Simulation-Based Guided Explorations in Process Dynamics and Control

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When people say ‘I hate math’ what you’re really saying is, ‘I hate the way mathematics was taught to me.’ Imagine an art class, in which, they teach you only how to paint a fence or wall, but never show you the paintings of the great masters. Then, of course, years later you would say, ‘I hate art.’ What you would really be saying is ‘I hate painting the fence.’ And so it is with math. When people say ‘I hate math’ what they are really saying is ‘I hate painting the fence.’

-UC Berkeley math professor Edward Frenkel (via we-are-star-stuff)

Knowledge, Abilities and Skills

1. Develop mathematical and transfer function models for dynamic processes.
2. Analyze process stability and dynamic responses.
3. Empirically determine process dynamics for step response data.
4. Understand different types of feedback controllers.
5. Analyze and tune PID controllers to desired performance.
6. Read process and instrumentation diagrams and translate to block diagrams.
7. Perform frequency domain analysis of linear dynamic processes.
8. Design feedforward control, cascade control and time-delay compensation.
9. Analyze multivariable process interactions.
10. Define a process control problem, based on a flowsheet, in terms of objectives, manipulated variables, controlled variables, and constraints.

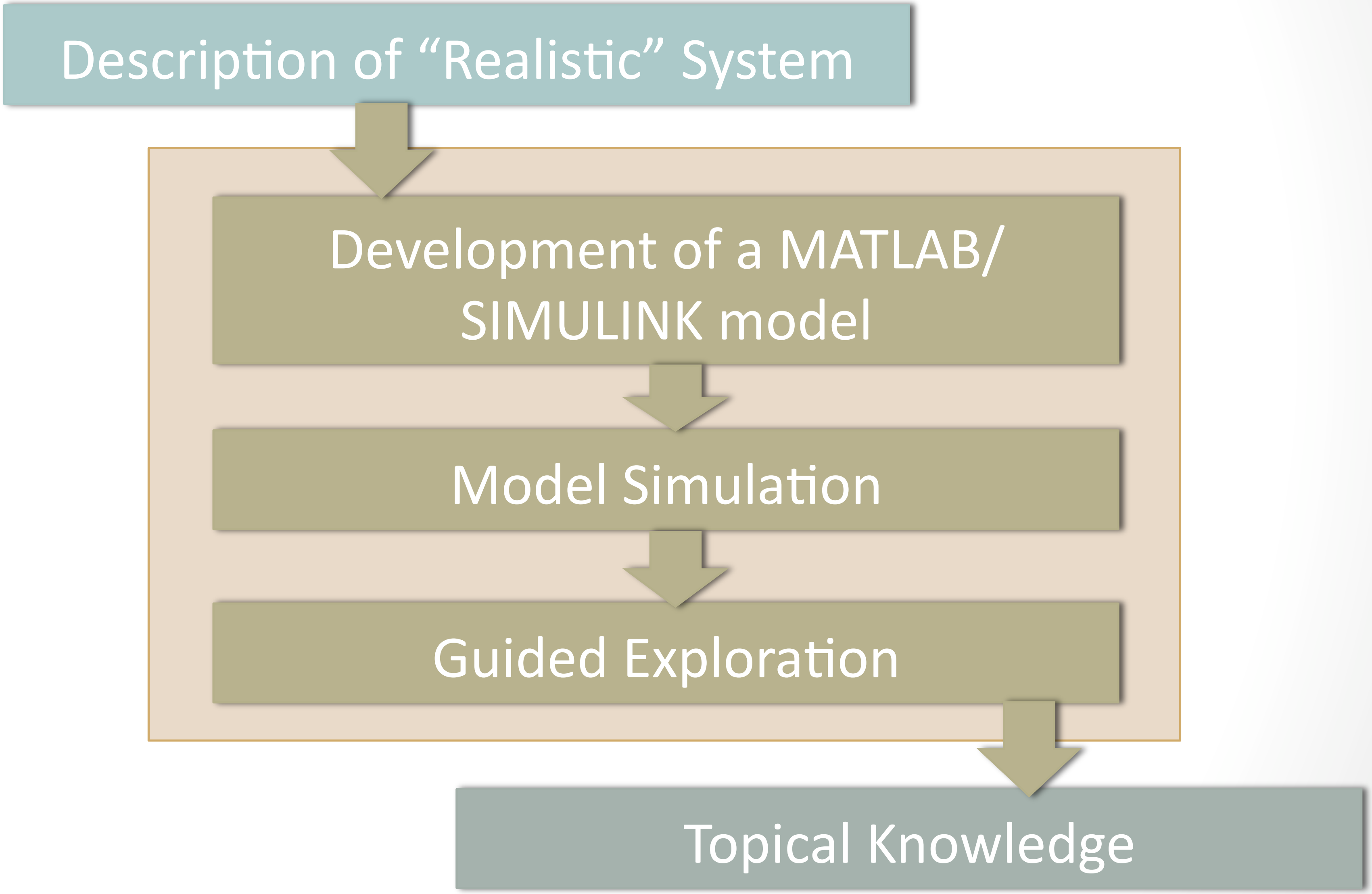
Edgar, T.F., B.A. Ogunnaike, J.J. Downs, K.R. Muske, B.W. Bequette, (2006). *Renovating the undergraduate process control course*. Computers and Chemical Engineering, 30(10-12): 1749-1762.

Process Dynamics and Control

- Students seem to struggle with "learning the language" and translating written or oral descriptions into problems that they can solve.
- They also seem to have difficulty connecting the math and theory to the physical system.
- Furthermore, we have faced challenges in implementing experiential learning and hands on laboratory experiences.

"If Train #1 leaves Los Angeles at 8:47 AM going 63 MPH and Train #2 leaves New York at 9:13 AM going 56 MPH, how long will it take for your mind to wander to something more interesting?"

Simulation Modules



Implementation at Rowan

- Fall 2011 and Fall 2012
- 25-30 students per class
- 3 s.h. course, Three 75-minute class periods per week
- One class period reserved for "Computer Lab"
  - Simulation Modules (≤12 during the semester)
  - Work in self-selected pairs for collaborative learning
  - Assignment due at the end of the class period
  - 15% of course grade
  - Immediate instructor feedback
  - Develop an "intuition"

Example: *Feedback Control*

Objectives:

- Create a SIMULINK model for a closed loop system under feedback control.
- Identify the closed loop transfer function and characteristic equation, and discuss stability criteria.
- Implement different controllers (P, PI, PID).
- Develop an intuition about the roles of the P, I, and D actions of a PID controller.
- Observe the system's ability to track set point changes and reject disturbances.

Example: *Feedback Control*

Company A produces a highly explosive material for use in Company B. The two companies are nearly 500 miles apart, and the material must travel between the two locations. The temperature of the liquid material leaving Company A cannot exceed 20°C or the material will spontaneously combust and eradicate a 3 mile radius around the transporting truck. Company B cannot use the material if it has ever frozen, which occurs at 15°C. Therefore, it is required that the material's temperature remains between 15 and 20°C at all times.

Example: *Feedback Control*

A 200 gallon tank of material X sits in the center of the refrigerated truck compartment. The material lining the truck walls is designed to dampen any explosive force, and we have implemented a feedback control system *to maintain the tank temperature at 17℃*.

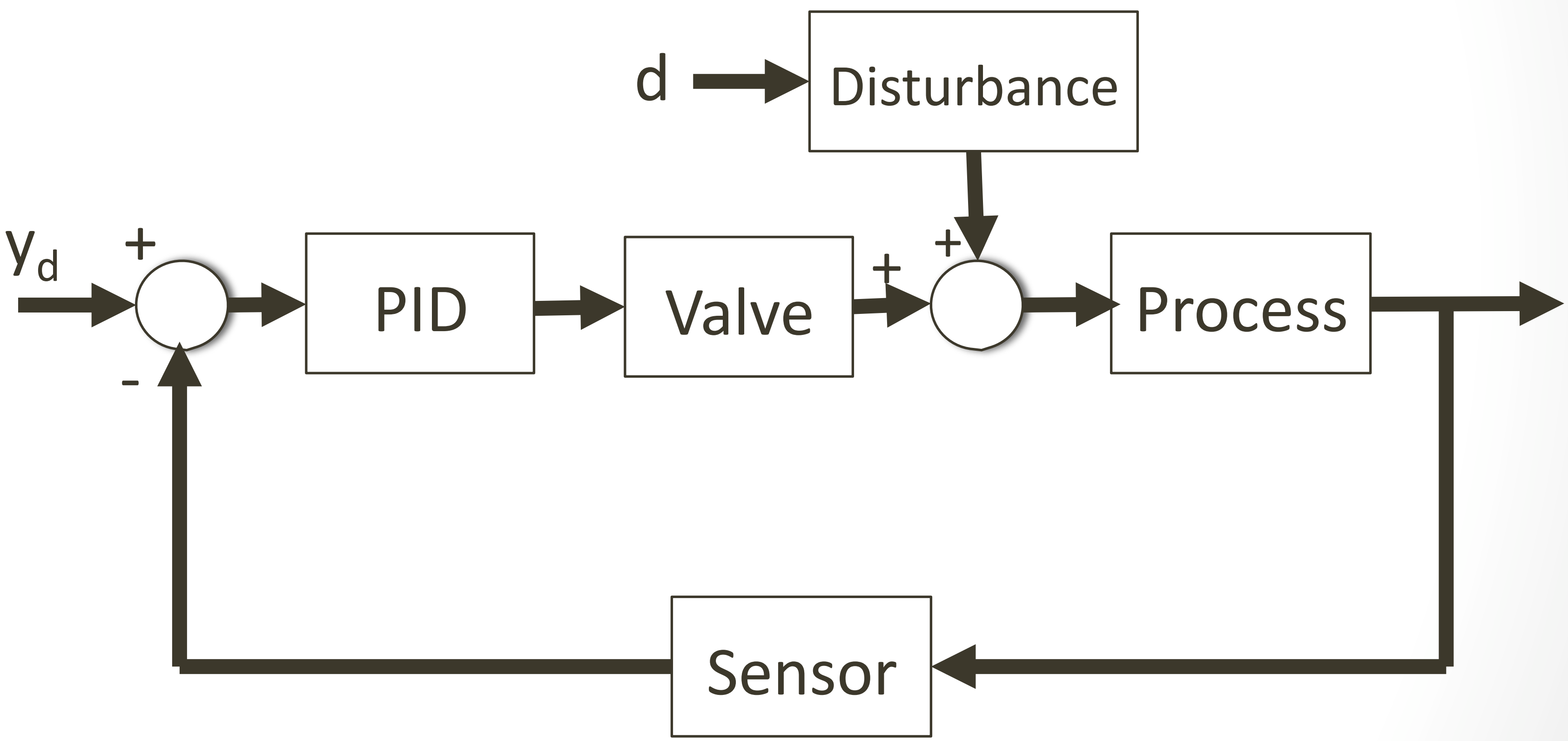
The temperature set point is 17°C, and the temperature is modulated by an ethanol cooling stream which spirals around the tank. We found that as an isolated system, the open loop *response of material X temperature to changes in coolant flow rate can be described by the following transfer function*: y=Au/(Bs+C) , where y is the deviation in material X temperature from its original temperature; u is deviation of the coolant flow rate in m^3/s; A was empirically determined to be 4°C*s/m^3; B was empirically determined to be 8sec; C was empirically determined to be 4. These results are valid for temperatures between 15.5°C and 19.5°C.

We have installed *a PID controller* that manipulates the coolant flow rate via a valve. The valve manufacturer, ValvesRUs, ensures that the *valve adds only a proportional gain to the system* equal to 0.95.

The temperature of material X in the tank is measured by a high sensitivity thermocouple and transmitted via a negative feedback loop to the PID controller*. The high sensitivity thermocouple can be approximated as a first order system* with the following transfer function: 0.995/(0.1s+1) .

Finally, we have approximated *the disturbance effect* of ambient temperature on the coolant flow rate to be second order. We have designed the truck refrigeration system to maintain the temperature within the truck between 18°C and 20°C."

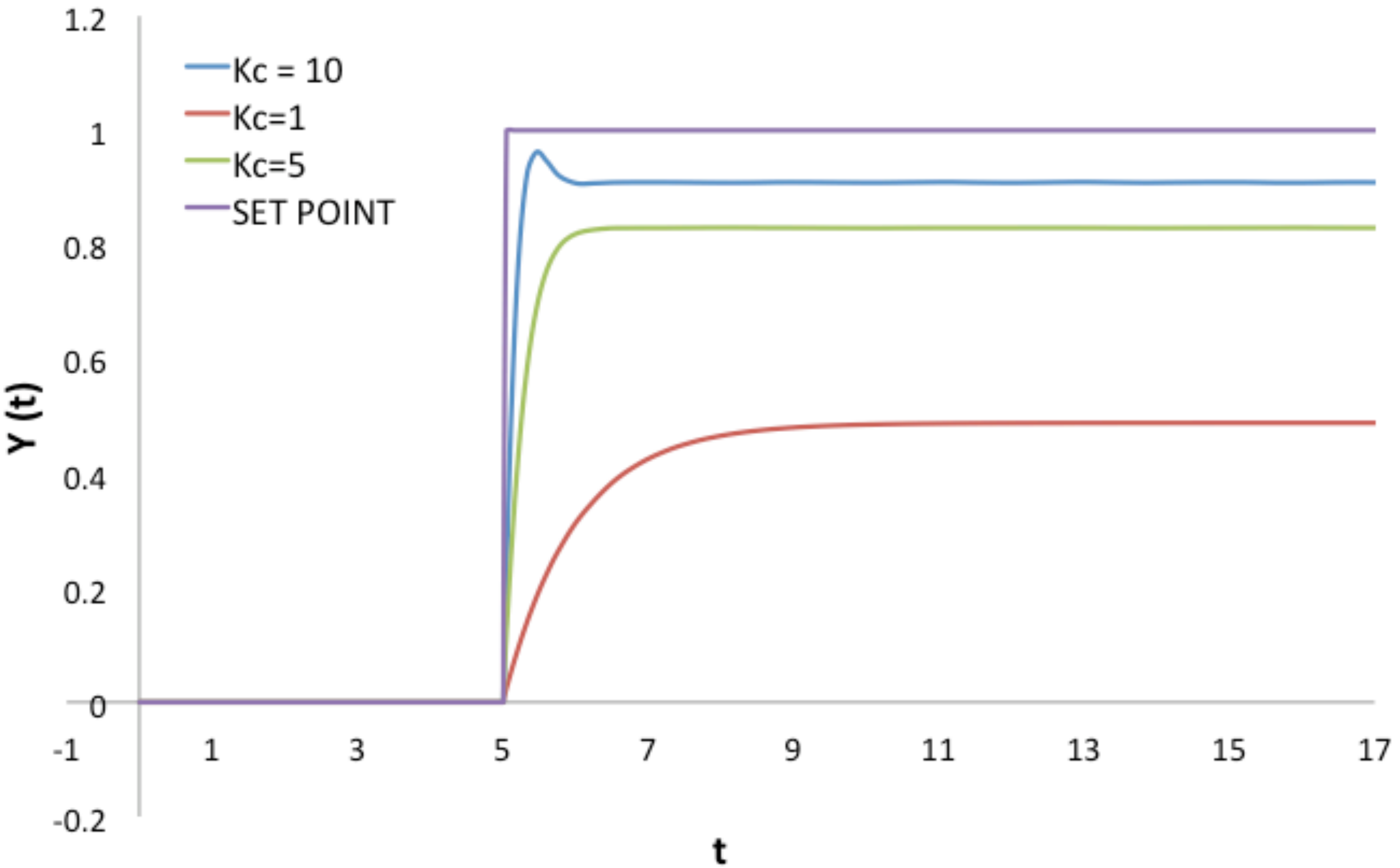
Example: *Feedback Control*



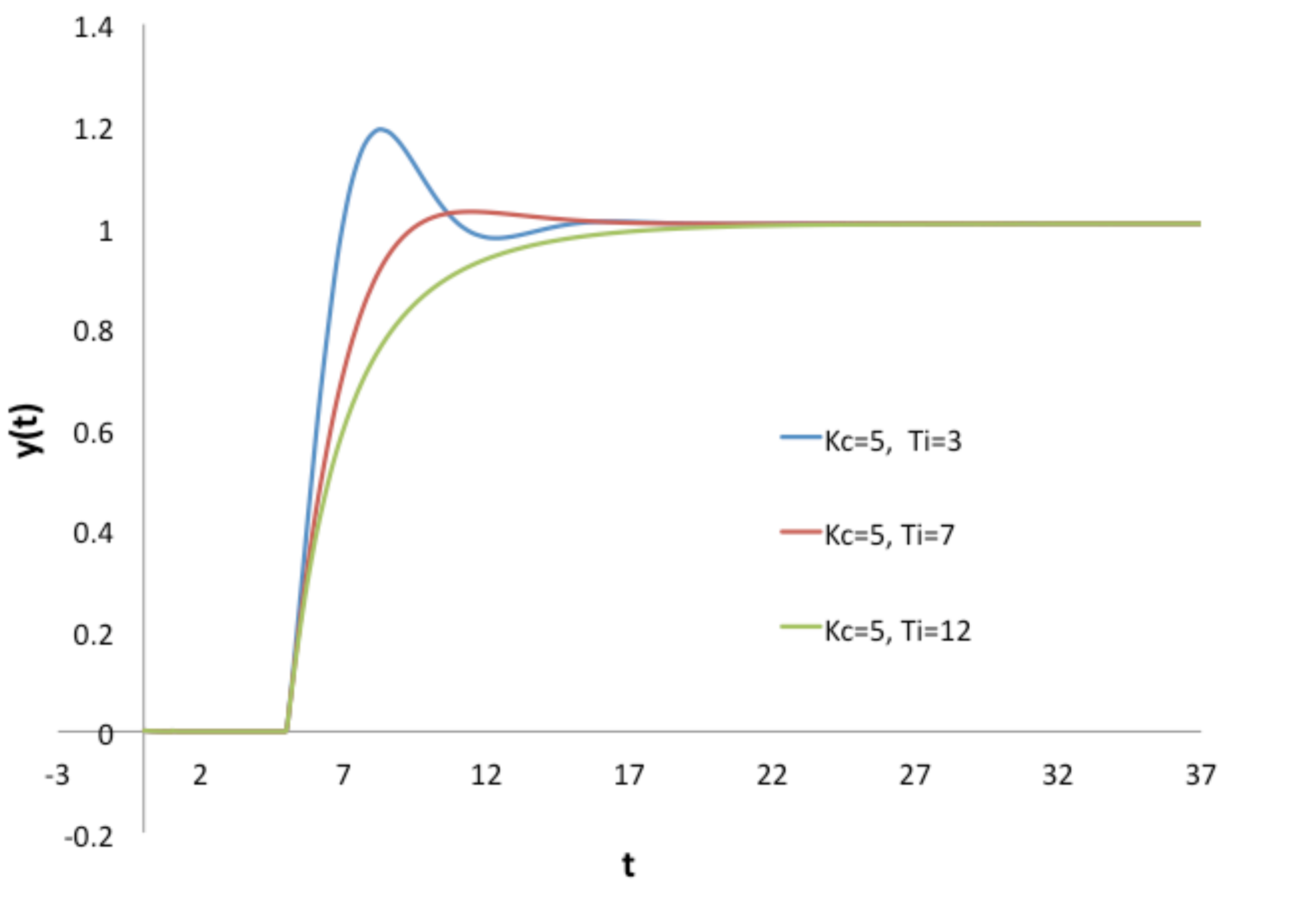
Example: *Feedback Control*

- Derive the closed loop transfer function equation
- Identify the characteristic equation (for stability)
- Implement a variety of controllers (where they choose the parameters)
  - P controllers
  - PI controllers
  - PID controllers
- Investigate the role of each of the parameters

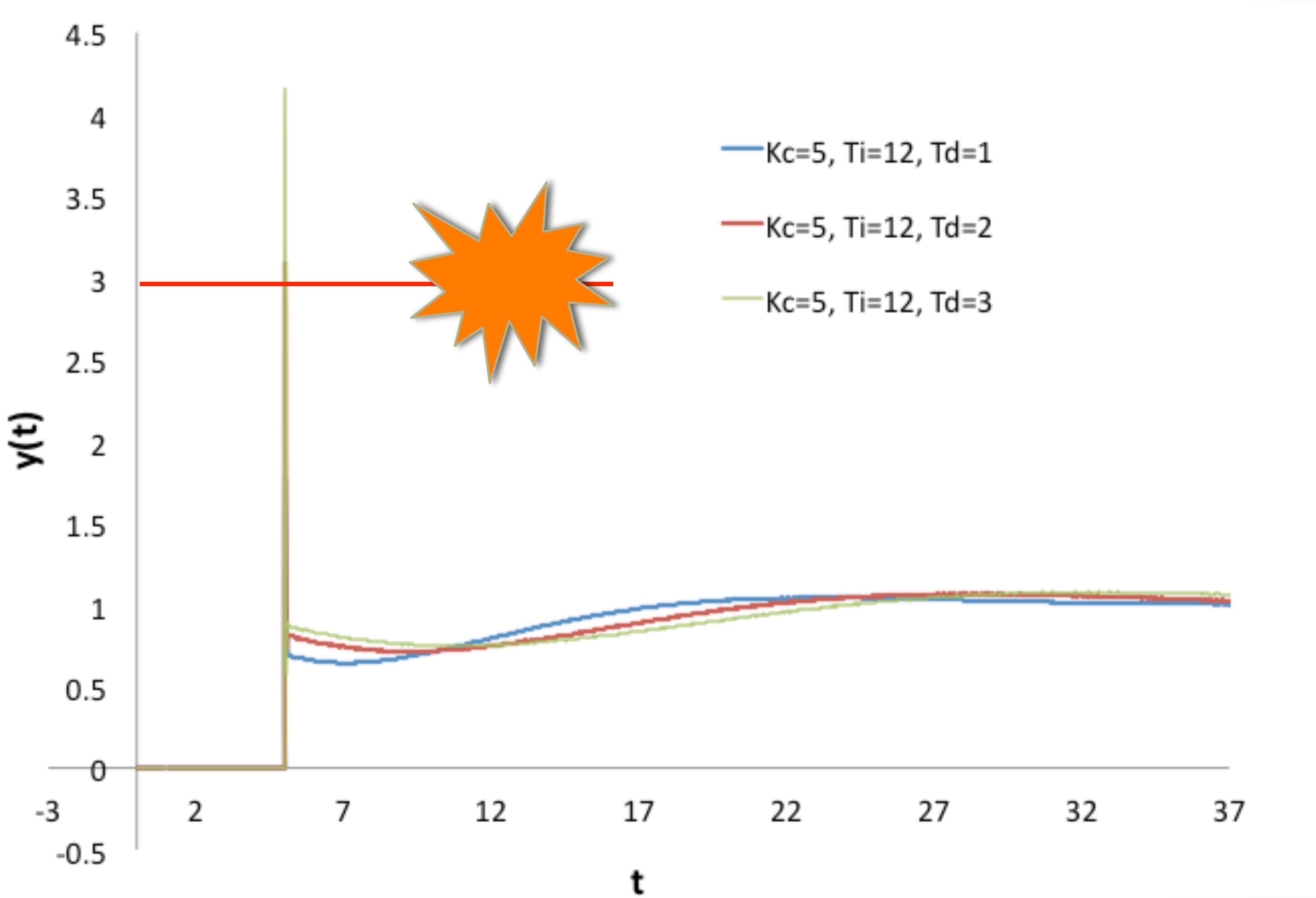
P-Controller



PI-Controller



PID-Controller



Student Responses

- Final course evaluations:
  - "How helpful were the computer labs in achieving the course objectives?"
  - **4.45**±0.23 out of 5 (n=53, error is 95% confidence interval)

- In a mid-semester survey that asked about both homework assignments and "computer labs", students were asked to answer on a scale of 1 (poor/strongly disagree) to 5 (excellent/strongly agree)
  - 1) The computer labs are helpful in learning course material.
  - 2) The computer labs are a waste of my time.
  - 3) I would like to have more computer labs in this course.
  - 4) I like working with a partner to complete the computer labs.

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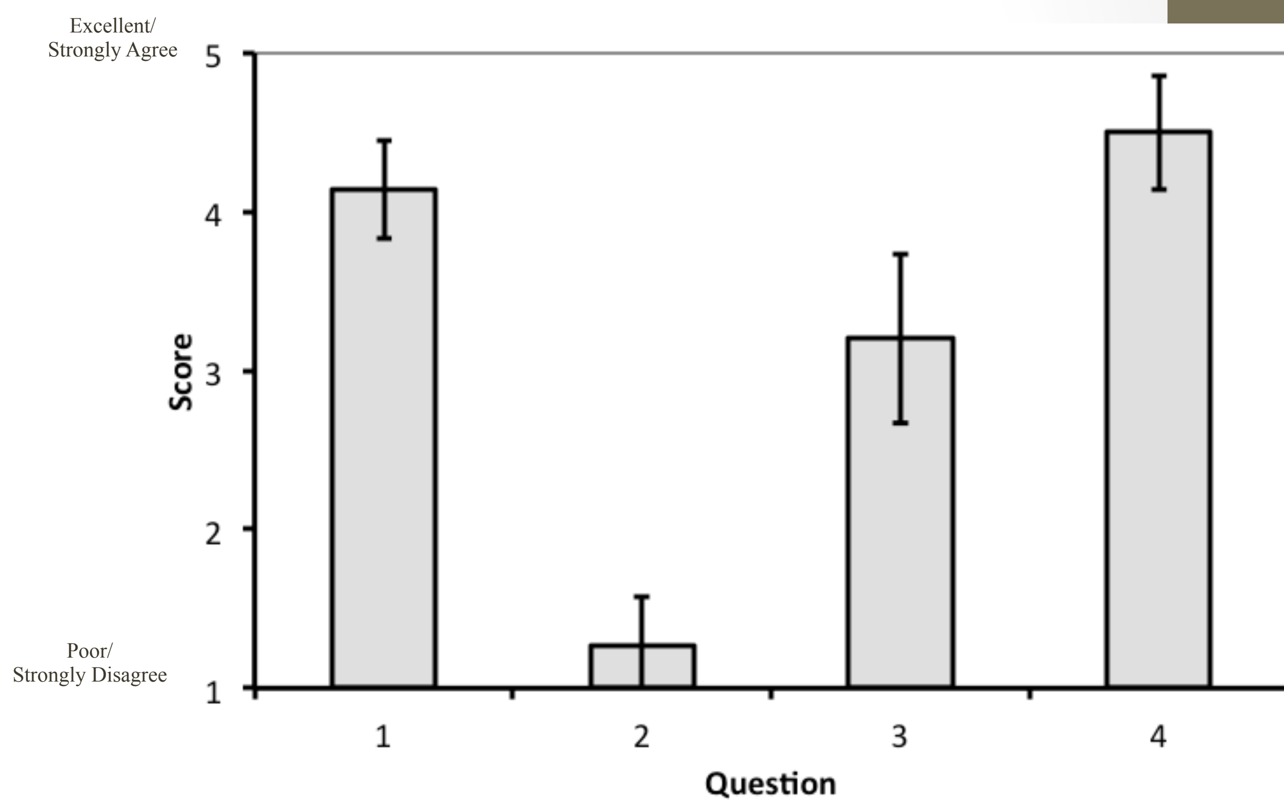

n=22, Error Bars=95% CI

Summary, Conclusions, and Future Work

- We have developed a series of simulation modules that provide opportunities for guided exploration in Process Dynamics and Control Courses.
- Overall, the feedback from the students has been very positive.
- I have seen qualitative improvements in their comprehension.
- Future Work
  - Overall assessment of improved/enhanced learning as a result of the modules
  - Assessment of individual modules

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