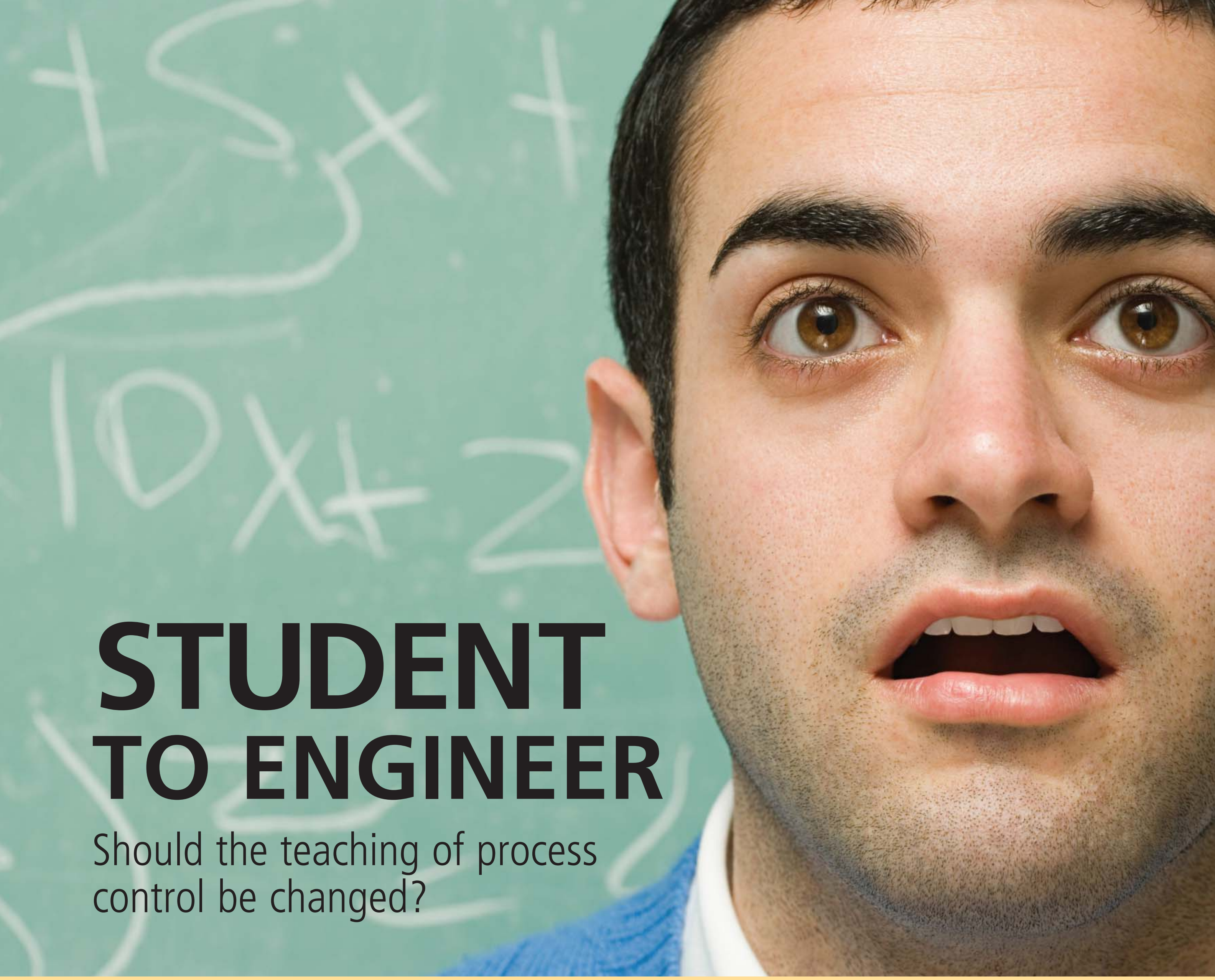

STUDENT TO ENGINEER

Should the teaching of process control be changed?

By Thomas F. Edgar

Part 1 of a two-part series

Let's face it, even under the best circumstances engineering graduates today face a daunting task taking on the massive responsibilities waiting for them in the automation industry. But the underlying debate among academics and those in industry is: Are graduates getting the correct education?

Students trained in chemical engineering are typically not well prepared to support process control in industrial chemical plants, said Eli Lilly's Joseph Alford, especially regarding batch processes, which has been the focus of most of his career. Alford said he checked with engineers who have graduated at different time periods over the past 30 years, and the story is usually the same: Their process control course (typically required for a B.S. chemical engineering degree) is full of content regarding Laplace transforms, frequency domain analysis, Bode diagrams, and root locus, Nyquist, Routh, and other stability algorithms, which they rarely use once they start a job. In addition, these engineers report getting very little practice in practical loop tuning, valve selection, loop diagnostics, and dealing with non-steady state processes in their process control course. It seems most process control courses rely heavily on steady-state continuous kinds of processes (e.g., petrochemicals) that dominated the chemical industry 30 to 60 years ago, but are not a good fit for the extensive use of non-steady state, multi-step batch processes, and also discrete manufacturing processes, in common use today. While Alford's statement reflects the batch industry, it can also apply throughout automation.

In a paper written for the Chemical Process Control 7 conference, my co-authors and I took the position that B.S. chemical engineering graduates don't make the grade if they cannot operate equipment they design, control processes, or understand the dynamic nature of how a process behaves. The following questions capture the important issues:

(1) What is the industrial view of control education?
(2) What control concepts are most important?
(3) Should there be more emphasis on batch control?
(4) What should be the balance of simulation vs. experiments in control education?
(5) How might the future process control course change from its current emphasis?
(6) What topics could be removed?

Traditional process course

One difficulty with the one-semester process control course taught at most schools is its starting point is still the same as it was when the textbook, *Process Systems Analysis and Control*, by Coughanowr and Koppel first hit the classroom in 1965. In order to incorporate all the advances in control engineering from over the past 40 years (as well as projected developments), considerable streamlining of the existing curriculum must occur. Unfortunately, some instructors still teach the same type of course they had when they were students. We have not adapted the course in a feedforward fashion so it will mesh with technologies encountered in a modern chemical plant.

Topics covered in a typical 15-week undergraduate process control course include dynamic behavior (using Laplace transforms and analytical solutions to ordinary differential equations), physical and empirical modeling, computer simulation, measurement and control hardware technology, basic feedback and feedforward control concepts, and advanced control strategies.

Prior to taking the standard university process control course, students take a mathematics course on solving ordinary differential equations as well as other courses in numerical analysis and mathematical modeling. Laplace transforms are a basic mathematical tool in process control, and the teaching of this subject (along with frequency response) has historically been a major part of a process control course. However, given the emergence of software for linear systems analysis and simulation, the level of emphasis on Laplace transform manipulations should undergo re-evaluation. The early dependence on Laplace transforms arose out of necessity because computational and graphical tools were not available prior to 1990.

FAST FORWARD

- To incorporate advances in control engineering from over the past 40 years, streamlining of the existing curriculum must occur.
- How to control processes using measurement feedback is applicable to most every job and should be a basic building block.
- Optimization of a process or operation ranks number one in a list of 10 skills and concepts.

Industrial feedback

"While the need for a B.S. graduate to understand Laplace transforms, frequency domain analysis, or relative gain arrays may not appear to be widely applicable, the knowledge of how to control processes using measurement feedback is applicable to most every job a young graduate may encounter and should be considered a basic building block of their education," said Dr. Jim Downs, an engineer at Eastman Chemical. "The new engineer should also understand that process control is a natural extension of material and energy balances, that is, dynamic loops are used to keep the material and energy balances in balance. The practical aspects of process control such as understanding control objectives, how a control strategy fulfills these objectives, how to tune control loops, and understanding dynamic interactions among process variables are often currently learned on the job. The disturbing fact is that many recent graduates feel shortchanged when they learn how critical process control is to their job effectiveness and how little they understand about it from their undergraduate education," he said.

To further illuminate process control skills and concepts that industrial employers find important in a chemical engineering graduate, Ken Muske, a chemical engineering professor at Villanova University, conducted a survey of 34 industrial practitioners working in the systems and control

Process control course content

Topic	No. of weeks
Mathematical modeling and dynamic simulation	2
Laplace transforms, transfer function	1.5
Linear dynamic responses (various inputs)	1.5
Controllers	1.5
Instrumentation, valves	1
Closed-loop analysis, stability	2
Controller tuning	2
Frequency response	1
Feedforward and advanced control	2

Numbers are averages based on a survey of 60 process control instructors in the U.S. (one-semester course of 15 weeks, three 50-minute lectures per week).

The typical distribution of process control course time for each topic, obtained from a survey of over 60 U.S. departments teaching process control.

area who represent the biotechnology, pharmaceutical, petroleum and petrochemical, chemical, consumer product, and process control consulting business areas. All ranked a list of 10 skills and concepts in order of importance, with 10 being the most important and 1 being the least important. The following gives the 10 skills and concepts in order with the average 10-1 ranking in parentheses:

(1) Optimization of a process or operation (8.6)
(2) Statistical analysis of data and design of experiments (7.2)
(3) Physical dynamic process models (7.0)
(4) Statistical/Empirical dynamic process models (6.9)
(5) Multivariable interactions and multivariable system analysis (6.6)
(6) Statistical process control and process monitoring (5.3)
(7) Design and tuning of PID loops (5.1)
(8) Nonlinear dynamics and analysis of nonlinear systems (3.9)
(9) Frequency domain analysis (2.4)
(10) Expert systems and artificial intelligence (1.9)

Process economic optimization received the highest average rank, so this skill is clearly valued in a cross-section of industries; however, it is not typically covered in process control courses. Process modeling and identification (items 2-4) may be a skill that should have a stronger emphasis in the process control course. PID loop tuning and design did not rank as high as modeling; engineers from more mature industries and consultants rated this skill highly, while respondents from the biotechnology and pharmaceutical industries ranked it rather low.

Three forms of processing

It is surprising batch processing is not a major emphasis in the typical university process control course because companies use batch processing to manufacture specialty chemicals, metals, electronic materials, ceramics, polymers, food and agricultural materials, biochemicals and pharmaceuticals, multiphase materials/blends, coatings, and composites. These are an extremely broad range of processes and products. Only a few departments report they cover batch process control in any meaningful way.

Batch operational practices and control system design differ markedly from continuous plants. Batch control systems operate at various levels, such as batch sequencing and logic control; control during the batch; run-to-run control, and batch production management scheduling.

A batch processing theme in the control course would emphasize different topics than normally covered. In one case, they would want to learn about discrete logic with PLCs because they would need it for the control steps and for safety interlocks to protect personnel, equipment, and the environment from unsafe conditions. Control during the batch requires treatment of nonlinear fundamental models because there is no steady state to use for linearization. Run-to-run (or batch-to-batch) control comes into play when recipe modifications occur from one run to the next, which is common in specialty chemicals and semiconductor manufacturing. Batch scheduling brings in principles of optimization with continuous and integer variables.

Automation engineers at Lilly said there is a third major area of process control, which deals with the manufacture and inspection of discrete objects (e.g., making/inspecting automobile parts, filling/inspecting insulin vials, etc.). There are sensors and automated process control logic that relate to the inspection (sometimes including weighing) of final discrete parts or products made in some industries. There can be a critical element of high throughput capacity involved, including the need to sense and accept/reject decisions on thousands of components per minute.

Thus, there are three major process control environments in industry: continuous, batch, and discrete event, but the current undergraduate course primarily focuses on just one of the three (continuous). However, adding these topics means some existing content will need to go away.

What can go?

In light of the need to add new topics to process control, coverage of topics such as Laplace transforms, analytical solutions to linear differential equations, linear algebra, frequency response, and multiple methods to tune a PID controller probably needs to change. Computer simulation should take a more prominent position compared to theoretical analysis. The availability of commercial simulation software permits new approaches for teaching process control.

Reducing the current course effort on linear systems analysis will rely on using interactive software. It will still be necessary to teach students s-transforms and transfer functions in order to use this software for simulation of closed-loop systems. In using MATLAB Simulink, students find the drag and drop approach for constructing feedback control block diagrams a welcome

Coursework and real-time automation

It is one thing to teach a course in process control, but when you look at the topics covered in automation, it is a whole new world.

In the book, *The Automation Body of Knowledge*, (www.isa.org/link/autoBK) published by ISA, the breadth of topics go far beyond what can be taught in a single process control course, and only two of the seven major headings match process control course topics.

While the book covers the main topics in automation today, it contains no content regarding Laplace transforms, Bode diagrams, and root locus. It does explain subjects not covered in the typical undergraduate course, such as digital systems, batch processes, and practical operating issues. The industrial book only presents PID controllers in the time domain, while the academic course presents PID in both the time and frequency domains. In a continuing education environment, it is not critical for an engineer to learn the mathematically rigorous approach. The best approach to covering the topics in the book should come in a continuing education environment after graduation, rather than in an undergraduate class.

—Thomas F. Edgar

alternative to writing programs to perform closed-loop simulation.

Chemical engineering students should have the tools so they can develop in their mind a model of how a process should behave, both in the steady state sense and in the dynamic sense, said Brian Ramaker of Shell Oil. The chemical engineering undergraduate curriculum emphasizes time domain ideas: flow rates, residence times, rate constants, etc. This contrasts with electrical engineering where a frequency response of a circuit displayed on an oscilloscope is part of their bread and butter. It makes sense the electrical engineer be taught control concepts in the frequency domain, while chemical engineers learn the same concepts in the time domain. Ramaker and his colleagues at Shell suggest teaching frequency domain analysis and design at the graduate level would work better, while the undergraduate course should tie closely to the time domain.

A related issue in the undergraduate course is the time spent on the design of PID controllers. It is clear from a review of current process control texts there are different ways to tune a PID controller. Methods based on stability considerations alone are generally not satisfactory; available performance-based methods are stable and predictable with respect to the design criteria. The emphasis in tuning should be on load responses, while the tendency in most control textbooks is to focus on set-point changes.

What about the model-based controller design approach presented in control textbooks?

Eastman Chemical control engineers report they receive requests to improve loop tuning online rather than using the step test method, because of time efficiency. Certainly for important loops the step test method works fine. However, when loops are performing poorly, being able to look at the trends and current tuning, and say, "increase the gain," "stretch out the reset," or "this isn't a tuning problem, it's a valve problem," is very important. The industrial impression is graduates have little ability to do such analysis.

Use of simulation

Computer simulation tools are widespread in the industry today. The engineer who knows how to effectively use modeling software has a significant advantage. The skills needed are not the details of syntax and software package familiarity or adeptness in numerical methods. Instead, the stumbling blocks to effective modeling are how to use process design specifications, how to handle trace components that build up to significant amounts within a plant, and how to build models to match process operating data. In addition, dynamic modeling can be very beneficial with steady-state modeling. Typical graduates, however, have little experience writing unsteady state balances and understanding how to use such balances.

If dynamic modeling is covered earlier in the chemical engineering curriculum, the process control instructor could focus on issues such as the extent of required modeling sophistication.

Down the road

The dilemma process control educators face is the breadth of material they can cover in a 12- to 15-week course. So an instructor must perform a delicate balancing act to cover the key ideas as well as optional topics in a single course.

The following is a suggested plan to renovate the undergraduate process control course:

(1) De-emphasize frequency response, but keep Laplace transforms.
(2) Reduce coverage of multiple approaches for PID controller tuning.
(3) Increase use of simulation in sophomore and junior courses.
(4) Introduce a number of short laboratory experiences.
(5) Use case studies to show how process control can solve real engineering problems.
(6) Teach process control in the senior year, given it is valuable integration course with many connections to other chemical engineering courses.

In July, Accreditation Board for Engineering and Technology revised criteria for chemical engineering programs. The proposed criteria state graduates must have sufficient knowledge in the application of these basic sciences to enable graduates to design, analyze, and control complex physical, chemical, and biological processes. It does not require a complete course on process control.

Along those lines, separate process control courses are beginning to disappear in some chemical engineering departments, and this trend will increase in the future. The academic process control and industrial communities need to promote the viability and visibility of process control. Without a solid understanding of the concepts of dynamic systems and feedback control, chemical engineers cannot make a contribution to emerging as well as traditional technologies. Dynamics, feedback, and stability are key intellectual underpinnings arising out of the current control course. If we remove or dilute this perspective in the education of chemical engineering undergraduates, then graduates will not have this unique perspective to offer and will not be valued as highly.

Next: Industry talks back on how, or if, courses should change.

For a more detailed version of this story, please visit www.isa.org/intech/20061003.

ABOUT THE AUTHOR

Thomas F. Edgar is with the Department of Chemical Engineering at the University of Texas-Austin. His e-mail is edgar@che.utexas.edu.

View the online version at www.isa.org/intech/20061003.

RESOURCES:

ISA
www.isa.org

***The Automation Body of Knowledge*, 2nd edition, Vernon L. Trevathan**
www.isa.org/link/autoBK

New twist in "blending" engineers' careers
www.isa.org/link/Blendcareers