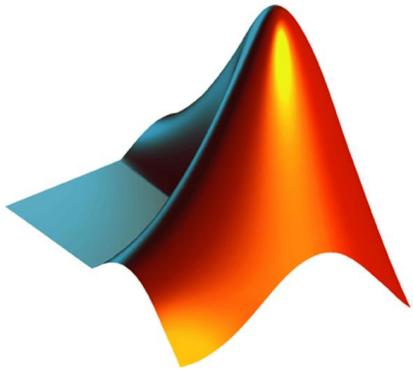


# Teaching Chemical Engineering with MATLAB, Simulink and TCLab



Aycan Hacioglu, Ph.D. (ahaciogl@mathworks.com)

Customer Success Engineer

Samvith Rao (samvithr@mathworks.com)

Industry Marketing

John D. Hedengren, Ph.D. (john.hedengren@byu.edu)

Associate Professor, Brigham Young University

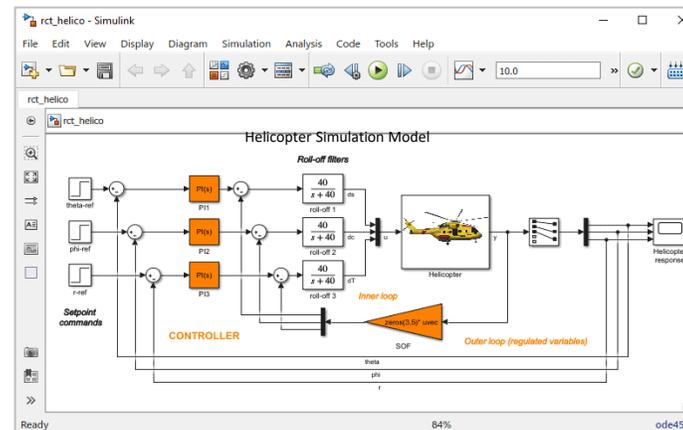
## Our Products

# MATLAB® & SIMULINK®

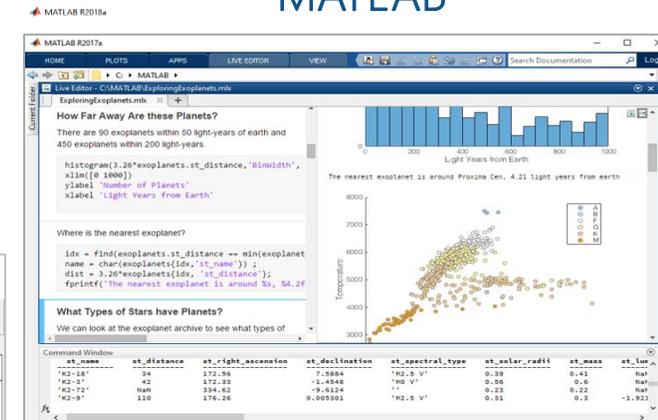


- MATLAB is a programming environment for algorithm development, data analysis, visualization, and numeric computation.
- Simulink is a graphical environment for designing, simulating, and testing systems.
- 100 add-on products for specialized tasks.

## Simulink



## MATLAB



# Integrating Computational Thinking to Chemical Engineering Curriculum



Introduce



Reinforce



Industry  
Applications



Getting Help

# Self-paced courses

## FREE COURSES (1-3 hours)

- MATLAB Onramp
- Simulink Onramp
- Machine Learning Onramp
- Deep Learning Onramp
- Reinforcement Learning Onramp
- Image Processing Onramp
- Signal Processing Onramp
- Simscape Onramp
- Stateflow Onramp
- Control Design Onramp with Simulink
- Optimization Onramp

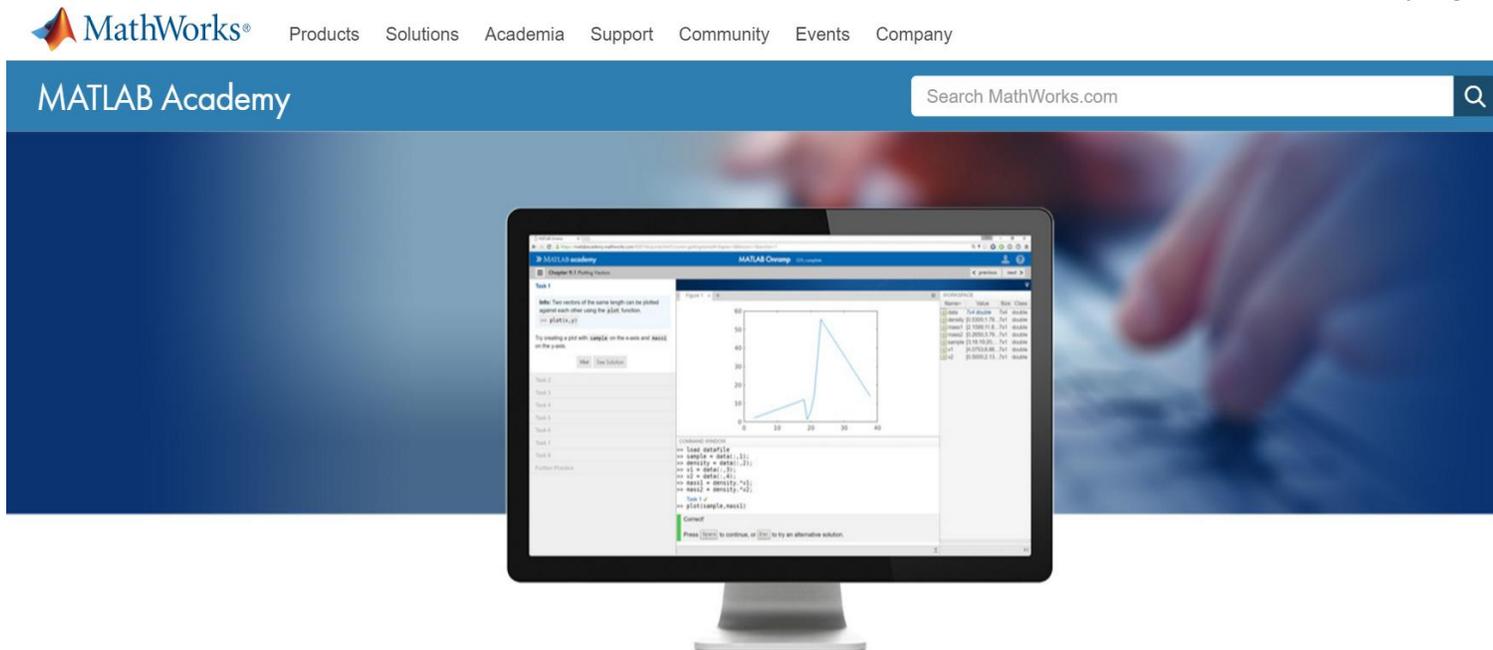
## FOCUSED COURSES

### FOUNDATIONAL COURSES (17-21 hours)

- MATLAB Fundamentals
- MATLAB Programming Techniques
- MATLAB for Financial Applications
- MATLAB for Data Processing and Visualization
- Image Processing with MATLAB
- Machine Learning with MATLAB
- Deep Learning with MATLAB

### COMPUTATIONAL MATH COURSES (2-3 hours)

- Introduction to Linear Algebra
- Solving Ordinary Differential Equations
- Introduction to Statistical Methods
- Solving Non-Linear Equations
- Introduction to Symbolic Math

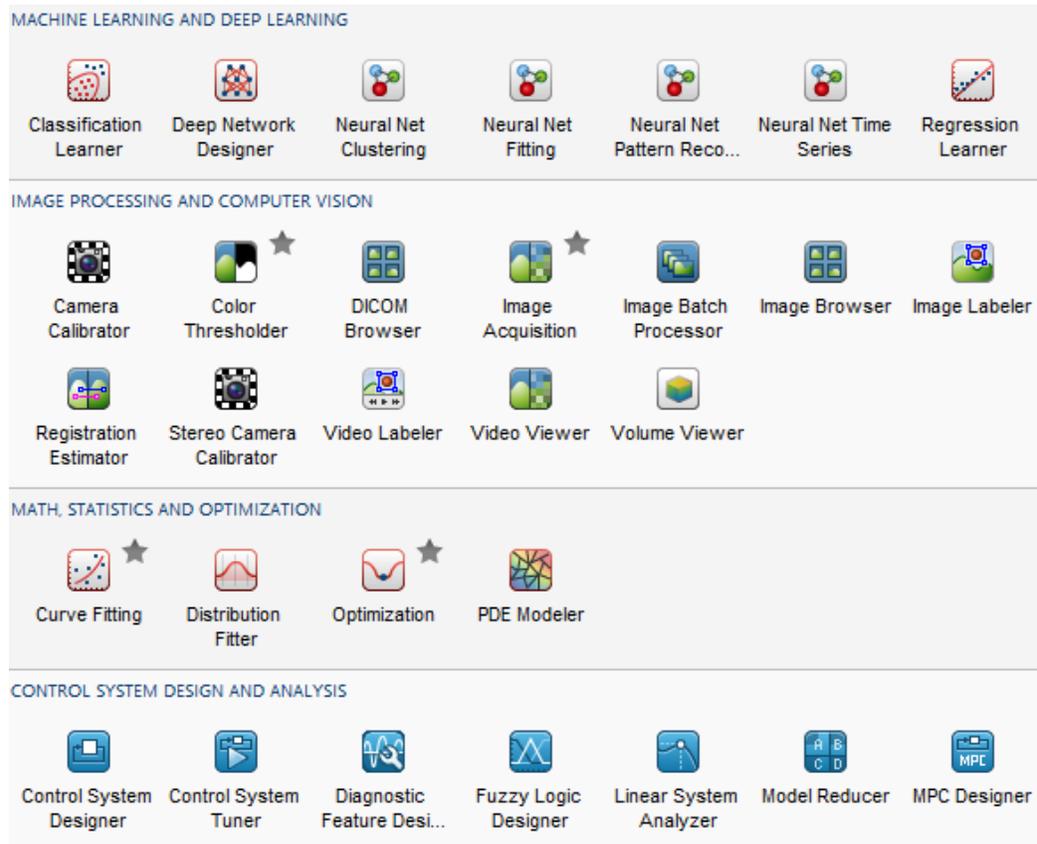


**Learn MATLAB for Free**

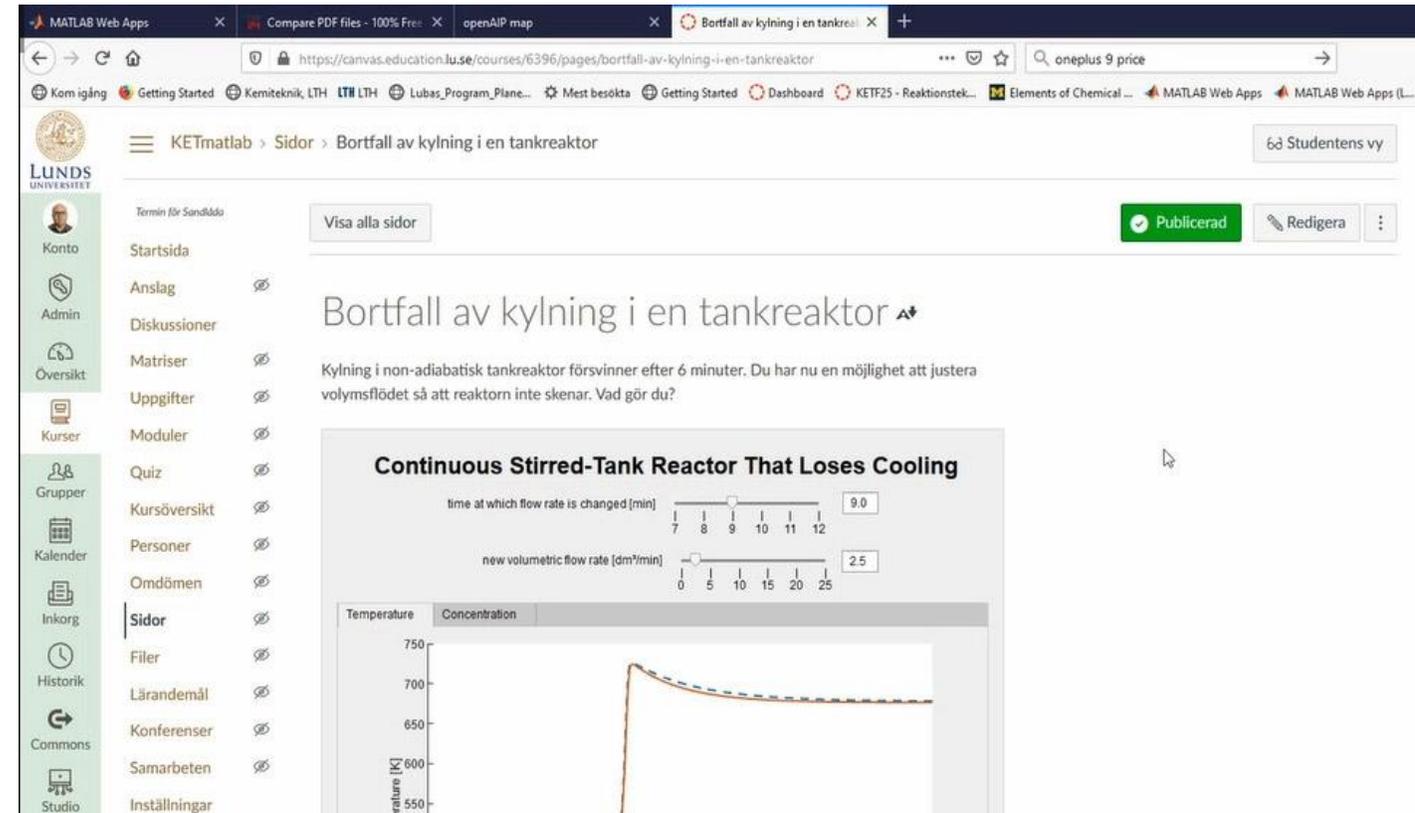
Launch MATLAB Onramp now

<https://www.mathworks.com/academia/targeted/online-learning.html>  
<https://matlabacademy.mathworks.com/>

# Creating and Hosting Custom Apps

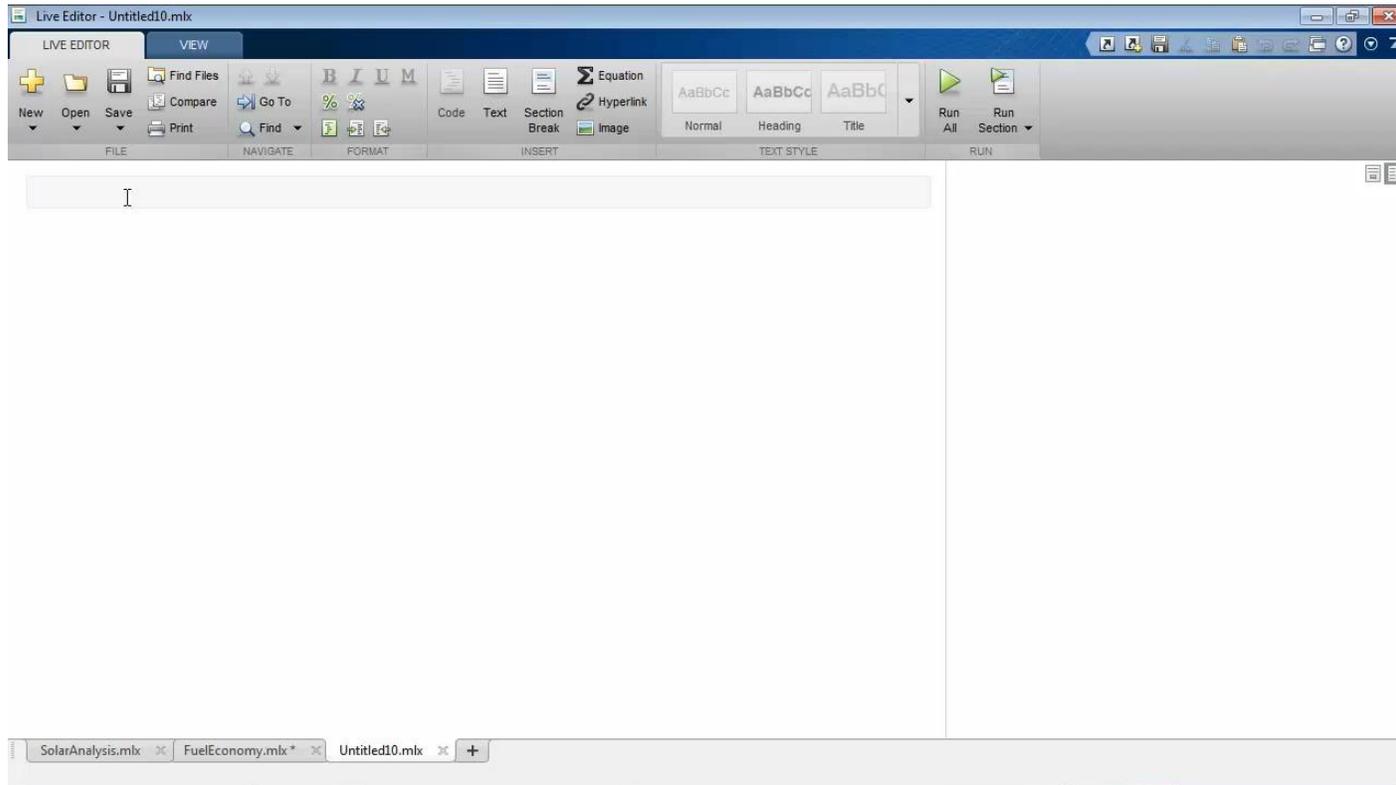


[MATLAB Apps](#)



[Using Virtual Labs to Teach Reaction Engineering](#) at Lund University

# Interactive programming with Live Editor



## Features

- Teach with interactive documents
- Accelerate exploratory programming
- Create an interactive narrative
- Publish consistent reports

[www.mathworks.com/products/matlab/live-editor.html](http://www.mathworks.com/products/matlab/live-editor.html)

<https://www.mathworks.com/products/matlab/live-script-gallery.html>

# MATLAB Grader for automatically grading MATLAB code in any learning environment

Your Script Save Reset MATLAB Documentation

```

1 % Load the data. Every day from 1900 - 2017.
2 BostonTemps = readtable('BostonDailyHighLowTemps.xlsx');
3
4 % Group by day of year. Then find the average low temperature
5 % for each day of the year and the standard deviation of the
6 % temperature for that day.
7 gDays = findgroups(day(BostonTemps.Date, 'dayofyear'));
8 avgTmin = splitapply(@mean, BostonTemps.Tmin, gDays);
9 stdTmin = splitapply(@std, BostonTemps.Tmin, gDays);
10
11 % Find the number of days in each year where Tmin < avgTmin - stdTmin
12
13

```

▶ Run Script ?

Assessment: 80%

Submit ?

|                                                                              |           |
|------------------------------------------------------------------------------|-----------|
| ✔ Is cross-sectional area correct?                                           | 10% (10%) |
| ✔ Is the Modulus of Elasticity correct?                                      | 30% (30%) |
| ✔ Is yield strength calculated correctly?                                    | 30% (30%) |
| ✔ Is ultimate strength correct?                                              | 10% (10%) |
| ✘ Is fracture strength correct?<br>Variable fracture has an incorrect value. | 0% (20%)  |

Verify that:

- strain data starts at 0 mm/mm, and stress starts at 0 Pa. Correct the raw data if necessary.
- fracture is assigned a stress value with units of Pa

Total: 80% (100%)

“The approach enables students to **learn more quickly** from their mistakes on their own.”

– Dr. Bob Canfield, Virginia Tech

MATLAB Grader Search MathWorks.com

[Overview](#) [System Requirements](#) [What's New](#) [Problem Collections](#)

## Introduction to Programming:

Collection of 111 problems on introductory programming using MATLAB.

- Intended for use in Introduction to Programming courses and courses that require prerequisite knowledge of introductory programming concepts.
- Problems draw from a variety of applications including physics, engineering, and finance, but do not require prerequisite knowledge in these fields.
- Concepts covered: Introduction to variables and data types, Matrices & Operators, Input/Output, Flow Control and Loops, Functions, and Graphing.

### Prerequisites:

- Problems assume prerequisite mathematics knowledge up to and including pre-calculus.
- No prior computer programming experience is required.

## Numerical Methods:

Collection of 10 problems on concepts taught in courses on numerical methods.

- Intended for use in Numerical Methods and Analysis courses. The problems can also be used in courses that require corequisite knowledge of numerical methods.
- Concepts covered: modeling, computers and error analysis, equation solving, linear algebraic functions, curve fitting/approximation, numerical quadrature, numerical differentiation, and ordinary differential equations.

### Prerequisites:

- Problems assume prerequisite knowledge of calculus, linear algebra, and differential equations.
- Beginner-level programming experience is recommended, which can be achieved by taking MATLAB

# Integrating Computational Thinking to Chemical Engineering Curriculum



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Industry  
Applications



Getting Help

# Resources for Chemical Engineering Courses with MATLAB

## Reaction Kinetics

MathWorks® Products Solutions Academia Support Community Events

File Exchange

MATLAB Central ▾ Files Authors My File Exchange ▾ Contribute About

**ANNOUNCEMENT**  
Enter Cody Contest 2020. Win prizes!

Solve coding problems. Improve MATLAB skills. Have fun. [See details and register.](#)

**Chemical Kinetics with MATLAB**  
version 1.0.0.0 (187 KB) by Balaji **STAFF**  
This interactive MATLAB document covers concepts relating to chemical kinetics and reaction rates.

Overview **Examples**

This interactive MATLAB document covers concepts relating to chemical kinetics and reaction rates. This module covers concepts that are typically a part of courses on General Chemistry. Specifically, it would address the following questions:

- How are chemical reactions represented mathematically using differential equations?
- How can I use MATLAB to compute symbolic solutions to these representations?
- How can I use MATLAB to compute numerical solutions to these representations?
- How can I use MATLAB to import and evaluate experimental data to estimate reaction parameters?
- How can I use MATLAB to document and publish my solutions and conclusions?

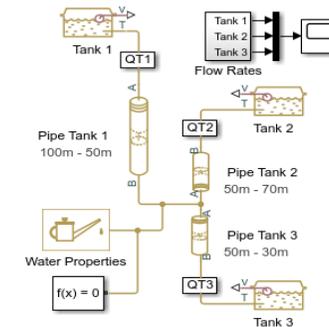
## Fluid Dynamics

### Three Constant Head Tanks

This example shows a classical problem of fluid transportation: to determine the flow rates in three pipelines combined together in a common node located at 50 meters with respect to a common reference level.

The pipelines are simulated with the Segmented Pipe LP block, which accounts for the pipe resistance and the liquid properties.

#### Model



## Process Design

Solutions Academia Support Community Events

Documentation Examples Functions Blocks Apps Videos Answers

**Design and Cosimulate Control of High-Fidelity Distillation Tower with Aspen Plus Dynamics**

This example shows how to design a model predictive controller in MATLAB for a high-fidelity distillation tower model built in Aspen Plus Dynamics®. The controller performance is then verified through cosimulation with Aspen Plus Dynamics.

**Distillation Tower**  
The distillation tower uses 29 ideal stages to separate a mixture of benzene, toluene, and xylenes (represented by p-xylene). The distillation process is continuous. The equipment includes a reboiler and a total condenser.

## Heat Transfer

MathWorks® Products Solutions Academia Support Community Events

Help Center

CONTENTS

- Documentation Home
- Partial Differential Equation Toolbox
- Category
- Get Started with Partial Differential Equation Toolbox
- Geometry and Mesh
- Structural Mechanics
- Heat Transfer
- Electromagnetics
- General PDEs

**Heat Transfer**  
Solve conduction-dominant heat transfer problems with convection and radiation occurring at boundaries.

Address challenges with thermal management by analyzing the temperature distributions of components based on material properties, external heat sources, and boundary conditions. A typical programmatic workflow for solving a heat transfer problem includes the following steps:

- Create a special thermal model container for a steady-state or transient thermal model.
- Define 2-D or 3-D geometry and mesh it.
- Assign thermal properties of the material, such as thermal conductivity  $k$ , specific heat  $c$ , and mass density  $\rho$ .
- Specify internal heat sources  $Q$  within the geometry.
- Specify temperatures on the boundaries or heat fluxes through the boundaries. For convective heat flux through the boundary  $h_c(T - T_\infty)$ , the ambient temperature  $T_\infty$ , emissivity  $\epsilon$ , and Stefan-Boltzmann constant  $\sigma$ .
- Set an initial temperature or initial guess.
- Solve and plot results, such as the resulting temperatures, temperature gradients, heat fluxes, and heat rates.

**Temperature at Time 50**

# Teaching Data Science to Chemical Engineers

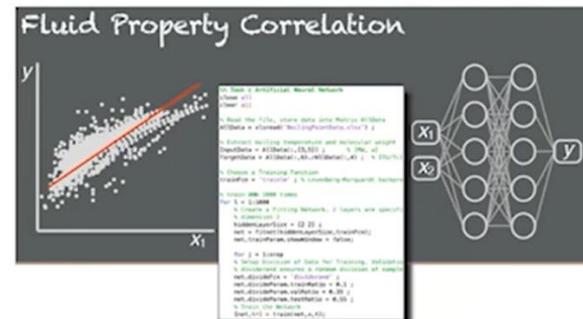
Imperial College  
London

## Employing Machine Learning to Correlate Fluid Properties

Classroom Examples with MATLAB

Erich A. Müller

*Department of Chemical Engineering  
Imperial College London U.K.*



# Integrating Computational Thinking to Chemical Engineering Curriculum



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Industry  
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Getting Help

# MATLAB and Simulink for Process Control in Industry

# Customer Example: TATA Steel optimizes cooling tower operation via MPC on digital twin

## Challenge

- High energy consumption in cooling tower
- Changing weather conditions caused substantial variation in operation

## Solution

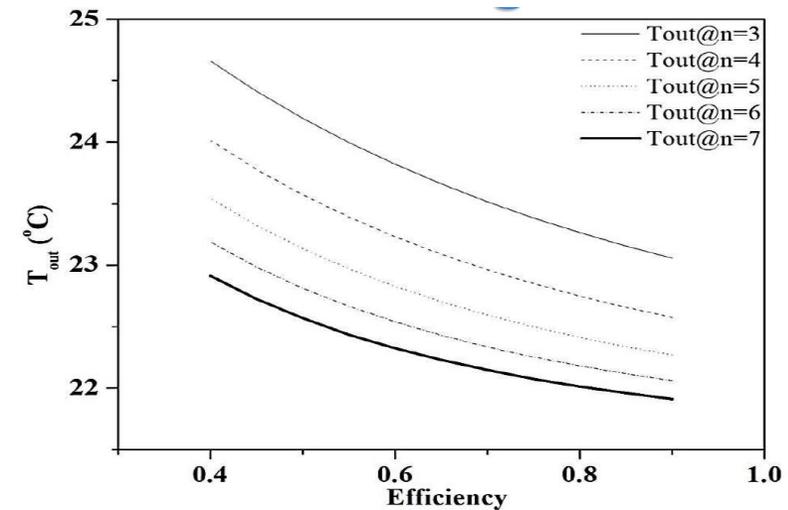
- Mass and energy balance equations modeled in MATLAB
- Model optimized and parameters calibrated with plant data
- MPC controller implemented

## Results

- Savings of \$40K per year for one CT
- Variation in outlet water temperature reduced
- Hundreds of tons of CO<sub>2</sub> reduction per year



Water cooling tower for the blast furnace



Effect of Murphree efficiency on number of stages

# Customer Example: Company Eliminates Environmental Impact of Discharged Wastewater with pH Control System

## Challenge

- To control pH levels in a wastewater treatment facility that was performing inconsistently
- No programming experience

## Solution

- Model plant in Sys Id Toolbox using process data
- Use Control System Toolbox to develop a controller to find best parameter settings graphically
- Implemented on Yokogawa DCS

## Results

- Acceptable pH levels rose to 100% from 84%
- Controller performance improved
- Development streamlined in just 3 months



Main Control Panel

*“Using Model-Based Design with MATLAB and Simulink enabled us to quickly try out multiple control strategies and validate the system before putting it into operation. This approach saved us time and ensured a better product.”*

*- Process Engineer*

# Customer Example: Genentech Builds a Supervisory Control Algorithm Development Platform for Bioreactors

## Challenge

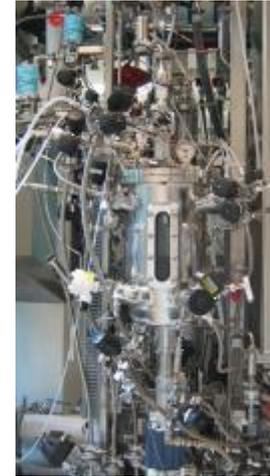
Accelerate the development of control algorithms for microbial fermentations

## Solution

Use MATLAB and OPC Toolbox to develop a continuous-uptime supervisory control platform that enables rapid development, debugging, and verification of algorithms

## Results

- Algorithm development time cut from months to weeks
- Flexible, reliable infrastructure deployed
- Potential errors identified in minutes



A Genentech microbial pilot plant bioreactor

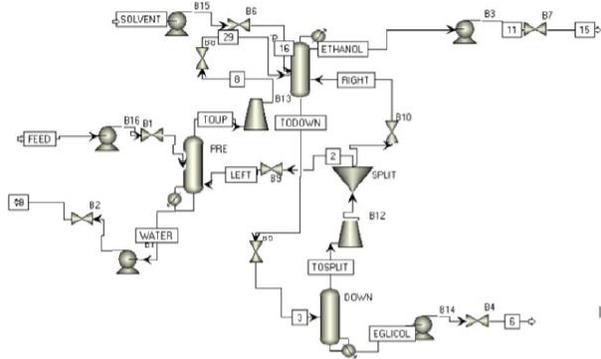
*“By partnering with MathWorks Consulting, we developed a robust platform for supervisory control with MATLAB and transitioned our pilot plant to a modern automation control system. This enabled our researchers to rapidly take algorithms from idea to implementation, simulation, and deployment.”*

*Dr. Ryan Hamilton*

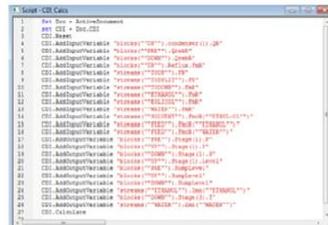
*Genentech*

# Import Aspen Dynamics and gPROMS models into Simulink to develop your control strategy

Aspen Plus  
Dynamic Simulation



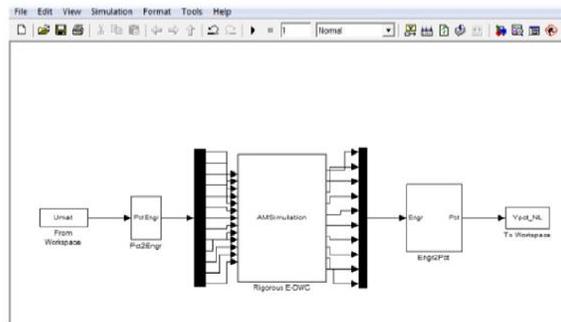
Aspen Plus  
Control Design Interface



MATLAB  
Linearized  
state space  
model

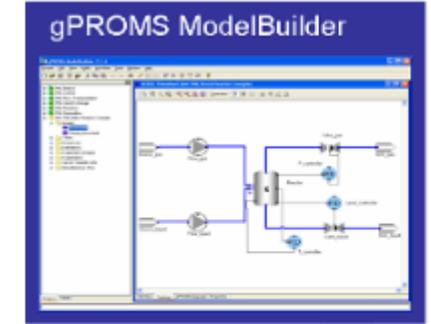
Generates

Linear model  
validation

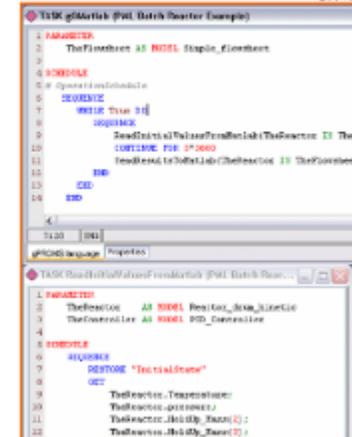


Simulink wrapper. Rigorous simulation

Step 1: Develop and test the gPROMS model inside the gPROMS ModelBuilder environment.



Step 2: Create a gPROMS schedule that periodically exchanges relevant data between gPROMS and MATLAB.

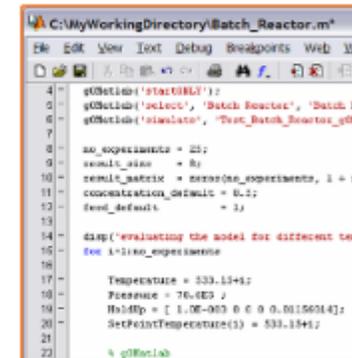


Step 3: Export the model gPROMS model

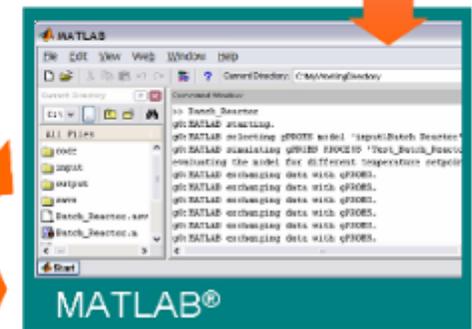
Exported file to be encrypted



Step 4: Create a MATLAB script file (e.g. cstr.m)



Step 5: Execute the gPROMS model from within MATLAB.



# Simulink is the preferred platform for APC

## IGCC - Current scenario

### IGCC Power plants in US

- Wabash River Power Station, West Terre Haute, IN
- Polk Power Station, Tampa, FL (350 MW)
- Pinon Rine, Reno, NV (failed)

### Obstacles

- High cost (without carbon regulation)
- Political – Recent emerging IGCC emission controversy
- Supreme court decision requiring Environment Protection Agency to regulate carbon



Wabash



Polk

IGCC Base Case in Aspen Plus

Modify base case

Separate Sub-sections

Prepare for export to Aspen Dynamics

Export Simulation

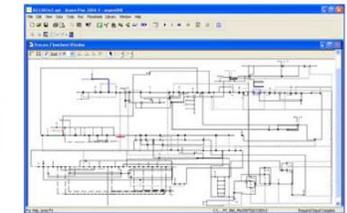
Add simple inventory control PID loops

Identify relevant inputs-outputs

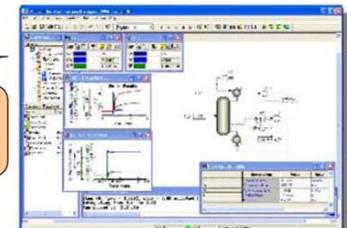
Interface w/ MATLAB/Simulink

Implement control strategies

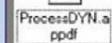
## Plant-wide IGCC Simulation *Aspen Plus to Aspen Dynamics to MATLAB*



Process.bkp



Process.dynf



ProcessDYN.a.pdf



**PLANT-WIDE**

Interconnect sub-sections

Decentralized plant-wide MPC and MMPC

# Customer Example: Tüpraş implements Control Loop Performance Assessment Solution in MATLAB

## Challenge

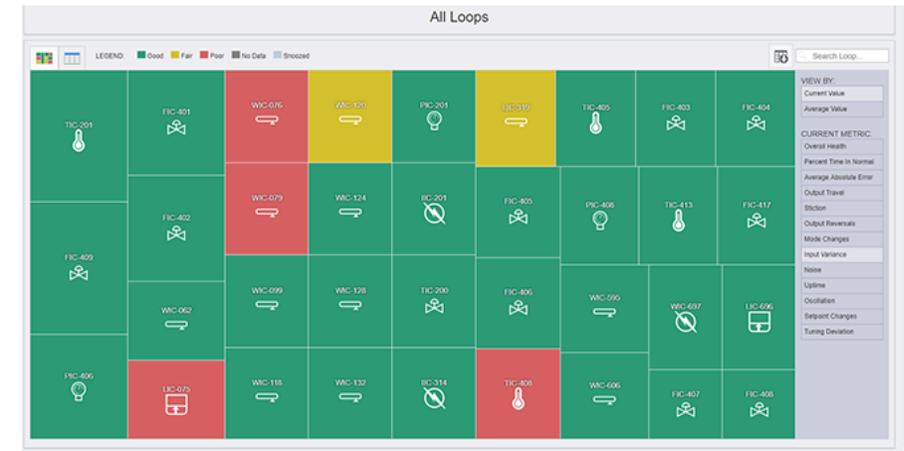
- Control loop performance deteriorates with time
- 5900 control loops spread across 4 refineries
- Expensive and non customizable enterprise software

## Solution

- Use a variety of signal processing techniques – spectral analysis, correlation analysis, pattern recognition, nonlinearity analysis, etc to diagnose the controller problems based on unique digital ‘signatures’

## Results

- **\$12-20 Million annual savings**
- Analysis automated, customized and simplified through in-house solution
- Savings of 250 man days annually for control engineers



**Controller health monitoring system dashboard**

*“MATLAB saved us a significant amount of time and expense by enabling us to develop our own software in-house. It also enabled us to save millions of dollars in costs that would have resulted from poor controller performance.”*

- Mehmet Yagci, Tüpraş

# Sign up for capstone project – ‘Monitoring and control of a bioreactor’

- Motivation & Benefits
  - Help transition pharmaceutical manufacturing to Industry 4.0 through application of APC
  - Learn about real industrial challenges
  - Learn MATLAB and Simulink
- [Capstone Project on Github](#)
  - Modeling a penicillin bioreactor
  - Analyze industrial ‘big data’ set (2.5 GB)
  - Identify CPPs
  - Develop control strategy



[Source](#)

# Integrating Computational Thinking to Chemical Engineering Curriculum



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Applications



Getting Help

# Getting Help

## MATLAB for Academia

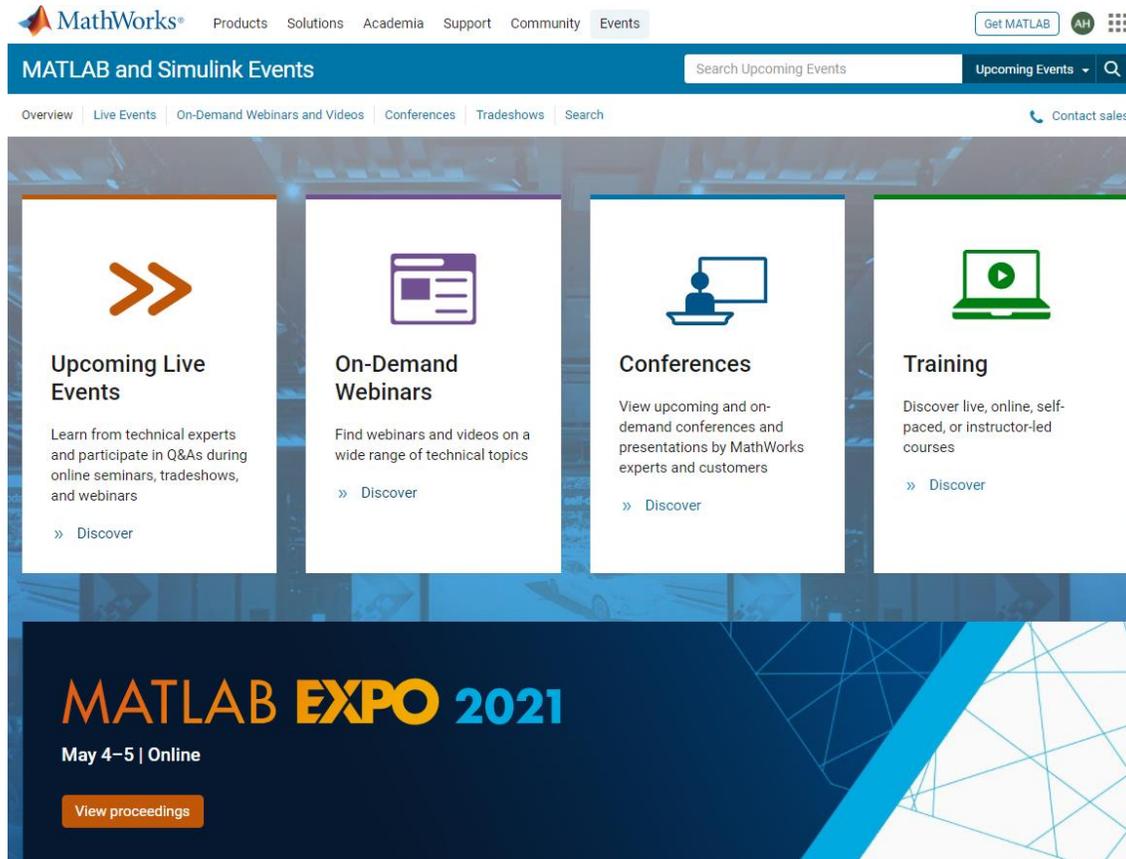
## Help Center

## MATLAB Central

## Customer Success Team

- Curriculum Support
- Research Support
- Awareness Resources

# MATLAB and Simulink Events



MathWorks® Products Solutions Academia Support Community Events

MATLAB and Simulink Events

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**MATLAB EXPO 2021**  
May 4-5 | Online  
View proceedings

# 2021 AIChE Annual Meeting

- [Integrating Data Science to Chemical Engineering Curriculum Using MATLAB](#)
- [Teaching Hands-on Process Control Courses with Arduino Based TCLab, MATLAB and Simulink](#)
- [Prediction of Atoms in Molecules with MATLAB Graph Convolutional Network](#)
- [Parallel and GPU Computing with MATLAB and Simulink for Chemical Engineering](#)

<https://www.mathworks.com/company/events.html>

<https://aiche.confex.com/aiche/2021/meetingapp.cgi/ModuleProgramBook/0>

# Resources

## [MathWorks - Academia](#)

## [MATLAB and Simulink for the Chemicals and Petrochemicals Industry](#)

### Fluid Dynamics

- [Simscape Fluids](#)
- [Three Constant Head Tanks Documentation Example](#)
- [Hydraulic Resistive Tube Documentation Example](#)

### Reaction Kinetics

- [SimBiology](#)
- [Chemical Kinetics with MATLAB File Exchange Entry](#)
- [Teaching Chemistry with MATLAB](#)
- [SimBiology Documentation Example for Reaction Kinetics](#)

### Heat Transfer

- [Partial Differential Equation Toolbox](#)
- [Heat Transfer Documentation Examples](#)

### Process Control

- [Simulink](#)
- [Control System Toolbox](#)
- [Water Tank Simulink Model Documentation Example](#)
- [Design Internal Model Controller for Chemical Reactor Plant Documentation Example](#)
- [Teaching Controls with MATLAB and Simulink](#)

### Process Design

- [Linking MATLAB to Process Simulators](#)
- [Design and Cosimulate Control of High-Fidelity Distillation Tower with Aspen Dynamics Documentation Example](#)

# Teaching Chemical Engineering with MATLAB, Simulink and TCLab



Joshua Hammond  
Research Assistant  
John Hedengren  
Associate Professor  
Brigham Young University



**BYU PRISM**  
MODEL OPTIMIZE CONTROL

# Webinar and Interactive Module Interest



**John Hedengren**  
Associate Professor

[View full profile](#)



**John Hedengren**  
Associate Professor  
6d • 🌐

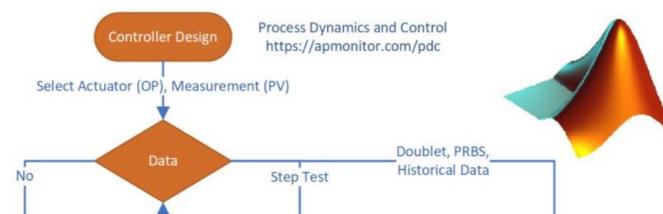
⋮

📄 35 NEW interactive modules in MATLAB, Simulink, and Live Scripts for Dynamics and Control. Join the MathWorks webinar on Teaching Chemical Engineering with MATLAB, Simulink and TClab on Tuesday, Aug 17.

Webinar Registration: <https://lnkd.in/etEs4DP>  
35 Modules (GitHub): <https://lnkd.in/e6hpFrc9>  
Course Schedule: <https://lnkd.in/eDEJPqP>

The flowchart guides students through the course with one or more modules for each block. Thanks to [Joshua Hammond](#), [Colin Anderson](#), and [Nathanael Martin-Nelson, EIT](#) for their development work on these new modules over the past year and to MathWorks for technical and financial student support.

[#chemicalengineering](#) [#teaching](#) [#matlab](#) [#simulink](#) [#processcontrol](#) [#processautomation](#) [#education](#)



Controller Design    Process Dynamics and Control  
<https://apmonitor.com/pdc>

Select Actuator (OP), Measurement (PV)

Data

No    Step Test    Doublet, PRBS, Historical Data

👍👎❤️ 449 • 15 comments

Reactions



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Your post posted on August 10, 2021

449 reactions · 15 comments

20,497 views    27 reshares



172 people from MathWorks viewed your post

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| Shell                    | 77  |
| Brigham Young University | 71  |
| Honeywell                | 54  |
| Baker Hughes             | 35  |
| Schlumberger             | 34  |
| Halliburton              | 32  |



1,278 people who have the title Engineer viewed your post

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| Research Fellow                  | 908 |
| Software Developer               | 847 |
| Student                          | 739 |
| University Professor             | 700 |
| Manufacturing Operations Manager | 343 |
| Hardware Engineer                | 307 |
| Laboratory Scientist             | 287 |

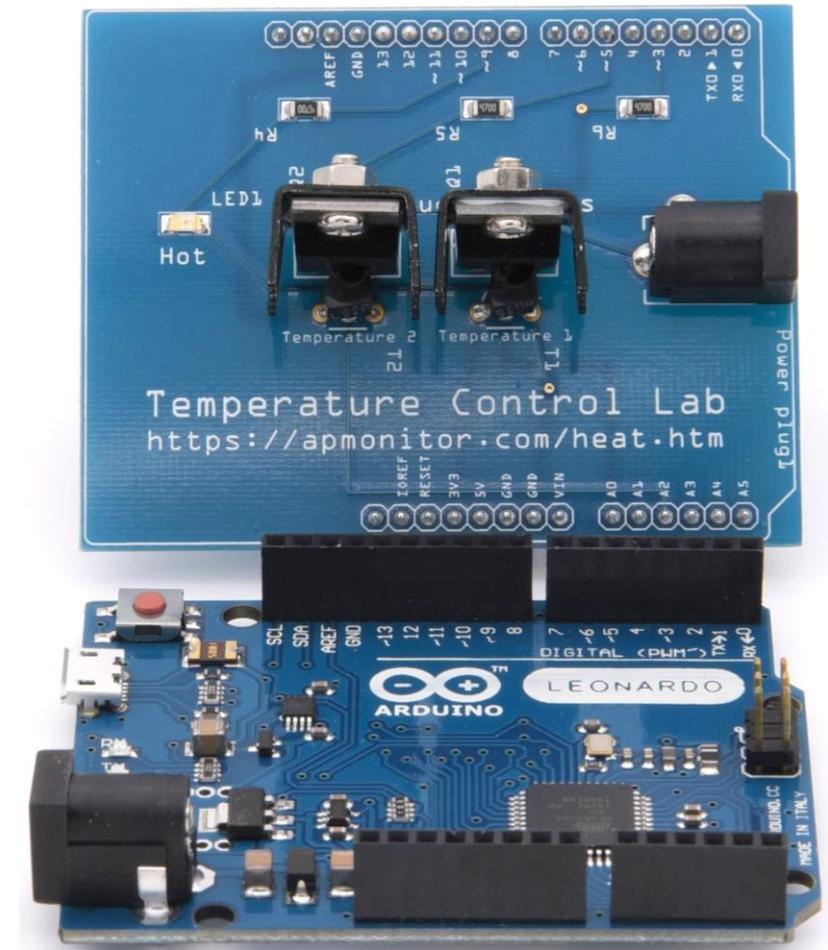


530 people viewed your post from Houston, Texas Area

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| San Francisco Bay Area | 257 |
| Provo, Utah Area       | 233 |
| São Paulo Area, Brazil | 200 |
| Mumbai Area, India     | 181 |
| Greater Boston Area    | 176 |
| Kalyan Area, India     | 174 |
| Chennai Area, India    | 169 |

# Overview

- Automation needed across industries
- 35 Lesson Modules
- Pocket-sized lab overview
  - Teaching resource with learning objectives
  - MATLAB, Simulink, and Live Script demos
- Collaborative community resources





Medical Automation



People Transportation



Product Transportation

## Oil and Gas Industry



New Topics: Data Science, Analytics, Machine Learning, Cybersecurity, Digitalization

# MATLAB, Simulink, and Live Script Resources

- Dynamics and Control Course

- Learning Modules (35)

- Theory: Lesson

- Simulation: Assignment

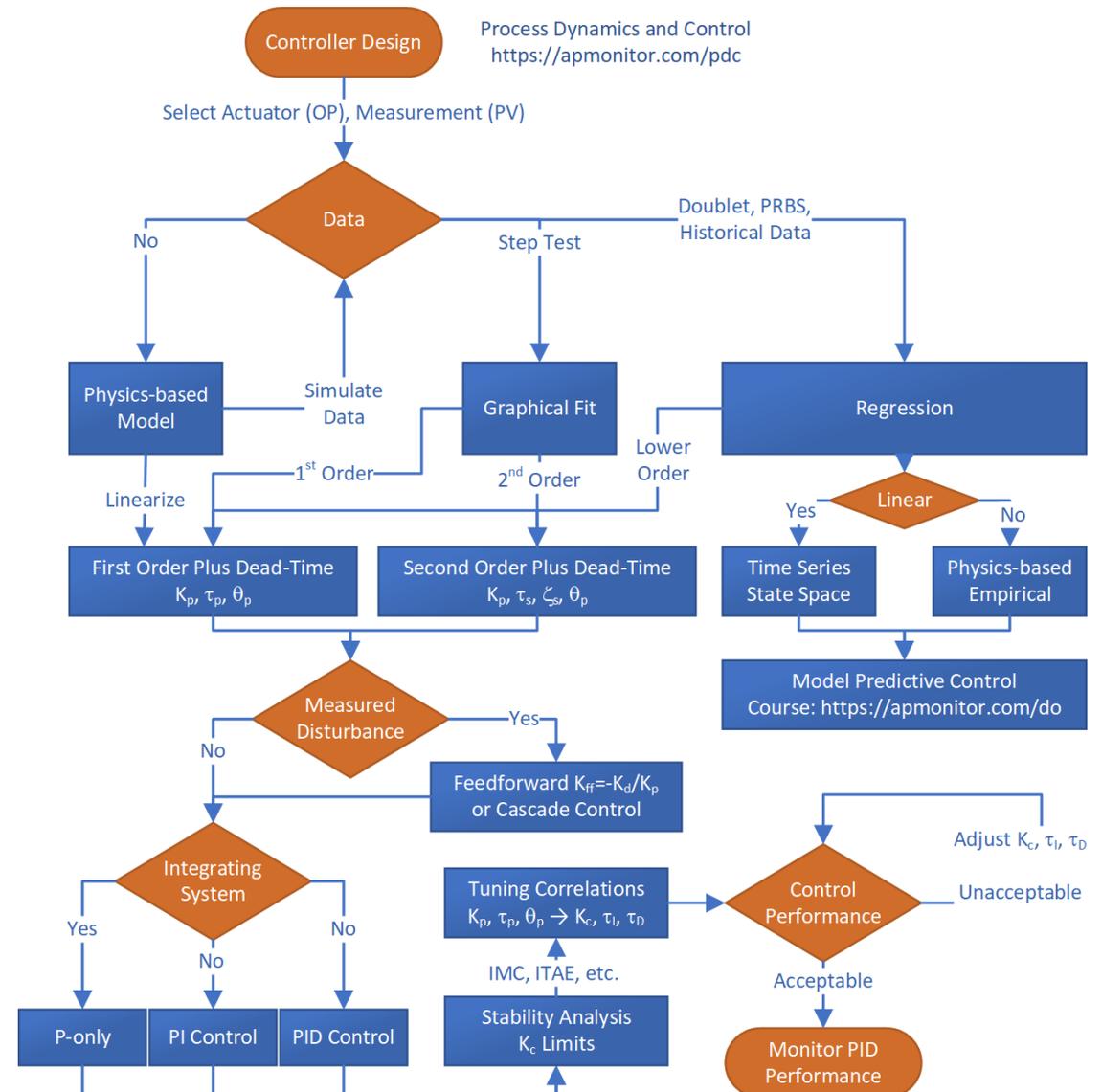
- Lab: Temperature Control

- Course

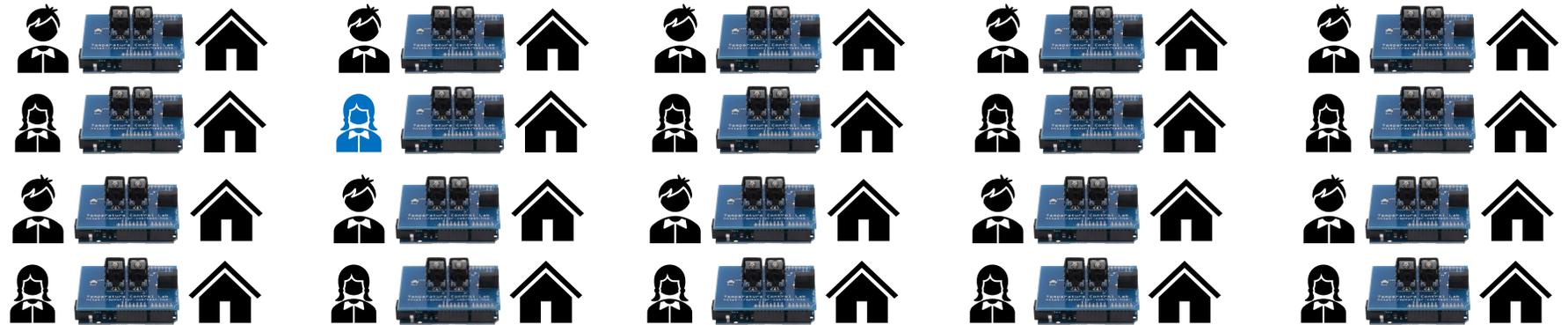
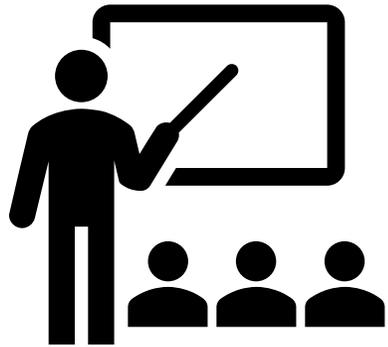
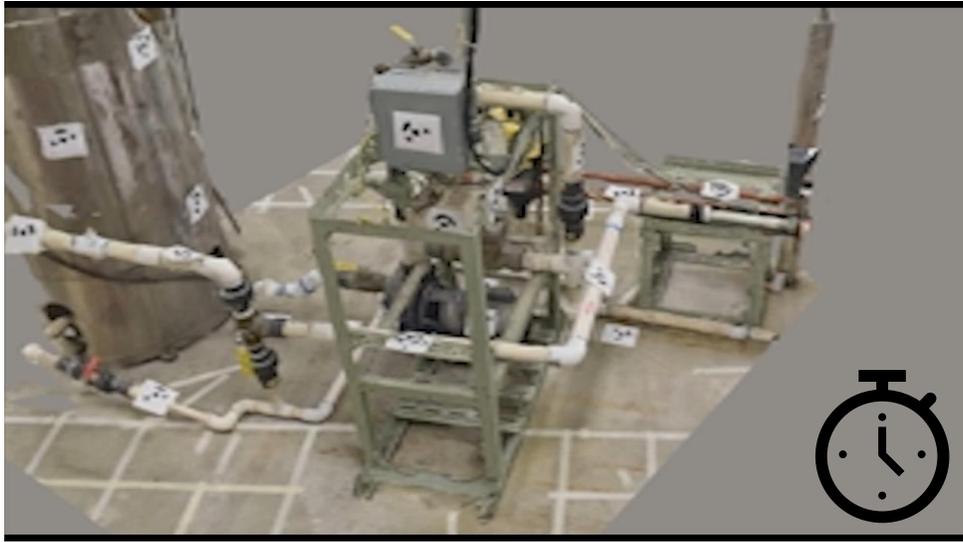
- <https://apmonitor.com/pdc>

- MathWorks Modules

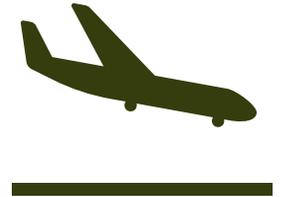
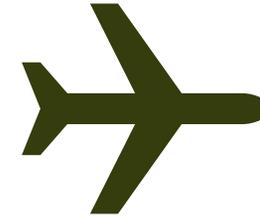
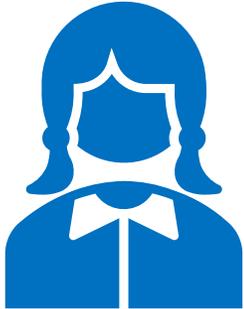
- <https://github.com/APMonitor/mdc>



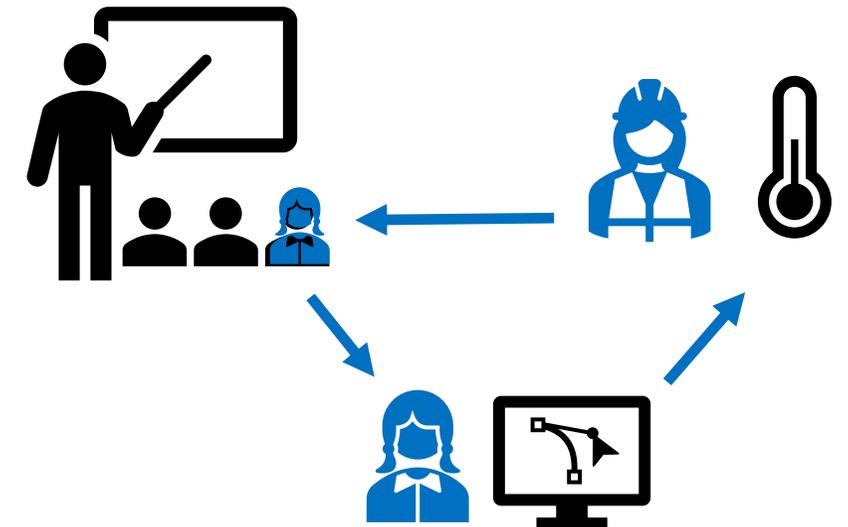
# Learning from Instructor Perspective



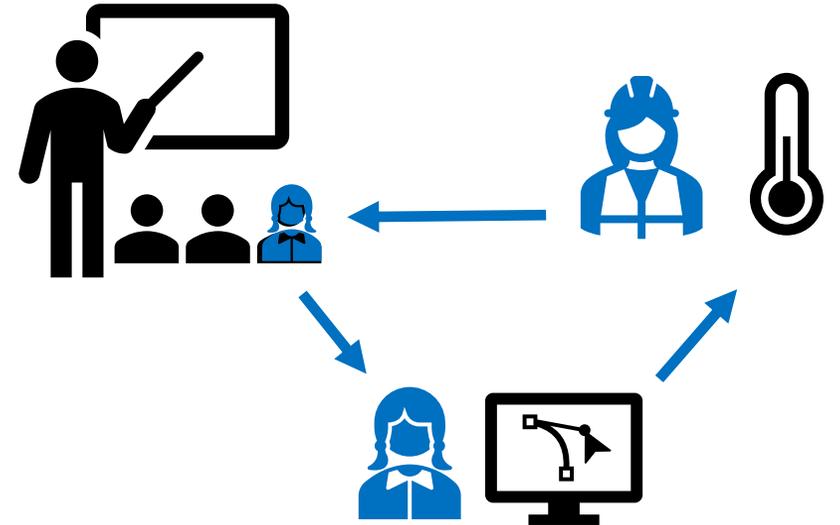
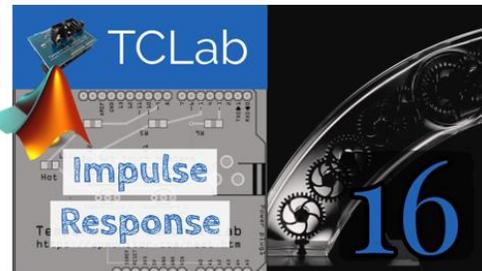
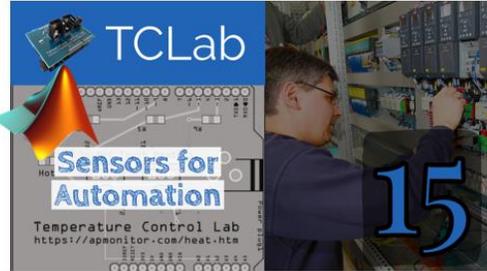
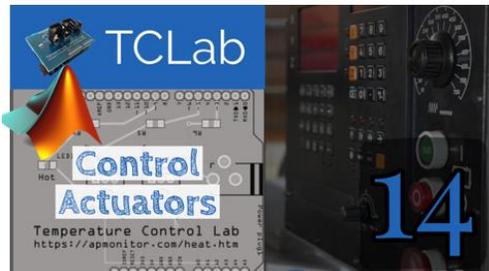
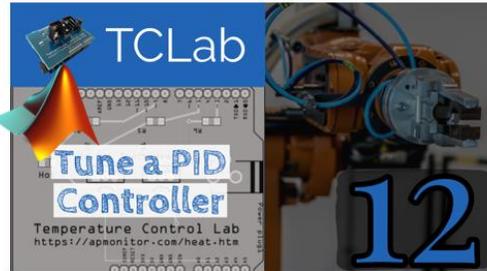
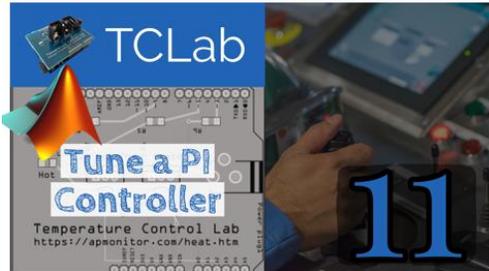
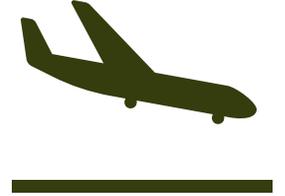
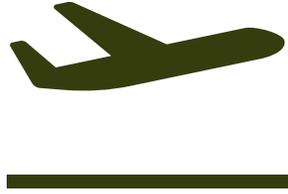
# Learning from Student Perspective: Foundations



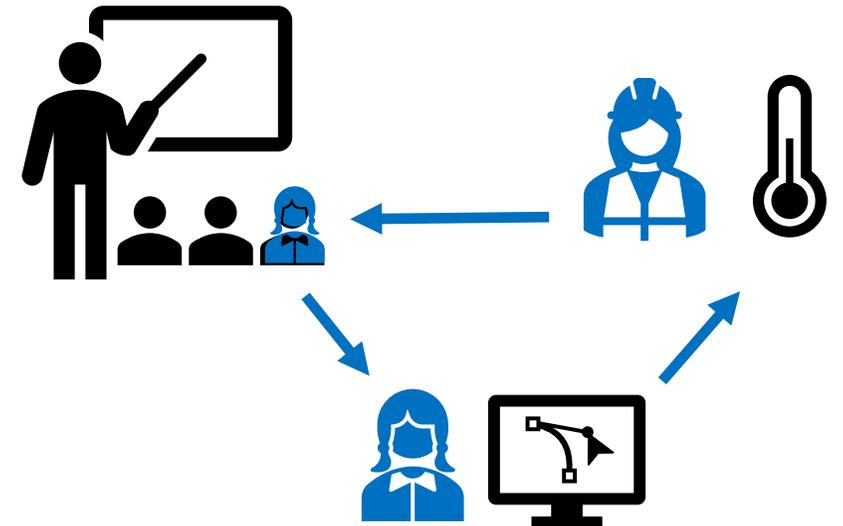
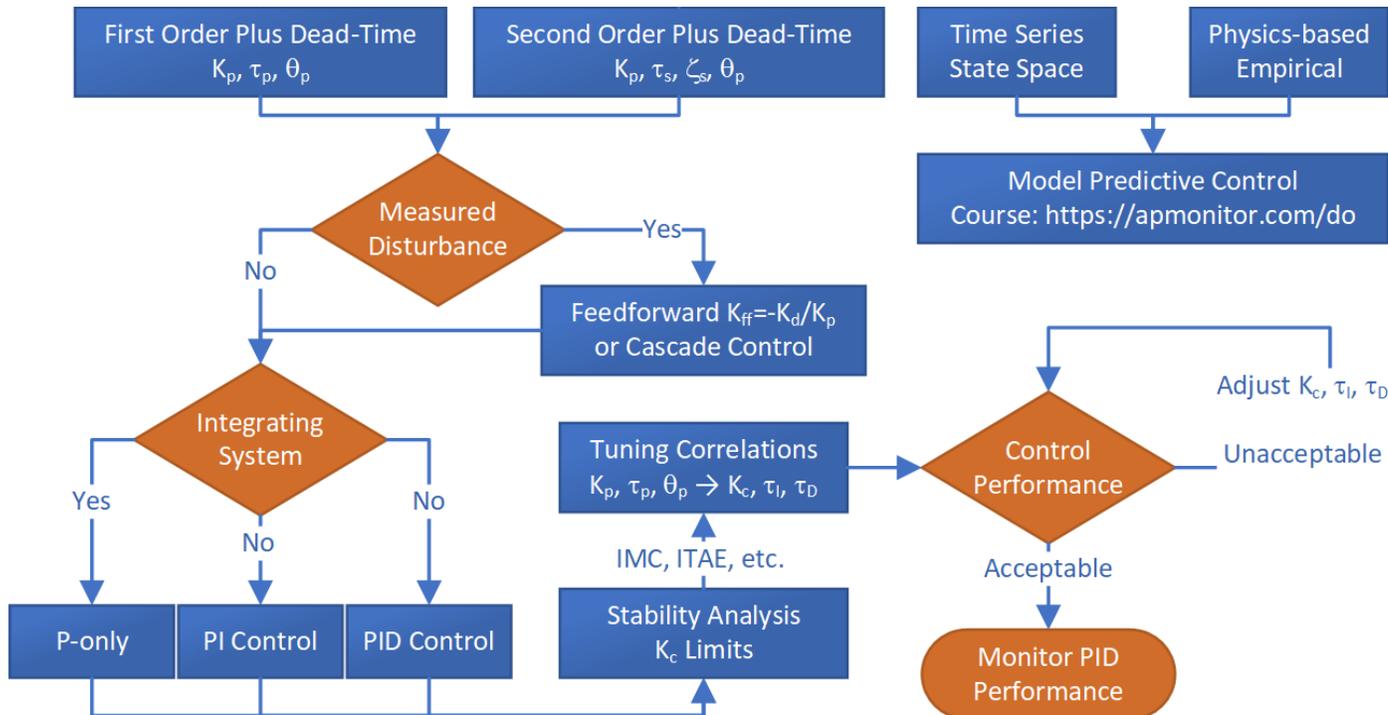
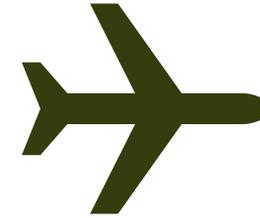
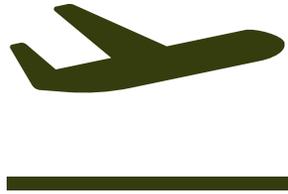
|                                         |                                             |                                              |
|-----------------------------------------|---------------------------------------------|----------------------------------------------|
| TCLab Course<br>Begin Matlab Overview 1 | TCLab Course<br>Begin Matlab Debugging 2    | TCLab Course<br>Begin Matlab Variables 3     |
| TCLab Course<br>Begin Matlab Printing 4 | TCLab Course<br>Begin Matlab Arduino 5      | TCLab Course<br>Begin Matlab Functions 6     |
| TCLab Course<br>Begin Matlab Loops 7    | TCLab Course<br>Begin Matlab Input 8        | TCLab Course<br>Begin Matlab If Statements 9 |
| TCLab Course<br>Begin Matlab Arrays 10  | TCLab Course<br>Begin Matlab Cell Arrays 11 | TCLab Course<br>Begin Matlab Plotting 12     |



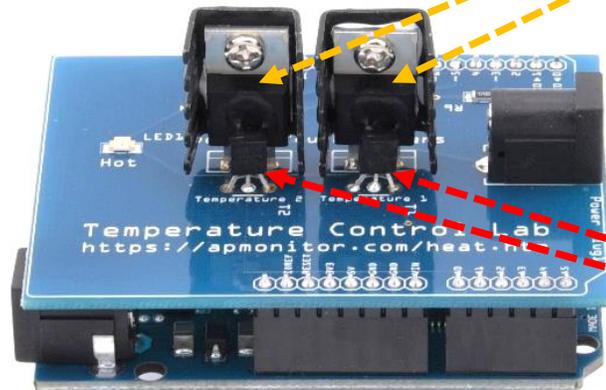
# Learning from Student Perspective: Active Learning



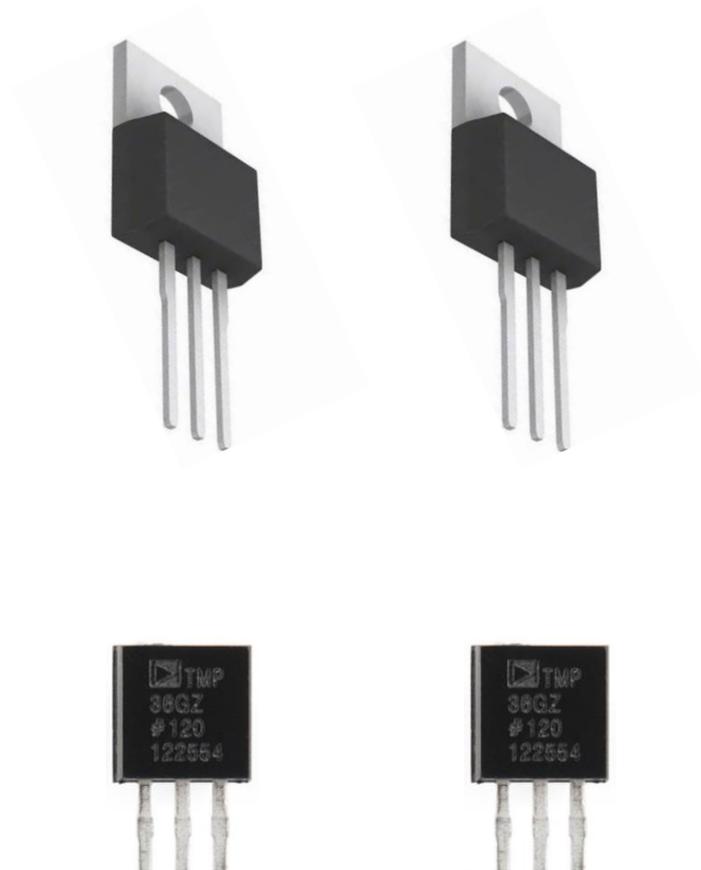
# Learning from Student Perspective: Synthesize







[apmonitor.com/heat.htm](http://apmonitor.com/heat.htm)



Actuator  
Heaters



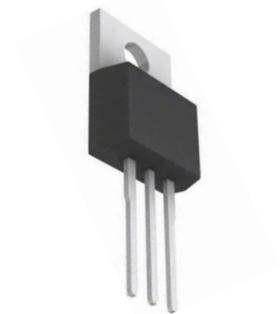
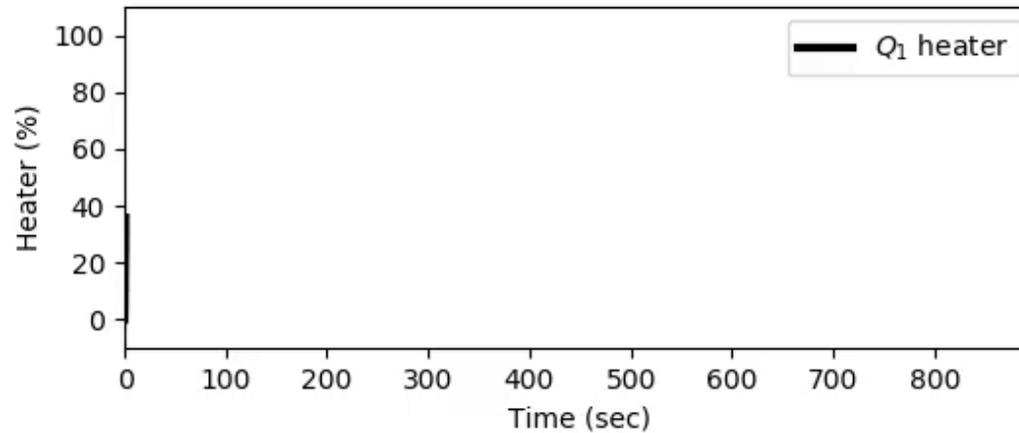
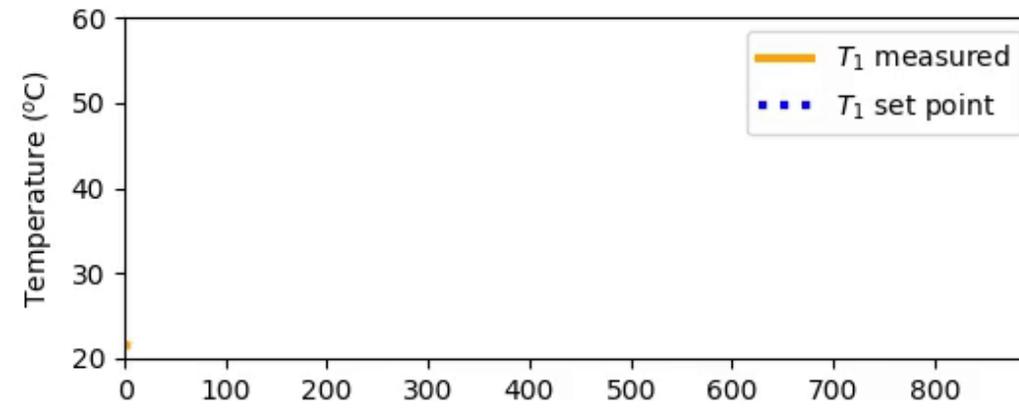
Sensors  
T (°C)

```
lab = tclab; % load TCLab
```

```
lab.LED(80)
```

```
disp(lab.T1)
```

```
lab.Q1(50)
```



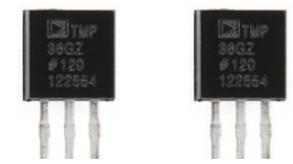
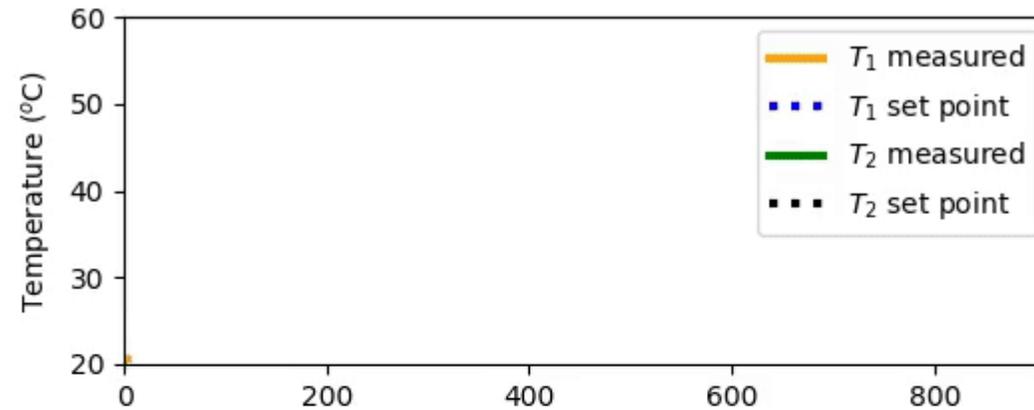
```
lab = tclab; % load TCLab
```



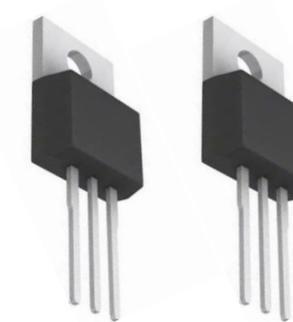
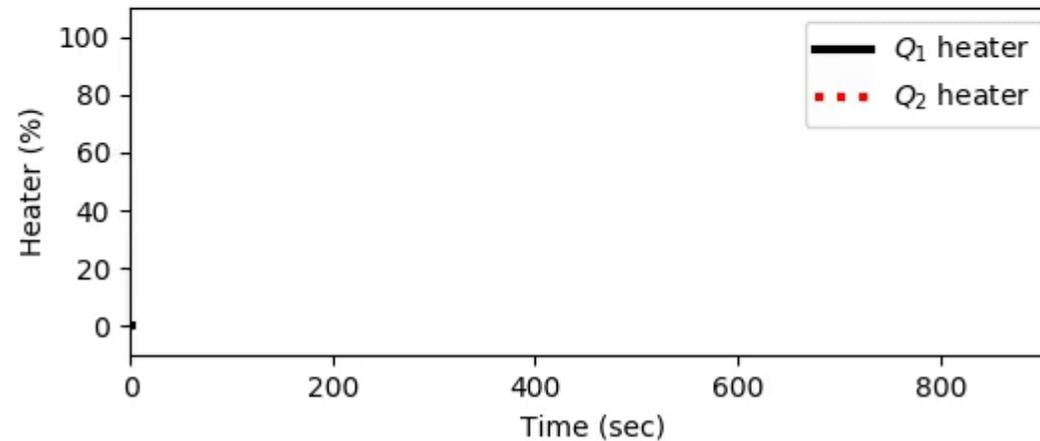
```
lab.LED(80)
```



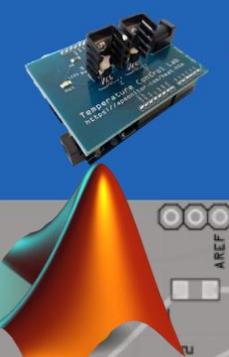
```
disp(lab.T1)
disp(lab.T2)
```



```
lab.Q1(50)
lab.Q2(0)
```

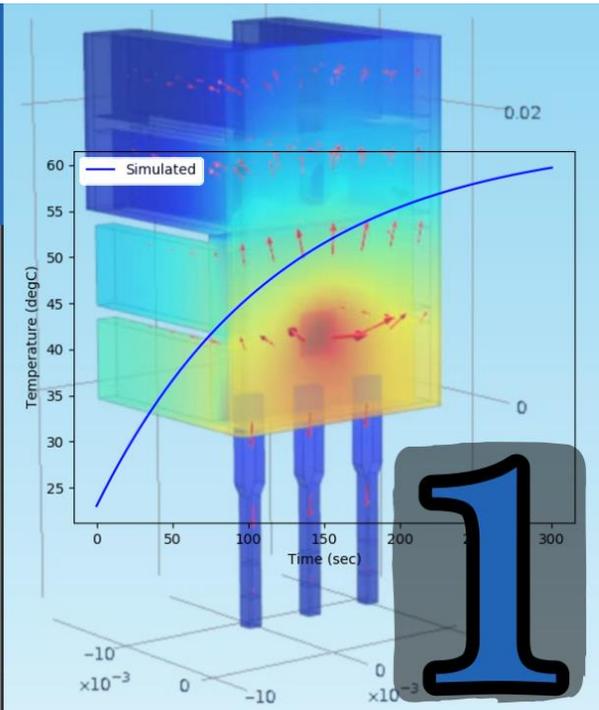


# TCLab



## Step Test

Temperature Control Lab  
<https://apmonitor.com/heat.htm>



# TCLab

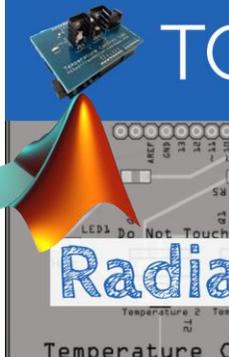


## Convective

Temperature Control Lab  
<https://apmonitor.com/heat.htm>



# TCLab

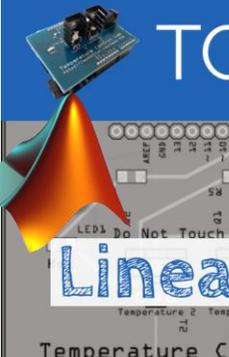


## Radiative

Temperature Control Lab  
<https://apmonitor.com/heat.htm>

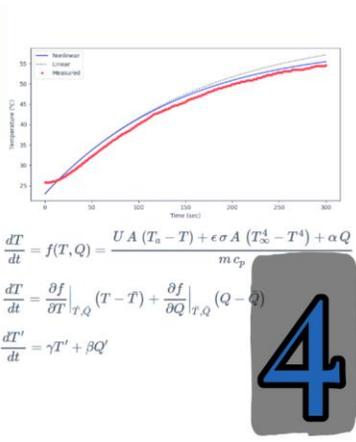


# TCLab



## Linearize

Temperature Control Lab  
<https://apmonitor.com/heat.htm>



TCLab\_2019a - Simulink academic use

File Edit View Display Diagram Simulation Analysis Code Tools Help

TCLab\_2019a

## Adjust Heaters With Sliders

Heater 1 (Q1) Value: 50

Heater 2 (Q2) Value: 0

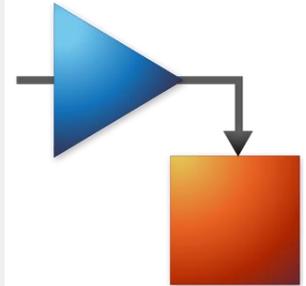
Q1

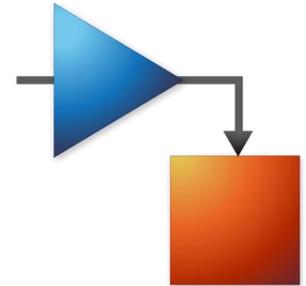
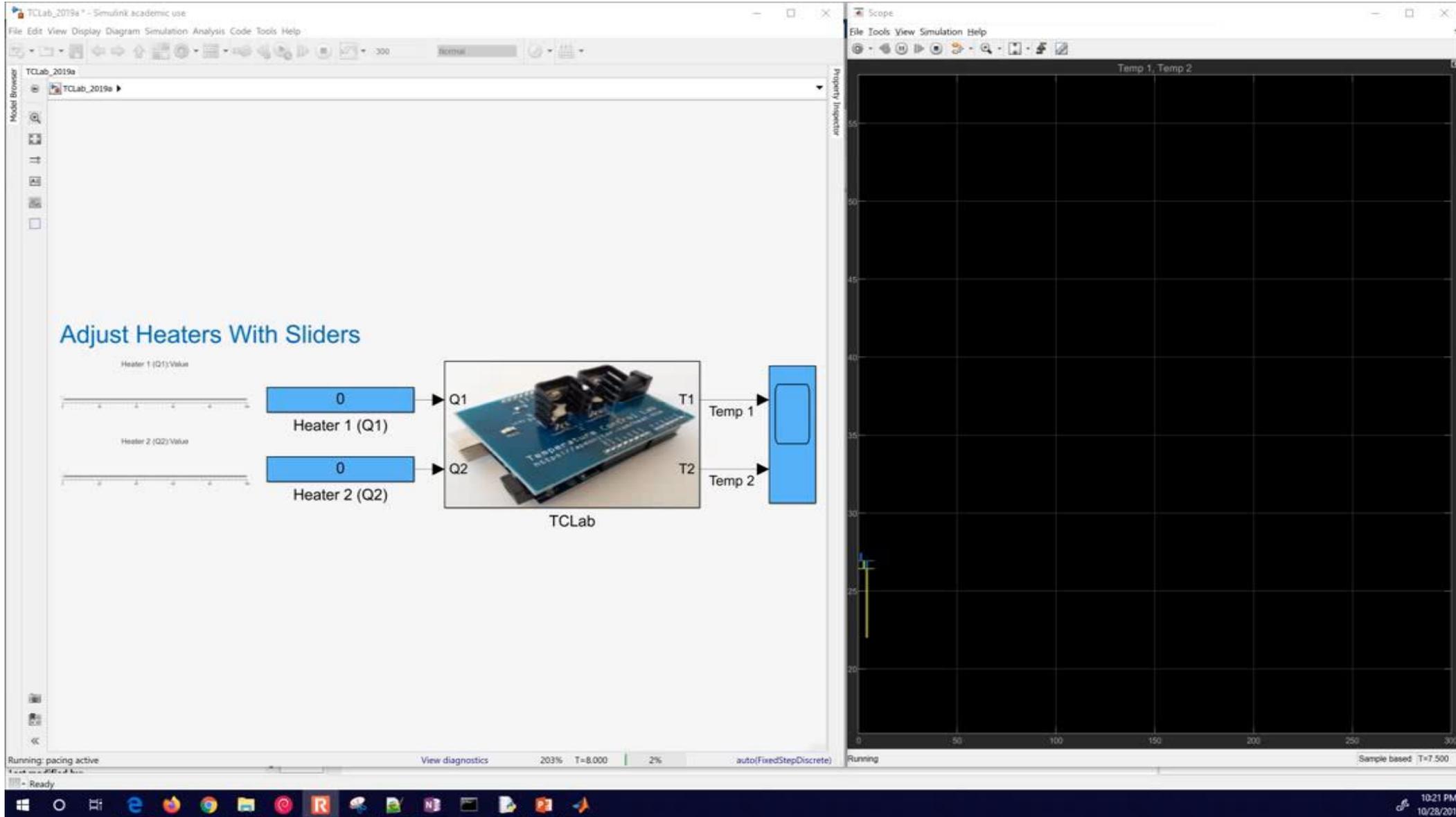
T1

Temp 1

Temp 2

TCLab



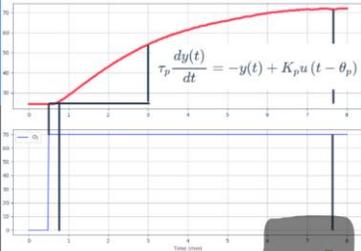


TCLab

FOPDT

Graphical

Temperature Control Lab  
<https://apmonitor.com/heat.htm>



$K_p$  = Process gain  
 $\tau_p$  = Process time constant  
 $\theta_p$  = Process dead time

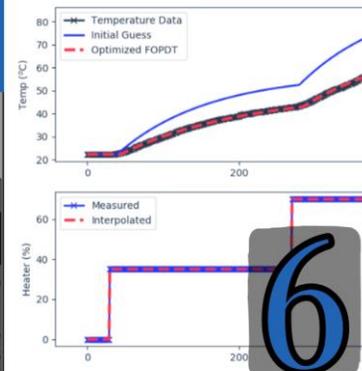
5

TCLab

FOPDT

Regression

Temperature Control Lab  
<https://apmonitor.com/heat.htm>

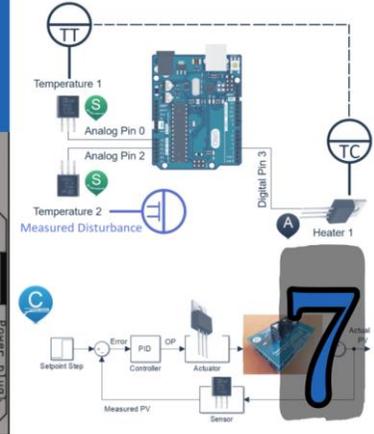


6

TCLab

Control Design

Temperature Control Lab  
<https://apmonitor.com/heat.htm>



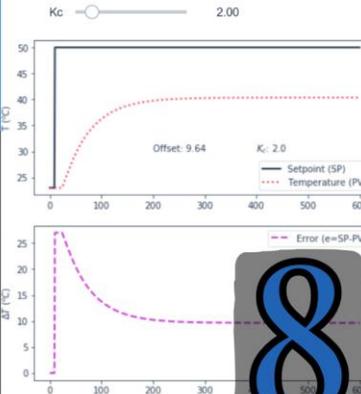
7

TCLab

Offset with

P-only Control

Temperature Control Lab  
<https://apmonitor.com/heat.htm>



8

TCLab

PI Control

Temperature Control Lab  
<https://apmonitor.com/heat.htm>



9

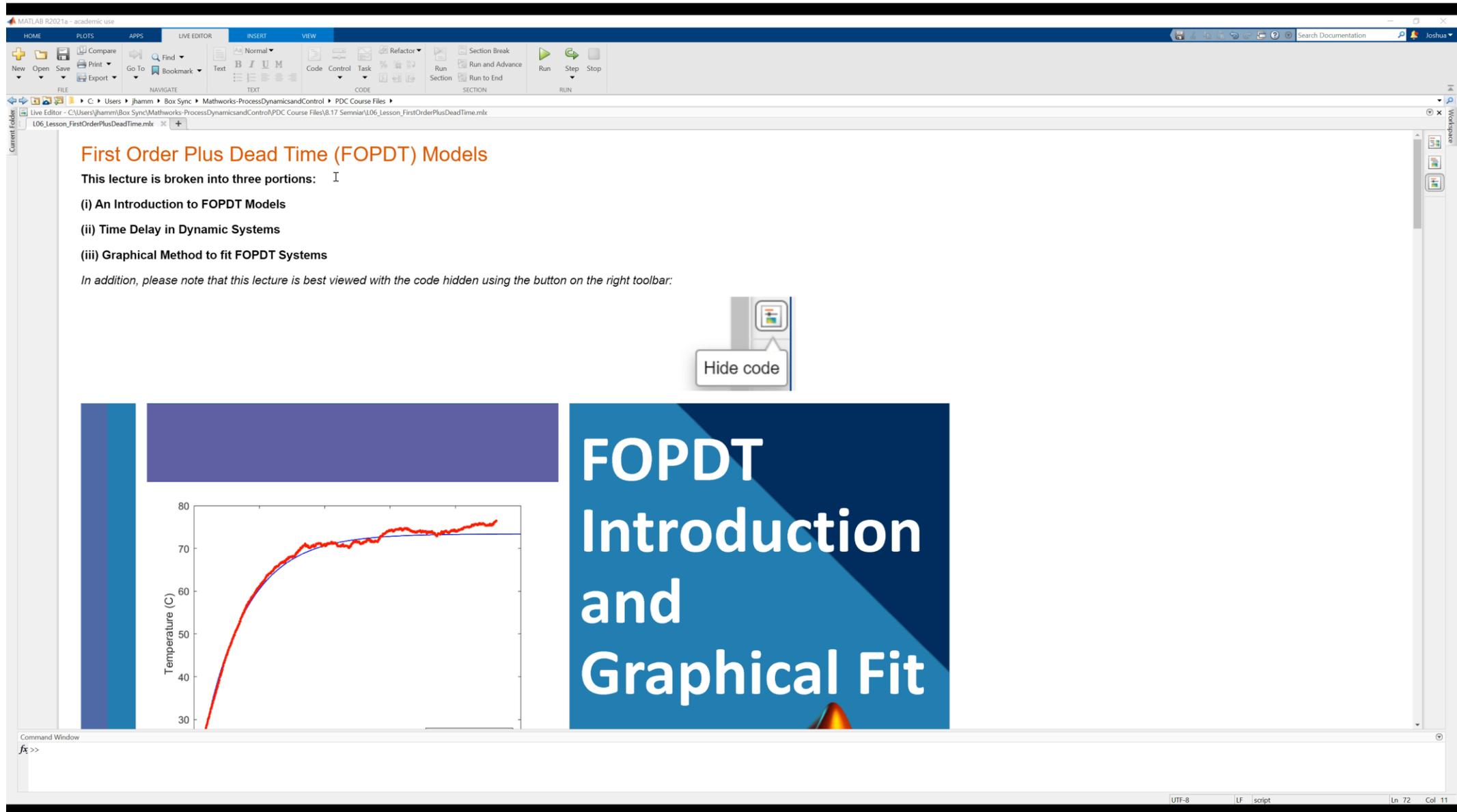
TCLab

PID Control

Temperature Control Lab  
<https://apmonitor.com/heat.htm>



10



MATLAB R2021a - academic use

HOME PLOTS APPS LIVE EDITOR INSERT VIEW

File Edit View Tools

Current Folder: C:\Users\jhamm\Box Sync\Mathworks-ProcessDynamicsandControl\PDC Course Files

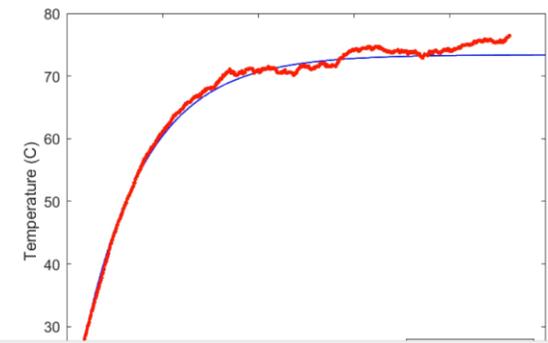
## First Order Plus Dead Time (FOPDT) Models

This lecture is broken into three portions: I

- (i) An Introduction to FOPDT Models
- (ii) Time Delay in Dynamic Systems
- (iii) Graphical Method to fit FOPDT Systems

*In addition, please note that this lecture is best viewed with the code hidden using the button on the right toolbar:*

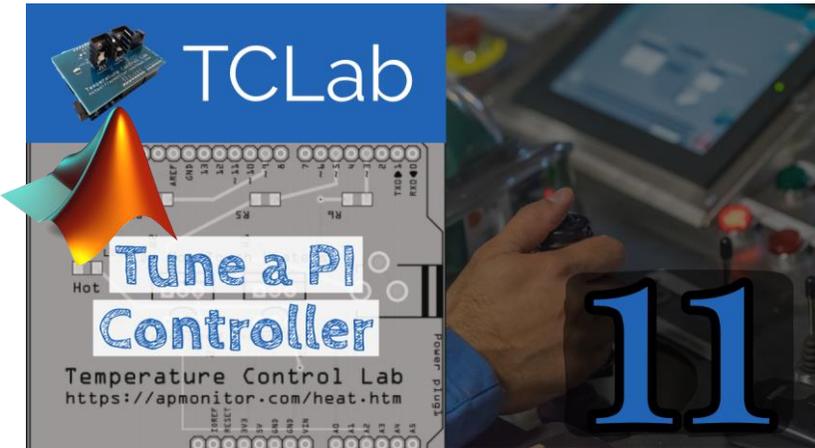
Hide code



# FOPDT Introduction and Graphical Fit

Command Window  
fx >>

UTF-8 LF script Ln 72 Col 11

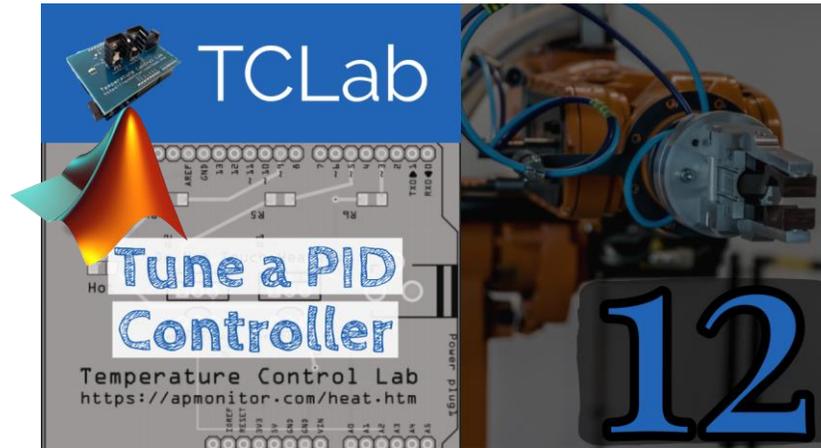


TCLab

**Tune a PI Controller**

Temperature Control Lab  
<https://apmonitor.com/heat.htm>

11



TCLab

**Tune a PID Controller**

Temperature Control Lab  
<https://apmonitor.com/heat.htm>

12

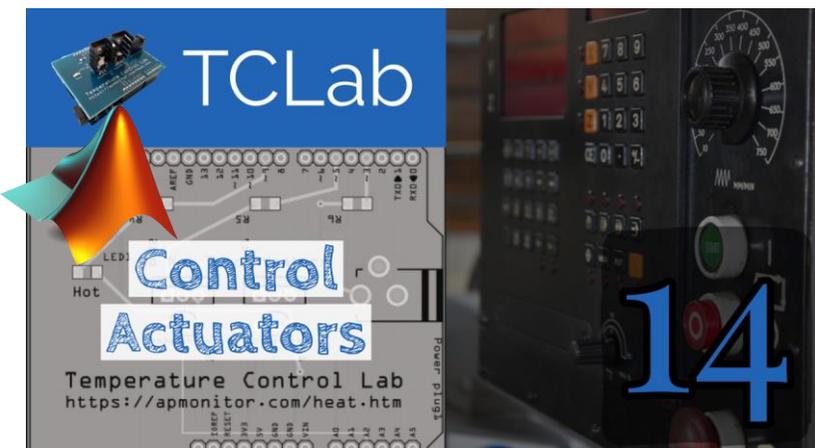


TCLab

**Feedforward Control**

Temperature Control Lab  
<https://apmonitor.com/heat.htm>

13

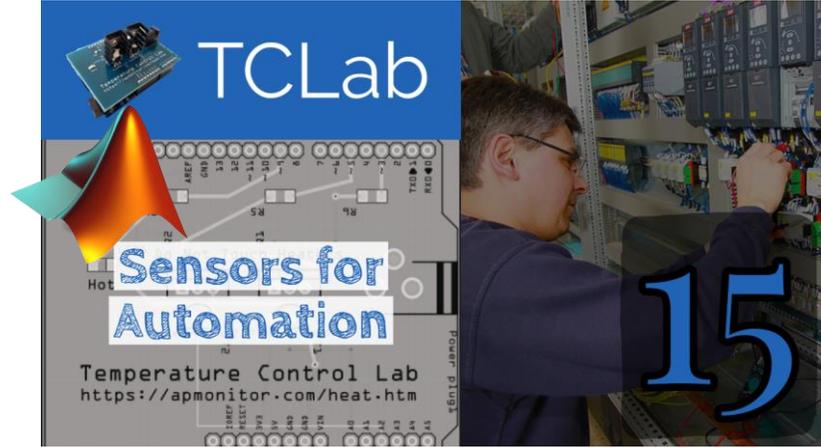


TCLab

**Control Actuators**

Temperature Control Lab  
<https://apmonitor.com/heat.htm>

14

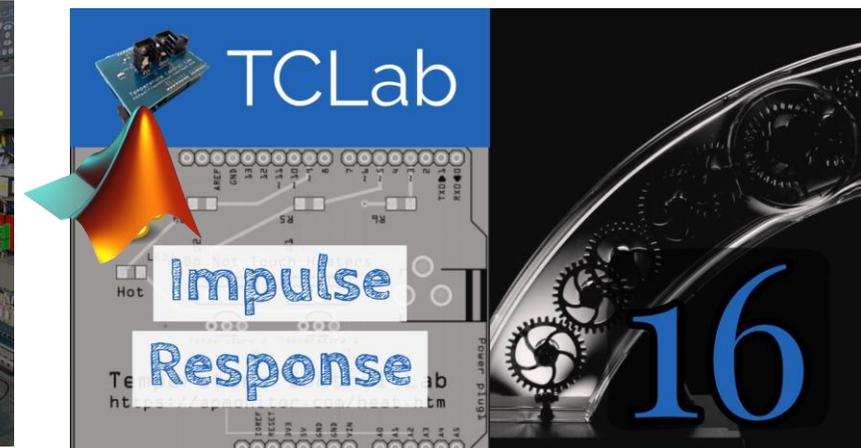


TCLab

**Sensors for Automation**

Temperature Control Lab  
<https://apmonitor.com/heat.htm>

15



TCLab

**Impulse Response**

Temperature Control Lab  
<https://apmonitor.com/heat.htm>

16

MATLAB R2021a - academic user

HOME PLOTS APPS LIVE EDITOR INSERT FIGURE VIEW

Single Left/Right Tabs Position Shrink Tabs to Fit Line Numbers Datatips Full Screen Clear all Output on Right Output Inline Hide Code

TILES DOCUMENT TABS DISPLAY OUTPUT VIEW

Live Editor - C:\Users\jhamm\Box Sync\Mathworks-ProcessDynamicsandControl\PDC Course Files\B.17 Semnar\L15\_TCLab\_PIDTuning.mlx

L15\_TCLab\_PIDTuning.mlx x L11\_TCLab\_pOnlyControl.mlx x L12\_TCLab\_PIDControl.mlx x L13\_TCLab\_PIDControl.mlx x L07\_Tcab\_fitFOPDT.mlx x

## PID Tuning

**Objective:** Tune a discrete PID controller and test the performance with a series of setpoint changes over 10 min in the sequence from initially, 50°C at 10 sec, and 40°C at 300 sec. Modify the tuning parameters to achieve a low Integral Absolute Error between the measured temperature and the setpoint.

### TCLab PID Control Simulator

A simulator is a useful tool to help evaluate changes in tuning before testing on a physical system. Use the PID simulator to find acceptable control performance that minimizes the integral absolute error between the setpoint and measured temperature.

```

1 Kc = 0 ;
2 tauI = 180 ;
3 tauD = 0 ;
4 pidPlot(Kc, tauI, tauD)

```

### TCLab PID Control Test

```

5 viewSolution( )

```

Using the PID Parameters from the simulation, implement PID control in the TCLab with a series of setpoint changes over 10 min in the sequence from 23°C initially, 50°C at 10 sec, and 40°C at 300 sec.

```

6 params = [Kc tauI tauD];
7

```

Command Window

```

'TCLab heaters and LED off'
>> clear lab
fx >>

```

Temperature (C)

Time (s)

Heater Setting

Time (s)

Setpoint

Temperature

UTF-8 LF script Ln 2 Col 11

TCLab\_2019a - Simulink academic use

File Edit View Display Diagram Simulation Analysis Code Tools Help

TCLab\_2019a

Model Browser

TCLab\_2019a

2.5x Speed

### Adjust Heaters With Sliders

T1 Set Point Value

Heater 1 (Q1)

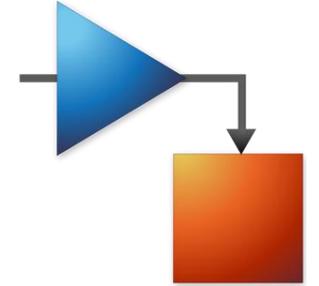
Heater 2 (Q2) Value

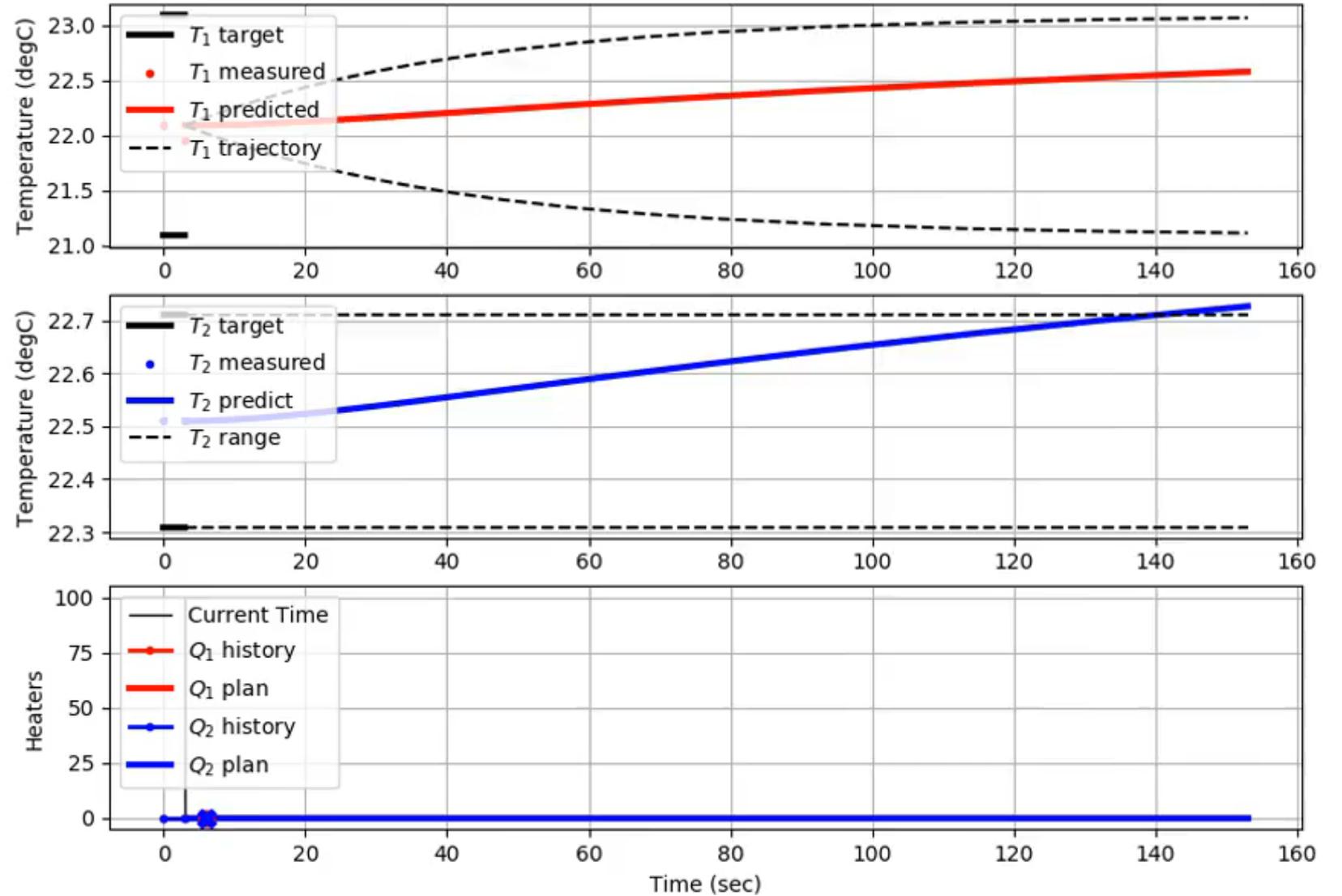
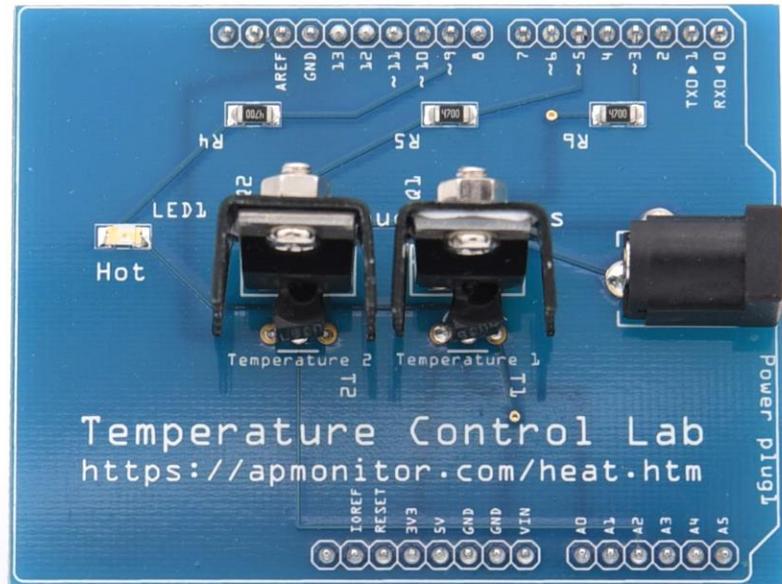
Heater 2 (Q2)

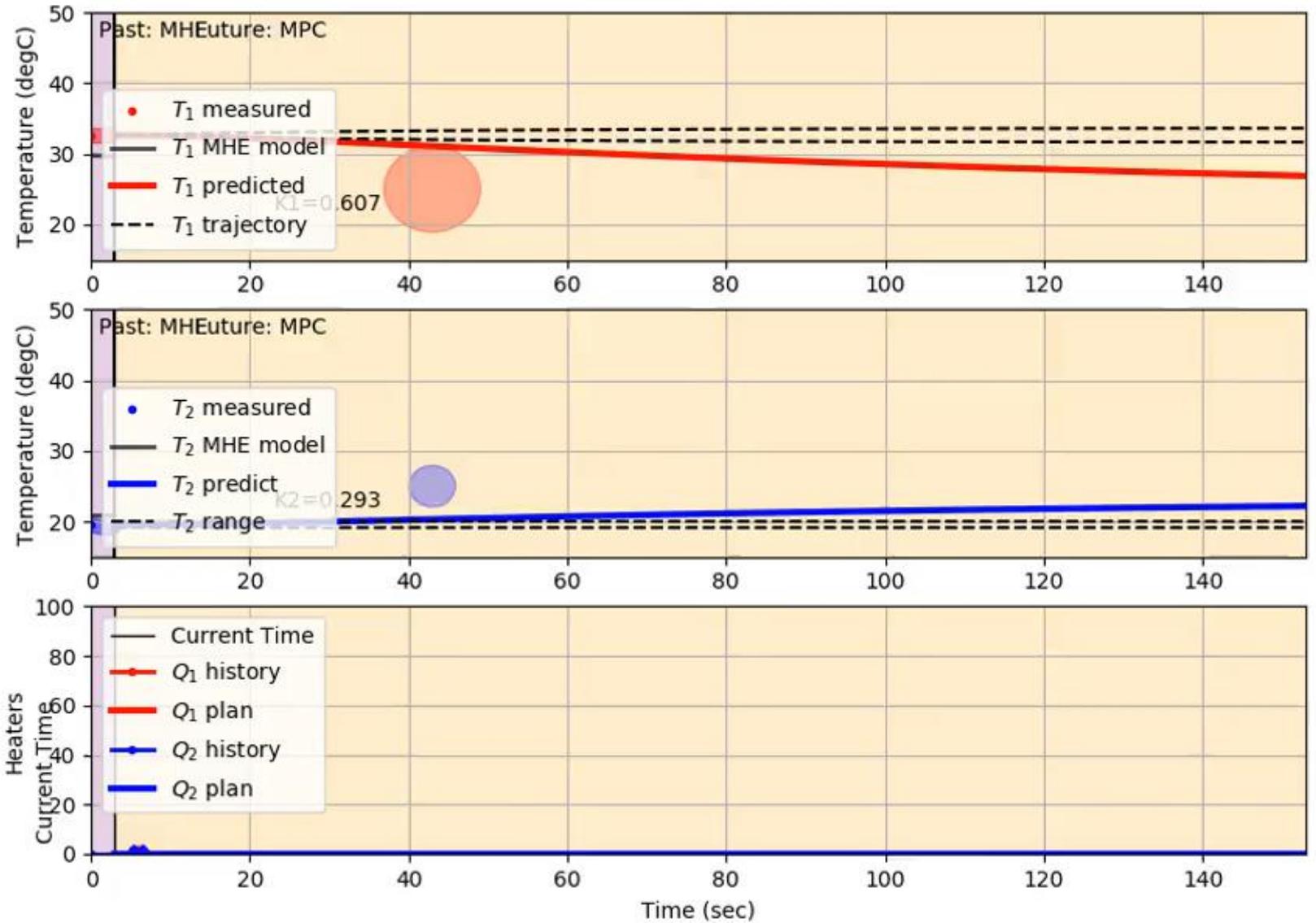
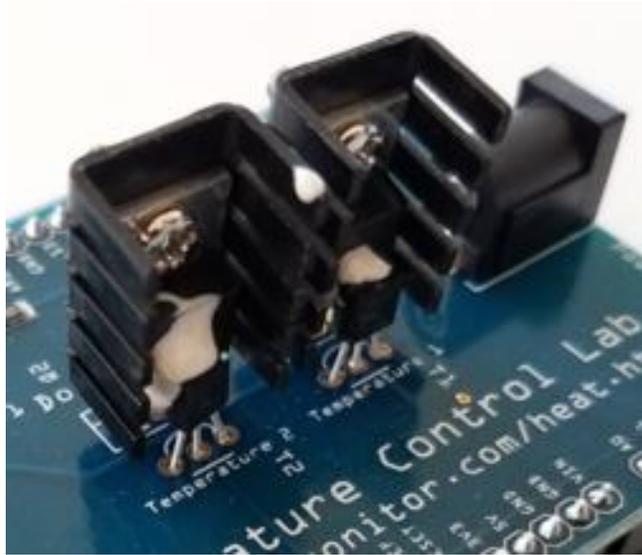
TCLab

Temp 1

Temp 2







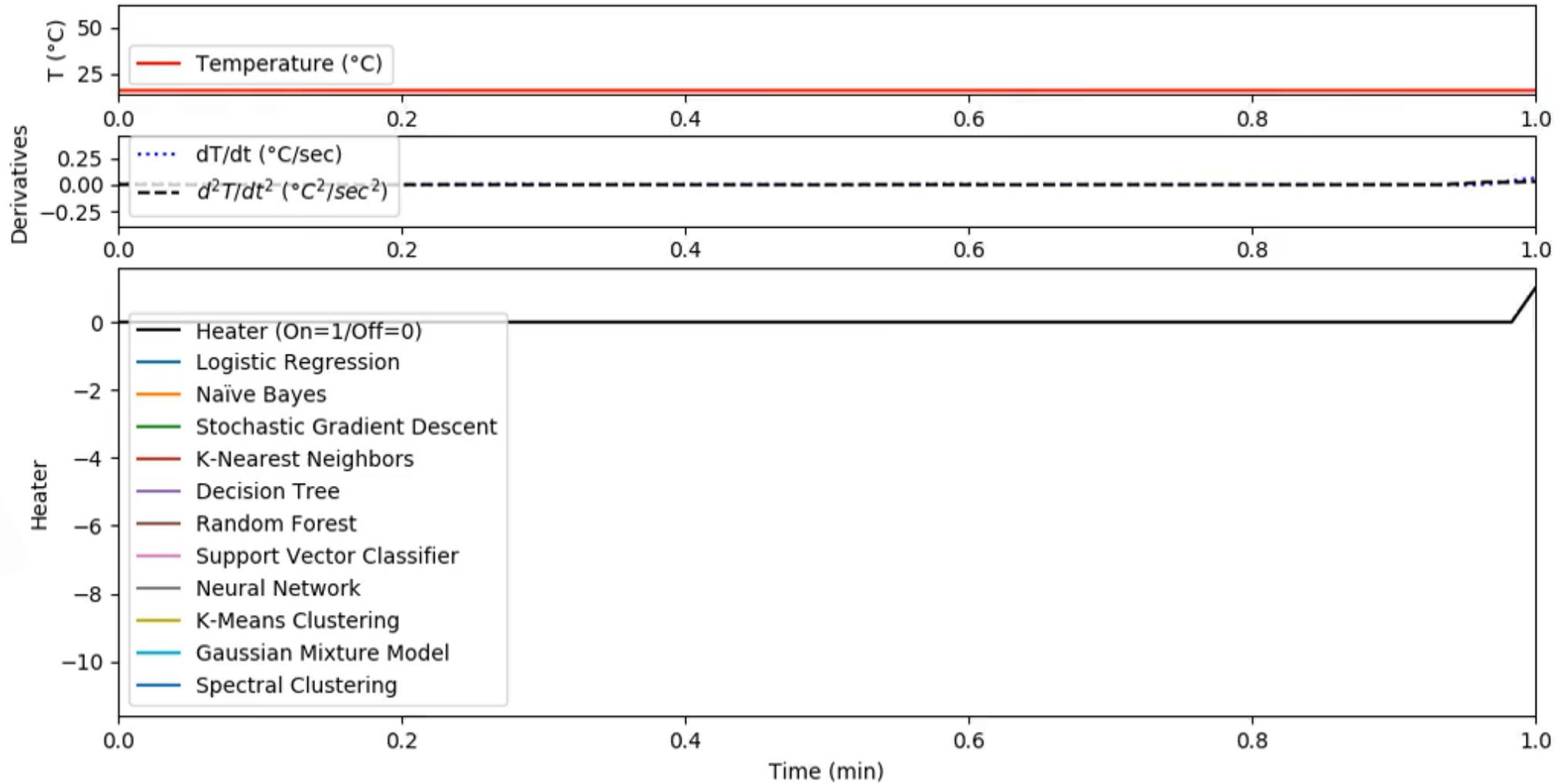


English

[https://github.com/APMonitor/data\\_science](https://github.com/APMonitor/data_science)

Spanish

[https://github.com/APMonitor/ciencia\\_de\\_datos](https://github.com/APMonitor/ciencia_de_datos)



# TCLab for Instructor Evaluation

- Send email to [john.hedengren@byu.edu](mailto:john.hedengren@byu.edu)
  - Name
  - Shipping Address
  - Course Information
- Arrives in 2-3 business days (US)
- Arrives in 6-20 business days (International)
- Student lab kits on Amazon
  - <https://amzn.to/2FopcMp>



## Temperature Control Lab

Brand: TCLab

★★★★☆ 27 ratings | 4 answered questions

Price: \$35.00 & FREE Returns

Get \$50 off instantly: Pay \$0.00 \$35.00 upon approval for the Amazon Rewards Visa Card. No annual fee.

- Arduino Leonardo, cables, and power supply included

Compare with similar items

New (2) from \$35.00 & FREE Shipping.

\$35.00

& FREE Returns

FREE delivery: **Monday, Aug 23**

Details

Fastest delivery: **Friday, Aug 20**

Details

Select delivery location

In Stock.

Qty: 1

Add to Cart

Buy Now

Secure transaction

Ships from Amazon

Sold by Advanced Process Solu...

Details

Return policy: This item is returnable

Support: Free Amazon tech support included

# Community Teaching Resources

## CACHE Teaching Resources

## Resourcium.org

### Teaching Resources

Teaching resources for faculty are organized here mostly by courses. These resources include syllabi, schedules, computer-aided tools, interactive simulations, screencasts, concept questions, textbook information, useful links, and in some cases, complete course notes. Send suggestions and corrections to [cache@umass.edu](mailto:cache@umass.edu).

|                                                   |                                               |                                            |                                                   |
|---------------------------------------------------|-----------------------------------------------|--------------------------------------------|---------------------------------------------------|
| <a href="#">Intro to Chemical Engineering</a><br> | <a href="#">Material/Energy Balances</a><br>  | <a href="#">Fluid Mechanics</a><br>        | <a href="#">Heat Transfer</a><br>                 |
| <a href="#">Process Data Analytics</a><br>        | <a href="#">Engineering Mathematics</a><br>   | <a href="#">Thermodynamics</a><br>         | <a href="#">Kinetics/Reaction Engineering</a><br> |
| <a href="#">Separations/Mass Transfer</a><br>     | <a href="#">Materials/Polymer Science</a><br> | <a href="#">Process/Product Design</a><br> | <a href="#">Process Control</a><br>               |
| <a href="#">Molecular Modeling</a><br>            | <a href="#">Bioengineering</a><br>            | <a href="#">Safety</a><br>                 | <a href="#">Conventional/Renewable Energy</a><br> |
| <a href="#">Teaching Topics</a><br>               | <a href="#">Computer Programming</a><br>      |                                            |                                                   |



Home Explore Participate Sign Up/In



# RESOURCIUM

BETA

The Educational Resource Compendium

We're still in beta. Check out [Participate](#) to learn how you can help us improve.

Search

**What is Resourcium?** Resourcium is a collection of control and automation resources. Some resources are combined to create ordered lists that we call journeys. If you want to see all of the resources and journeys we have in the database just click the search button without typing anything in the search field. If you'd like to see the range of topics that we cover check out explore in the navigation menu.

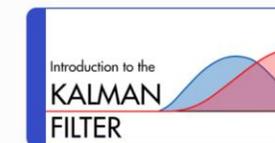
### Featured Journeys



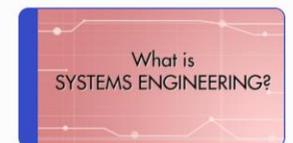
The Basics of the Nyquist Stability Criterion



PID Control - A Brief Introduction



Introduction to the Kalman Filter



What is Systems Engineering?

## Thanks to Collaborators

- Many collaborators have enabled this community resource
  - Melda Ulusoy @ MathWorks
  - Samvith Rao @ MathWorks
  - Aycan Hacioglu @ MathWorks
  - Abe Martin @ BYU, NAVAIR
  - Junho Park @ BYU
  - Colin Anderson @ BYU
  - Nathanael Nelson @ BYU
  - Jeff Kantor @ Notre Dame
  - Carl Sandrock @ Univ. of Pretoria, proquo ai
  - Paulo Moura Oliviera @ UTAD in Portugal
  - John Anthony Rossiter @ Univ. of Sheffield

# Additional Information

## References

- Moura Oliveira, P.B., Hedengren, J.D., Solteiro Pires, E.J., Swarm-Based design of Proportional Integral and Derivative Controllers using a Compromise Cost Function: An Arduino Temperature Laboratory Case Study, Special Issue: Algorithms for PID Controller, Algorithms, 13(12), 315, DOI: 10.3390/a13120315, 2020. [Article](#)
- Hedengren, J.D., Kantor, J., Computer Programming and Process Control Take-Home Lab, Computer Aids for Chemical Engineering (CACHE) News, Summer 2020. [Article](#)
- Moura Oliveira, P., Hedengren, J., Rossiter, J.A., Introducing Digital Controllers to Undergraduate Students Using the TCLab Arduino Kit, 21st IFAC World Congress, Berlin, Germany, July 12-17, 2020.
- Moura Oliveira, P., Hedengren, J., Boaventura, J., Bridging Theory to Practice: Feedforward and Cascade Control with TCLab Arduino Kit, 14th International Conference on Automatic Control and Soft Computing (CONTROLO), Bragança, Portugal, July 2020. [Proceedings](#)
- Park, J., Martin, R.A., Kelly, J.D., Hedengren, J.D., Benchmark Temperature Microcontroller for Process Dynamics and Control, Computers & Chemical Engineering, Special Issue in Honor of Thomas F. Edgar, 135, 6 April 2020. [Preprint](#) | [Article](#)
- Rossiter, J.A., Jones, B.L., Pope, S., Hedengren, J.D., Evaluation and Demonstration of Take-Home Laboratory Kit, Invited Session: Demonstration and poster session, 12th IFAC Symposium on Advances in Control Education, July 7-9, 2019, 52 (9), pp. 56-61, Philadelphia, PA, USA. [Preprint](#)
- Hedengren, J.D., Martin, R.A., Kantor, J.C., Reuel, N., Temperature Control Lab for Dynamics and Control, AIChE Annual Meeting, Orlando, FL, Nov 2019. [Abstract](#)
- Moura Oliveira, P., Hedengren, J.D., An APMonitor Temperature Lab PID Control Experiment for Undergraduate Students, 24th IEEE Conference on Emerging Technologies and Factory Automation (ETFA), Sep 10th - 13th, 2019, pp. 790-797, Zaragoza, Spain. [Preprint Paper](#)
- Park, J., Patterson, C., Kelly, J., Hedengren, J.D., Closed-Loop PID Re-Tuning in a Digital Twin By Re-Playing Past Setpoint and Load Disturbance Data, AIChE Spring Meeting, New Orleans, LA, April 2019.

## Questions and Discussion

