2015 ASEE ANNUAL CONFERENCE & EXPOSITION

Making Value for Society

A Unit Operations Laboratory Experiment Combined with Computer Simulation to Teach PID Controller Tuning

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Curriculum

3 Projects
12 of 14 Core Courses

Term → / Year ↓	A	B	C	D
First Year		Intro to ChE		
Sophomore ***HUA Project***	Chemical Engineering Fundamentals	Elementary Chemical Processes	Applied Thermodynamics	Advanced Chemical Processes
Junior ***Interdisciplinary Project***	Fluid Mechanics	Heat Transfer	Mass Transfer	Kinetics and Reactor Design
Senior ***Research Project***	Unit Operations Laboratory I	Unit Operations Laboratory II	Process Control	Applied Math
	Process Design and Economics	**Capstone Design**		

Motivation

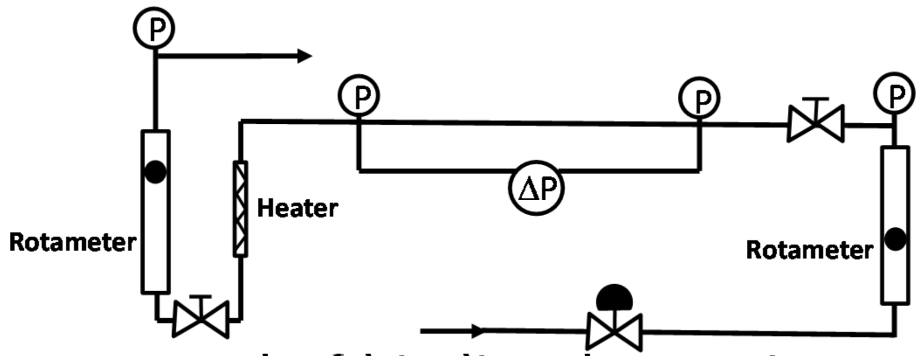
- Only 50 % of student took process control class
- We and ABET wanted more exposure to control in the curriculum

Tim Wescott, “PID Without a PhD”, Embedded Systems Programming, October, 2000, 86-108.

“PID (proportional, integral, derivative) control is not as complicated as it sounds. Follow these simple implementation steps for quick results.”

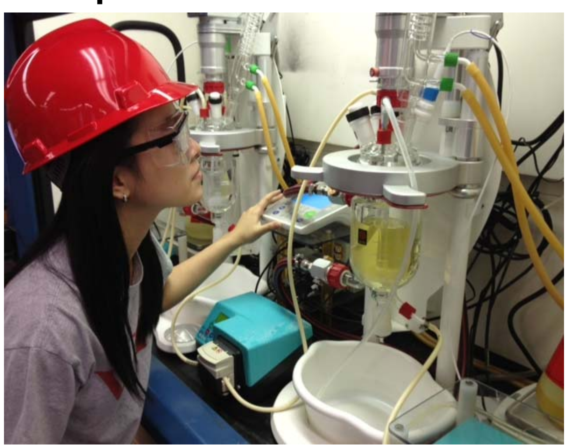
Process Control in UO Lab?

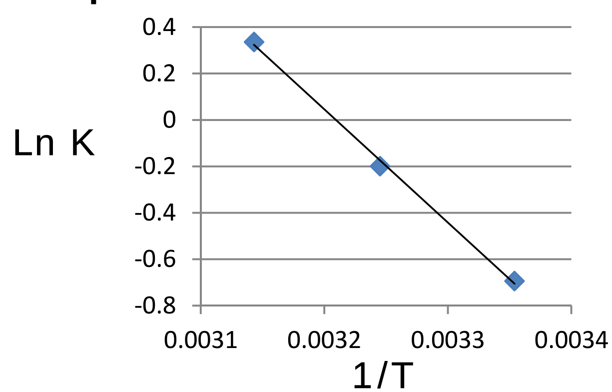
- Computer control of a heat exchanger no longer works
- T control for oven on packed bed reactor experiment
- Control of in-line heater in air flow experiment



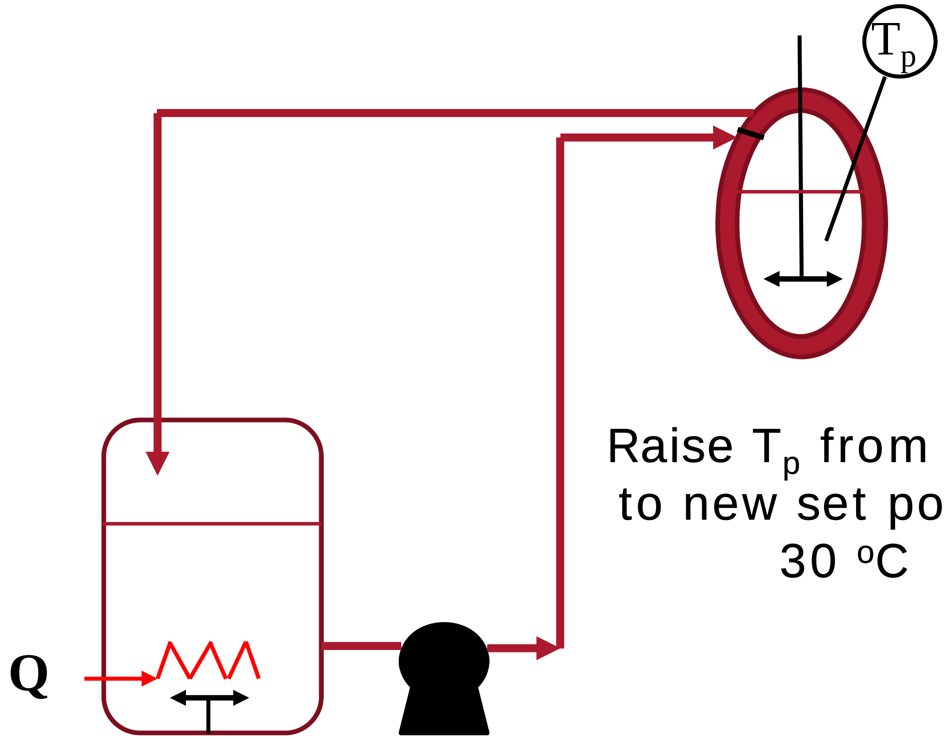
Omega controller difficult to program

- Temperature control of biodiesel experiment batch reactor





Temperature Control of Batch Reactor



Raise T_p from 20 ^oC to new set point of 30 ^oC

$$Q(t) = Q_o[K_p E(t) + K_i \int_0^t E(t)dt + K_d \frac{dE(t)}{dt}]$$

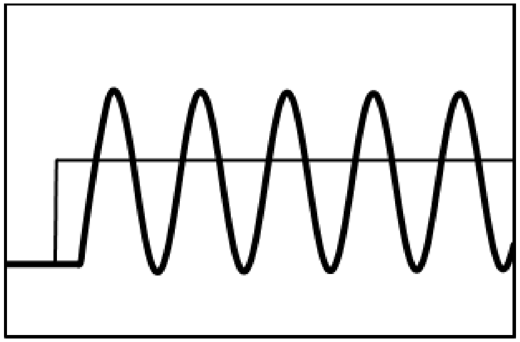
$$E(t) = T_{sp} - T_p$$

Temperature Control of Batch Reactor

Limitations

- 30 min to heat reactor, 30 minutes to cool again
- Limited range of applicable control parameters before boiling or freezing of water
- Unable to determine ultimate gain for sustained oscillations to test tuning methods

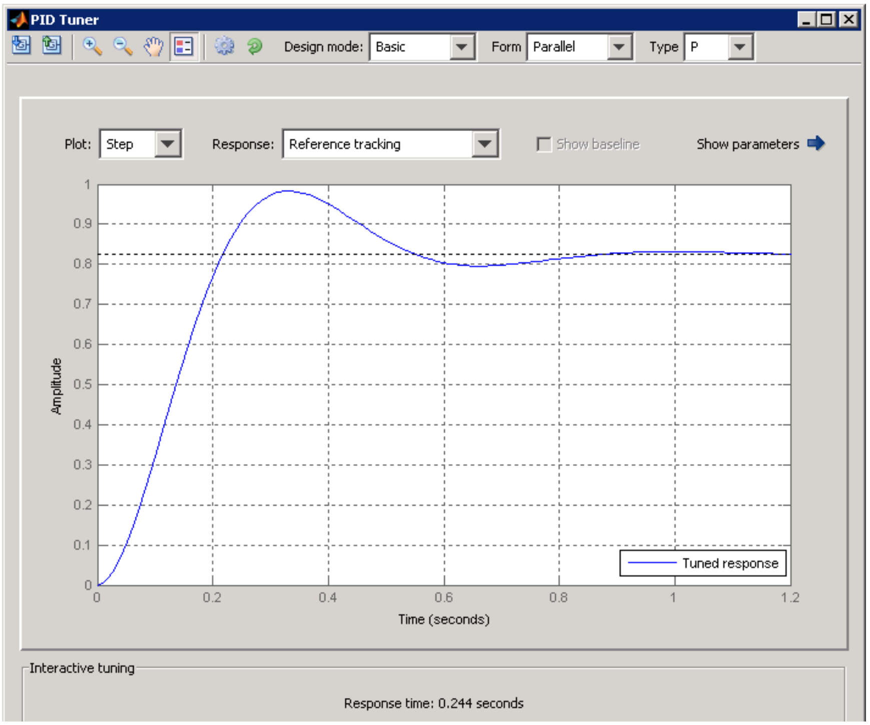
Ziegler-Nichols Kp = 0.45 Ku
Ki = 1.2 / Pu

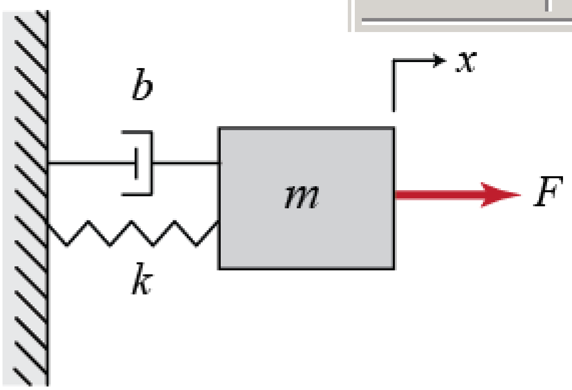


MATLAB PID Tuner Application

MATLAB PID Tuner Application with University of Michigan tutorial: http://ctms.engin.umich.edu/CTMS/index.php?example=Introduction&section=ControlPID#28

- Good learning tool
- Mass, spring, damper not ChE process
- Transfer function based analysis
- Not “lab experiment”





COMSOL Multiphysics Model of Reactor

Captures essential physics of the process

- 2-D axial symmetry
- Hose outlet connects to inlet via periodic b.c.
- Turbulent flow, k-ε model
- Coupled with energy balance
- Q(t) is volume heat source in temperature bath

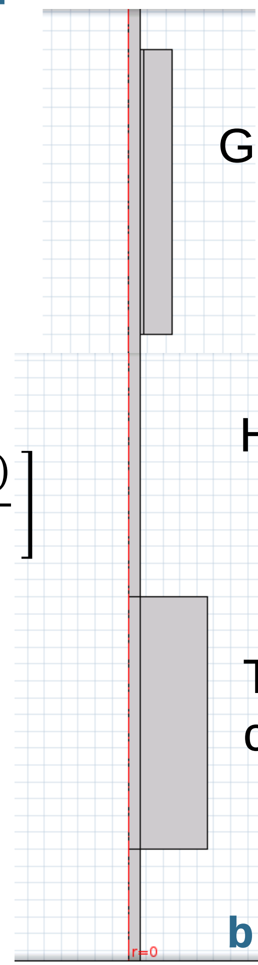
$$Q(t) = Q_o \left[K_P\, E(t) + K_I \int_0^t E(t)dt + K_D \frac{dE(t)}{dt} \right]$$

Estimated:

- Flow rate, hose, bath, and jacket volumes
- Heat transfer coefficients
- Heat loss

Assumed:

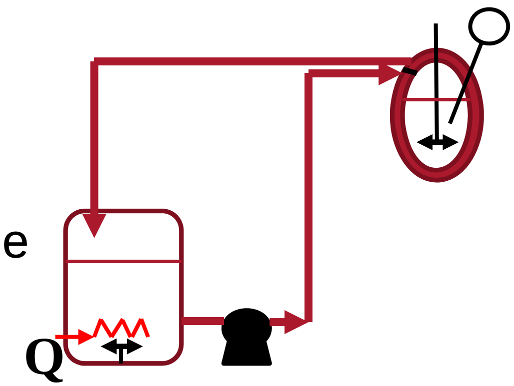
Q_o cooling = - Q_o heating



Glass reactor

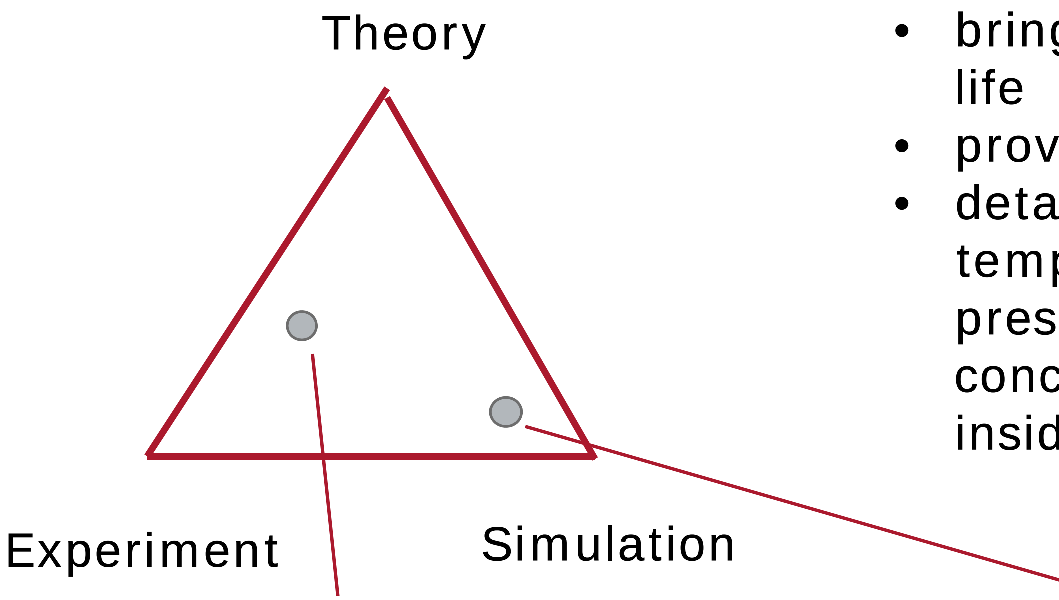
Hose

Temperature controlled bath



Allows more runs over larger parameter space before, during, and after lab

COMSOL Multiphysics in Lab



Simulation

- brings equations to life
- provides visualization
- details of velocity, temperature, pressure, concentration, etc. inside equipment

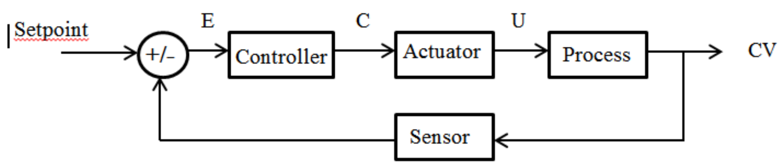
Fluid Flow
Heat Exchanger
Membrane
Absorber
Packed Bed Reactor

As Pre-Lab Exercise

PID Control
As Lab Exercise

Lab Description and Objectives

Brief introduction to practical aspects of process control and PID controller tuning methods



PID control

$$Q(t) = Q_o \left[K_P\, E(t) + K_I \int_0^t E(t)dt + K_D \frac{dE(t)}{dt} \right]$$

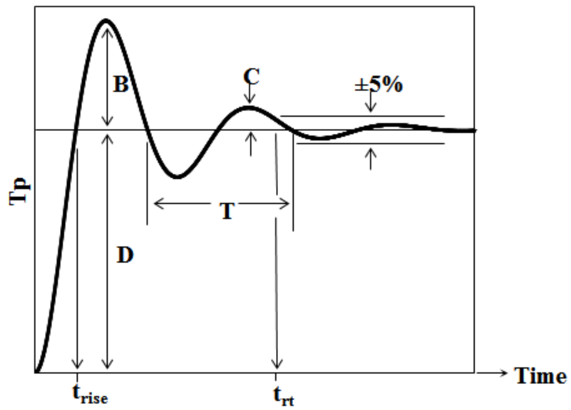


Figure 5. Response for an under damped controlled process [1].

Table 1. Definition of terms in process under damped response.

Term	Definition
Rise time	t_{ris}, the time required for T_p to first reach T_{sp}
Overshoot	B/D
Decay ratio	C/B, ratio of height of successive peaks
Period of oscillation	T, time for a complete cycle
Response time (settling time)	t_{rt}, time required for response to remain within +/- 5% of T_{sp}, i.e. T_{sp} +/- 0.05 T_{sp}.

$$IAE = \int_0^\infty |\, E(t)\, |dt$$

Lab Description and Objectives

Table 2. Ziegler-Nichols and Tyreus-Luyben PID Controller Settings

Tuning Methods

Riggs method

	Ziegler-Nichols			Tyreus-Luyben		
Controller	K_P	K_I	K_D	K_P	K_I	K_D
P	0.5 K_U	-	-	-NA-	-NA-	-NA-
PI	0.45 K_U	1.2/P_U	-	0.31 K_U	0.45/P_U	-
PID	0.6 K_U	2/P_U	P_U/8	0.45 K_U	0.45/P_U	P_U/6.3

Objectives:

Before going to lab:

1. Study background material and tutorial on the COMSOL simulation
2. Use simulation to study P-only control. Discover the effect of changing P.

During the lab:

1. Use simulation to find Ku and Pu
2. Use simulation to study Z-N, T-L, and Riggs tuning methods
3. Use simulation to discover effect of Ki and Kd
4. Evaluate IAE for each run and seek to minimize IAE
5. Run at least 3 physical experiments to demonstrate effect of changing parameters Kp and Ki

Lab Description and Objectives

Objectives:

After the lab:

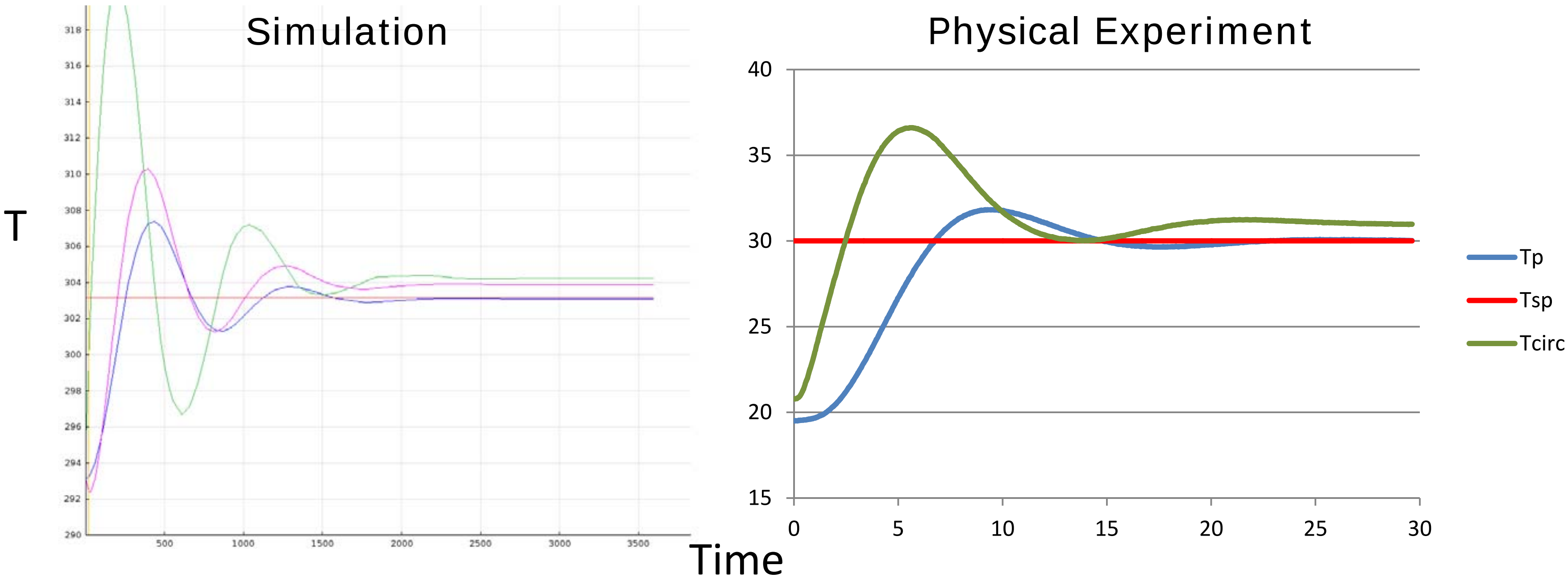
1. Use simulation as needed to understand effect of Kp, Ki, and Kd
2. Find best parameters that give lowest IAE and or “best” control
3. Written report to include:

- Explanation of the main effect of each parameter,
- Critique of the three tuning methods studied,
- Discussion of the physical experiment results,
- Parameters that gave lowest IAE or “best” control

Contest with promise of a “prize” for group that found the lowest IAE

Many groups already found Ku and Pu and “discovered” or demonstrated the effect of Ki and Kd, as well as Kp, at the pre-lab stage

Results

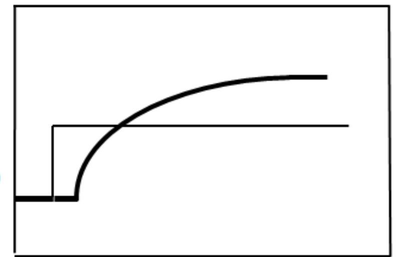


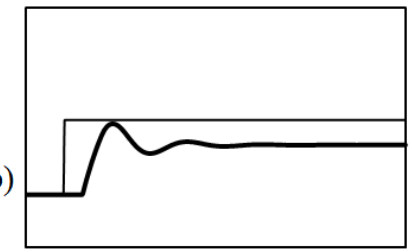
- Most correctly identified the main effect of Kp, Ki, and Kd, but some failed to see the interdependence
- Some expected Z-N and/or T-L to give optimal results without further refinement
- Some expected the simulation to be perfect
- Many enjoyed the competition to find the lowest IAE

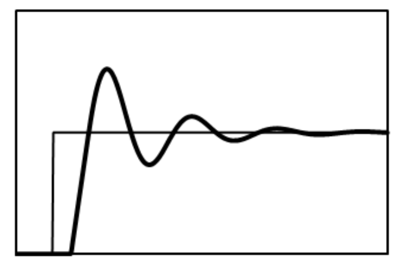
Assessment: Pre / Post Quiz

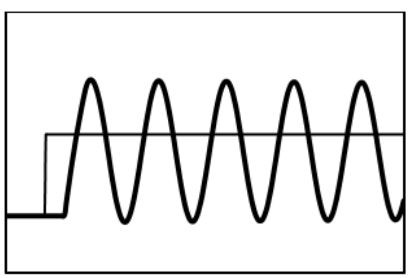
1. Which figure above looks like a typical open-loop control response curve?
(a) (b) (f) (h)

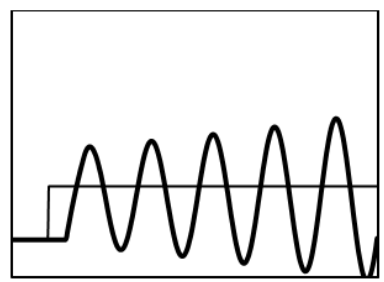
3. When using the Ziegler-Nichols tuning method, the closed-loop response curve used for determining the ultimate gain should look like which figure above?
(c) (e) (g) (h)


(a)


(b)

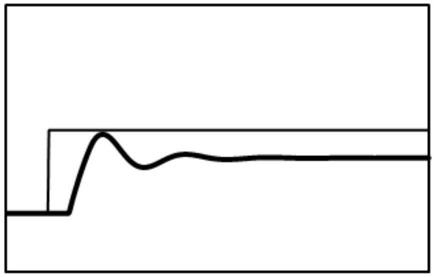

(c)

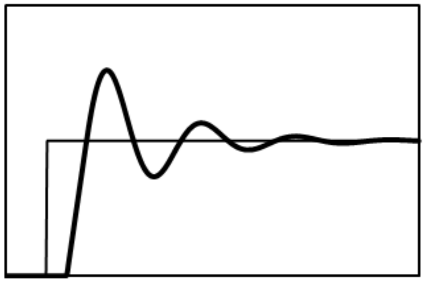

(g)


(h)

Assessment: Pre / Post Quiz

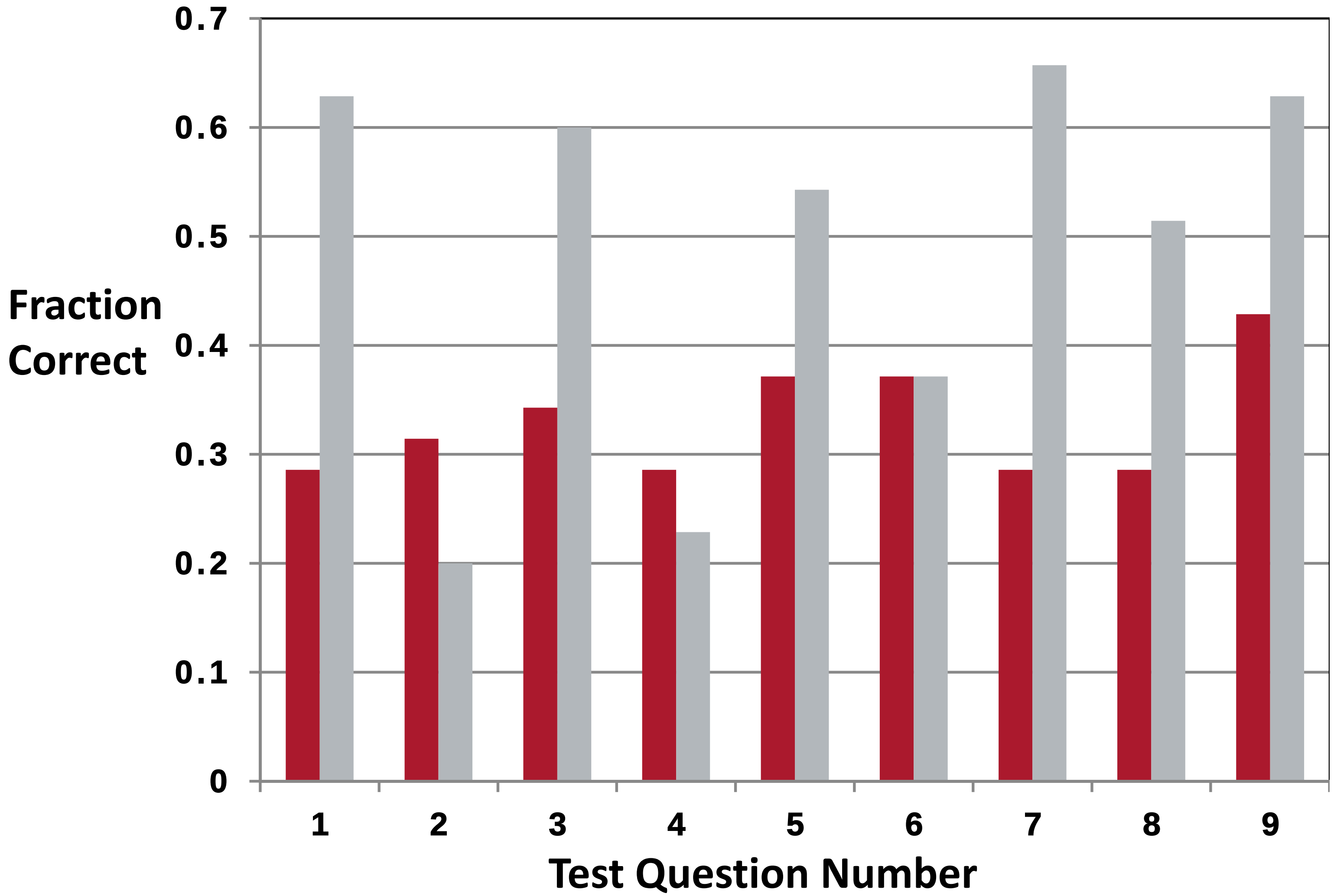
7. Regarding a setpoint change and a PID process controller, the primary benefit of increasing the proportional control parameter is
(a) increasing the speed of the response
(b) eliminating offset of the response
(c) reducing the oscillatory nature of the response
(d) increasing the setpoint

(b)


(c)


4. When using a PID controller for a set point change, to change the response from figure (b) to figure (c) you should
(a) increase the proportional control parameter, K_P
(b) increase the integral control parameter, K_I
(c) increase the derivative control parameter, K_D
(d) increase all three parameters

Assessment: Pre / Post Quiz



Assessment: Attitude Survey

Question	a	b	c	d	e
1. If you were to do this again, would you rather run:	only physical experiments	only simulations	one physical experiment and many simulations	3 physical experiments and many simulations	more than 3 experiments and fewer simulations
	3 %	3 %	22 %	53 %	19 %
2. Using the simulation software was:	very difficult	difficult	neither difficult nor easy	easy	very easy
	0 %	0 %	44 %	42 %	14 %
3. Simulation helped me to understand PID control:	not at all	just a little	somewhat	much	very much
	0 %	0 %	28 %	53 %	19 %
4. Simulation helped me to understand PID tuning methods:	not at all	just a little	somewhat	much	very much
	0 %	3 %	44 %	30 %	22 %

Conclusion

- Experiment combined three or four physical experiments with extensive computer simulations,
- Discovered the main effect of proportional, integral, and derivative control parameters,
- Evaluated three parameter tuning methods,
- Obtained “optimal” control by minimizing integral absolute error,
- New experiment was well received by the students,
- Some wanted more physical experiments and to bring the simulation and experiment in closer agreement,
- Interesting, enjoyable, and effective way to teach practical aspects of process control.

Enrollment in our second semester control course went from < 50 % to > 66 % of seniors after this lab was introduced.

ABET visit result not final but preliminary indications are good.