learning environment for students.

While the benefits of simulation-based learning are evident, some challenges remain. Students with limited prior experience with MATLAB may find it difficult to fully engage with Live Scripts without adequate support. To address this, we recommend providing additional resources, such as introductory tutorials that cover the basics of MATLAB and its application to simulations. Providing troubleshooting guides and step-by-step instructions would help students navigate common technical issues, while supplementary workshops or help sessions could offer real-time support. Future research should explore the long-term impact of simulation-based learning on students' academic performance and retention of knowledge. Additionally, expanding the use of MATLAB Live Scripts to other engineering courses could further validate their effectiveness as an educational tool.

Conclusion

The tailored integration of MATLAB Live Scripts into process dynamics and control courses presents a valuable opportunity to enhance chemical engineering students' understanding of mathematical concepts. Our observations suggest that simulation-based learning can significantly improve students' comprehension and educational experience in chemical engineering courses. By bridging the gap between theoretical knowledge and practical application, simulation-based learning can effectively supplement traditional teaching methods and provide a more engaging and interactive learning experience for students. The positive feedback from students highlights the potential of this approach to enhance chemical engineering education. Future research should continue to explore the long-term impact of simulation-based learning and investigate its potential benefits and challenges in other engineering disciplines. By expanding the use of MATLAB Live Scripts and other simulation-based tools, educators can further improve the quality of engineering education and better prepare students for the challenges of the professional world.

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Acknowledgment

This document was edited with the assistance of generative AI tools, such as OpenAI's ChatGPT, for proofreading and language enhancement. All content, revisions, and final decisions were made by the authors.

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