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A proposal for charting the undergraduate process control course for the 21st century

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ABSTRACT

Chemical engineering has been one of the leading industries since the Industrial Revolution; however, in the green age, chemical engineering is deemed a major culprit of the environmental problems. To deal with the challenges facing the industry, the related departments in higher education systems should contemplate adapting to the trend and providing a series of courses that meet the needs of the new era. The same is true for *process systems engineering* (PSE). This paper aims to point out a clear direction for future development of the core courses in PSE education, especially process control (PC), hoping the PSE to gain fresh momentum to play a key role in leading the industry and improving the welfare of human beings.

1. Introduction

Nearly two decades ago, a prominent professor, when asked in a feast about the characteristics and functions of the required courses of chemical engineering, mentioned that he could remember nothing more than Laplace transforms after taking the course of process control. This comment implied that most teachers in the field of chemical engineering were strangers to process control. Although process control has in fact a clear connection with other chemical engineering core courses (such as material and energy balance, thermodynamics, reaction engineering, unit operations and process design), a large group of professors and students would think otherwise [1]. This discrepancy has to be closed with the efforts of process control teachers. They should, in the current environment, interweave process control with relevant subjects (*i.e.* process design, simulation and optimization) to form a broader professional framework – *process systems engineering* (PSE) – to play a central role in chemical engineering [2].

On the other hand, there have been criticisms of process control education and research from the industry and graduates. For example, Shinskey, a long-time practitioner, claimed that there has been “no progress in 35 years” in closing the industrial-academic gap in process control, leading to “research results left unused by industry and graduates left unprepared for industrial assignments” [3]. Control engineers at Eastman Chemical reported that they are almost always requested to improve loop tuning online rather than using the step test method for time efficiency [2], and Downs stated, “Recent graduates have zero ability to do such analysis. The most requested training from new employees is process control because they didn’t learn any of this in school …” Also, many graduates feel shortchanged when learning “how critical process control is to their job effectiveness” and “how little they understand about it from their undergraduate education” [2].

In response to the criticisms, while aiming to make room for new material (*i.e.* biosystems) in the undergraduate process control course, Edgar et al. [2] proposed the following steps:

1. Deemphasize frequency response but keep Laplace transforms;
2. Reduce coverage of multiple approaches for PID controller tuning;
3. Increase the use of simulation in sophomore and junior chemical engineering courses, and then use more dynamic simulation in the capstone design and operations course;
4. Use case studies to show how process control can be employed to solve real engineering problems;
5. Integrate process control with other chemical engineering courses.

However, these recommendations do not seem much reflected in the recent edition of Process Dynamics and Control [4]. Table 1 presents the contents of this most popular process control textbook, in which there is still too much emphasis on (i) modeling,

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Table 1
Contents of process dynamics and control, third edition [4].

Part I: Introduction to process control	
1.	Introduction to process control
2.	Theoretical models of chemical processes
Part II: Dynamic behavior of processes	
3.	Transfer function models
4.	Dynamic behavior of first-order and second-order processes
5.	Dynamic response characteristics of more complicated processes
6.	Development of empirical models from process data
Part III: Feedback and feedforward control	
7.	Feedback controllers
8.	Control system instrumentation
9.	Process safety and process control
10.	Dynamic behavior and stability of closed-loop control systems
11.	PID controller design, tuning, and troubleshooting
12.	Control strategies at the process unit level
13.	Frequency response analysis and control system design
14.	Feedforward and ratio control
Part IV: Advanced process control	
15.	Enhanced single-loop control strategies
16.	Multiloop and multivariable control
17.	Digital sampling, filtering, and control
18.	Batch process control
19.	Real-time optimization
20.	Model predictive control
21.	Process monitoring
Part V: Applications to biological systems	
22.	Biosystems control design
23.	Dynamics and control of biological systems

linearization and transfer functions, (ii) simple PID equations plus many tuning rules, (iii) printed dynamic responses, (iv) theoretical stability analysis, and (v) frequency-domain analysis, giving pure lecturing to passive students. At the same time, it does not seem to offer enough coverage of (i) in-depth PID control modes, (ii) interactive tools for dynamic responses, (iii) useful techniques for enhanced PID performance, (iv) control strategies for optimal unit operations, and (v) laboratory instruction. These shortcomings, however, can be overcome by setting appropriate learning objectives, which may be to:

1. Understand how the basic components of control systems (*i.e.* processes, controllers, sensors and valves) work.
2. Develop basic mathematical dynamic process models to assist in the analysis, design and operation of control systems.
3. Master PID feedback controllers for design, tuning and troubleshooting.
4. Implement a variety of enhanced feedback control strategies, including cascade, selective, override, feedforward and ratio control.
5. Master the fundamentals of dynamic simulation of process control systems using MATLAB®/Simulink® [5].
6. Be familiar with control system design for common unit processes.
7. Understand plantwide process dynamics and control.

With this, the suggested course outline, on the use of textbooks of Seborg et al. [4] and/or Smith and Corripio [6], is given in Table 2. Some relevant materials from Wade [7], Liptak [8] and Luyben et al. [9] are also included.

The proposed process control course for undergraduates involves the use of Simulink® [5] and covers materials that were only taught in advanced courses, making it more challenging with time being a constraint. Note that Topics 11–15 in Table 2 are usually taught in the advanced process control course for graduate students. However, not many, or only a limited number of students would take advanced process control, and most graduates heading to the industry might not be well prepared to be a process or control engineer. For nurturing competent chemical engineers in a limited lecturing time, this paper provides a framework for a feasible process control course. The suggestions offered are expected to be helpful for improving the current undergraduate education in chemical process control. In addition to Simulink, there are also other software tools for process dynamics, such as Aspen Dynamics and gPROMS. Although useful, the latter are sophisticated software more often used for research and would be too advanced for undergraduate courses.

2. Proposal to improve undergraduate education in chemical process control

When a college graduate in chemical engineering is asked to name the most unfamiliar course, more often than not he/she would pick process control. The main reason is that the contents of process control are strikingly different from those of other core courses in chemical engineering. Therefore, integrating process control with other courses would be the definitive way to make process control a vital part of a comprehensive training of chemical engineers. On the other hand, some professors suggest that process control may be combined with process design to form an integrated course: PSE. Regardless of whichever to take, the course of process control can be enhanced in the following ways.

2.1. Strengthen the teaching of basic PID control

There is no doubt that most process control instructors make lots of efforts to teach the proportional-integral-derivative (PID) controller. However, most textbooks devote large space only to the description of mathematical formulae of the controller without elucidating the physical meanings, thus depriving the students of the chance to fully understand the essence of the PID controller.

We have tried to double the time to teach the PID controller configuration, elaborating on the structure and functions of several basic elements. The first and central part is the proportional (P) control, in which the regulating controller output $p(t)$ is proportional to the error $e(t)$ between the set point y_{sp} and the current process measurement $y(t)$, $e(t) = y_{sp} - y(t)$, as shown in Eq. (1), where u_b is a constant bias value at $e(t) = 0$ and $u(t)$ is the overall controller output [10].

$$u(t) = p(t) + u_b = K_c e(t) + u_b \tag{1}$$

Fig. 1(a) shows the current-error based P control configuration. The controller output $u(t)$ manipulates the steam flow rate to regulate the outlet stream temperature of a heat exchanger, $y(t)$. Here, $u(t)$ and $y(t)$ are normalized to be within 0 and 100%; K_c (%/%) is a tunable proportional coefficient.

With this basic P control configuration (Fig. 1(a)), the controller output can be adjusted by tuning the coefficient K_c according to the process characteristics and the desired control performance. A larger K_c value increases the control response to the same error magnitude. An aggressive P control command can in general speed up the control action. However, most physical processes themselves need sufficient time for dynamic responses. An alternative method to improve the P control performance is to regulate the P control action in advance by using future error information $e(t + T_d)$ instead of current error $e(t)$, as shown in Eq. (2a).

$$u(t) = K_c e(t + T_d) + u_b \tag{2a}$$

$$\cong K_c[e(t) + T_d de(t)/dt] + u_b \tag{2b}$$

To implement Eq. (2a), the future error signal $e(t + T_d)$ can be estimated by using the current error $e(t)$ and its trend, $de(t)/dt$. This forms a proportional-derivative (PD) control configuration, as