A learner-centered approach to teaching computational modeling, data analysis, and programming

Devin W. Silvia
Director of Undergraduate Studies, CMSE at MSU

ProDaBi Colloquium
January 24, 2024

MICHIGAN STATE DATA SCIENCE

MICHIGAN STATE UNIVERSITY
CMSE

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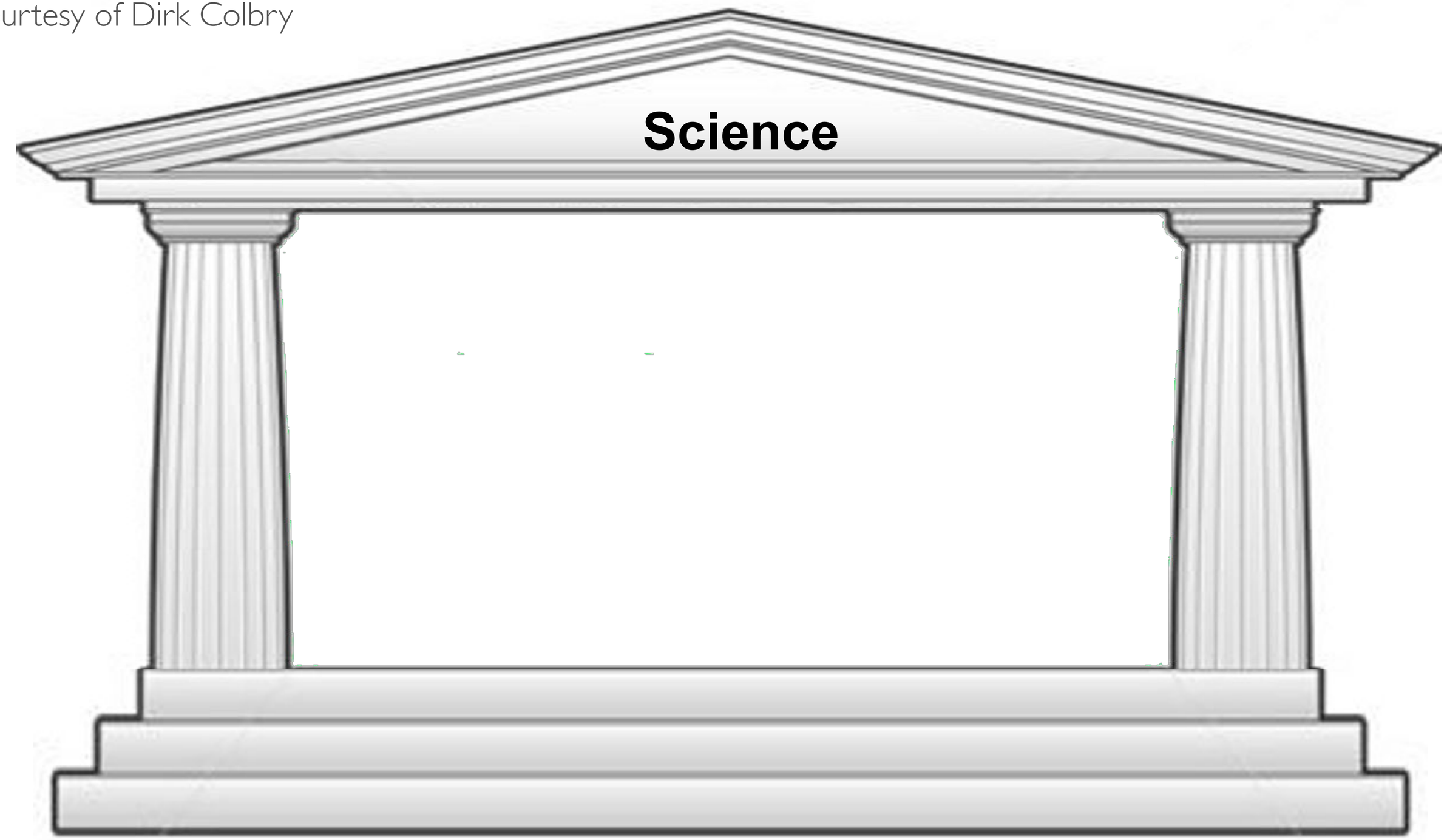
Courtesy of Dirk Colbry



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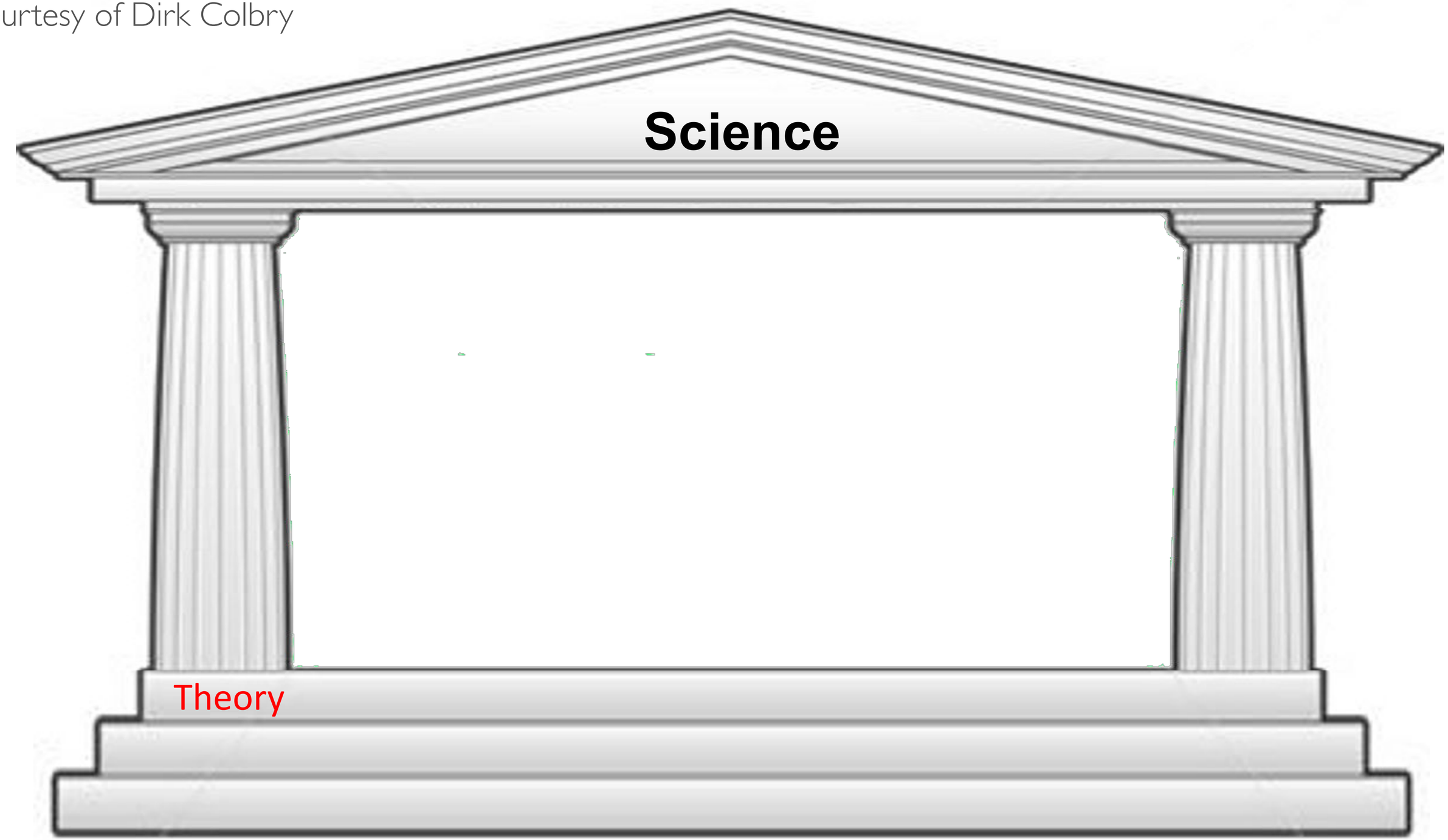

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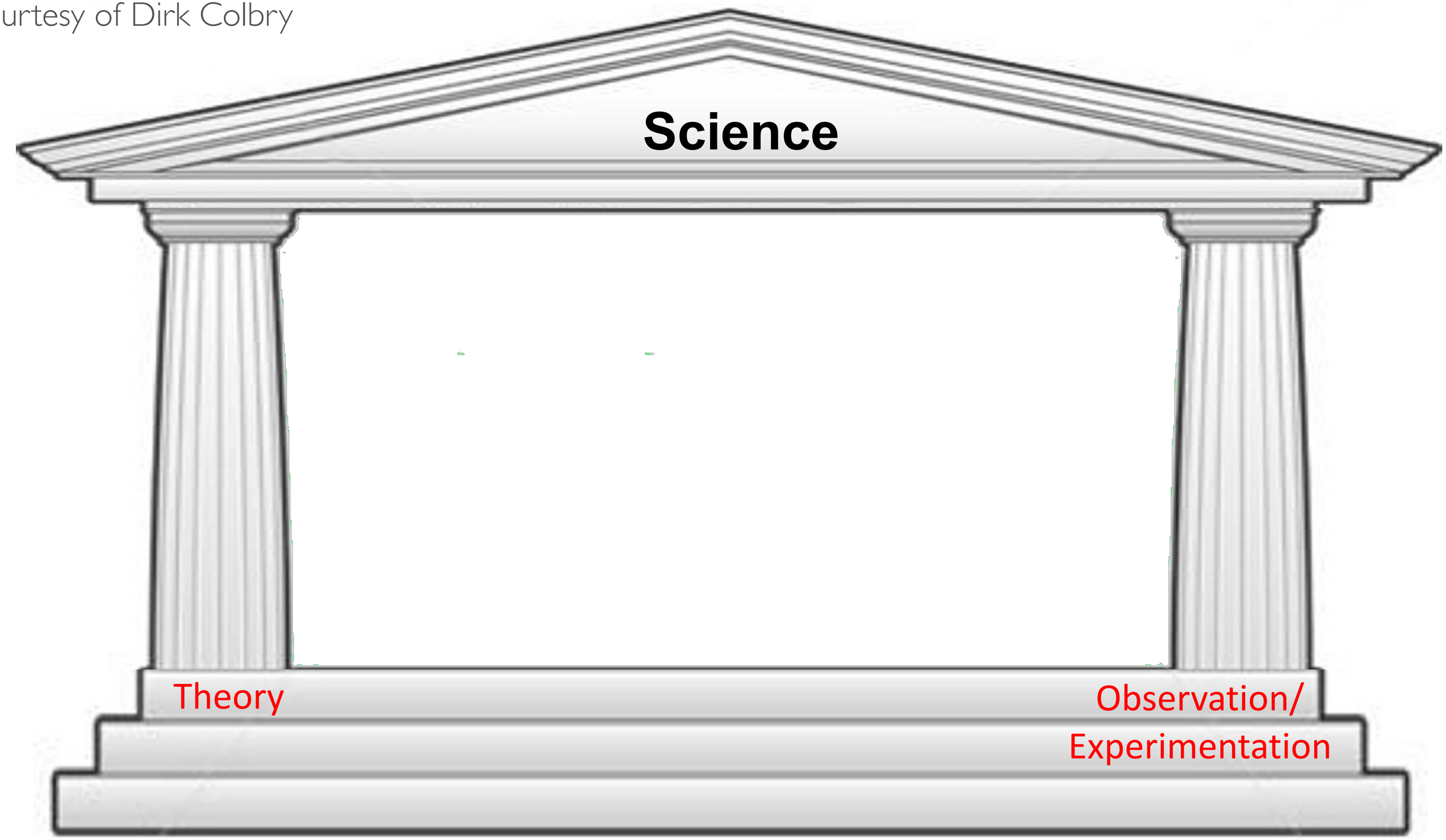

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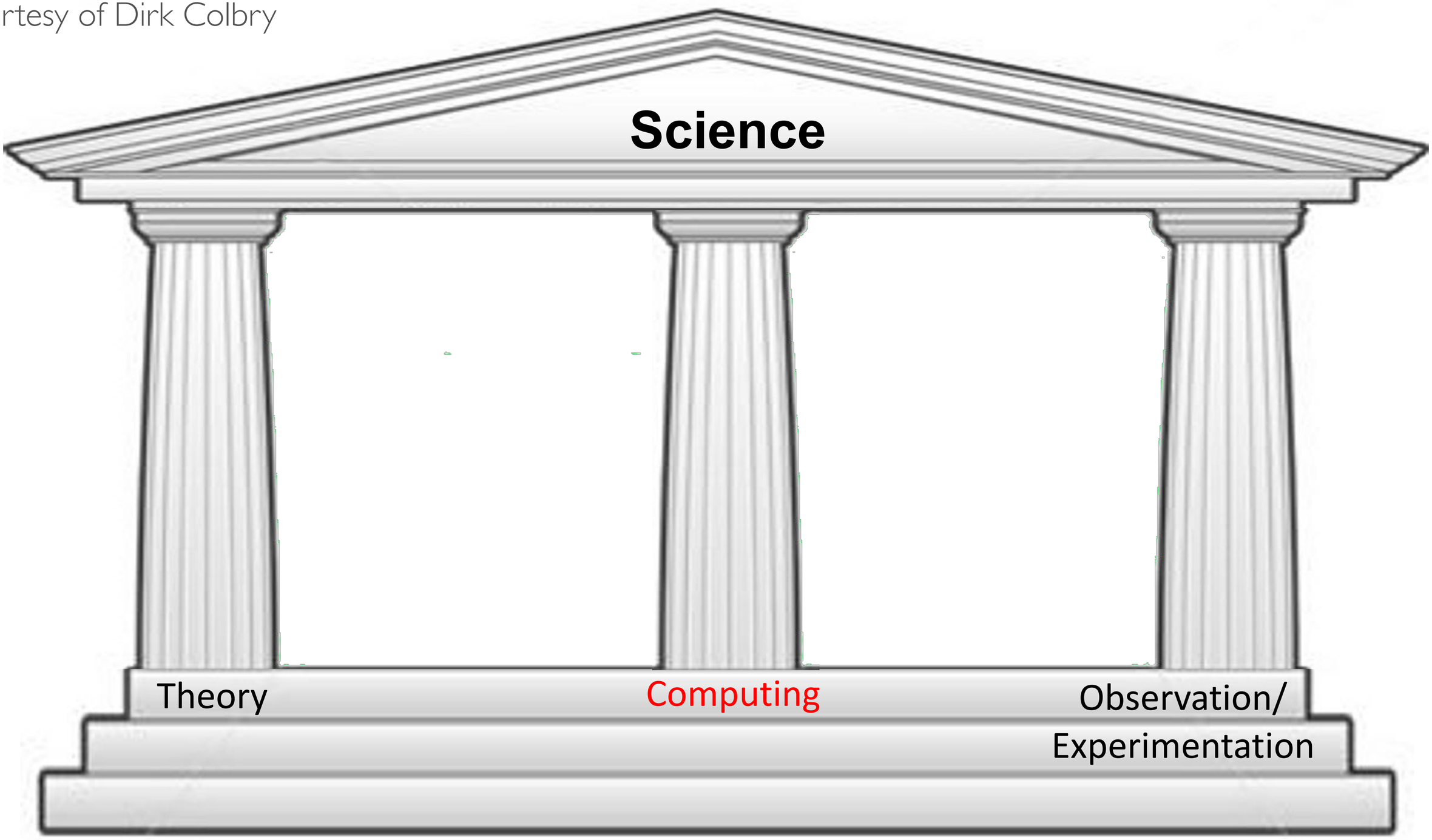

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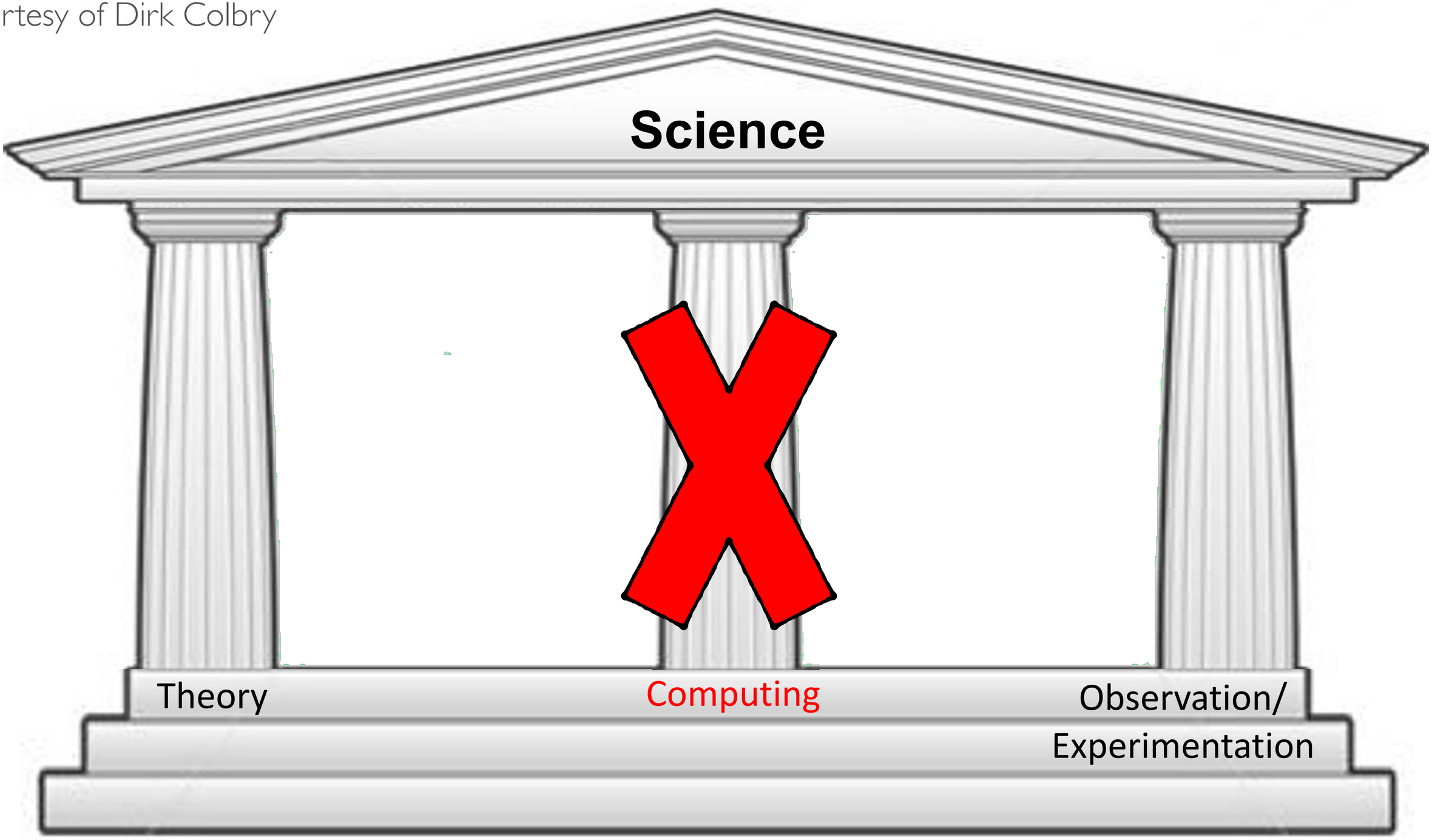

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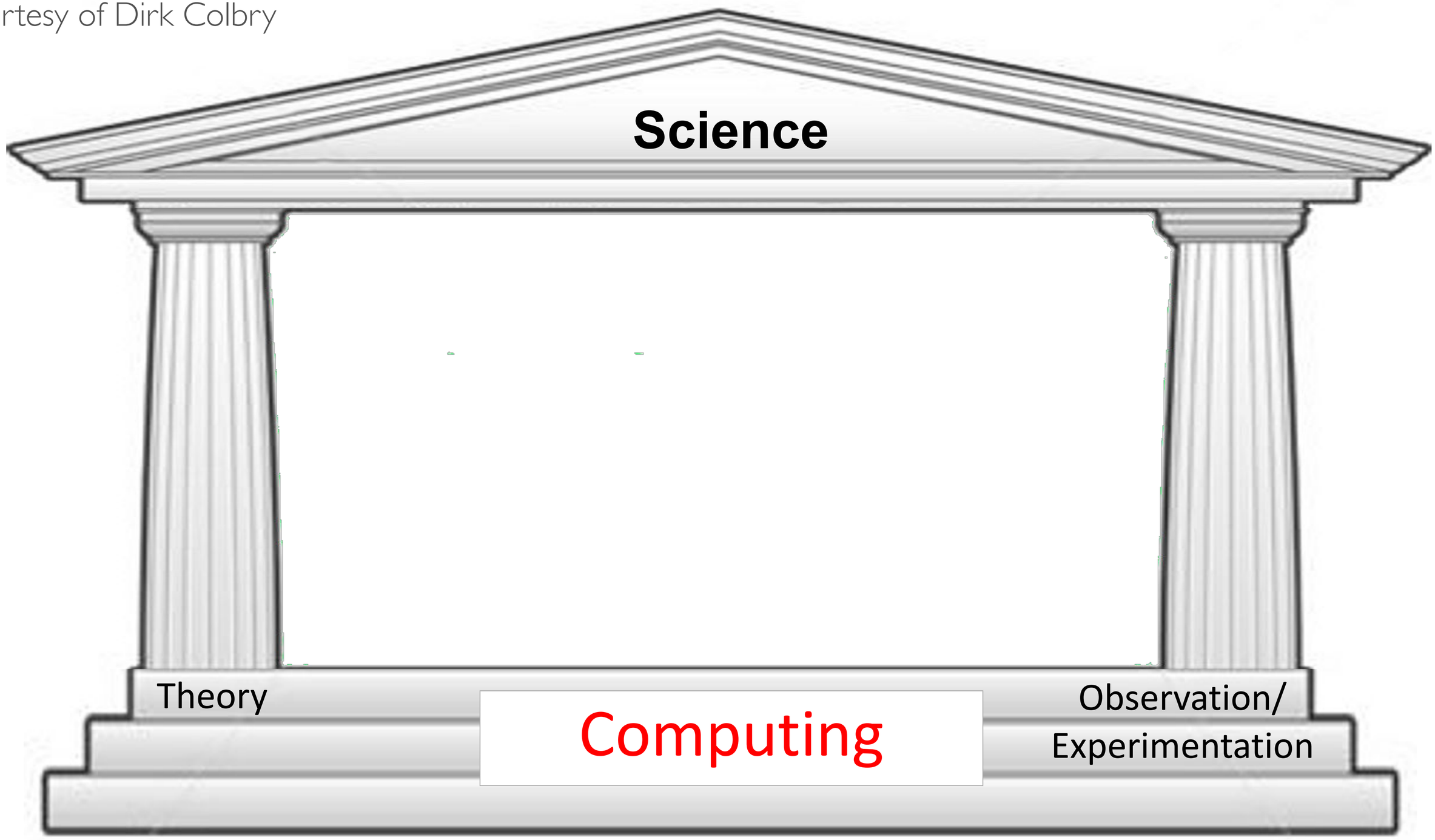

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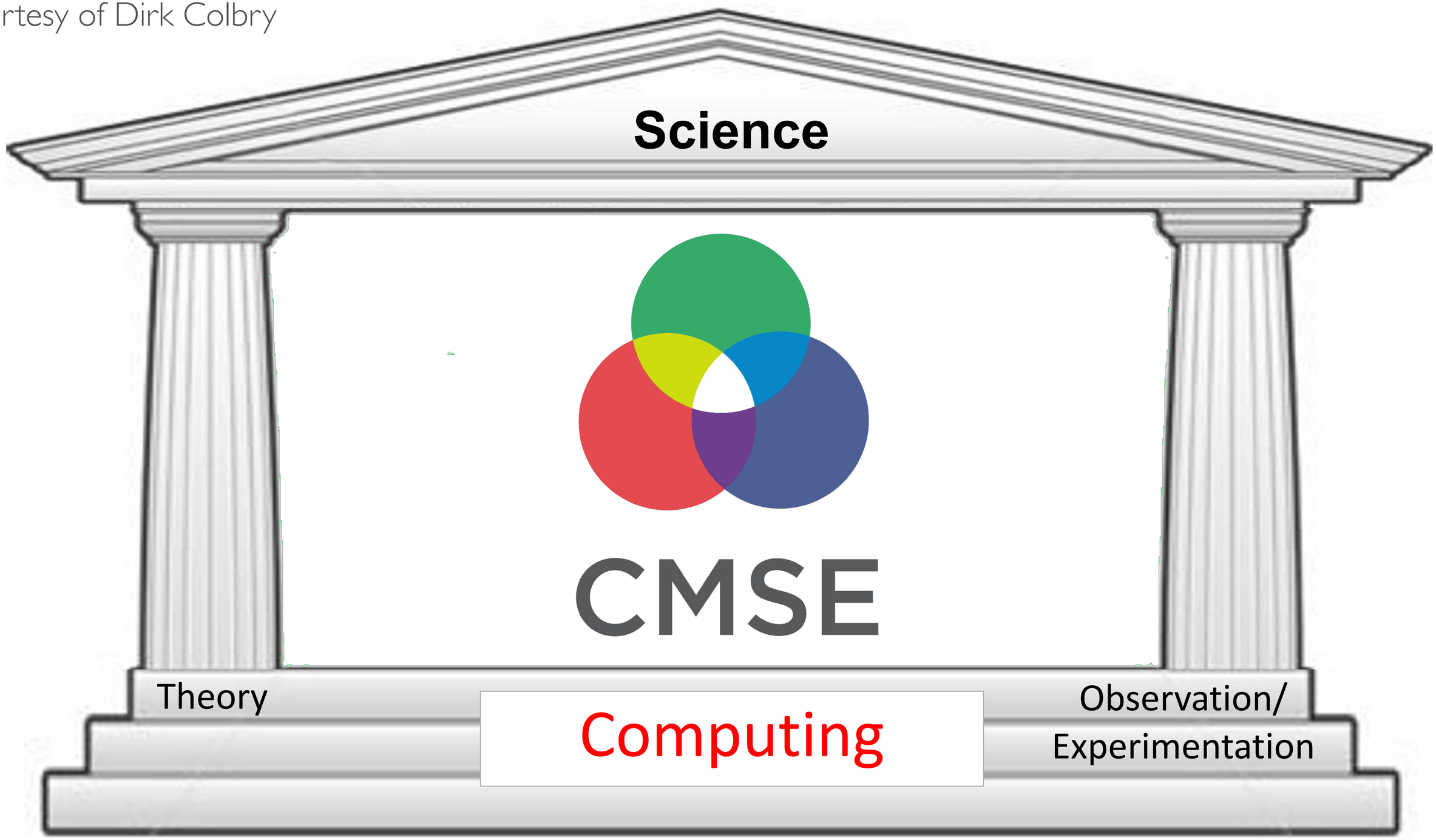


What is CMSE?

CMSE

The Department of Computational Mathematics, Science, and Engineering

What is CMSE?

College of Engineering

College of Natural Science

CMSE

The Department of Computational Mathematics, Science, and Engineering

Why CMSE?

College of Engineering

College of Natural Science

CMSE

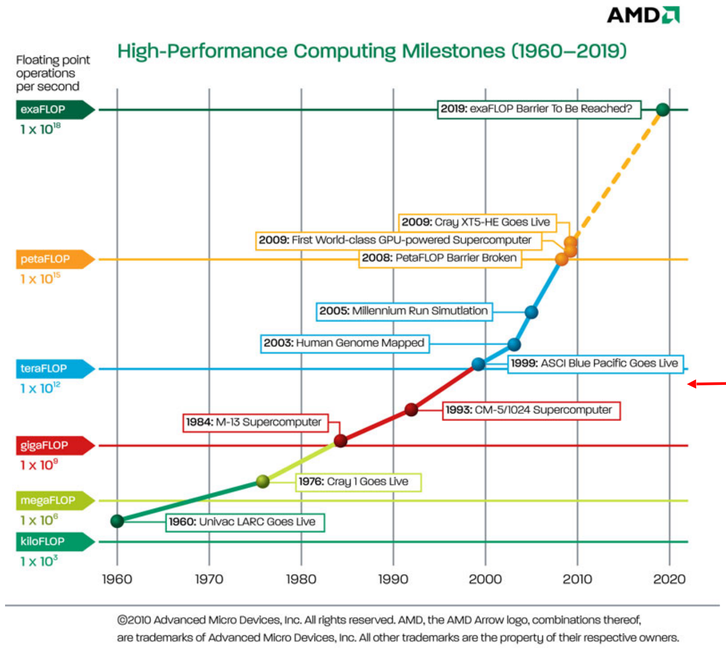
The Department of Computational Mathematics, Science, and Engineering

CMSE: Why?

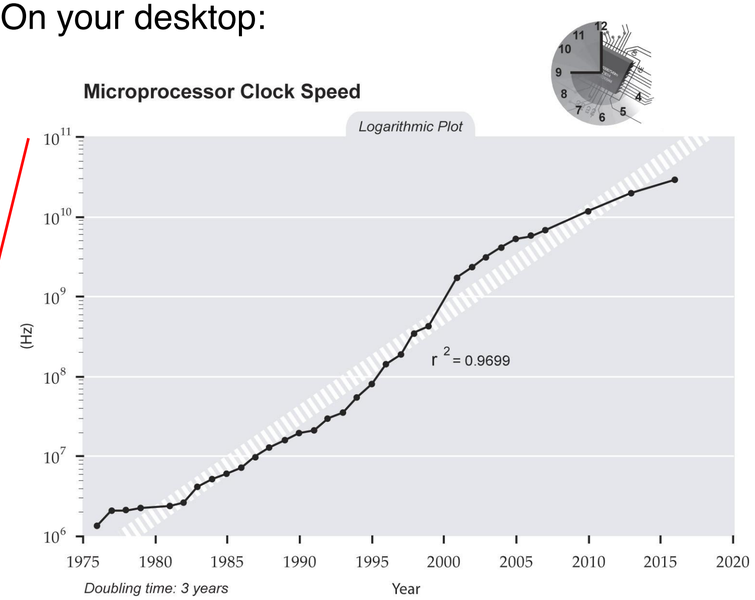
Courtesy of Andrew Christlieb

The world is changing, and MSU needs to change with it.

Create a home for scientists who lead scientific discovery through the develop and use computational tools to solve the worlds most challenging problems.



On your desktop:

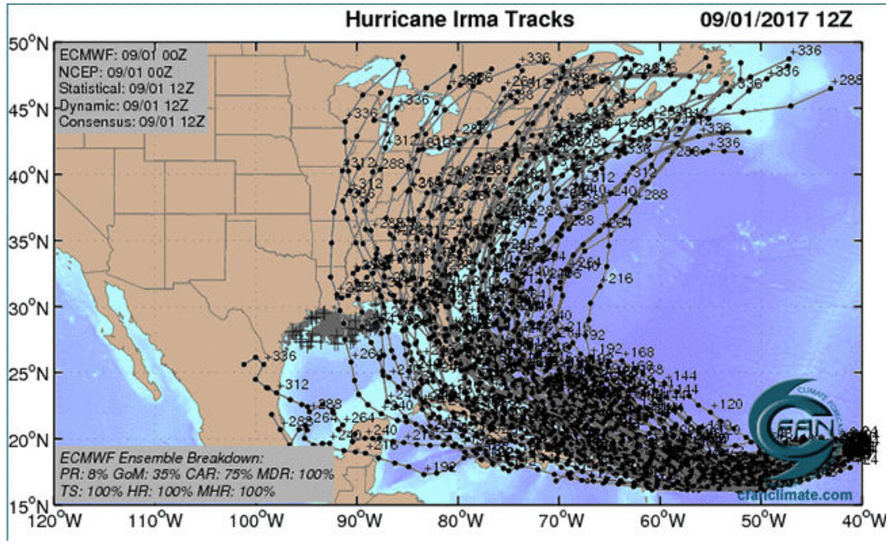


CMSE: Why?

Courtesy of Andrew Christlieb

The world is changing, and MSU needs to change with it.

Advanced **algorithms** are changing the way we predict and control our world.



CMSE: Why?

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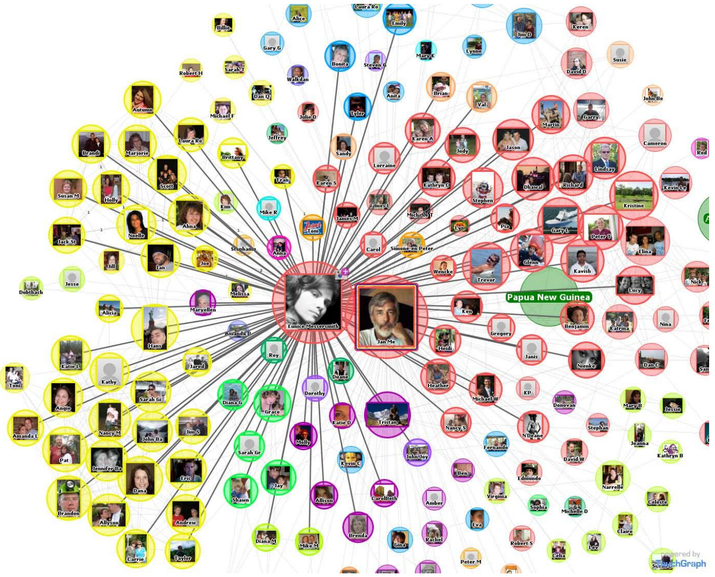
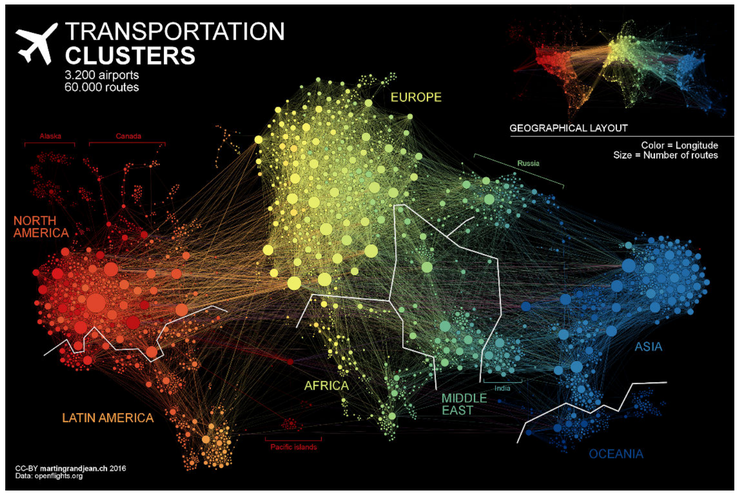
Data is be generated at unprecedented rates from unprecedented sources with unprecedented uses.



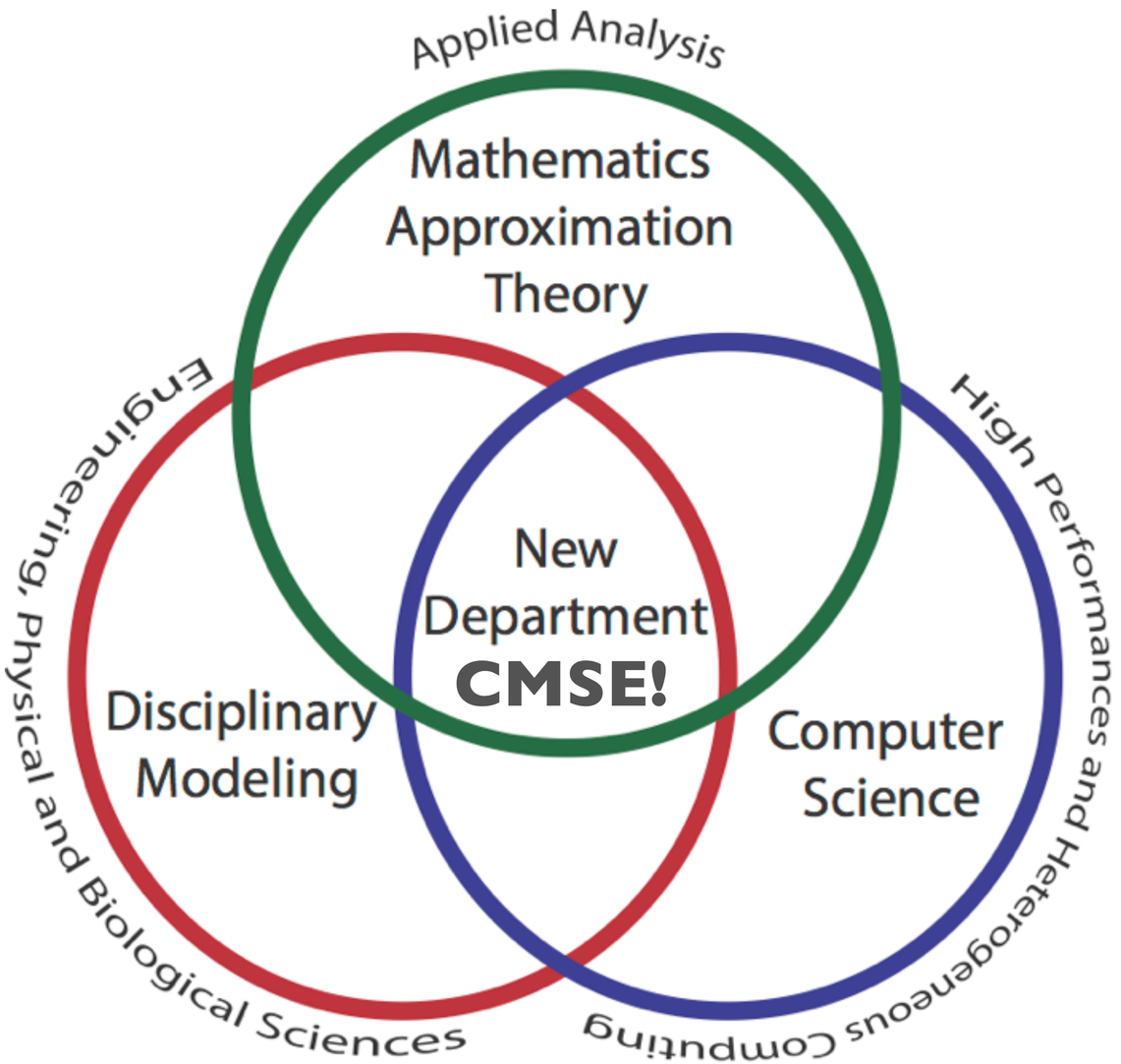


And thus: CMSE

Courtesy of Andrew Christlieb

Computational science: using computers to analyze and solve scientific and engineering problems.

Knock down silos



CMSE vs Computer Science?

Courtesy of Andrew Christlieb

- Computer Science focuses on the science of computing
- CMSE focuses on computing to do science

What about CMSE education?

CMSE

The Department of Computational Mathematics, Science, and Engineering

The challenge:

Teach computation in an applied way *outside* of a traditional computer science classroom

The challenge:

Teach computation in an applied way *outside* of a traditional computer science classroom

The solution(?):

CMSE 201

"Introduction to Computational Modeling and Data Analysis"*

(now called "Computational Modeling and Data Analysis I")

*Silvia et al. 2019

ICCS 2019 Conference Proceedings

CMSE 201 Learning Goals

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4. Manipulate, analyze, and visualize datasets and use to evaluate models.
5. Understand basic numerical methods and use them to solve problems.
6. Synthesize results from a scientific computing problem and present it both verbally and in writing.

How do we achieve these with the learner in mind?

Principles from "How Learning Works" (Ambrose et al. 2010)

- To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned.
- How students organize knowledge influences how they learn and apply what they know.
- Goal-directed practice coupled with targeted feedback enhances the quality of students' learning.
- Students' motivation determines, directs, and sustains what they do to learn.
- To become self-directed learners, students must learn to monitor and adjust their approaches to learning.

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Integrated progression

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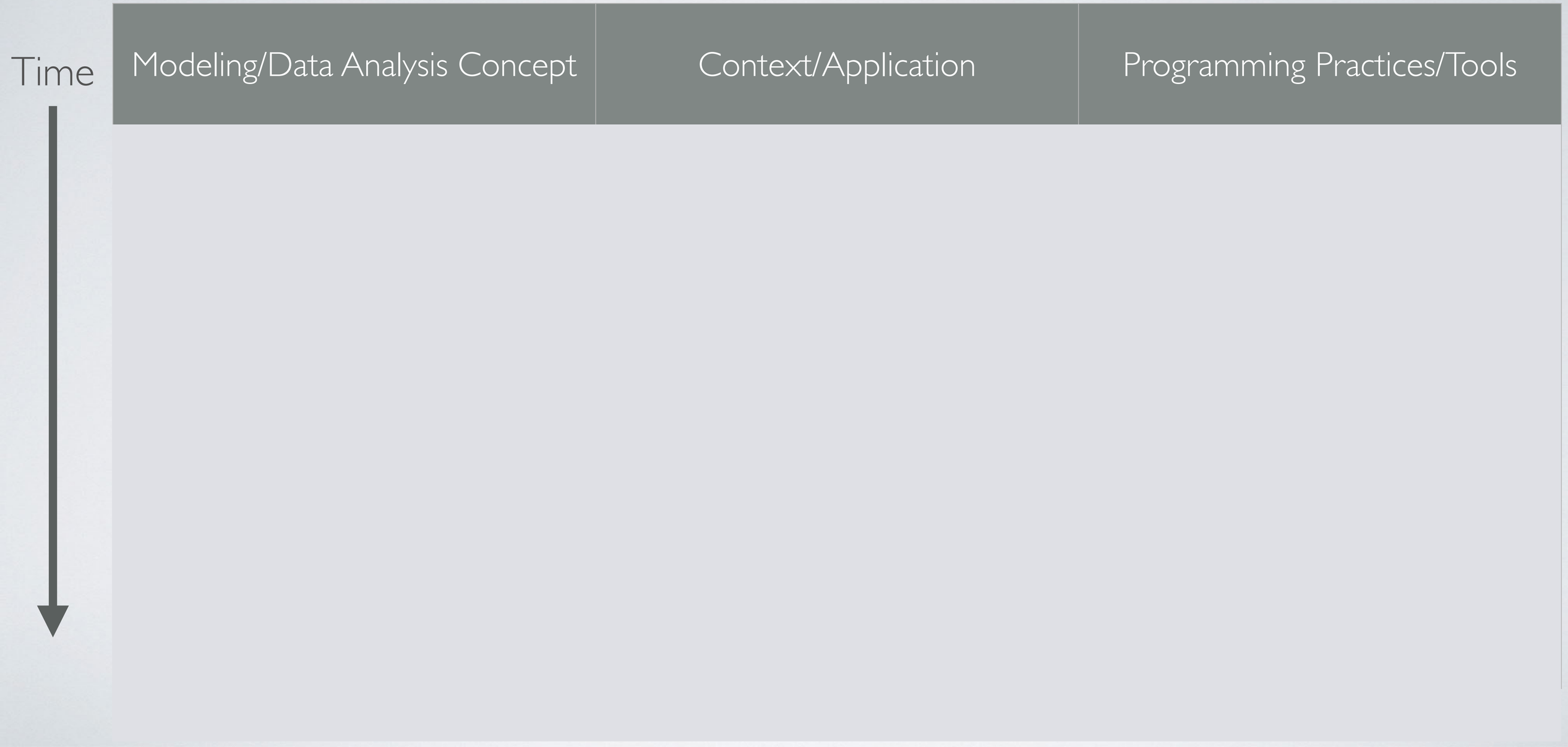

Integrated progression

Time

Modeling/Data Analysis Concept	Context/Application	Programming Practices/Tools
Order of magnitude estimation	Varied (e.g. estimating population)	Variable definiton, simple math
Mathematical representations of physical systems	Kinematics, projectile motion	Defining lists, writing loops
Evaluating the state of physical systems	Kinematics, projectile motion	Boolean logic/conditional statements, functions
Computing costs and optimizing solutions	Designing a ride share service	Functions, Python modules (e.g. matplotlib)
Visualizing models	Projectile motion and population growth	NumPy
Manipulating and visualizing data	Waters levels of the Great Lakes	Loading/reading data files, making plots

and so on…

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How do we implement this?

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Computational platform: Jupyter Notebooks

Course format: flipped classroom + active, collaborative learning

Basic Numerical Integration: the Trapezoid Rule

A simple illustration of the trapezoid rule for definite integration:

$$\int_a^b f(x)\,dx \approx \frac{1}{2}\sum_{k=1}^{N}\left(x_k - x_{k-1}\right)\left(f(x_k) + f(x_{k-1})\right).$$

First, we define a simple function and sample it between 0 and 10 at 200 points

In [1]:
```
%matplotlib inline
import numpy as np
import matplotlib.pyplot as plt
```

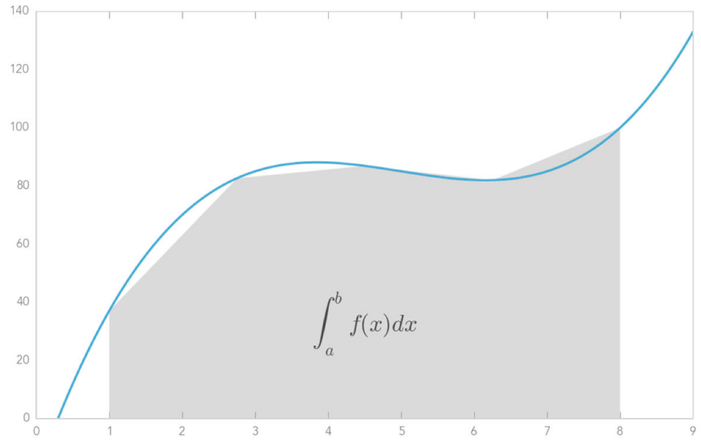
In [2]:
```
def f(x):
    return (x-3)*(x-5)*(x-7)+85

x = np.linspace(0, 10, 200)
y = f(x)
```

Choose a region to integrate over and take only a few points in that region

In [3]:
```
a, b = 1, 8 # the left and right boundaries
N = 5 # the number of points
xint = np.linspace(a, b, N)
yint = f(xint)
```

Plot both the function and the area below it in the trapezoid approximation

In [4]:
```
plt.plot(x, y, lw=2)
plt.axis([0, 9, 0, 140])
plt.fill_between(xint, 0, yint, facecolor='gray', alpha=0.4)
plt.text(0.5 * (a + b), 30,r"$\int_a^b f(x)dx$", horizontalalignment='center', fontsize=20);
```



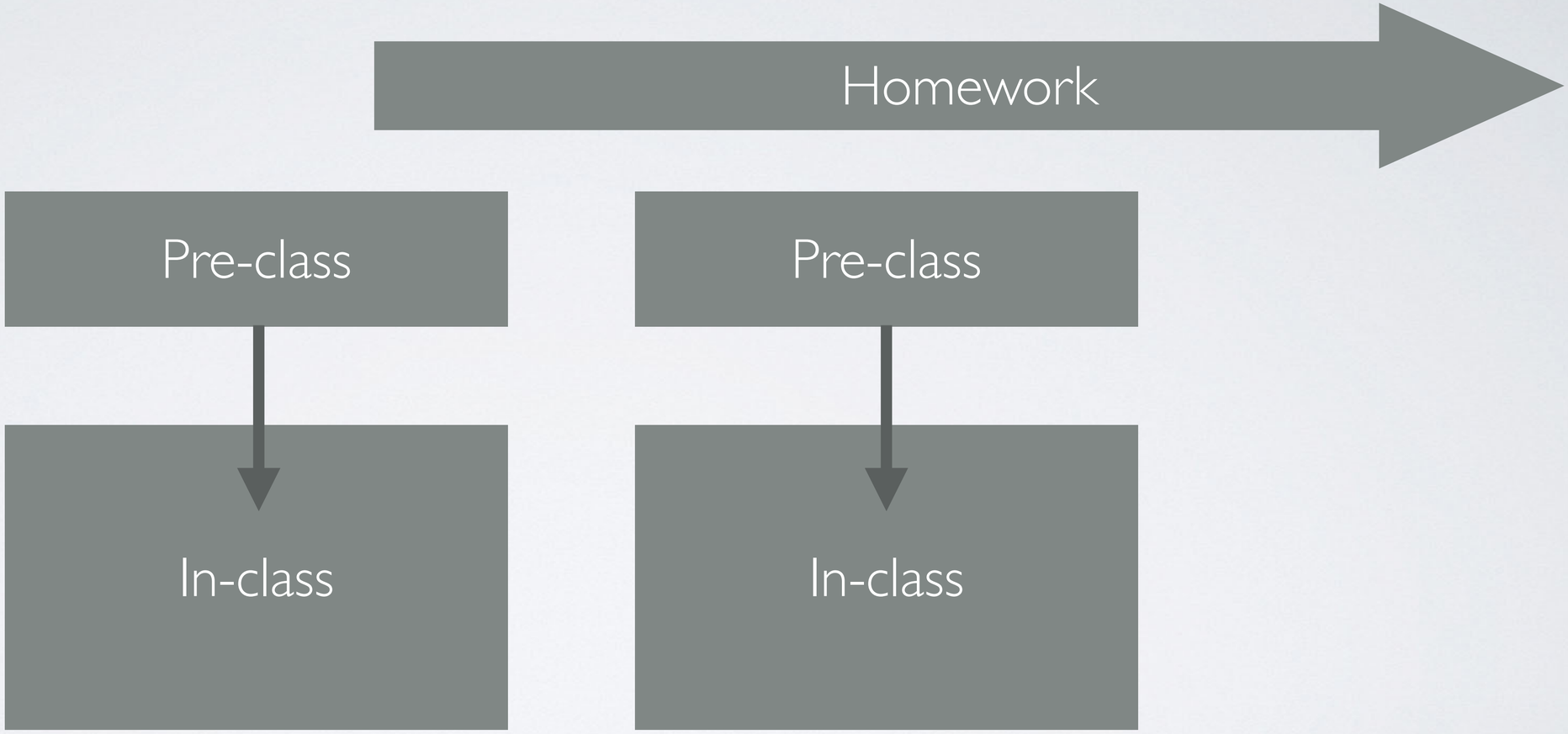
Compute the integral both at high accuracy and with the trapezoid approximation

Markdown + LaTeX

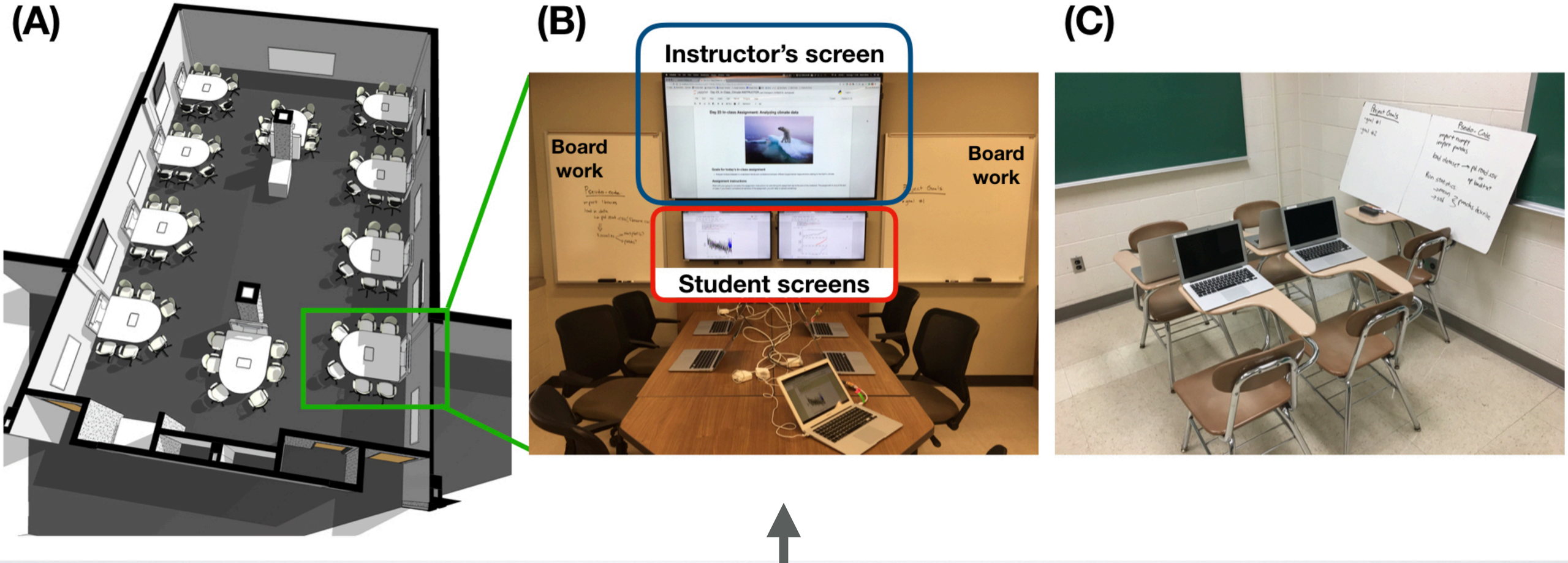
Python

Inline Plots

A typical week in our flipped classroom



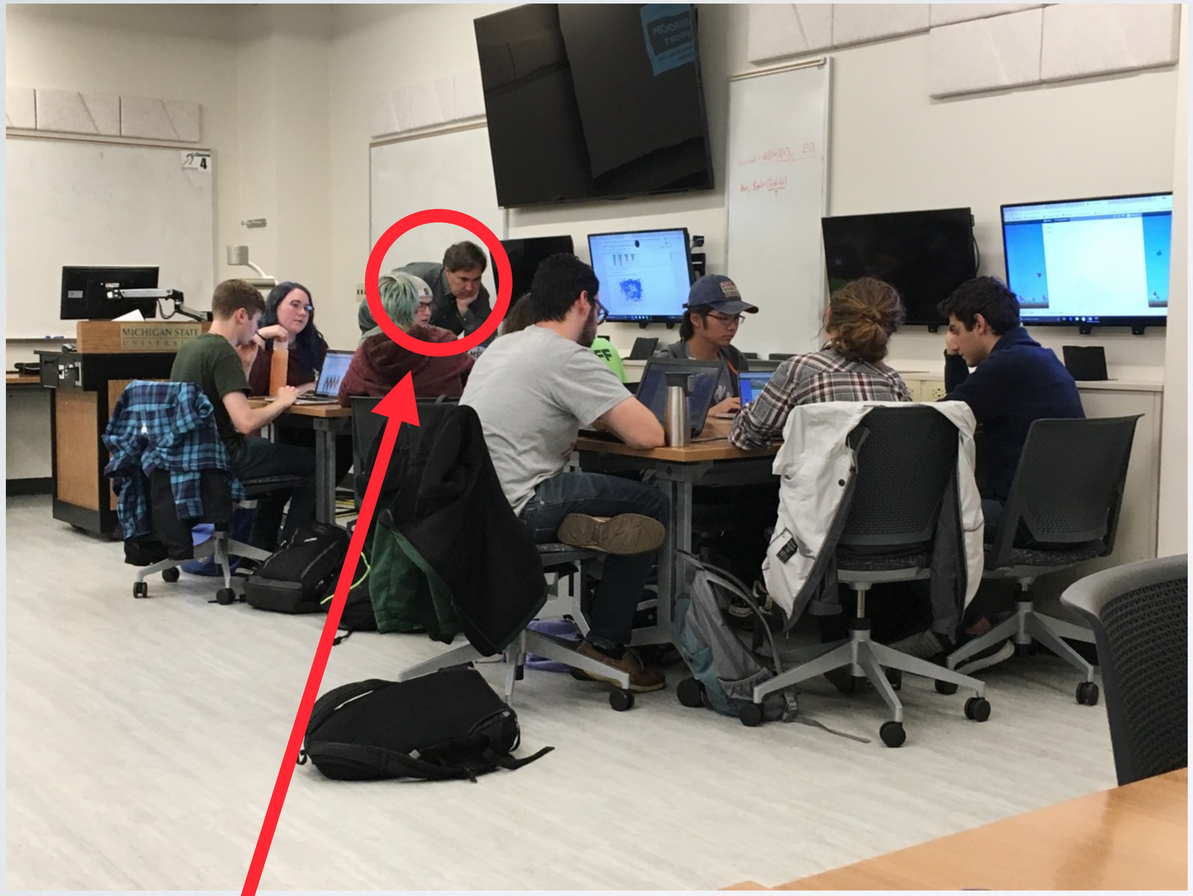
Classroom Environment



MSU "Room for Engaged and Active Learning" (REAL) classroom

Classroom Environment

Classroom Environment



Instructor! (currently maintaining a 16:1 ratio w/LAs and TAs)

Eye on the prize!

Can they independently choose, design, and implement a project all on their own and communicate the results?

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Can they independently choose, design, and implement a project all on their own and communicate the results?

“Semester projects”
(aka Computational Essays)

CMSE 201 Final Project

✅ [redacted]

✅ **Section_002**

✅ **4/18/2019**

Analyzing Flu & Pneumonia Related Deaths

Background and Motivation

Within the last century, mankind has seen a lot of improvements made in medical technologies and their availability to the general public. As a result, I am interested in whether or not these advancements have resulted in any significant reduction in deaths relating to the flu and pneumonia: two ailments that have caused countless deaths in human history. The resulting questions that I have are "what trend does the death rate of flu & pneumonia vs. time follow, if any?", and "How will death rate look within the the next decade or so given a trend?".

Methodology

Below are the modules that I will be utilizing for my project.

In [1]:
```
import matplotlib.pyplot as plt
%matplotlib inline
import numpy as np
import pandas as pd
from scipy.optimize import curve_fit
from pandas.plotting import lag_plot
import seaborn as sns
```

The data that I will be analyzing is a comprehensive dataset regarding the most prevalent causes of death in the United States (with each and every state as well as nationwide) and the numbers pertaining to it. It was obtained by the National Center of Health and Statistics and was published by the Centers for Disease Control and Prevention. Here is the data below:

In [2]:
```
leading_deaths = pd.read_csv("NCHS_-_Leading_Causes_of_Death__United_States.csv")
leading_deaths.head()
```

Out[2]:

	Year	113 Cause Name	Cause Name	State	Deaths	Age-adjusted Death Rate
0	2016	Accidents (unintentional injuries) (V01-X59,Y8...	Unintentional injuries	Alabama	2755	55.5
1	2016	Accidents (unintentional injuries) (V01-X59,Y8...	Unintentional injuries	Alaska	439	63.1
2	2016	Accidents (unintentional injuries) (V01-X59,Y8...	Unintentional injuries	Arizona	4010	54.2
3	2016	Accidents (unintentional injuries) (V01-X59,Y8...	Unintentional injuries	Arkansas	1604	51.8

A research effort that evolved from these projects:

Exploring student experiences and indicators of epistemic agency

collaboration with Tor Odden at UiO

First paper: Odden, Silvia, and Malthe-Sørenssen 2023; JRST

Are students aware of when they take up agency in their projects?
How do they feel about this experience?

Challenges and lessons learned

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- Resource intensive

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- Scaling can be a difficult

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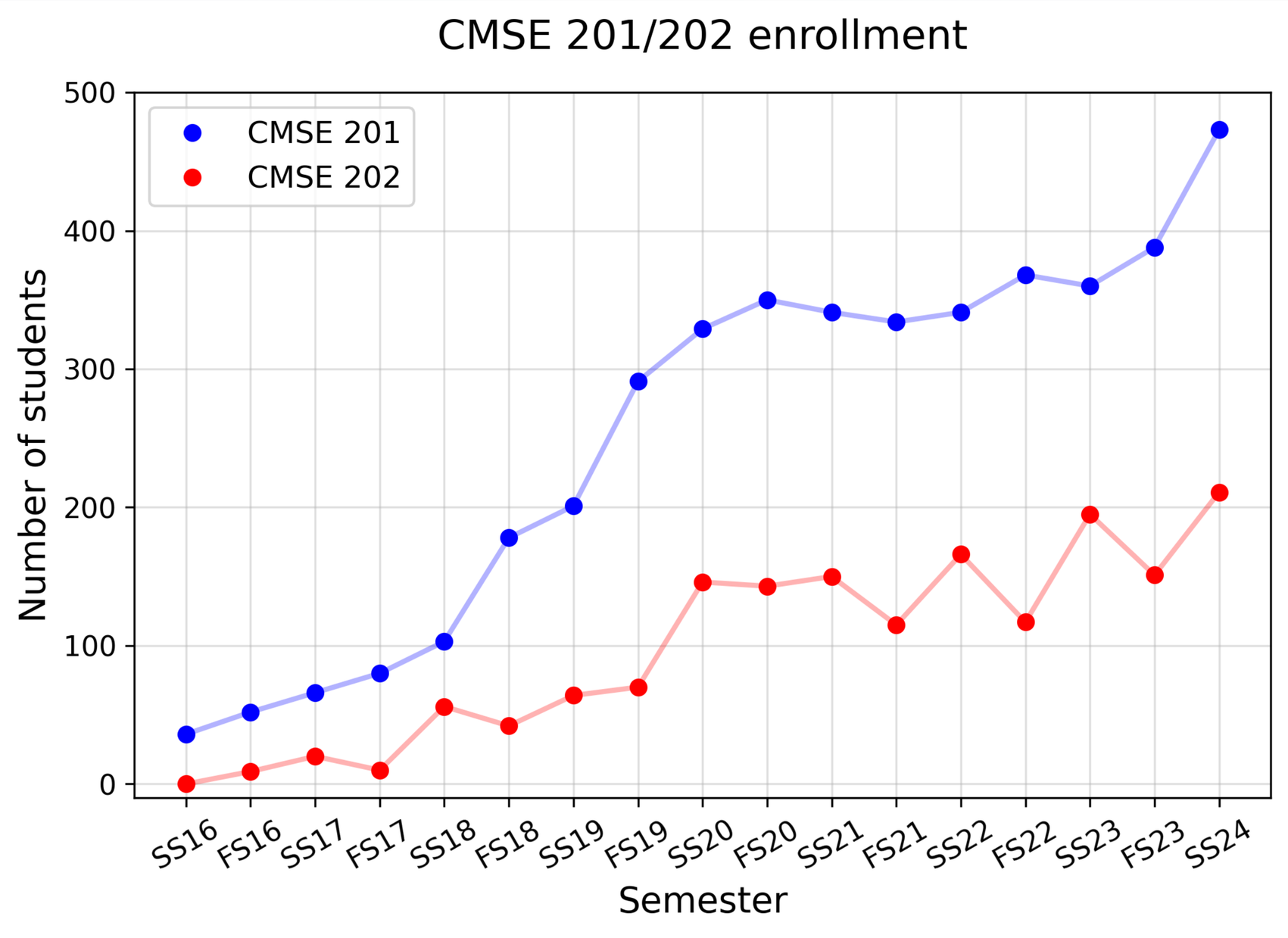
- Creating interdisciplinary content isn't easy

Challenges and lessons learned

- Resource intensive
- Scaling can be a difficult
- Creating interdisciplinary content isn't easy
- Demand grew rapidly and courses seem popular!

Lots of demand



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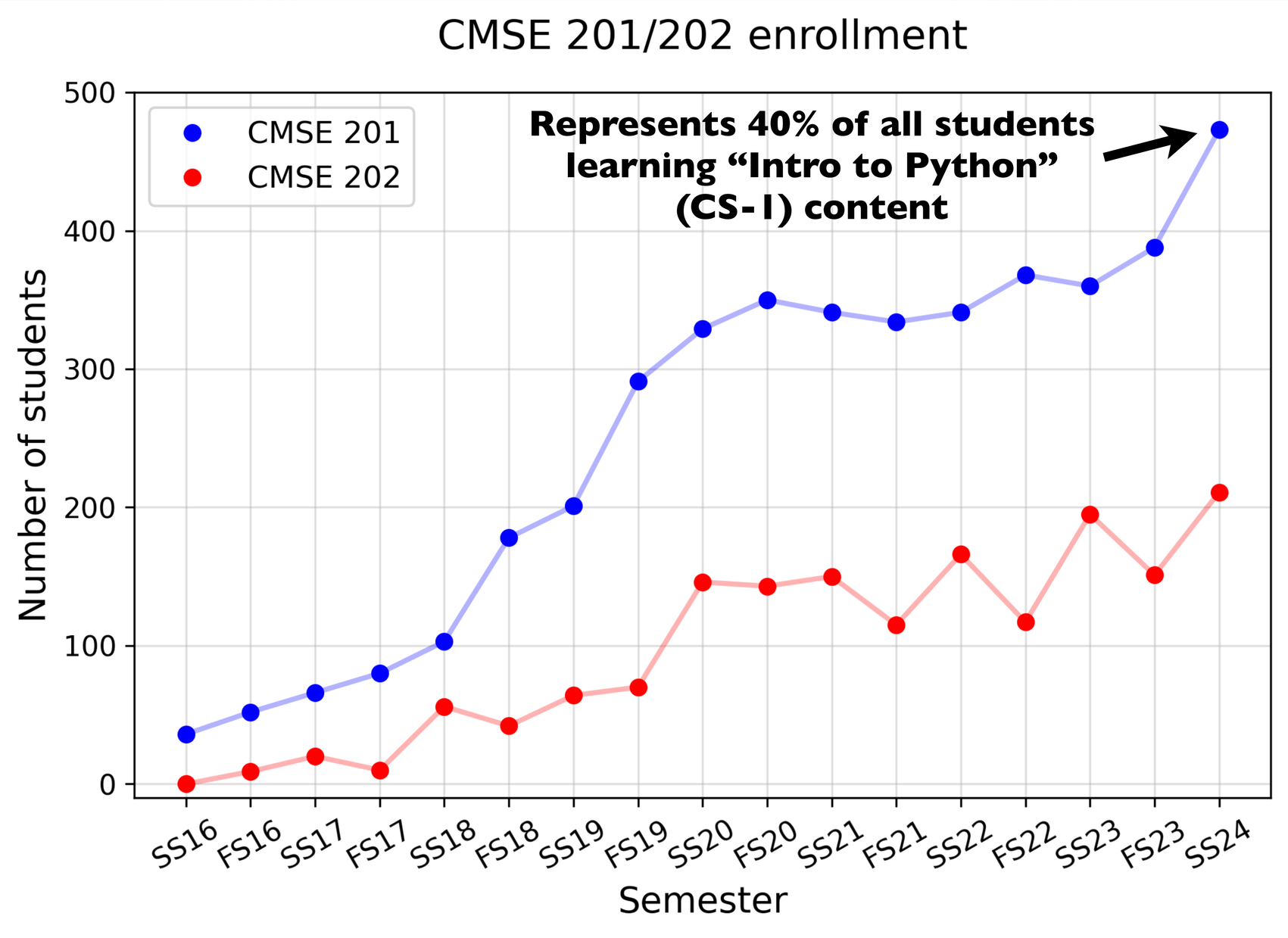

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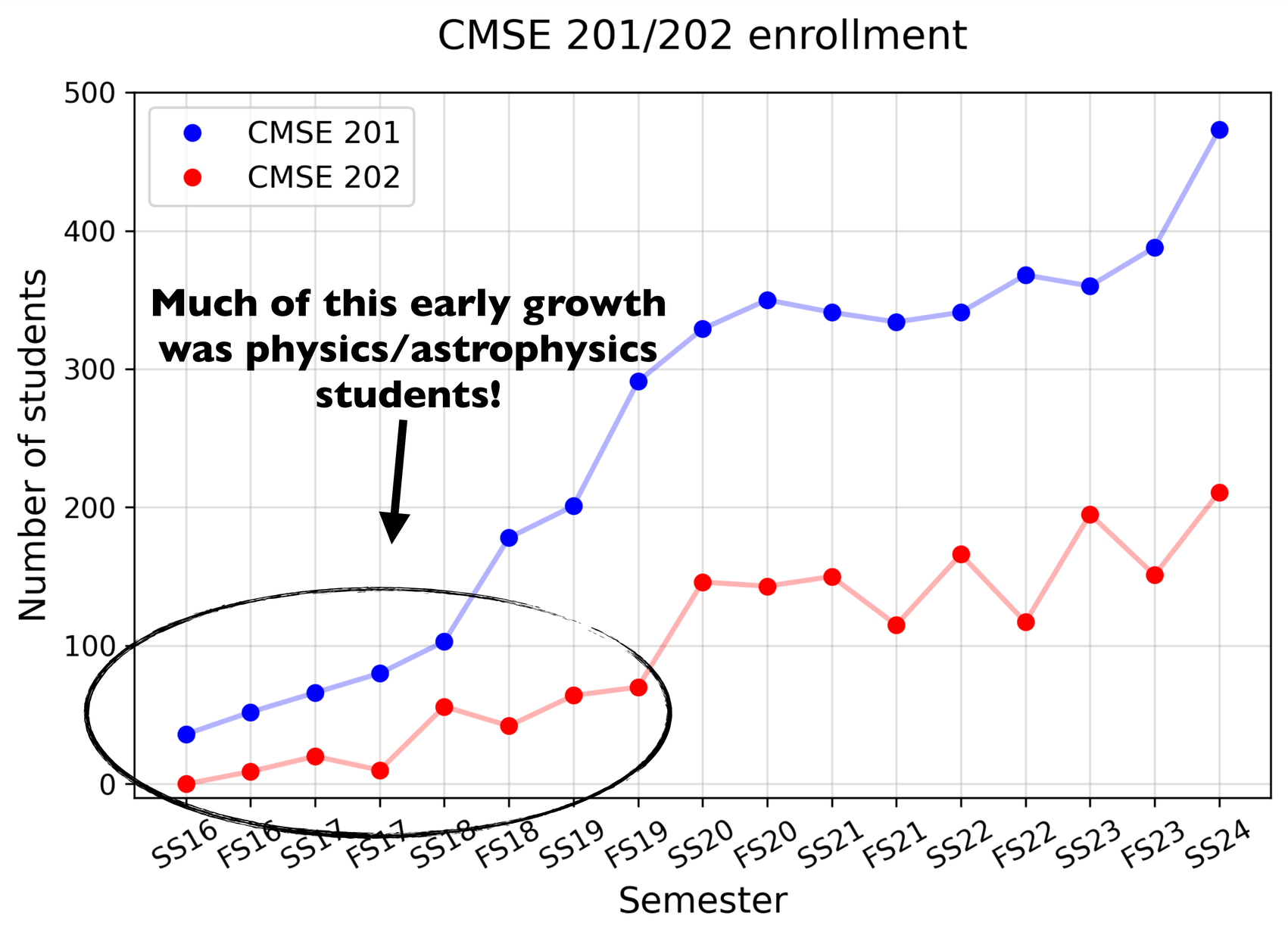

So what might the integration of computing in physics look like?

MICHIGAN STATE UNIVERSITY

Courtesy of Danny Caballero

Supporting the integration of computing in physics education

Michigan State University
17 Nov 22

Danny Caballero (he/him)
Department of Physics and Astronomy
Department of Computational Mathematics, Science, and Engineering
CREATE For STEM Institute

Courtesy of Danny Caballero

Open Questions

Courtesy of Danny Caballero

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- How do we support a broader cross-section of physics faculty to integrate computing?

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- What can physics departments do to support moves to integrate computing?

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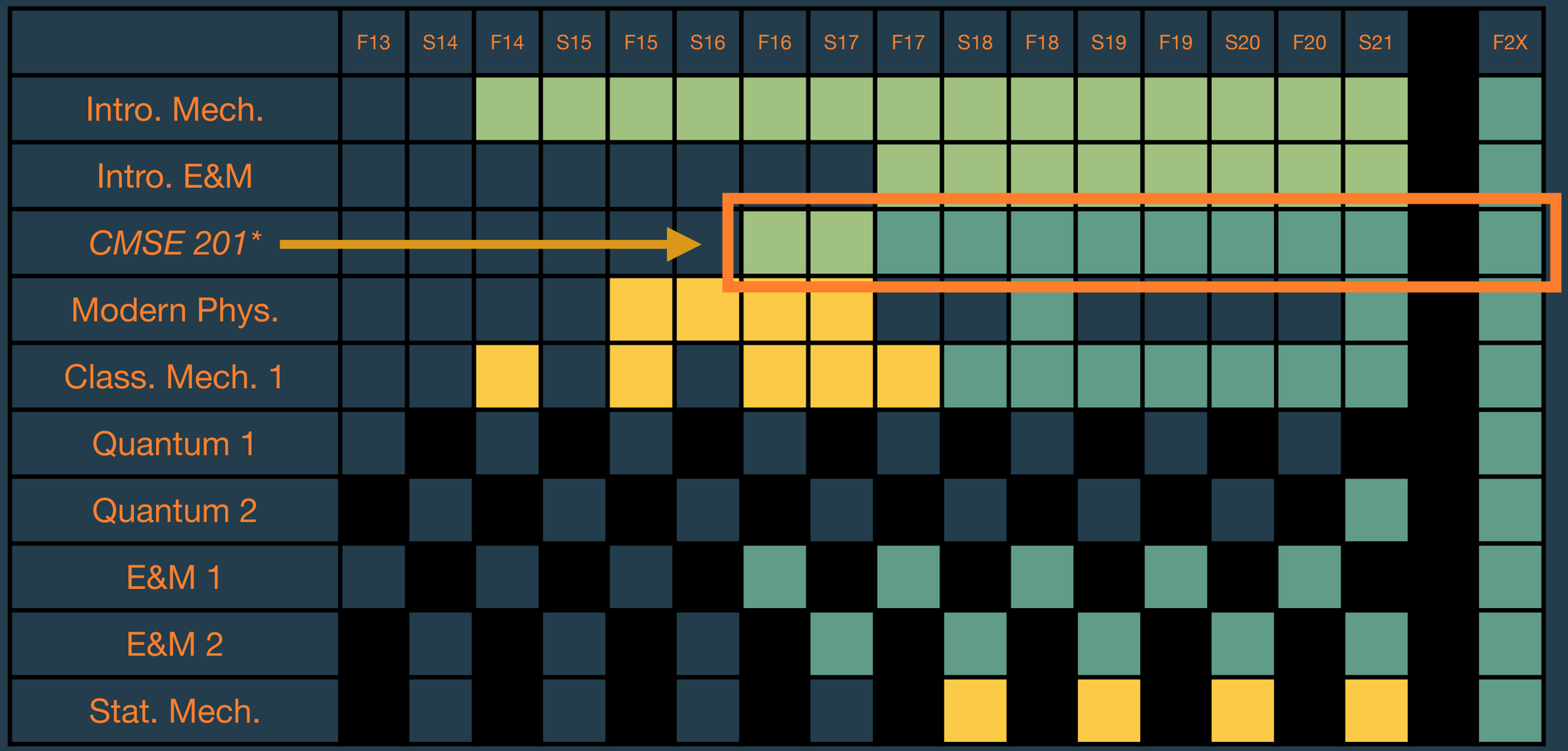
- How do we support a broader cross-section of physics faculty to integrate computing?
- What can physics departments do to support moves to integrate computing?
- How do we help physics faculty design courses, curricula, pedagogy, and activities to teach computing effectively?

Courtesy of Danny Caballero

How might you integrate computing across a physics department?

Timeline of Integrating Computation at MSU



Typical Course Progression

Use of computational environment (e.g., plotting)

Instruction in computation (some sections)

Instruction in computation

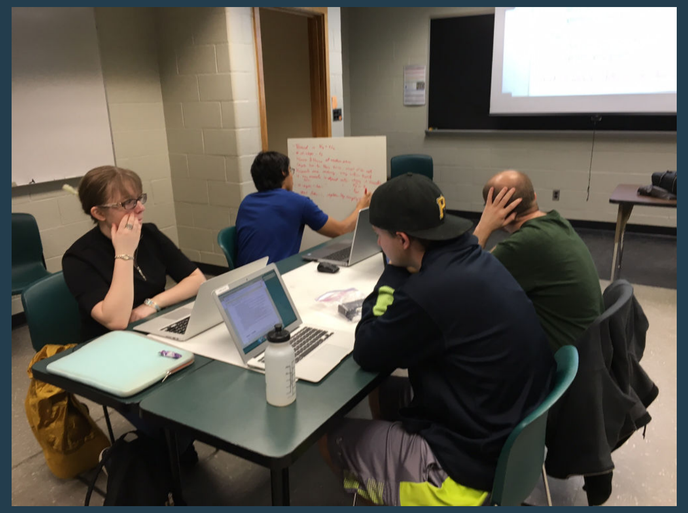
Not offered

Courtesy of Danny Caballero

External support can help accelerate the process of integration.

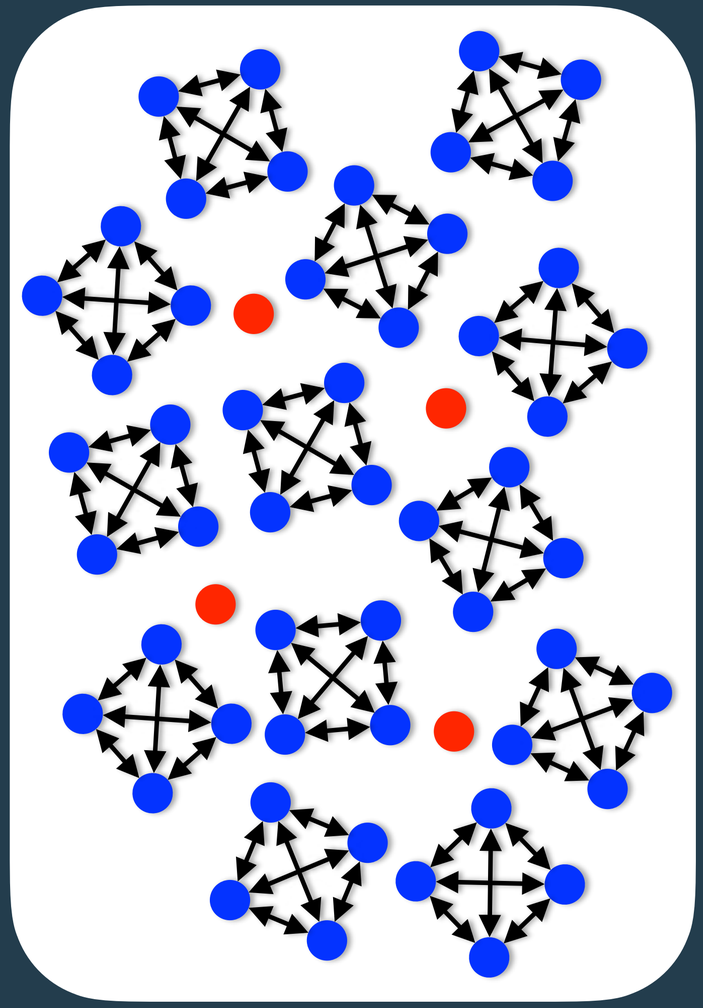
Courtesy of Danny Caballero

Intro. Comp. Modeling (CMSE 201)



Introductory course in data analysis and modeling
Taken by STEM majors (Calc 1 pre-req)
Required for Physics and Astronomy majors

50-70 students/section



Pre-class assignments: videos, reading, **small programming assignments**

Paper with detailed course description:
Silvia, O'Shea, and Danielak 2019, ICCS 2019

Courtesy of Danny Caballero

Day 8: In-class Assignment: Modeling extreme sports

Goals for Today's In-Class Assignment

By the end of this assignment, you should be able to:

- Use functions to define derivatives that model the evolution of a physical system.
- Use loops to update the state of an evolving system.
- Use `matplotlib` to plot the evolution of the system.
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Modeling the motion of a skydiver

Part 1: Modeling a falling skydiver without air resistance

Question to the room: In order to model this system, what variables do we need to keep track of?

For simplicity, we're going to model this problem in only one dimension. We'll define this dimension to be "height". which we'll call "h".

We know that the **change in height** over some **change in time** is the **velocity** of the sky-diver, which we can write as:

$$\frac{dh}{dt} = v$$

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Part 2: The falling skydiver meets air resistance

Part 3: Opening the parachute

Part 4: Modeling a bungee jumper

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Part 3: Opening the parachute

Part 4: Modeling a bungee jumper

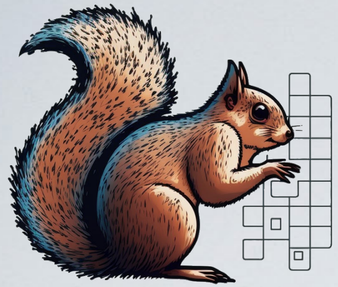
Now required for PA students Before Classical Mechanics 1

Courtesy of Danny Caballero

Can we expand this model further?
Will this work for other institutions?

How can computing be taught in a way that supports a wide range of disciplinary learning?

CMSE 201 is just one possible model.



The Computing Education Research Lab @ MSU

is exploring how students learn in the context of this interdisciplinary computing classroom.

https://msu-cerl.github.io/

- How do students develop an understanding of modeling, data science, and machine learning?
- How do students' expectations, experiences, and sentiments shape their learning and participation in computational and data science?
- What pedagogical and curricular elements are useful for learning data science and machine learning?

Questions?