MICHIGAN STATE UNIVERSITY

Slides

Teaching Computing in Introductory STEM Courses at Scale

2023 CCSE Juleseminar

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

Department of Physics and Astronomy

CMSE

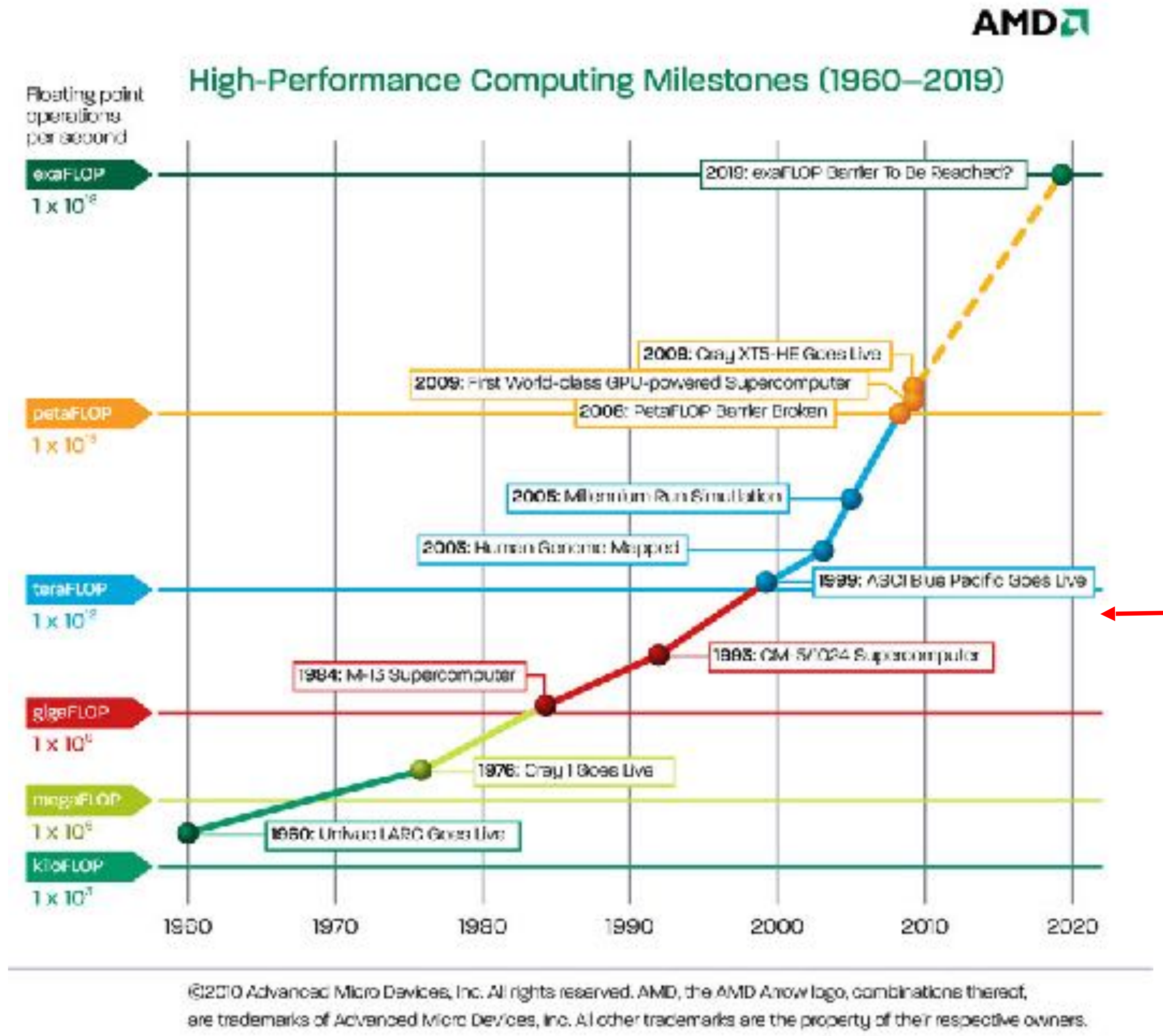
Computing: Why?

Courtesy of Andrew Christlieb (altered)

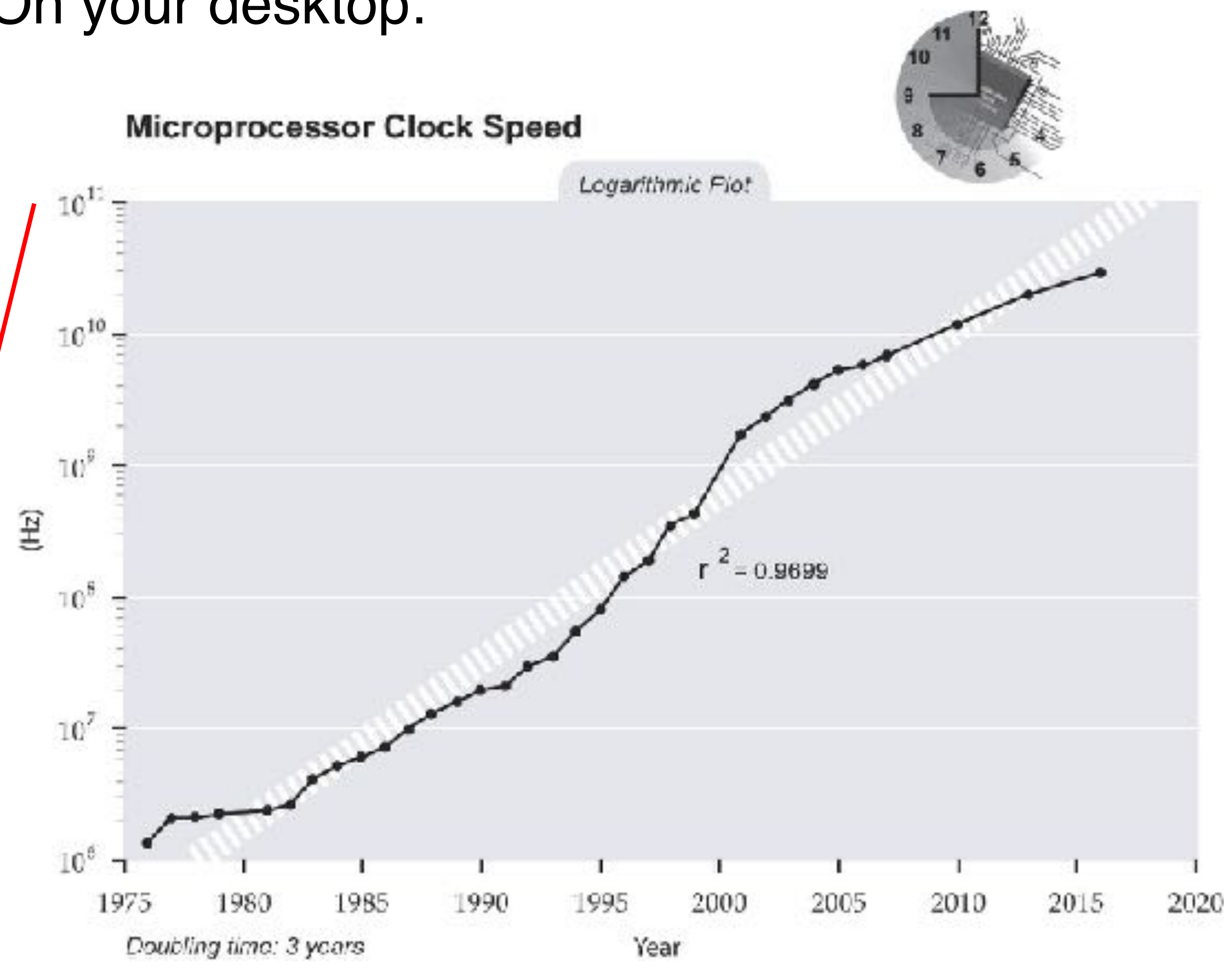
The world is changing, and MSU needs to change with it.

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

Milky Way (China): The most powerful computer on the planet.



On your desktop:



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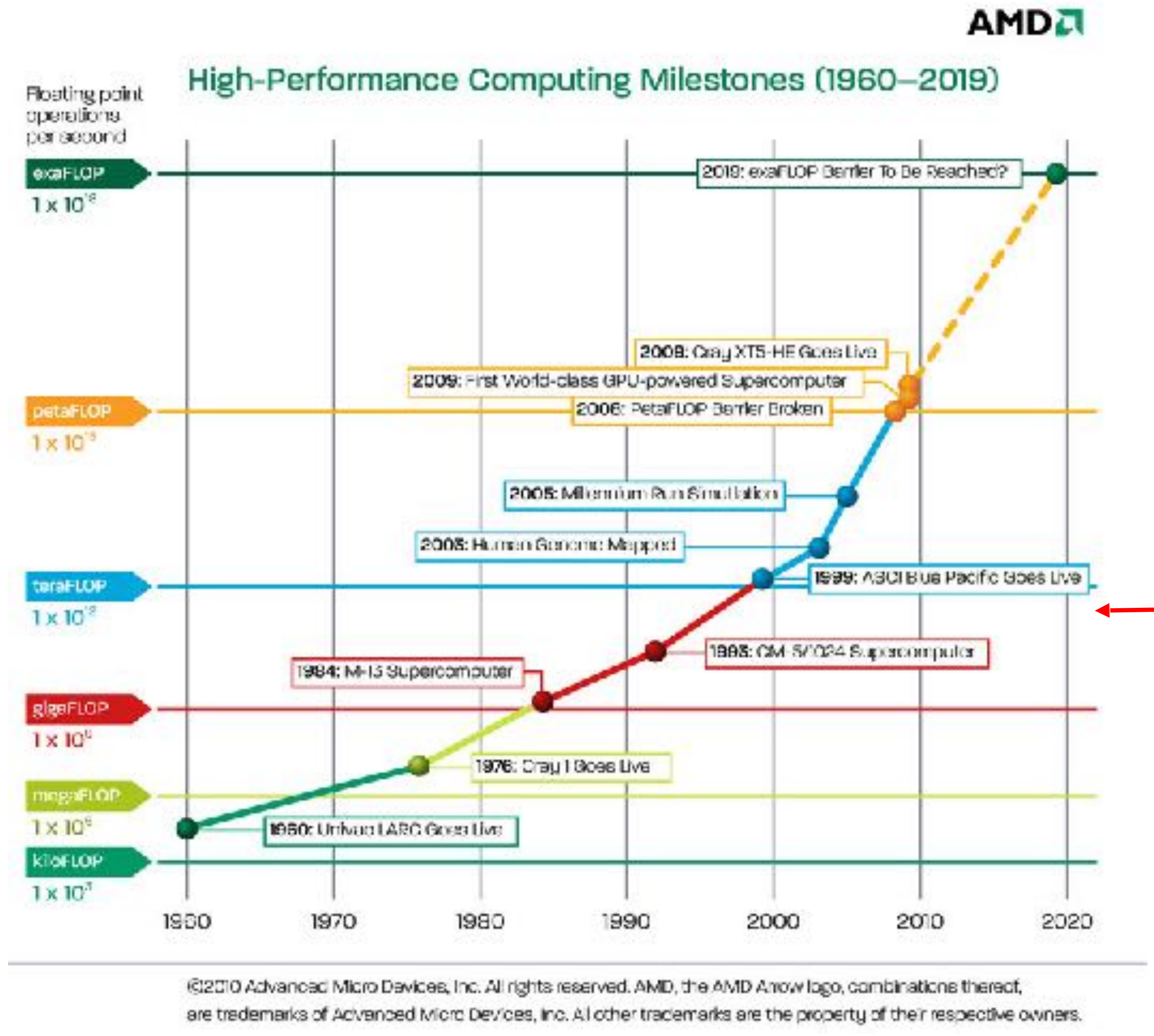

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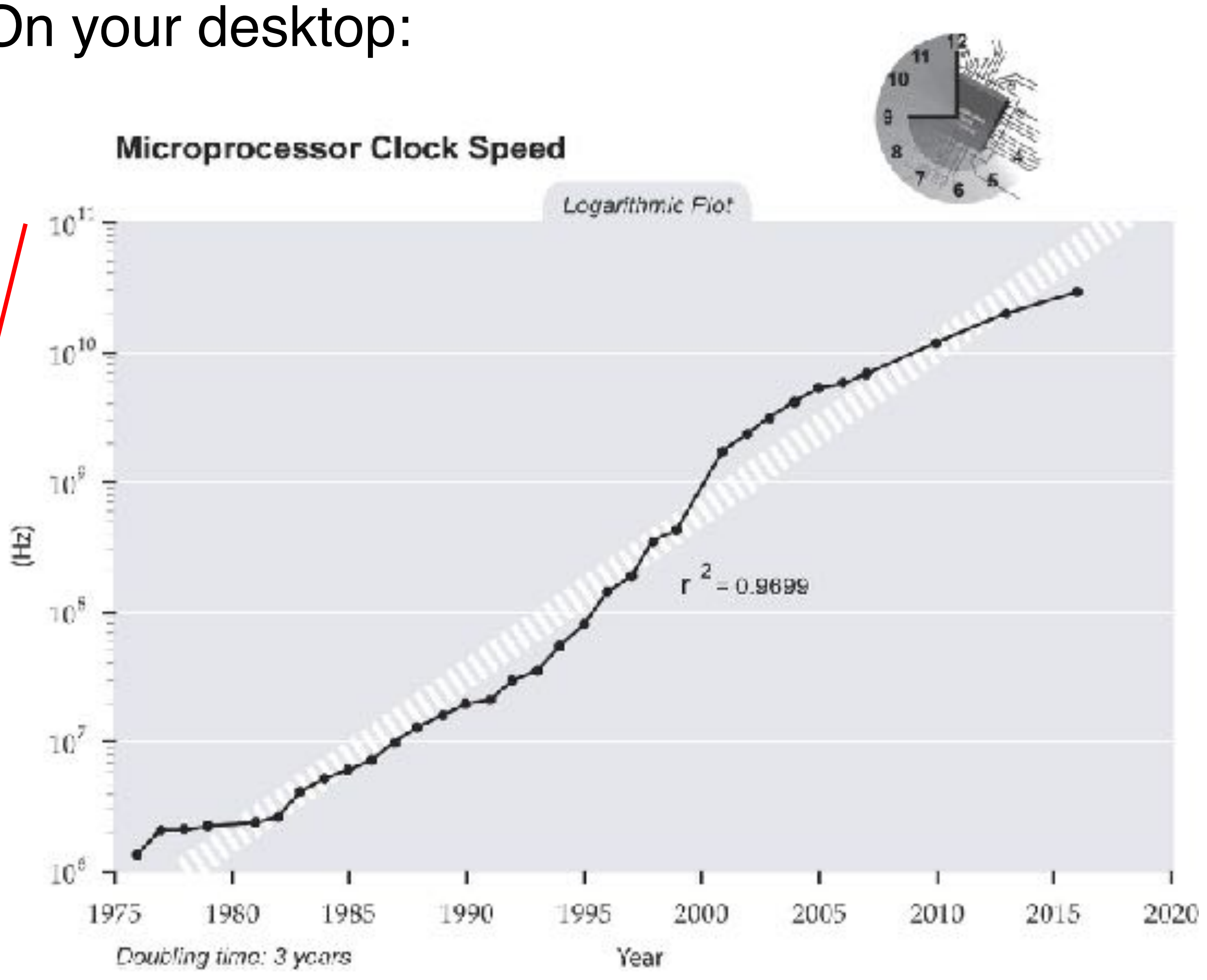

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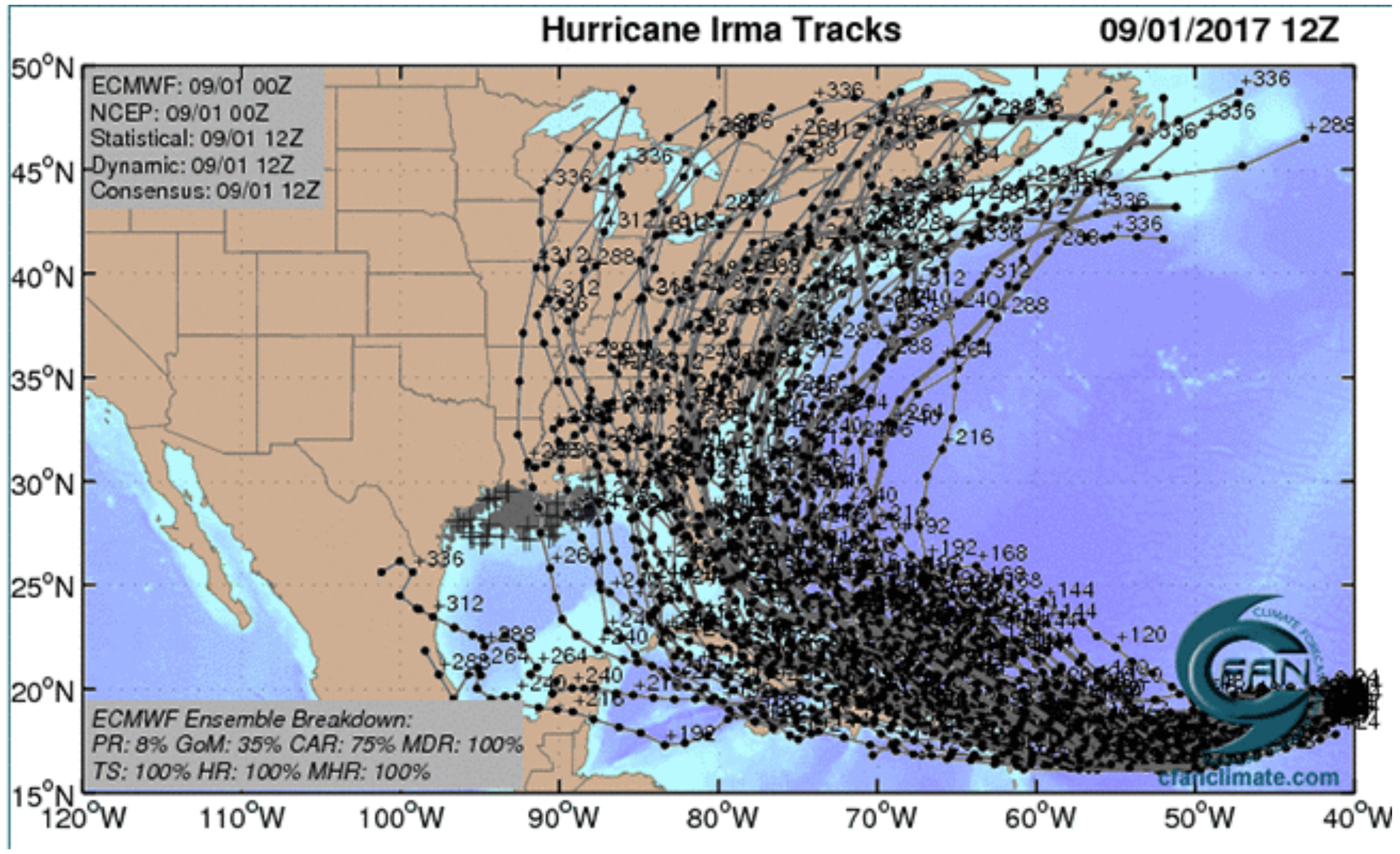
Advanced **algorithms** are changing the way we predict and control our world.



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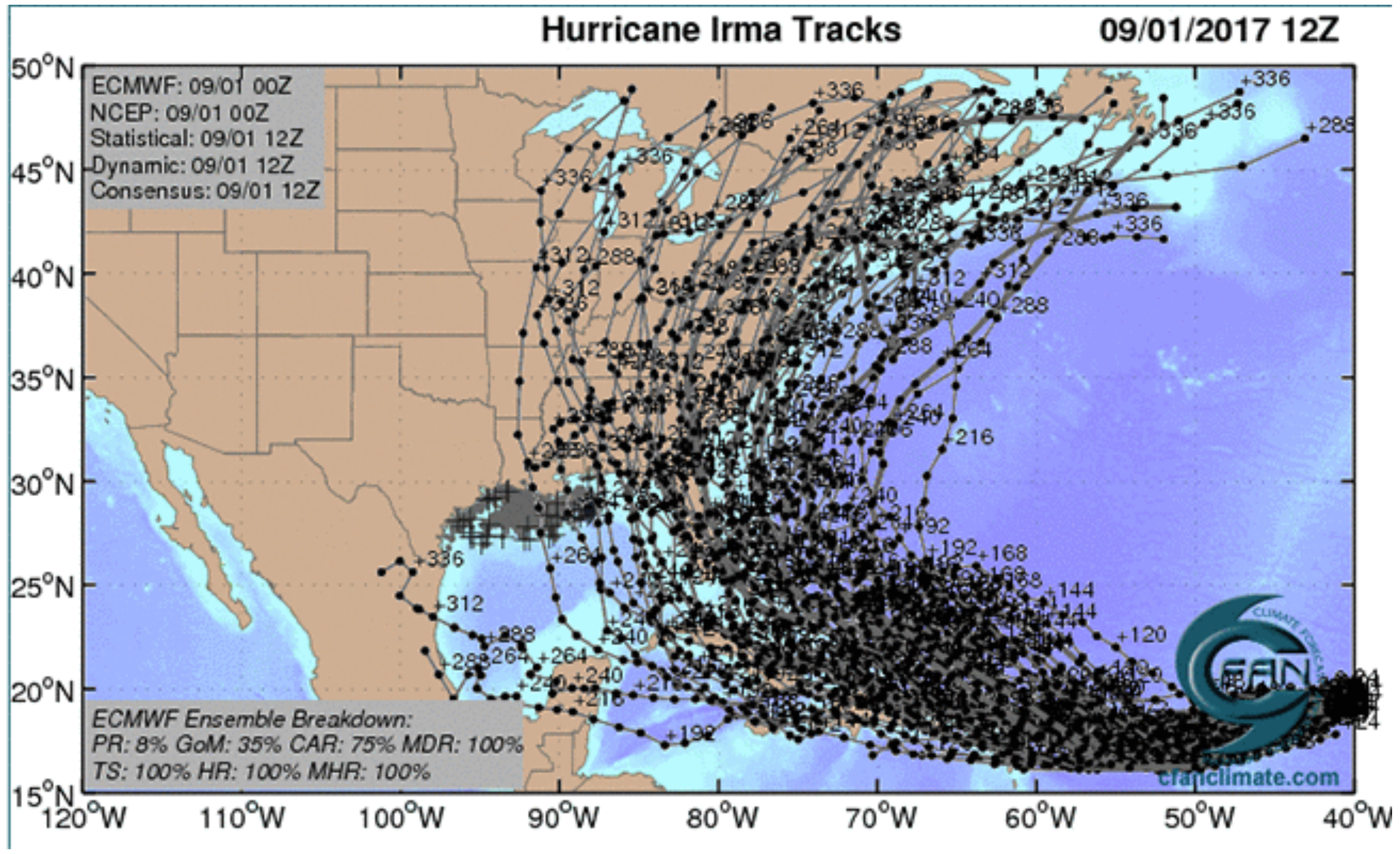

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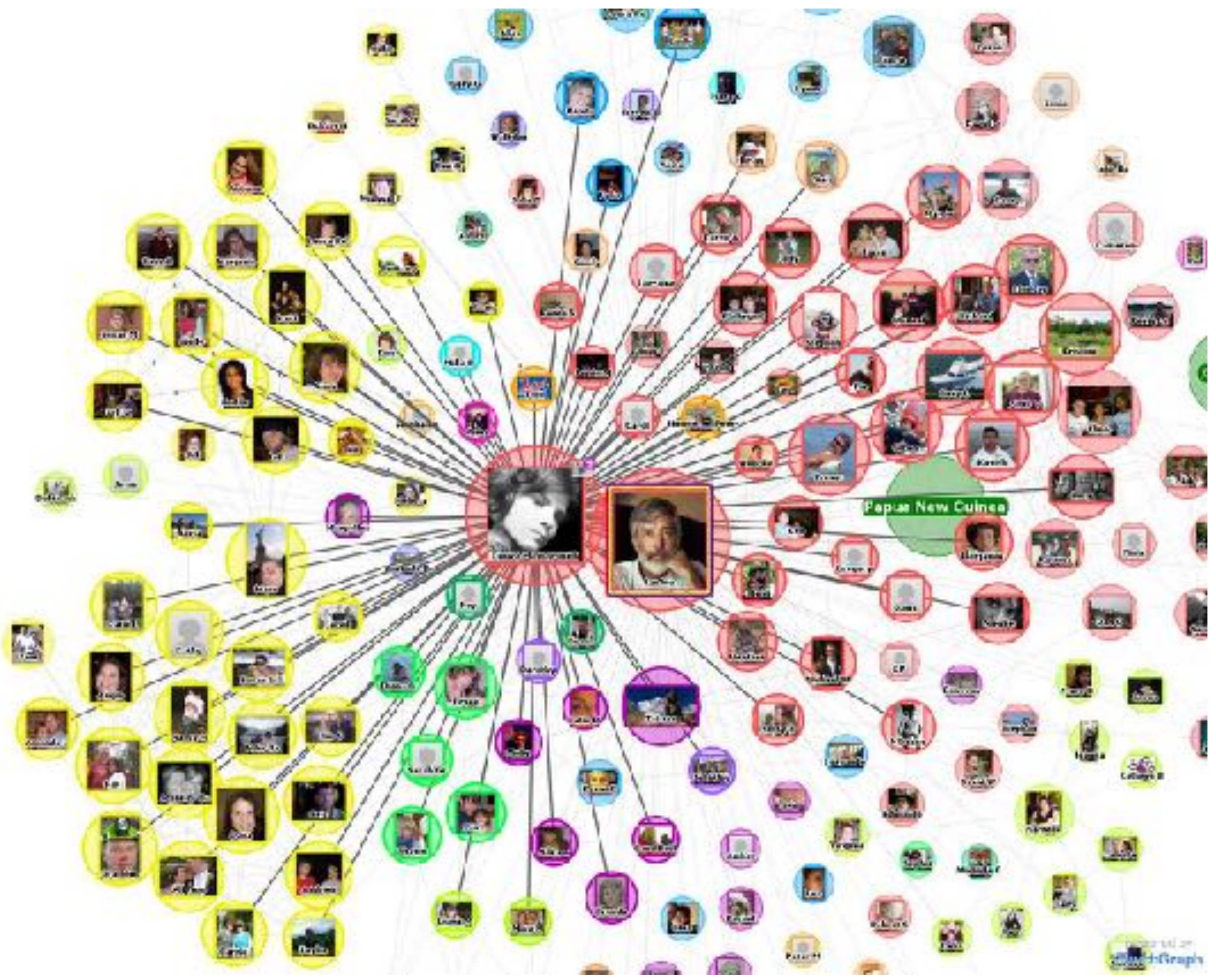

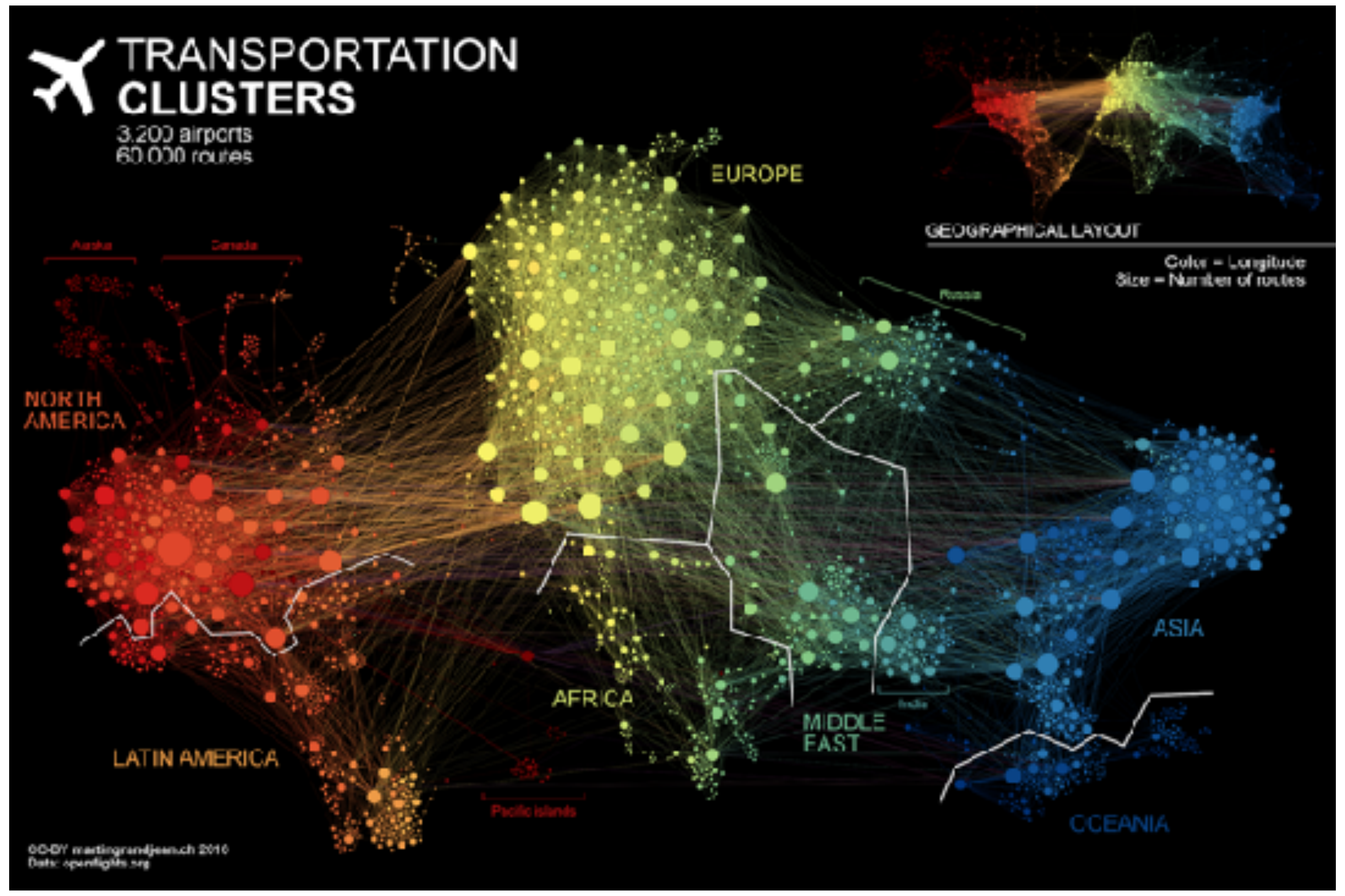

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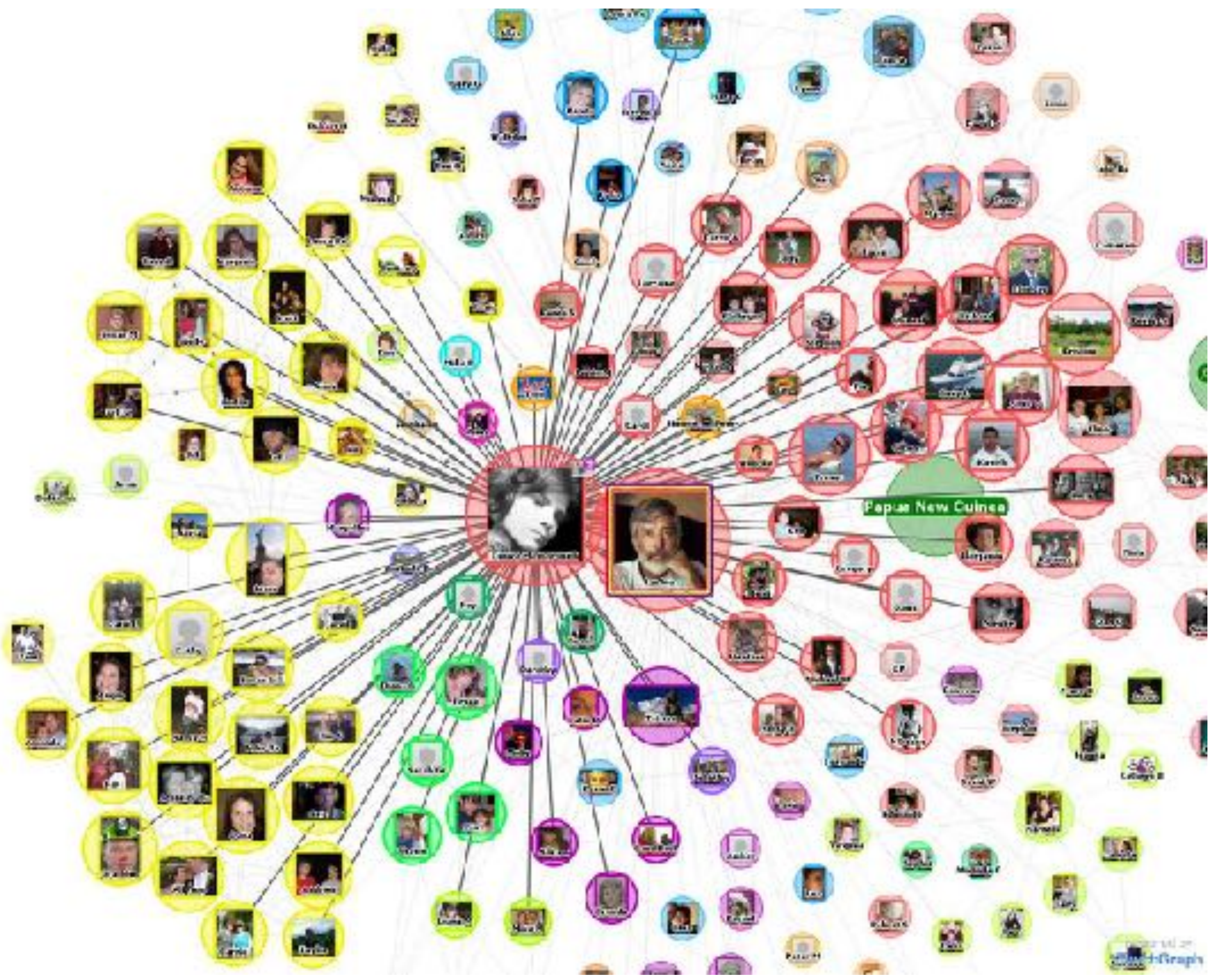
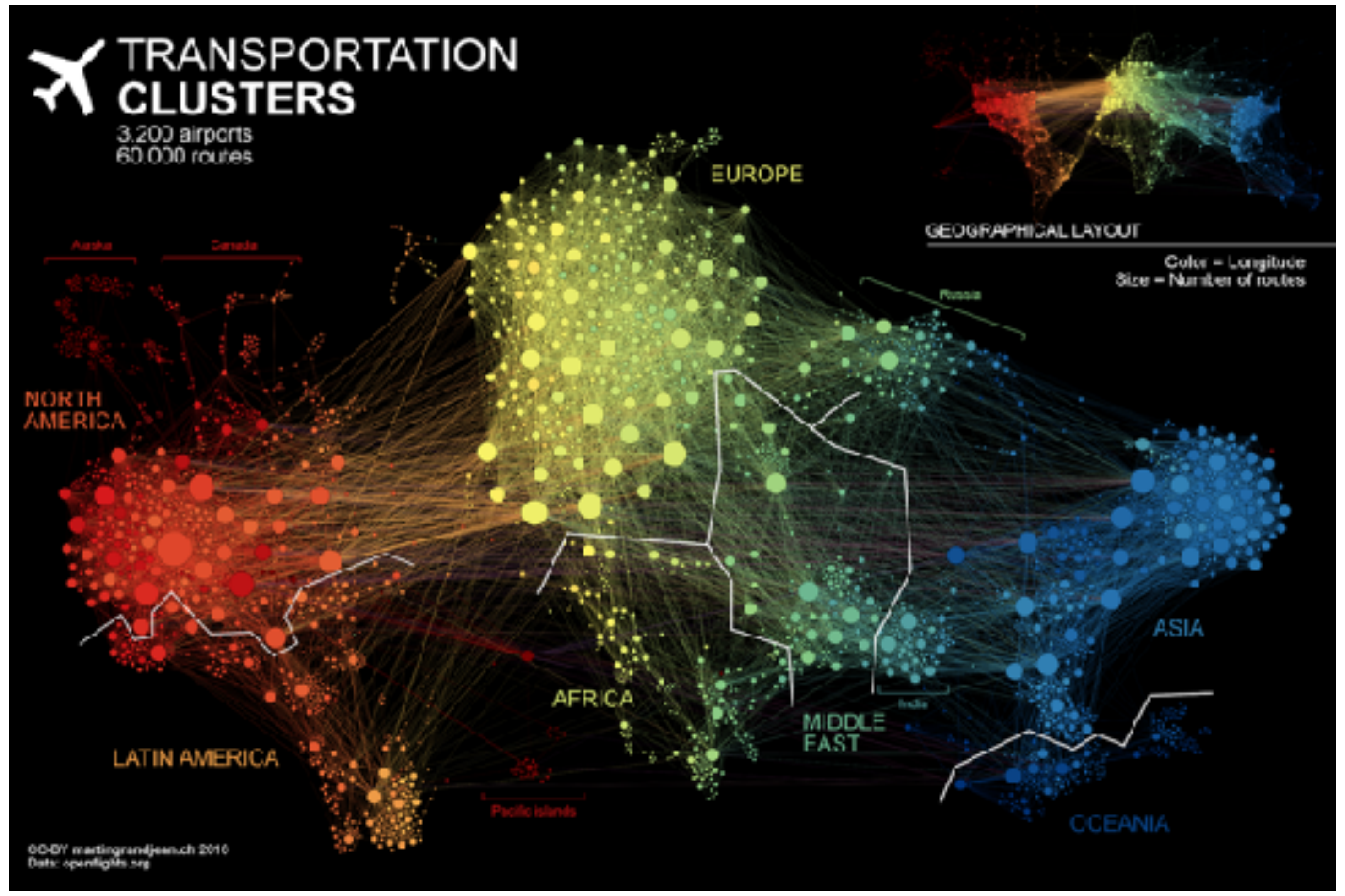




However…

We need to be critical of our goals, instruction, and outcomes

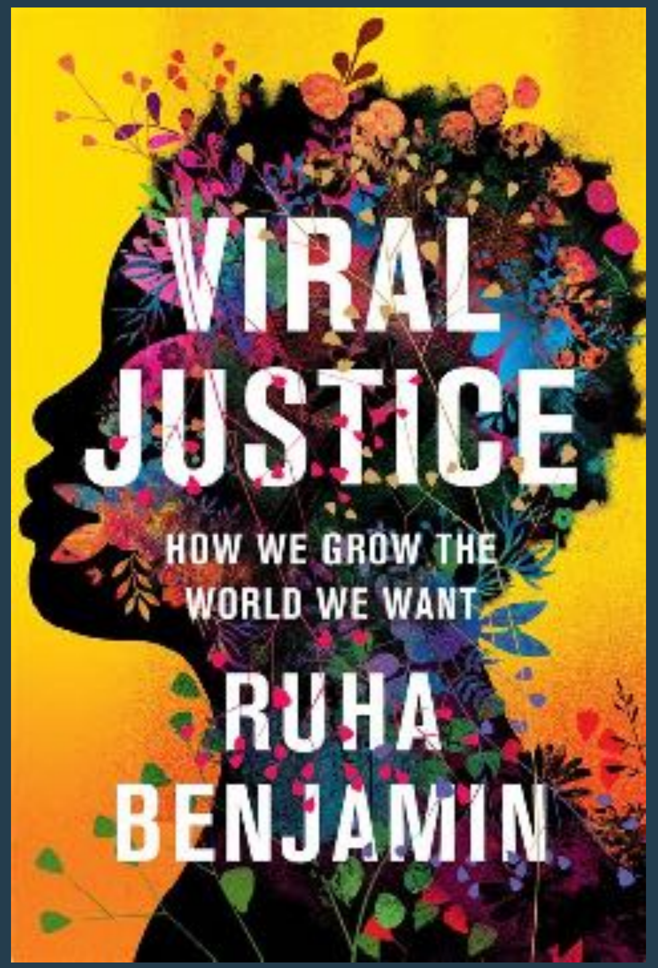

TechTrends
https://doi.org/10.1007/s11528-023-00835-z

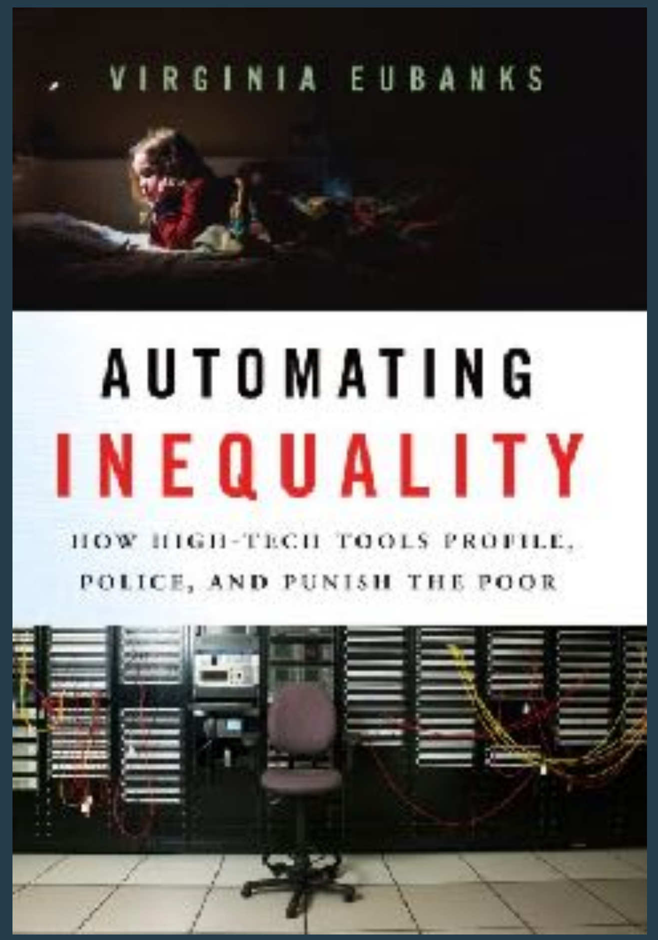
ORIGINAL PAPER

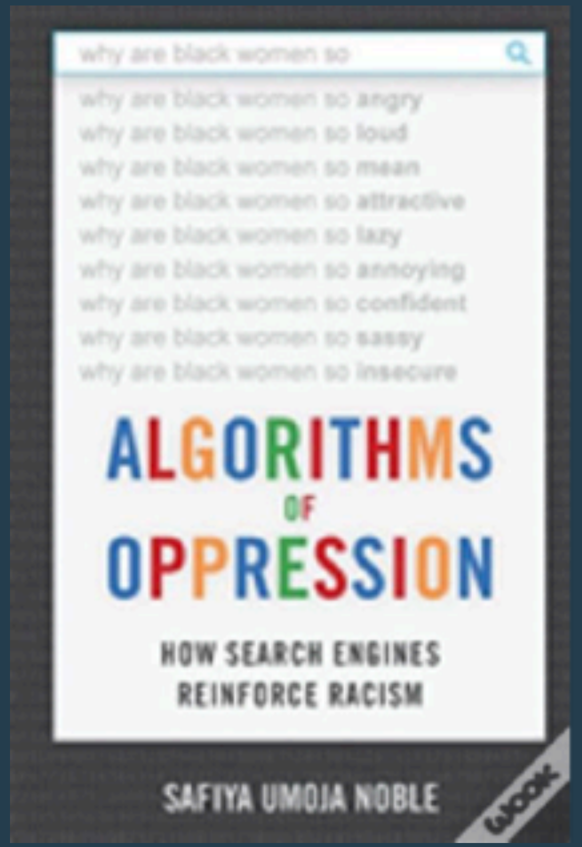
Racial Justice Amidst the Dangers of Computing Creep: A Dialogue

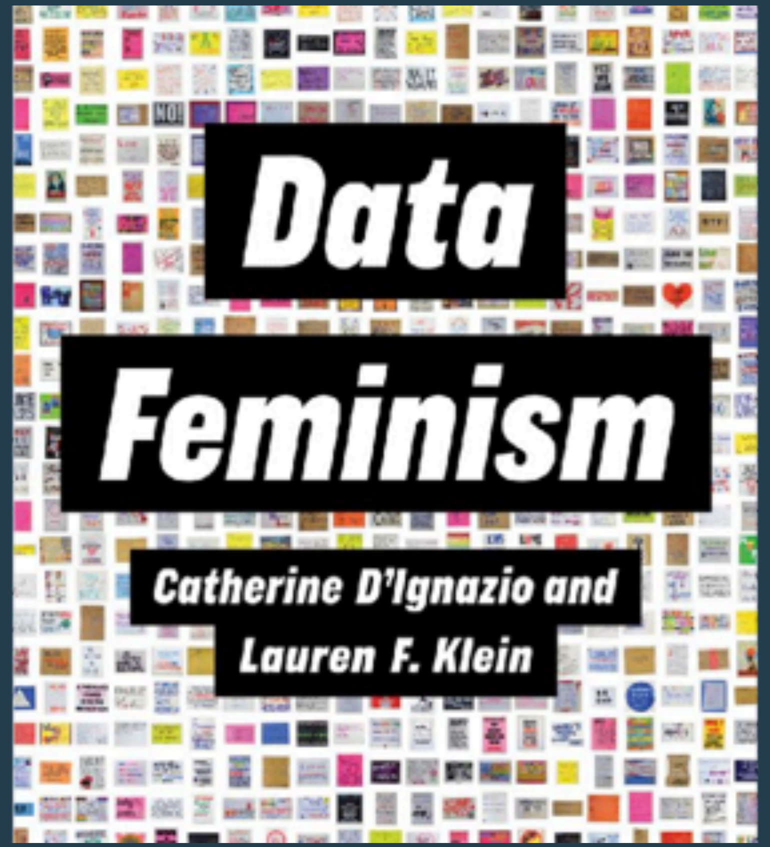
Niral Shah[1] · Aman Yadav[2]

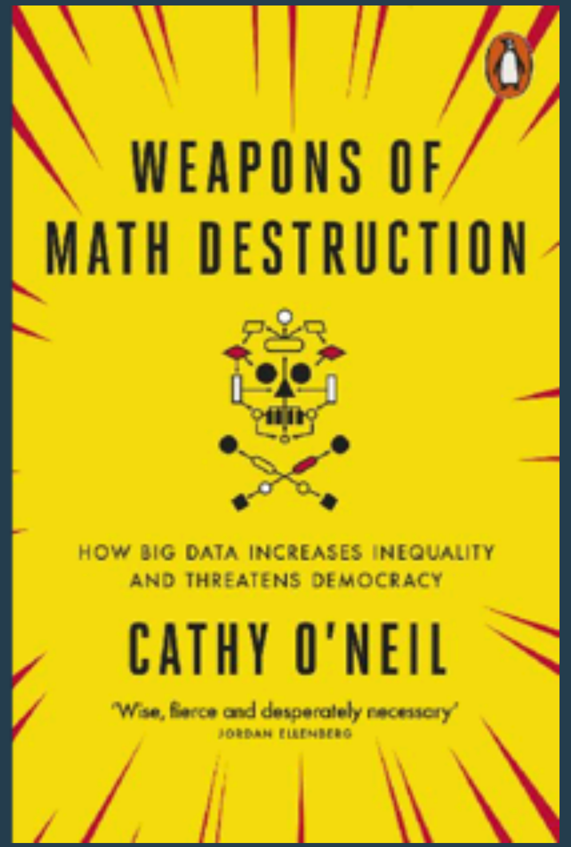
- Facial Recognition in Surveillance Systems
- Racial and Gender Bias in data & models
- Autonomous Weapons and Targeting
- Social Media and Polarization
- Discrimination in Hiring
- Discrimination in Healthcare
- Deepfakes and Misinformation
- AI-driven Stock Trading
- Rogue Usage of Generative AI





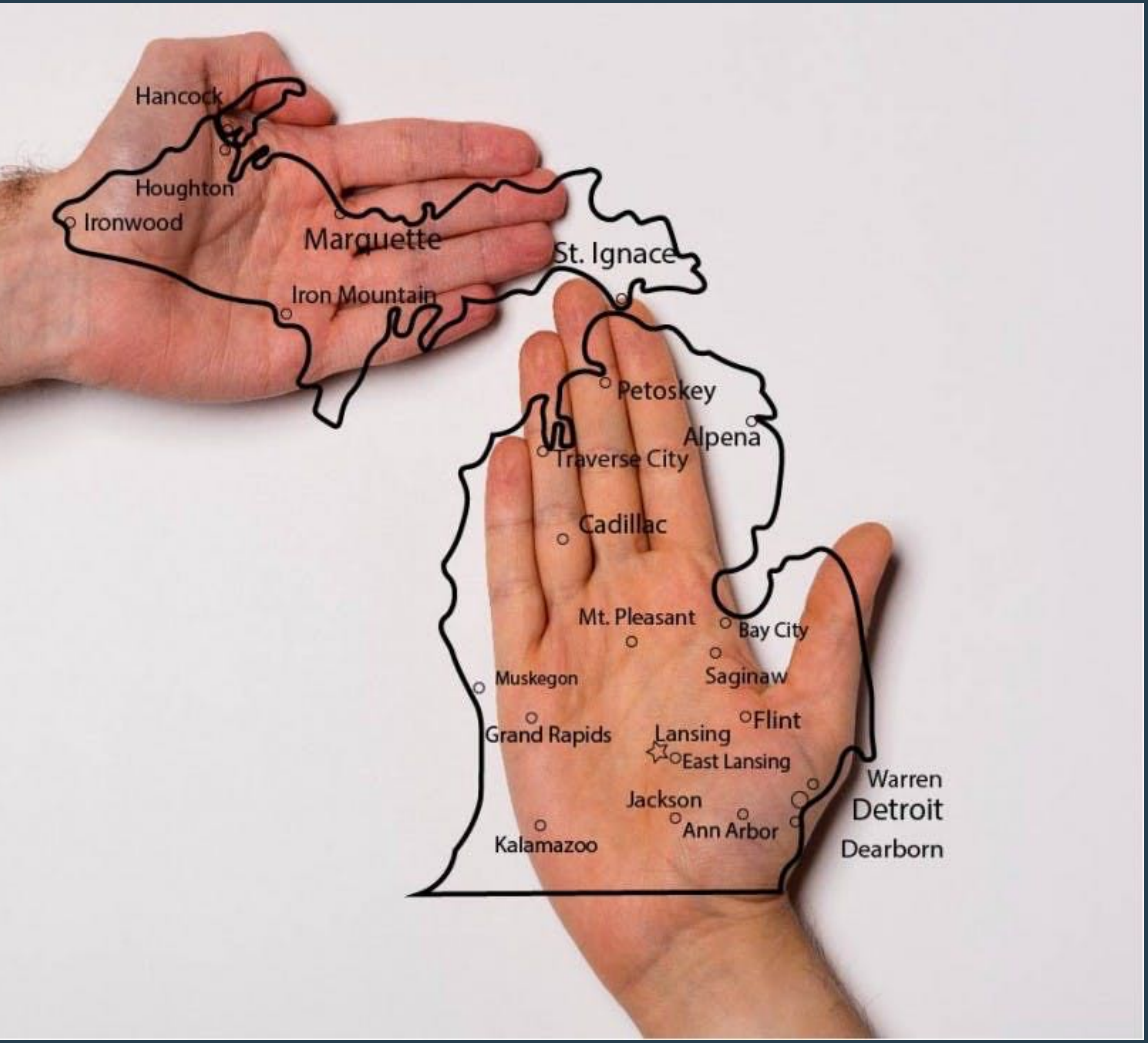






State of Michigan

Population: 9.9 million



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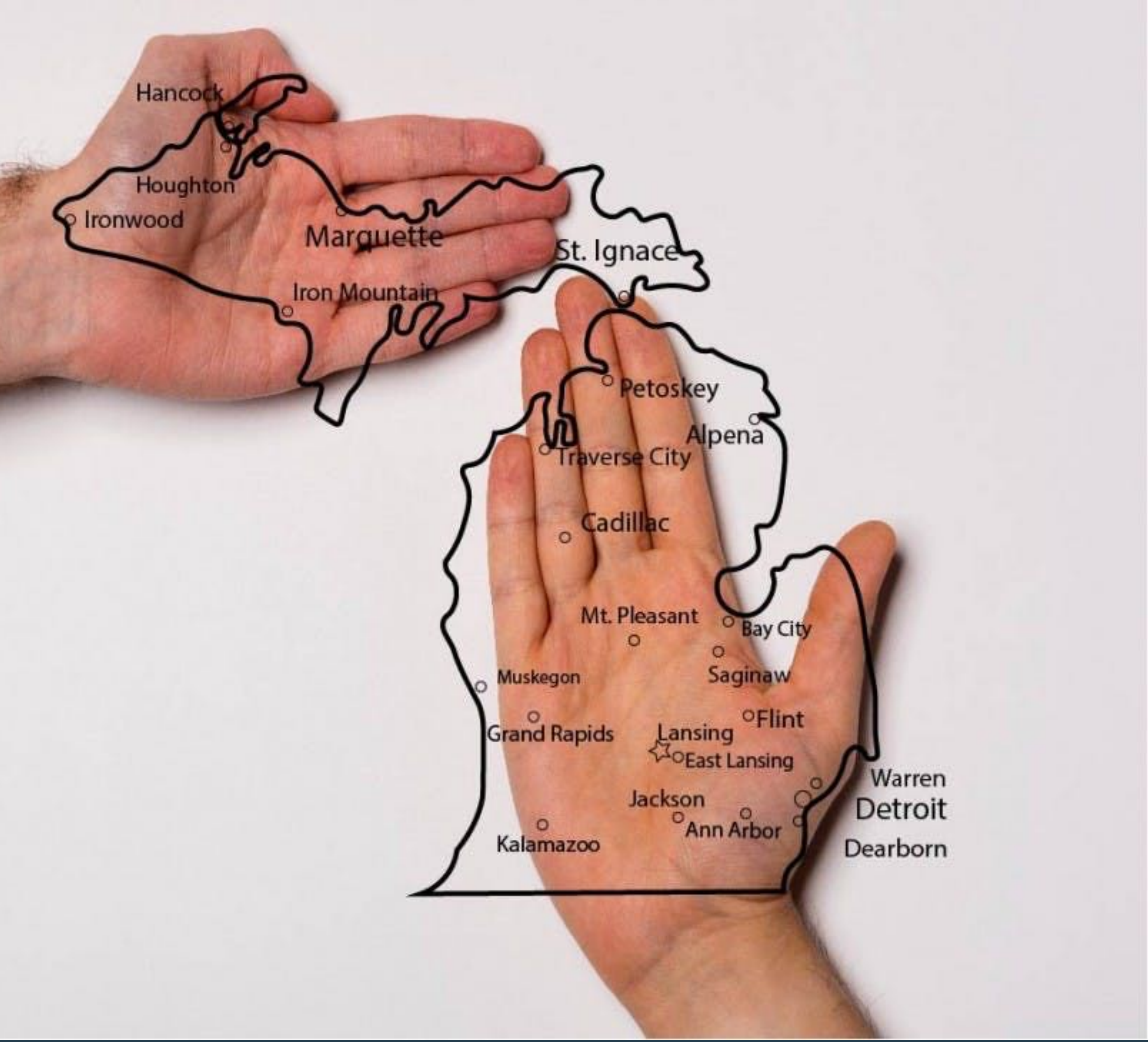

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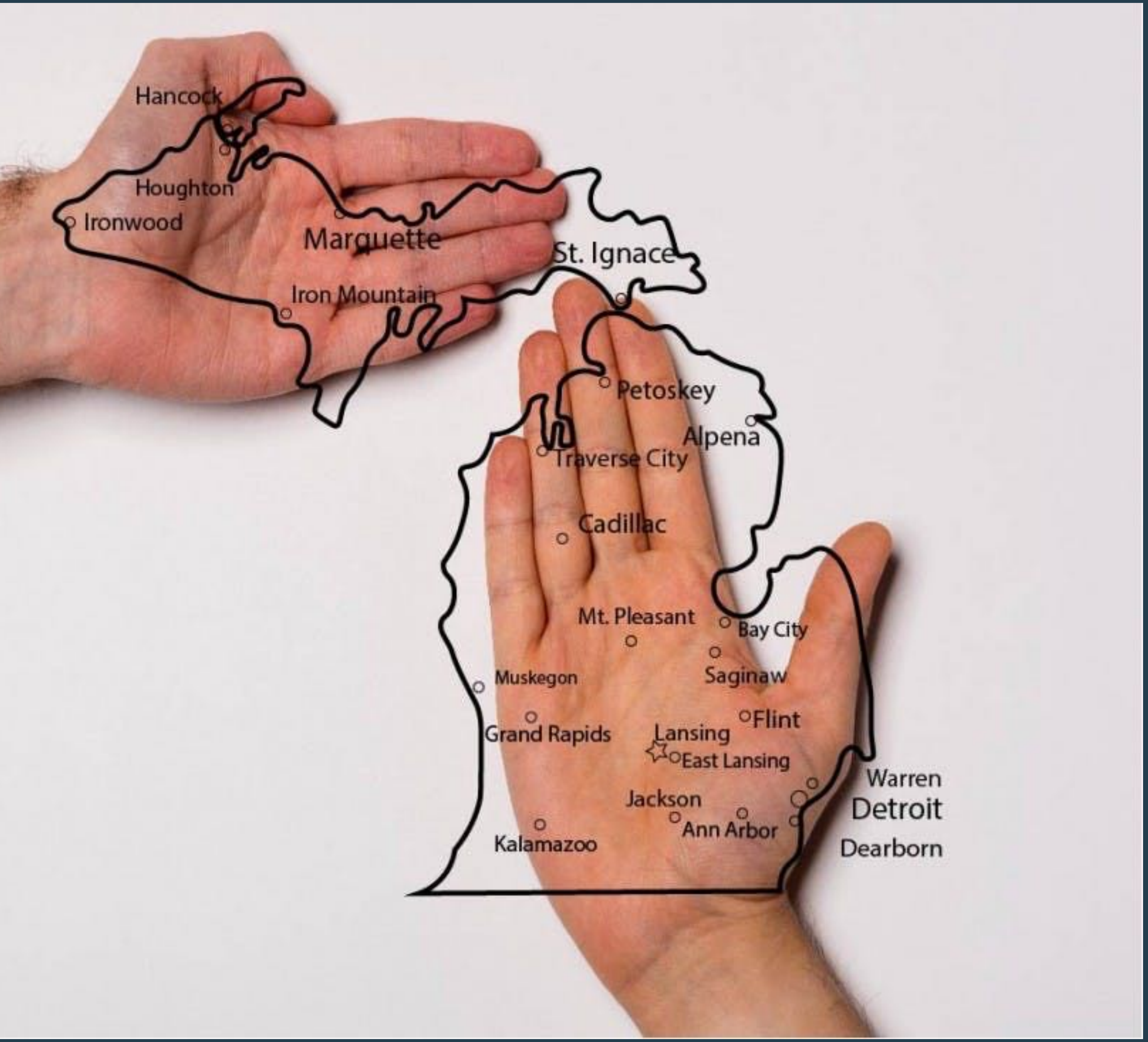
Population: 9.9 million

Major cities (all in the Lower Peninsula):

- Ann Arbor (University of Michigan blue/gold)
- Detroit
- Flint
- Grand Rapids
- Lansing (Michigan State green/white; state capital)



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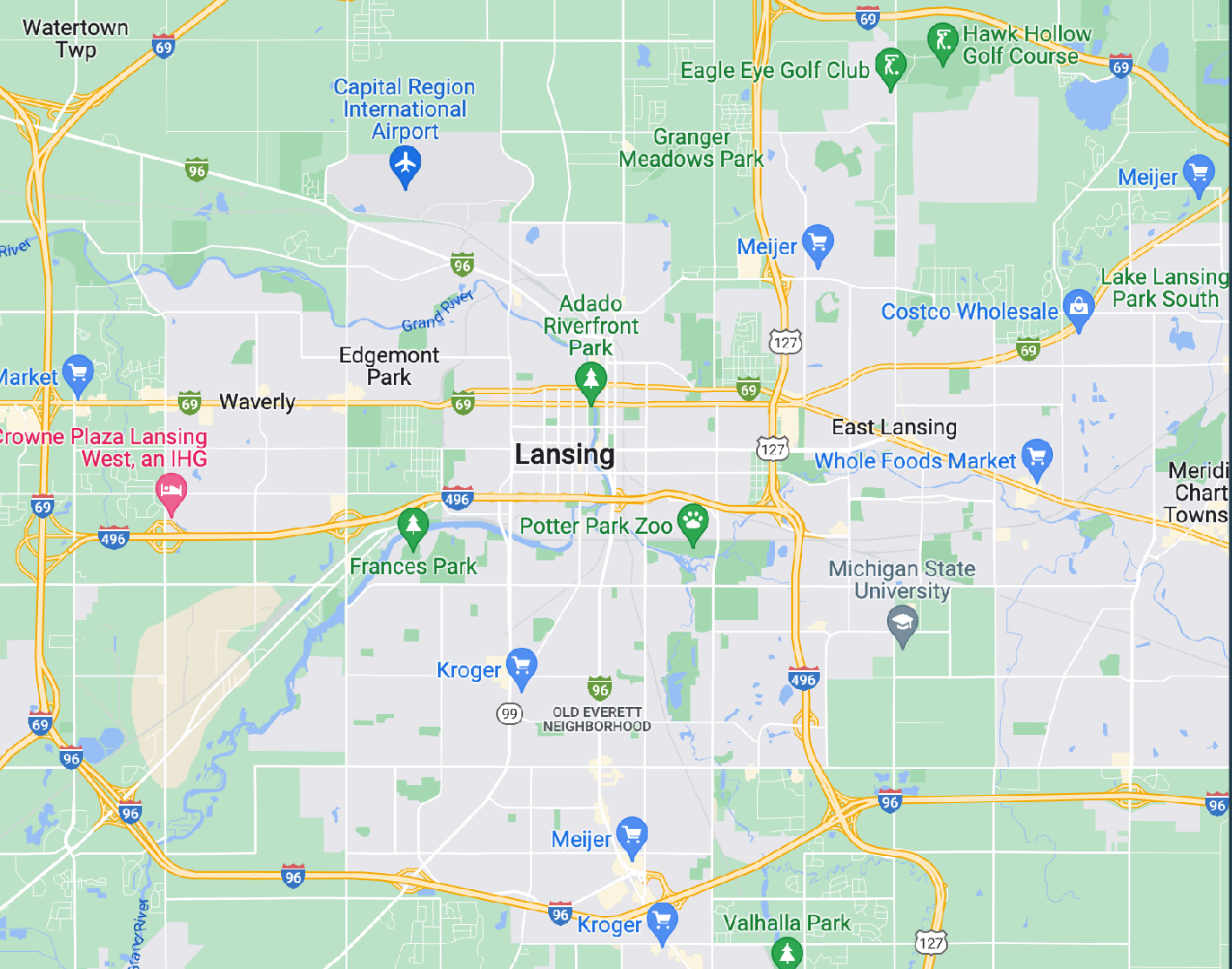
Major industries:

1. Automobile and mobility industry (e.g., Ford, GM, and suppliers)
2. Advanced Manufacturing (see above + e.g., Bosch)
3. Food and agriculture (e.g., Kellogg, General Mills)
4. Freshwater technology (we touch 20% of the world's surface freshwater)
5. Christmas trees (yes, seriously…it's the fifth biggest industry)



Greater Lansing Area

Population: 540k

Major industries:

- The State of Michigan
- Michigan State University
- Sparrow Health Systems
- McLaren Healthcare
- General Motors

MICHIGAN STATE UNIVERSITY

Located in East Lansing, MI
Population (2022):
48,437 permanent residents
50,344 students (39k are undergrads)
5,670 academic staff (2k tenure stream)

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Historically, and "primarily" an agricultural school

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Notable programs:
- Agriculture - consistently top 25 in world
- Communication - top 10 in world
- **Nuclear Physics** - top in the US; FRIB (top in world)
- **Education** - top in US; elementary and secondary
- **DBER** - wide breadth of DBER; large PER group

STEM in Michigan

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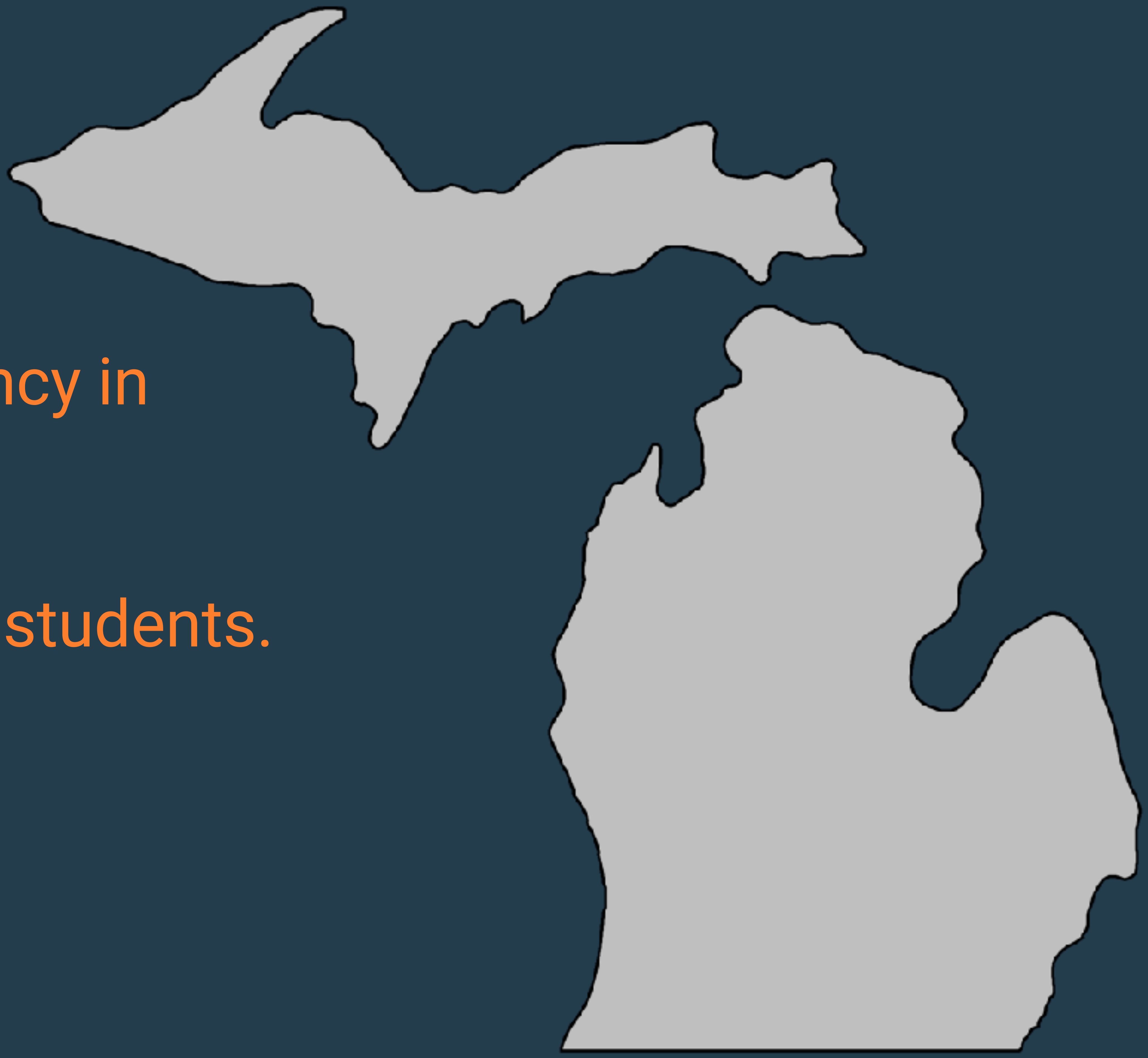

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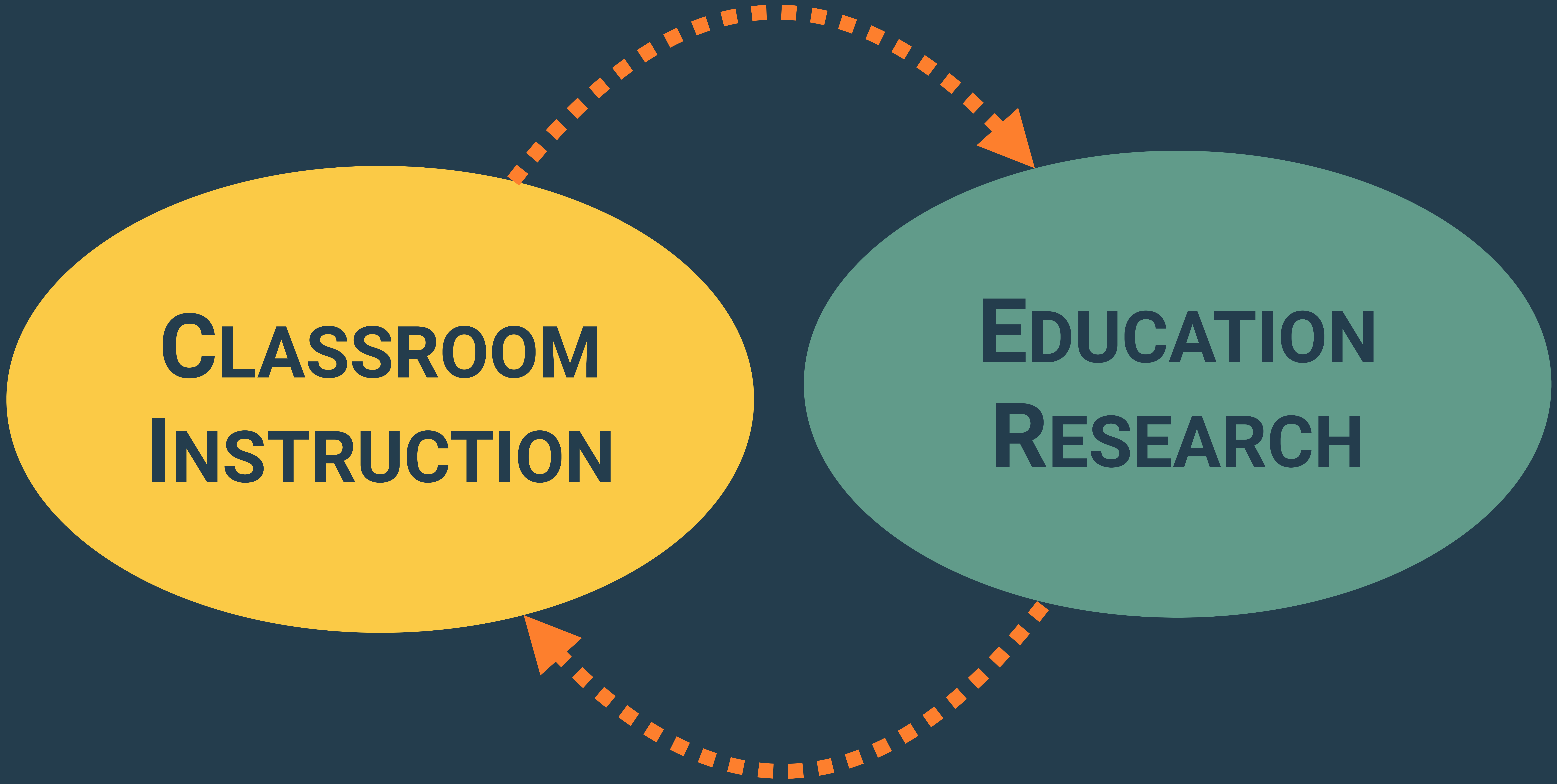
> 75% of MSU students are Michiganders.


Classroom Instruction
Education Research

Challenges for an R1 school

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Resourcing
Service courses make $$$
Courses taught at “scale”

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Changes needs to scale
~1000 students/intro course
~100 students/advanced course

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Research Demand/Expectations
Time, energy, and interest vary
Instruction by TAs/LAs

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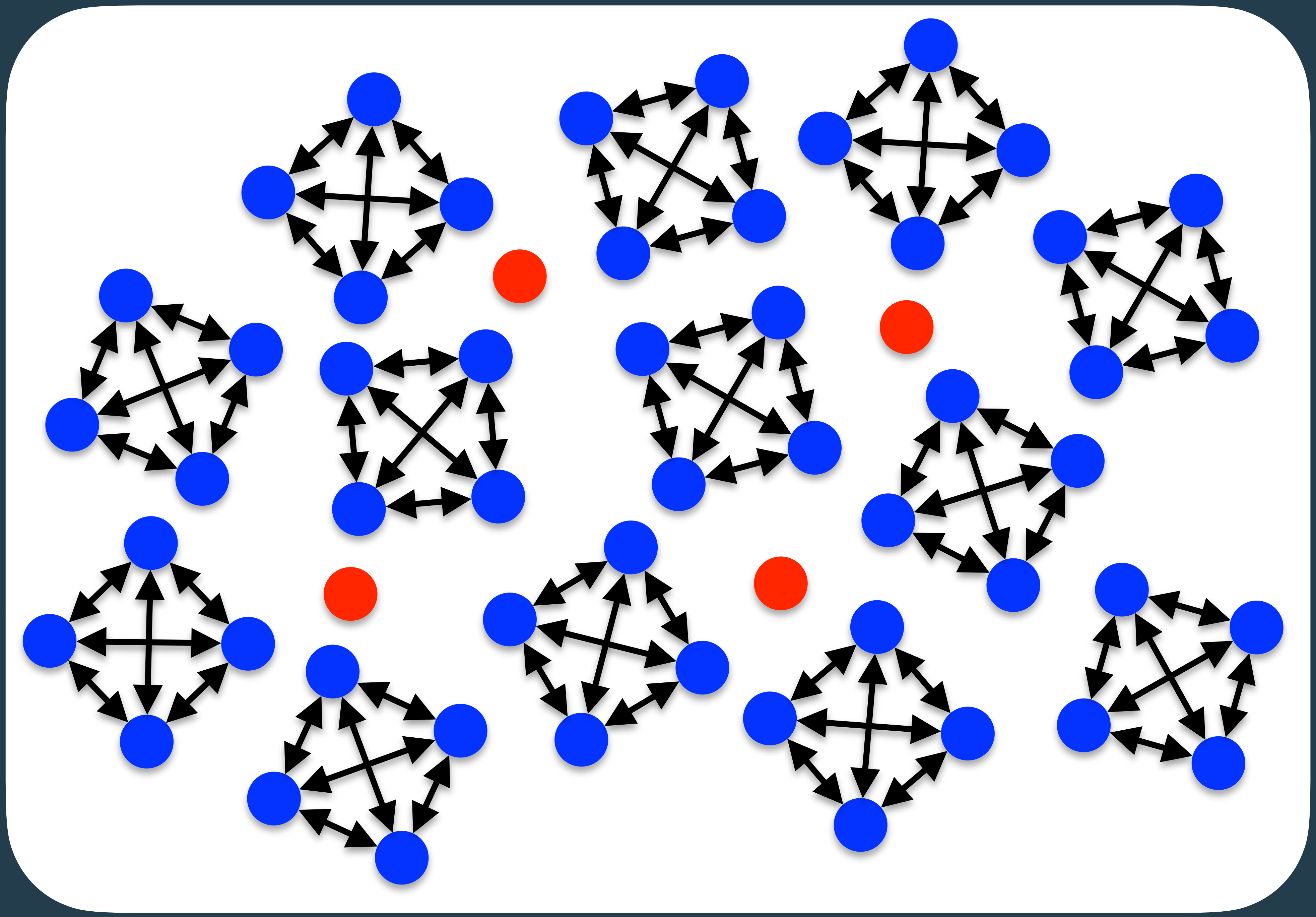
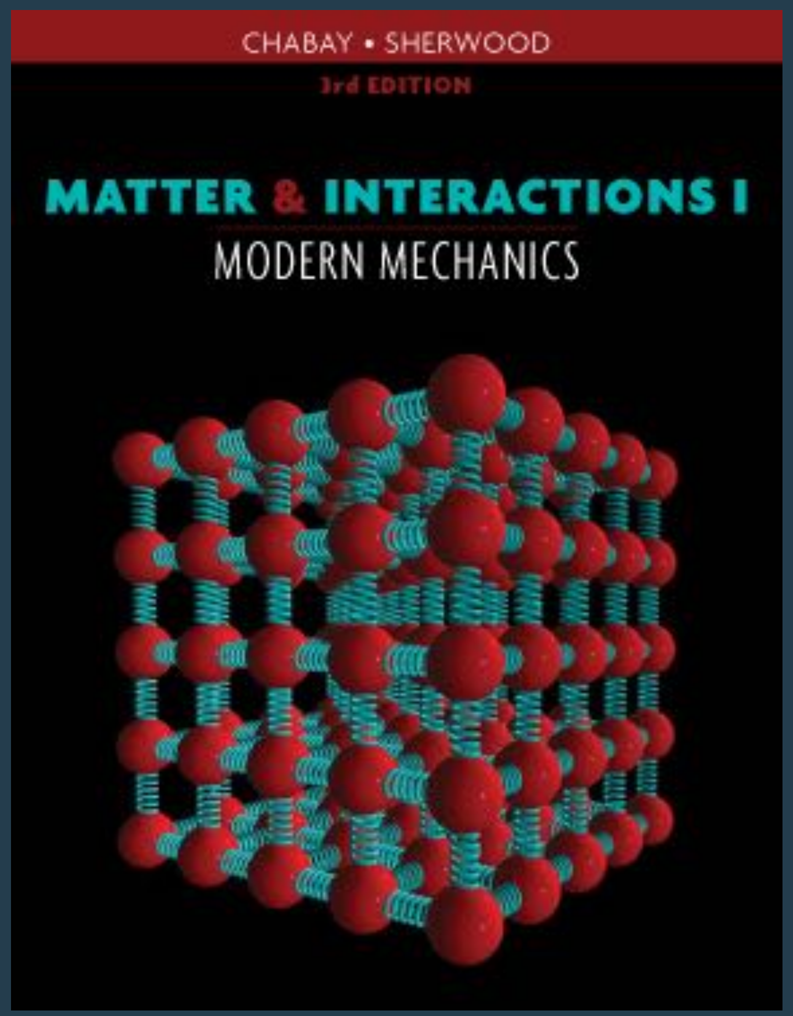
State-level Investment
New STEM Teaching Building

Projects and Practices in Physics

Physical Sciences & Engineering majors

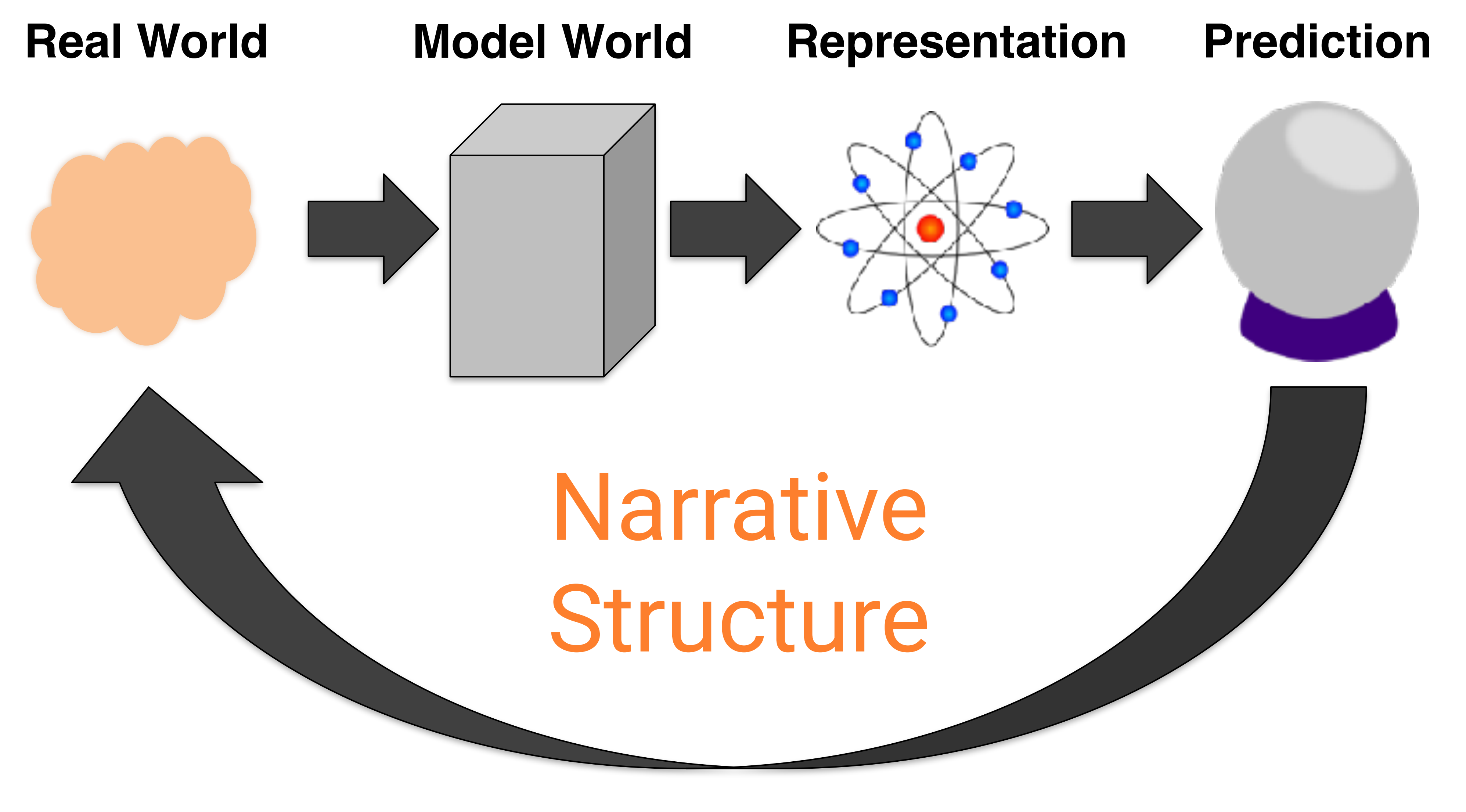


FUNDAMENTAL PRINCIPLES
- Forces cause changes in momentum
- Energy is conserved
- Torques cause changes in angular momentum
- Macroscopic phenomenon are the result of microscopic interactions



msuperl.org/wikis/pcubed/

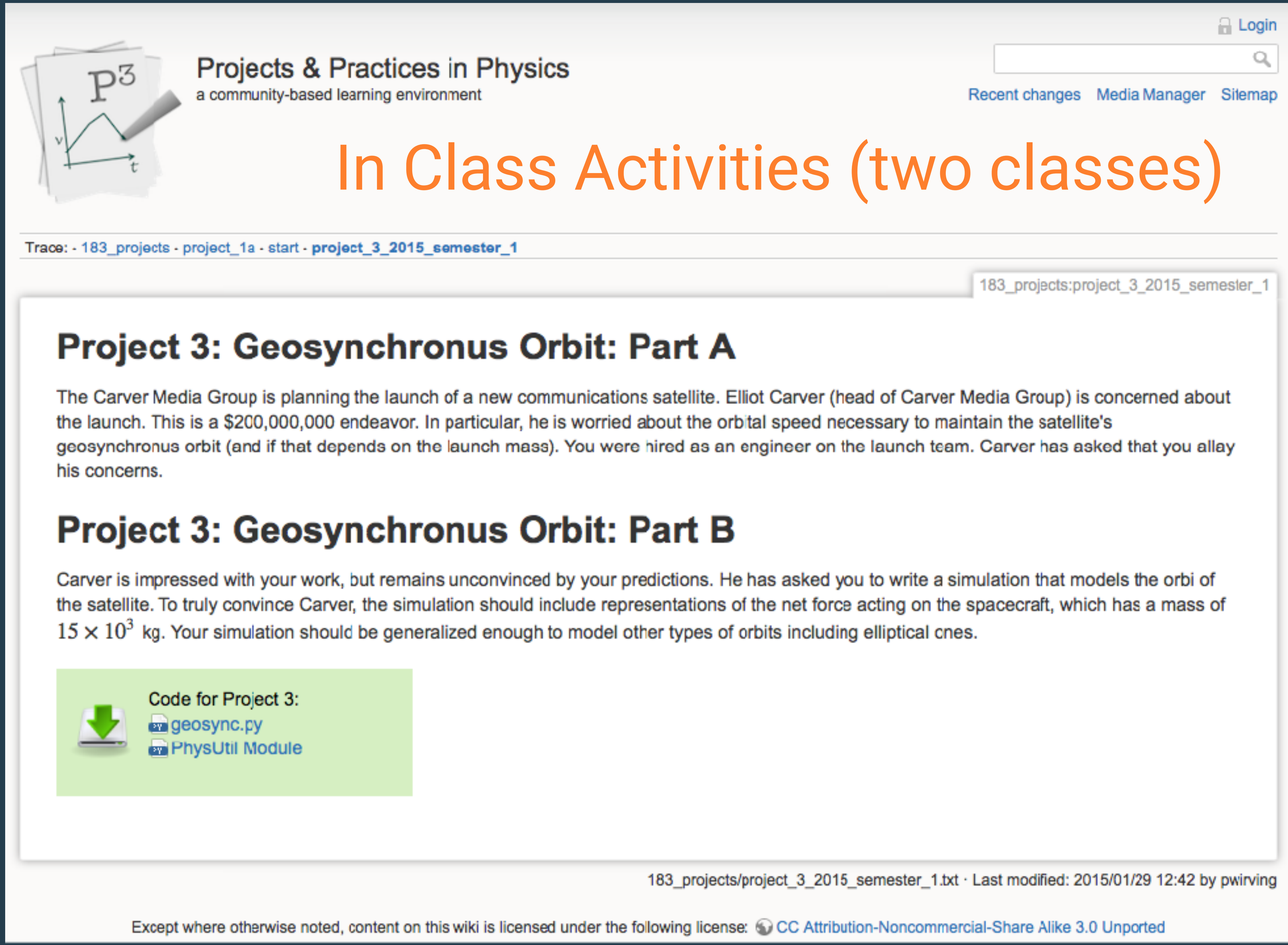
Irving, Obsniuk, & Caballero, EJP (2017)
Irving, McPadden, & Caballero Phys. Rev. PER (2020)



Sample Learning Goals

- Apply the momentum principle iteratively/ computationally to predict the motion or determine the properties of motion/net force acting on a single-particle system where the net force is not constant (e.g., due to spring-like restoring forces or dissipative drag forces).
- For a multi-particle and/or deformable system, use conservation of energy for the center of mass system to explain and/or predict the final state of the center of mass.

In Class Activities (two classes)



Login

Projects & Practices in Physics
a community-based learning environment

Recent changes Media Manager Sitemap

Trace: · 183_projects · project_1a · start · **project_3_2015_semester_1**

183_projects:project_3_2015_semester_1

Project 3: Geosynchronus Orbit: Part A

The Carver Media Group is planning the launch of a new communications satellite. Elliot Carver (head of Carver Media Group) is concerned about the launch. This is a $200,000,000 endeavor. In particular, he is worried about the orbital speed necessary to maintain the satellite's geosynchronous orbit (and if that depends on the launch mass). You were hired as an engineer on the launch team. Carver has asked that you allay his concerns.

Project 3: Geosynchronus Orbit: Part B

Carver is impressed with your work, but remains unconvinced by your predictions. He has asked you to write a simulation that models the orbi of the satellite. To truly convince Carver, the simulation should include representations of the net force acting on the spacecraft, which has a mass of 15×10^3 kg. Your simulation should be generalized enough to model other types of orbits including elliptical cnes.

Code for Project 3:
geosync.py
PhysUtil Module

183_projects/project_3_2015_semester_1.txt · Last modified: 2015/01/29 12:42 by pwirving

```
from __future__ import division
from visual import *
from visual.graph import *
from physutil import *

# Window setup
scene.width = 1024
scene.height = 760

# Objects
Earth = sphere(pos=vector(0,0,0), radius=6.4e6, material=materials.BlueMarble)
Satellite = sphere(pos=vector(42164e3, 0,0), radius=1e6, color=color.red, make_trail=True)

# More window setup
scene.range=12*Earth.radius

# Parameters and Initial conditions
mSatellite = 15e3
pSatellite = mSatellite*vector(0,3073,0)
G = 6.67e-11
mEarth = 5.97e24

# Time and time step
deltat = 1
t = 0
tf = 60*60*24

SatelliteMotionMap = MotionMap(Satellite, tf, 20, markerScale=2000, labelMarkerOrder=False)
FnetMotionMap = MotionMap(Satellite, tf, 20, markerScale=2000, labelMarkerOrder=False)

sepgraph = gcurve(color=color.red)

#Calculation Loop
while t < tf:
        theta = (7.29e-5) * deltat      #       IGNORE THIS LINE
        Earth.rotate(angle=theta, axis=vector(0,0,1), origin=vector(0,0,0))     #       IGNORE THIS LINE
        rate(10000)

        Fgrav = -G*mSatellite*mEarth*Satellite.pos/(mag(Satellite.pos)**3)
        Fnet = Fgrav

        Satellite.pos = Satellite.pos + pSatellite/mSatellite*deltat
        pSatellite = pSatellite + Fnet*deltat

        SatelliteMotionMap.update(t, pSatellite/mSatellite)
        FnetMotionMap.update(t, Fnet)

        sepgraph.plot(pos=(t,mag(Satellite.pos)))

        t = t +deltat
```

Incorrect/missing values

Add algorithm and viz

Investigating Learning Assistants' Instructional Approaches

```
# Objects
Earth = sphere(pos=vector(0,0,0), radius=6.4e6, material=materials.BlueMarble)
Satellite = sphere(pos=vector(7*Earth.radius, 0,0), radius=1e6, color=color.red, make_trail=True)

# More window setup
scene.range=12*Earth.radius

# Parameters and Initial conditions
mSatellite = 1
pSatellite = vector(0,5000,0)

# Time and time step
deltat = 1
t = 0
tf = 60*60*24

SatelliteMotionMap = MotionMap(Satellite, tf, 20, markerScale=2000, labelMarkerOrder=False)

#Calculation Loop
while t < tf:
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        Satellite.pos = Satellite.pos + pSatellite/mSatellite*deltat

        SatelliteMotionMap.update(t, pSatellite/mSatellite)

        t = t + deltat
```

How do learning assistants approach teaching computational problems?

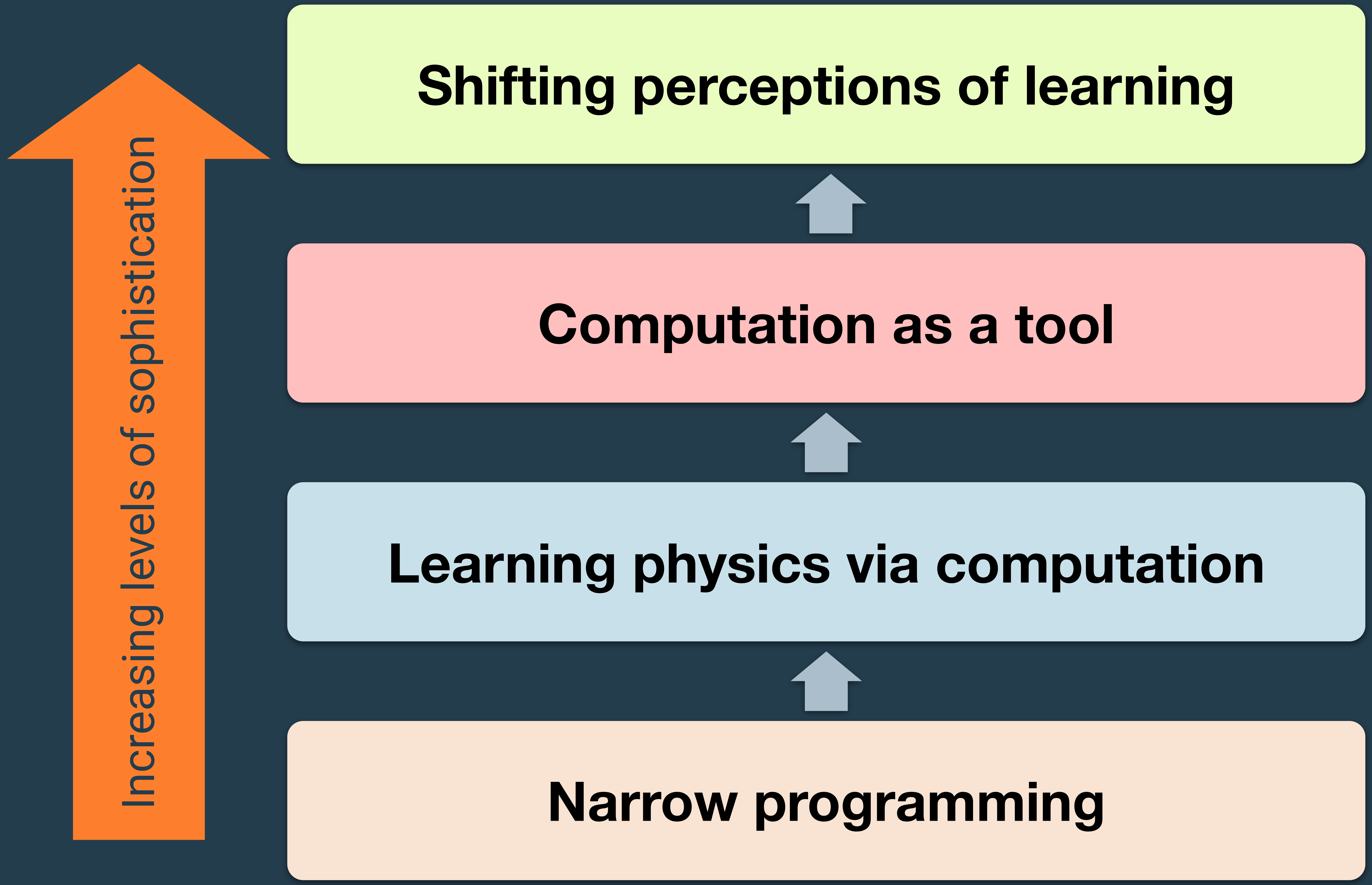
Irving, Obsniuk, & Caballero, EJP (2017)
Pawlak, Irving, & Caballero, Phys. Rev. PER (2020)
Irving, McPadden, & Caballero Phys. Rev. PER (2020)

Categories of description

Category of Description	Utility of coding	Teaching outcome	Characteristic to moderate	Teaching strategy
Narrow programming	Programming is an important skill	Programming skills	Student work pace	Focus on navigating programming errors
Learning conceptual physics via computation	Computation aids content learning	Physics-code connection	Impact of course design	Leverage affordances of computational problems
Computation as a tool for physics	Computation makes difficult problems easier	Capabilities of computation	Student attention to programming details	Encourage reflection on coding
Shifting perceptions of learning	Computation offers space for broader skills	A new approach to learning	Student attitudes	Leverage collaboration

Pawlak, Irving, & Caballero, Phys. Rev. PER (2020)

Outcome space



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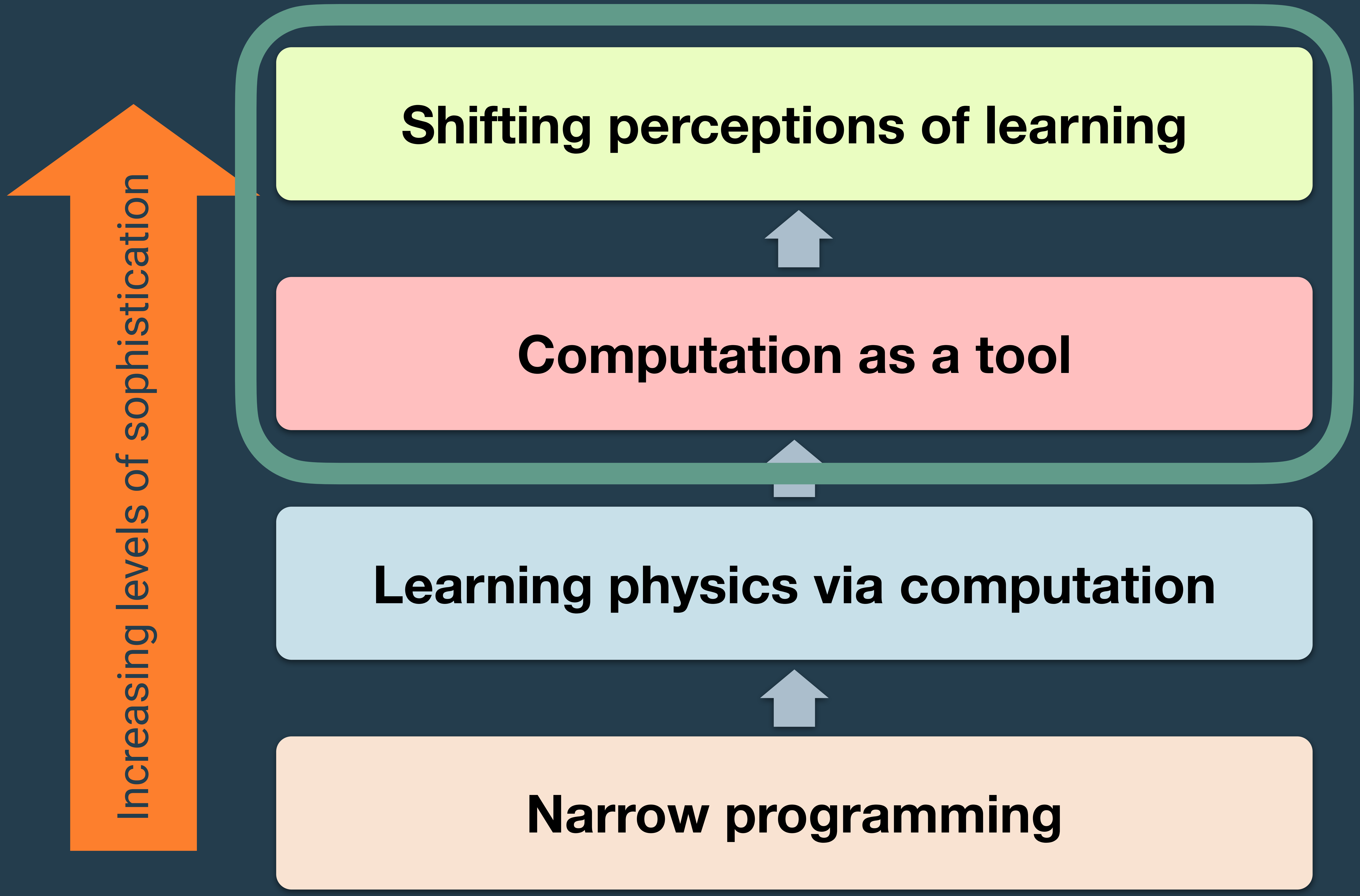


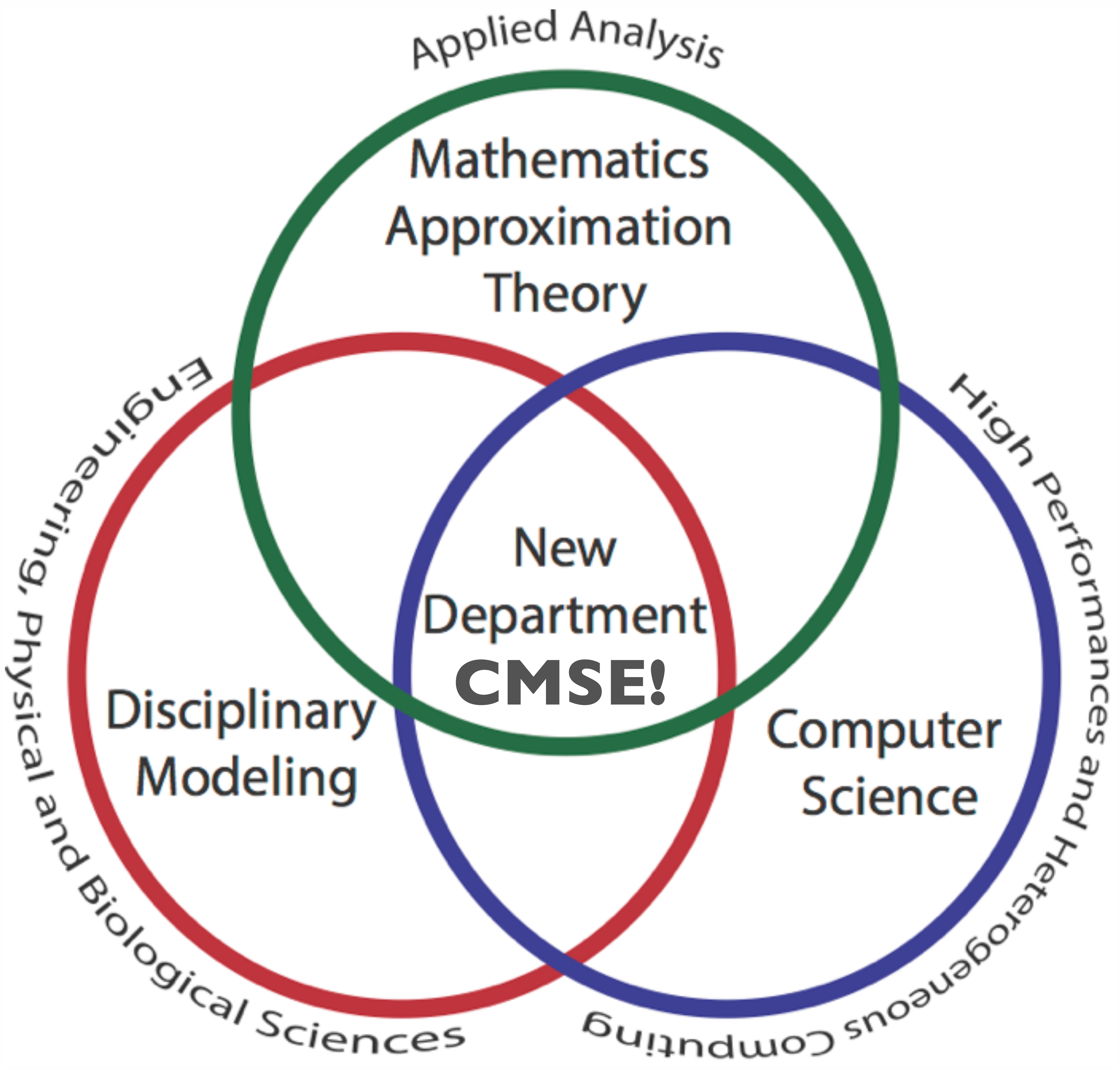
Pawlak, Irving, & Caballero, Phys. Rev. PER (2020)

Critical Components

- Flipped model with pre-class assignments using groups in class
- Minimally working programs
- Student-instructor ratios lowered to ~15:1 with LAs
- Twice weekly LA professional development
- Section coordination (counts as a teaching assignment)

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

Knock down silos



CMSE vs Computer Science?

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

Courtesy of Devin Silvia

The challenge:

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

Courtesy of Devin Silvia

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”*

*Silvia et al. 2019

ICCS 2019 Conference Proceedings

Courtesy of Devin Silvia

CMSE 201 Learning Goals

For any STEM major - pre-req: Calculus 1

Courtesy of Devin Silvia

CMSE 201 Learning Goals

1. Gain insight into physical, biological, and social systems through the use of computational algorithms and tools.

For any STEM major - pre-req: Calculus 1

Courtesy of Devin Silvia

CMSE 201 Learning Goals

2. Write programs to solve common problems in a variety of disciplines.

For any STEM major - pre-req: Calculus 1

Courtesy of Devin Silvia

CMSE 201 Learning Goals

3. Identify salient features of a system that can be codified into a model.

For any STEM major - pre-req: Calculus 1

Courtesy of Devin Silvia

CMSE 201 Learning Goals

4. Manipulate, analyze, and visualize datasets and use to evaluate models.

For any STEM major - pre-req: Calculus 1

Courtesy of Devin Silvia

CMSE 201 Learning Goals

5. Understand basic numerical methods and use them to solve problems.

For any STEM major - pre-req: Calculus 1

Courtesy of Devin Silvia

CMSE 201 Learning Goals

6. Synthesize results from a scientific computing problem and present it both verbally and in writing.

For any STEM major - pre-req: Calculus 1

Courtesy of Devin Silvia

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…

jupyter nbviewer   JUPYTER   FAQ

Courtesy of Devin Silvia

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
```

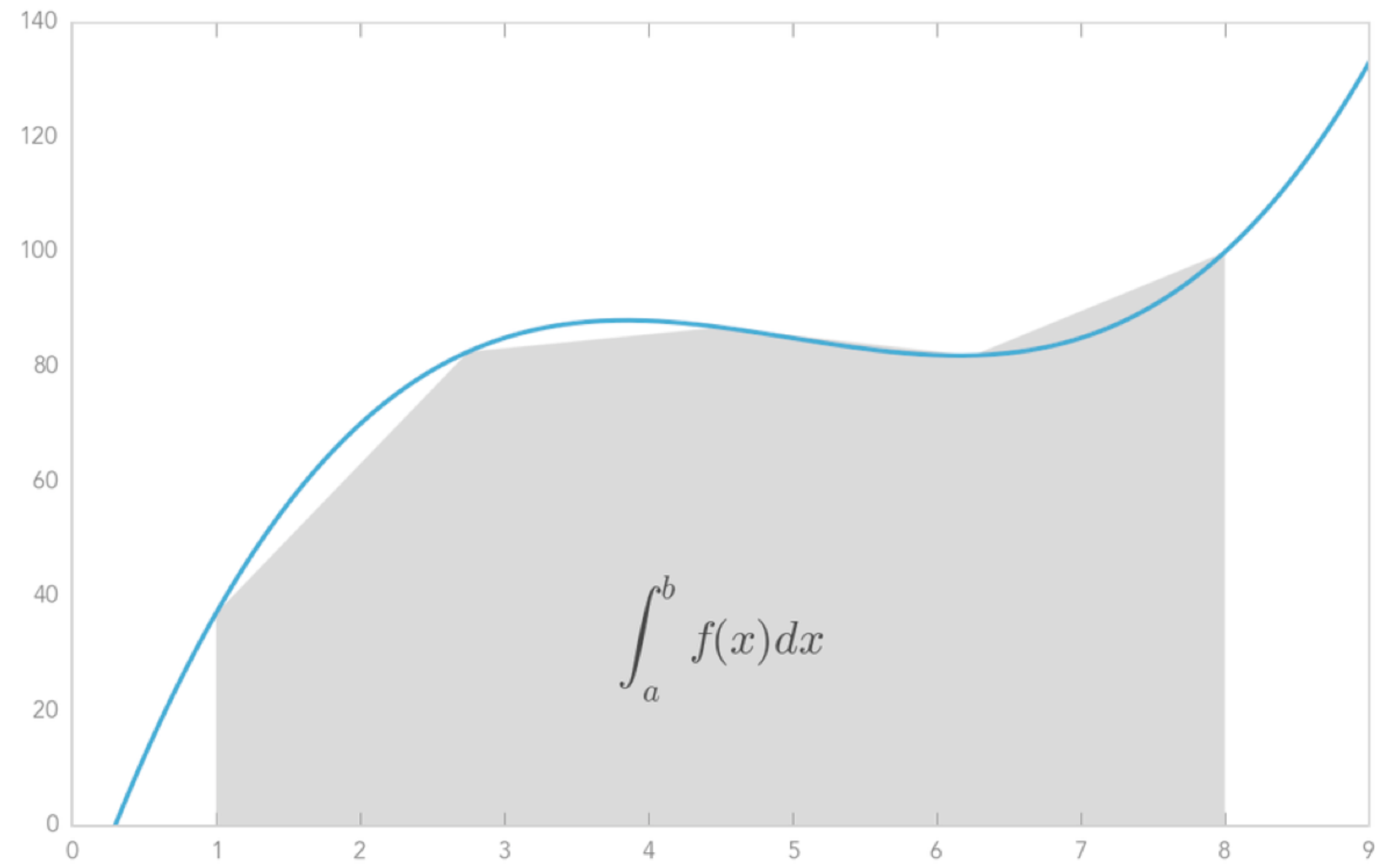
In [2]:
```
def f(x):
    return (x-3)*(x-5)*(x-7)+85

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

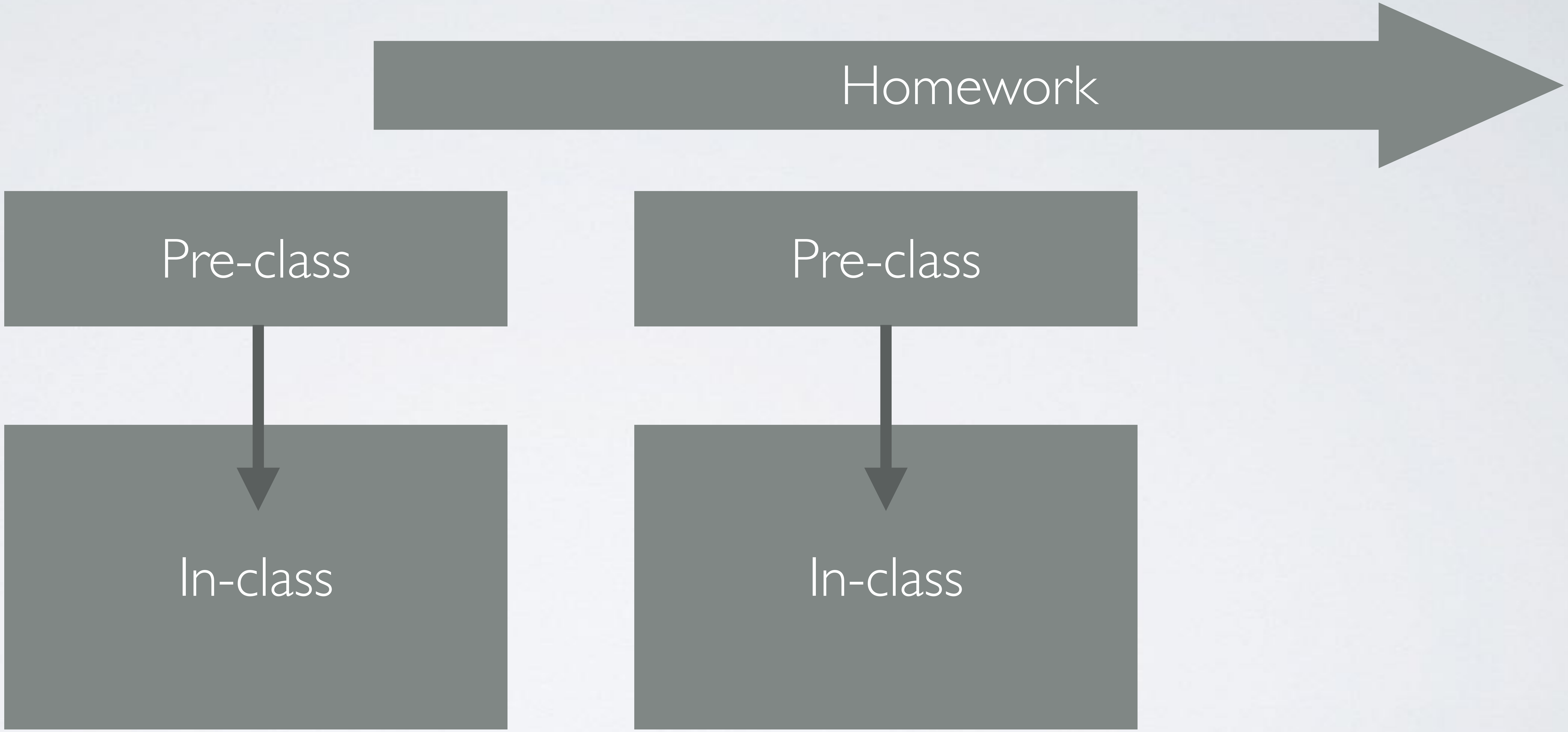
Markdown + LaTeX

Python

Inline Plots

Courtesy of Devin Silvia

A typical week in our flipped classroom



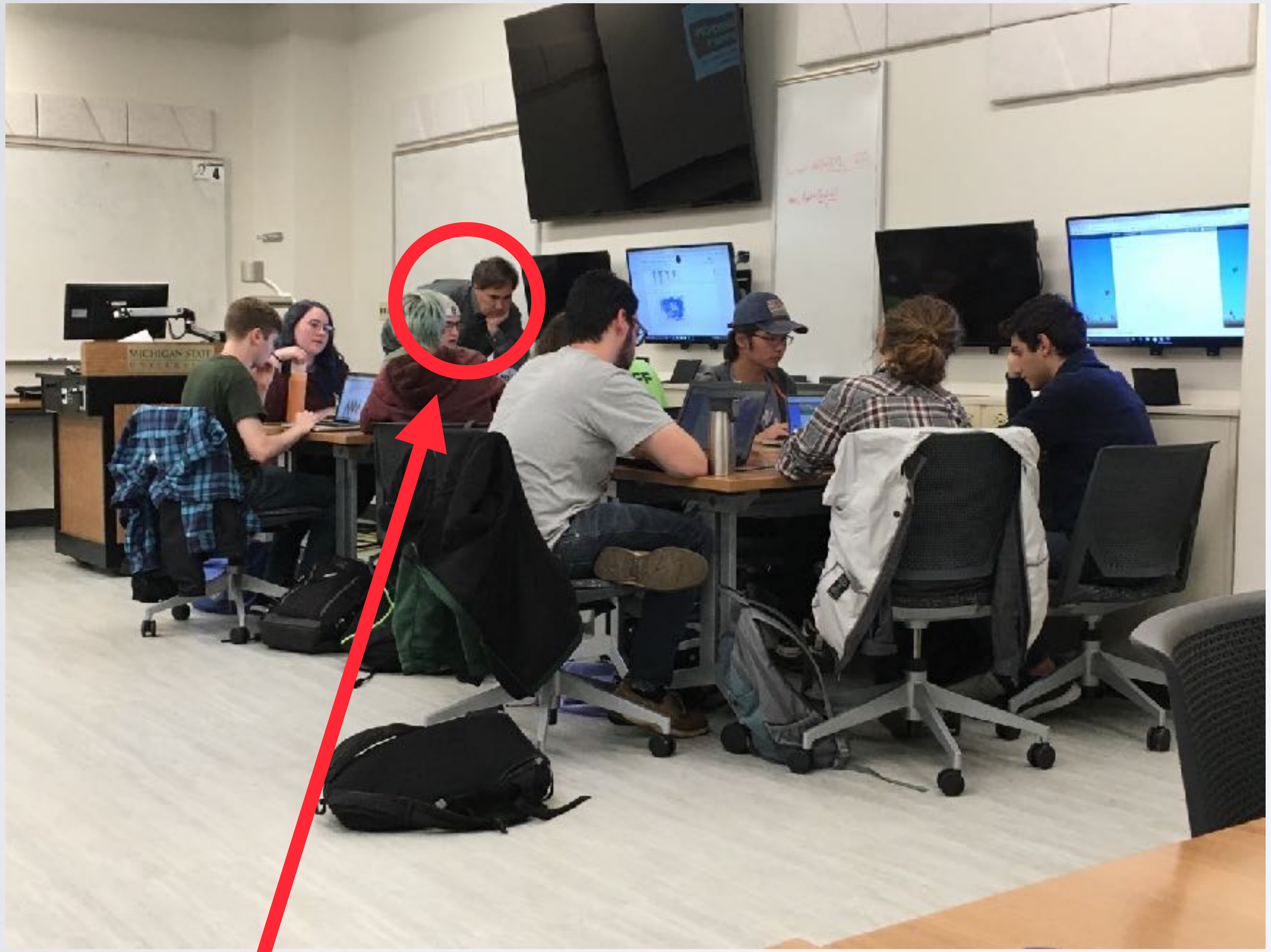
Courtesy of Devin Silvia

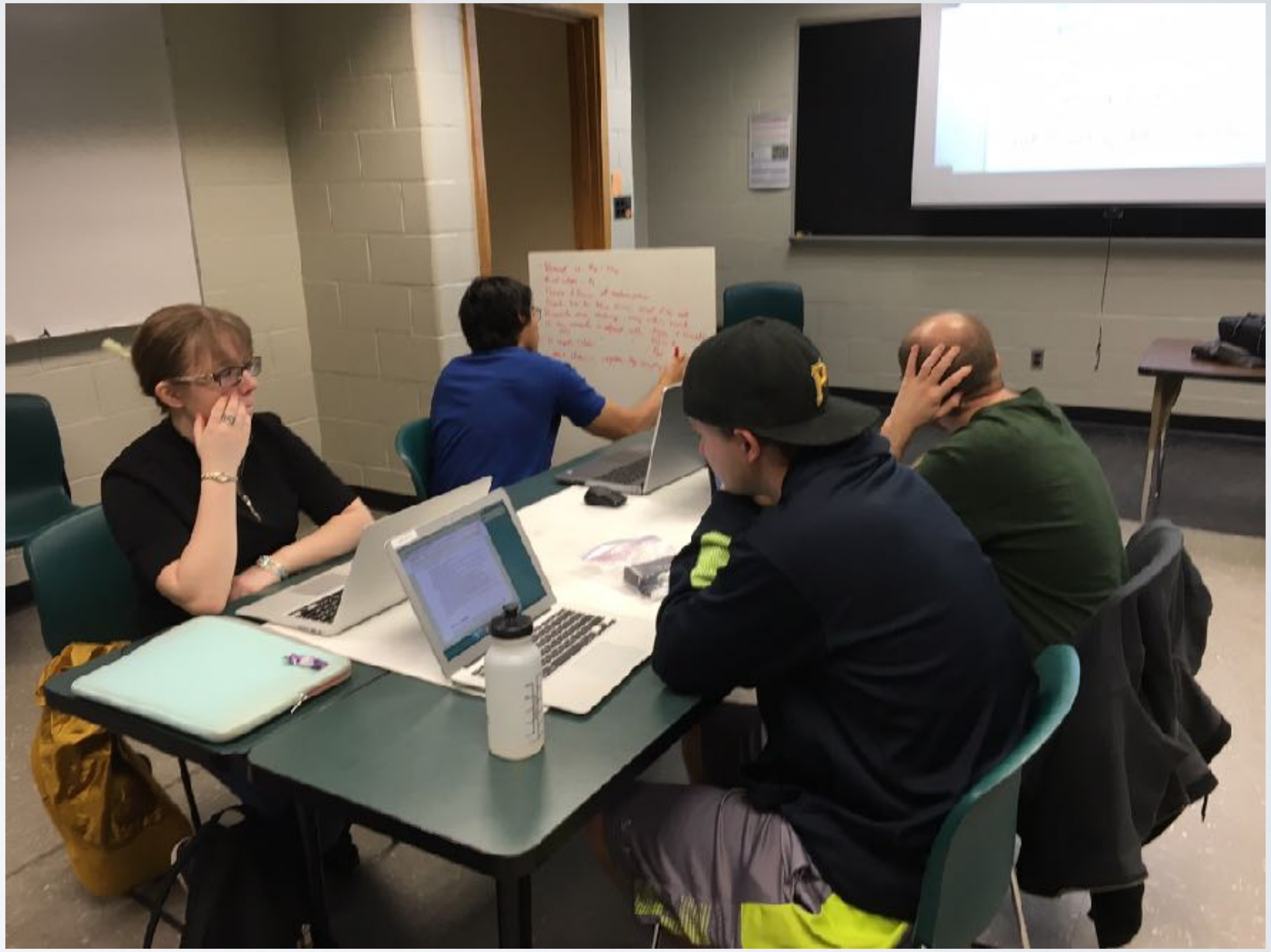
Classroom Environment

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

Courtesy of Devin Silvia

Classroom Environment





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

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.
- Use NumPy when necessary to manipulate arrays or perform mathematical operations

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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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jupyter

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Now required for PA students Before Classical Mechanics 1

Critical Components

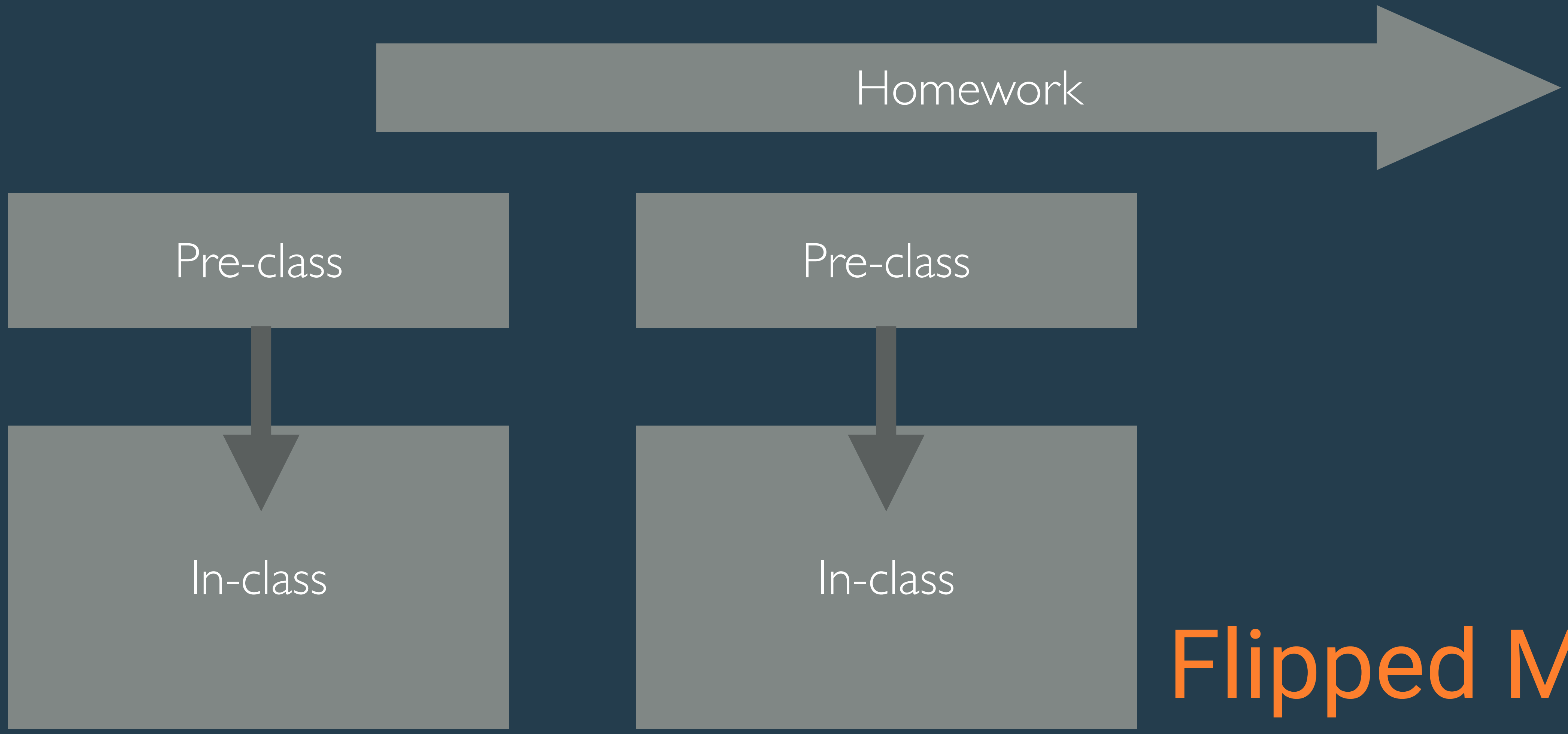
- *Flipped Model with pre-class activities*
- *Student-instructor ratios lowered to ~15:1 with LAs*
- *Section coordination (counts as a teaching assignment)*
- Integrated approach using modeling practices, different contexts, and introductory programming tasks
- All instruction is facilitated by Jupyter notebooks

In collaboration with Patti Hamerski

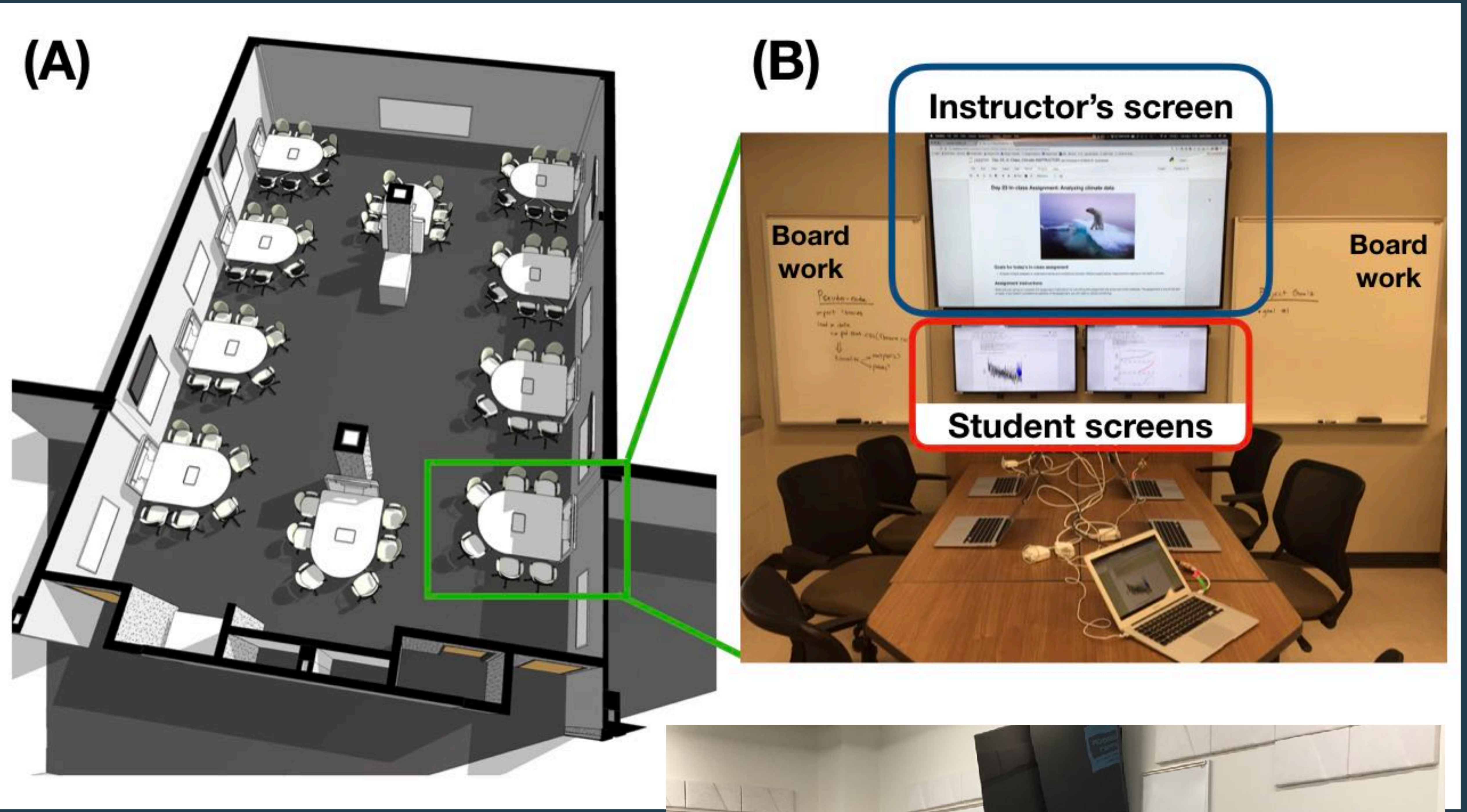
Introduction to Data Science - STT180

You will learn about:

- *data ethics,*
- *how to manipulate data objects,*
- *produce advanced graphics,*
- *tidy and wrangle data,*
- *generate reproducible statistical reports using R markdown,*
- *the fundamentals of probability and statistics, and*
- *rudimentary machine learning techniques.*



Flipped Model



Use RMarkdown

Course Progression

For STEM, EGR, Econ, Business…anyone taking Calc 1

- Using R & RMarkdown; data ethics
- Reading, manipulating, and filtering data
- Visualizing data
- Programming in R (skipped Spring 2023)
- Sampling, simulation, and statistical inference
- Linear regression, GLM, and classification tasks with ML

In-class Activities

From the articles:

Summarize the main points of the article you read. You had your choice of three linked on D2L (around 250–500 words).

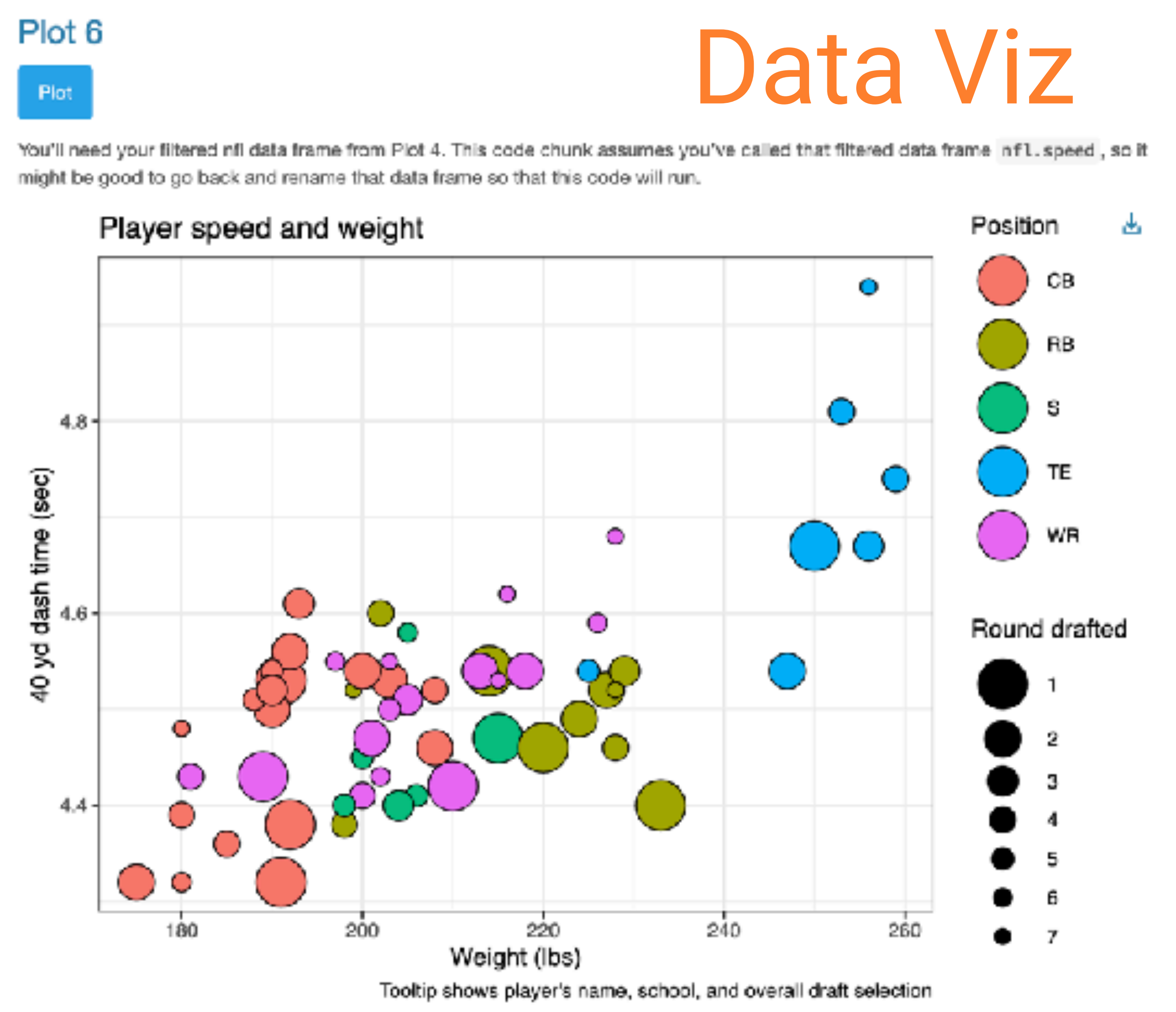
In your group, discuss how the articles and videos were related to data ethics and justice. Summarize your discussion below (around 250–500 words).

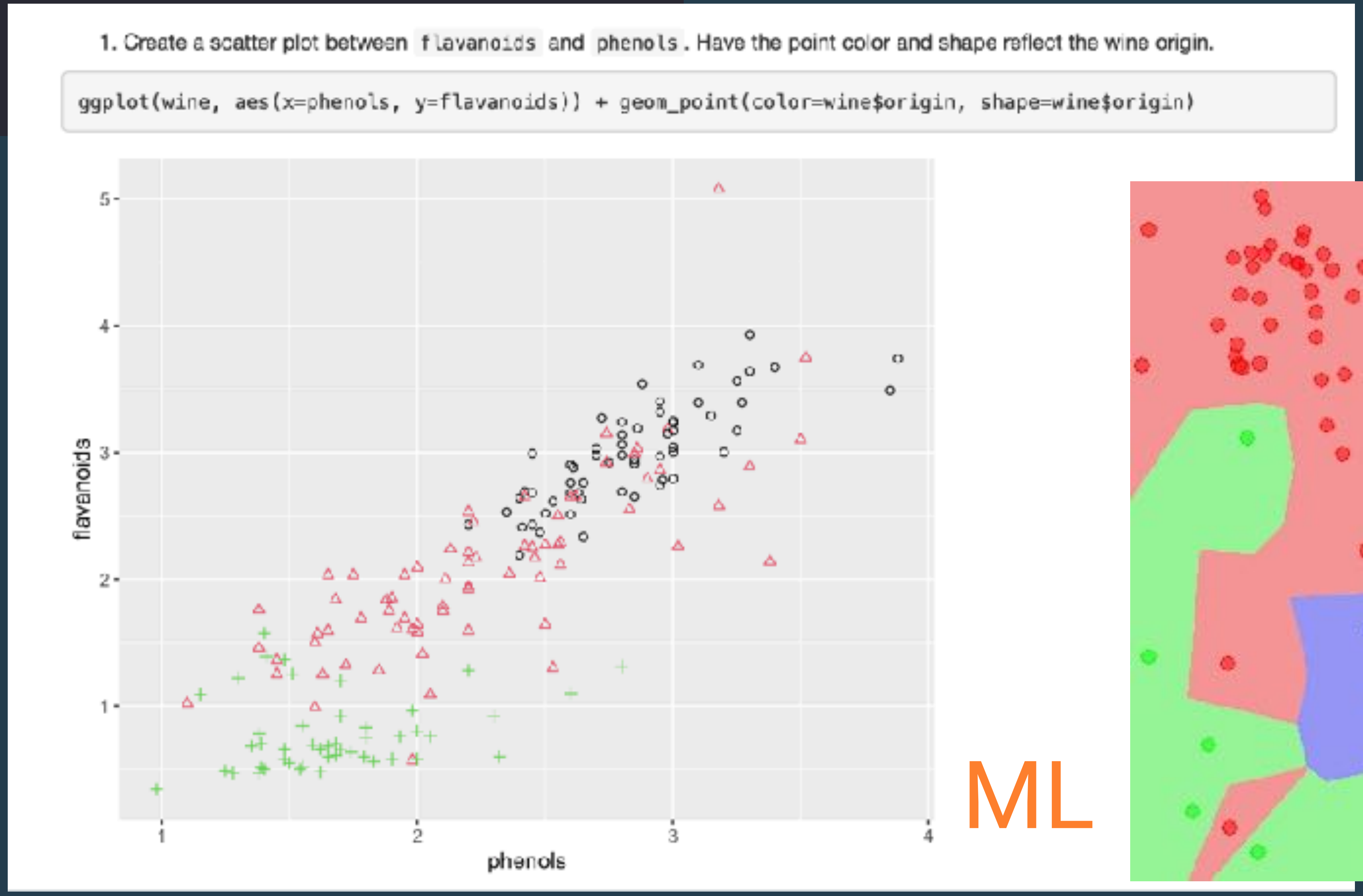
Some questions to consider:

- How is data being used?
- How does the actual usage of data relate to its intended usage?
- Who owns and/or controls the data?
- Who benefits from the data usage?
- How is data usage related to privacy?
- How is data usage related to bias?

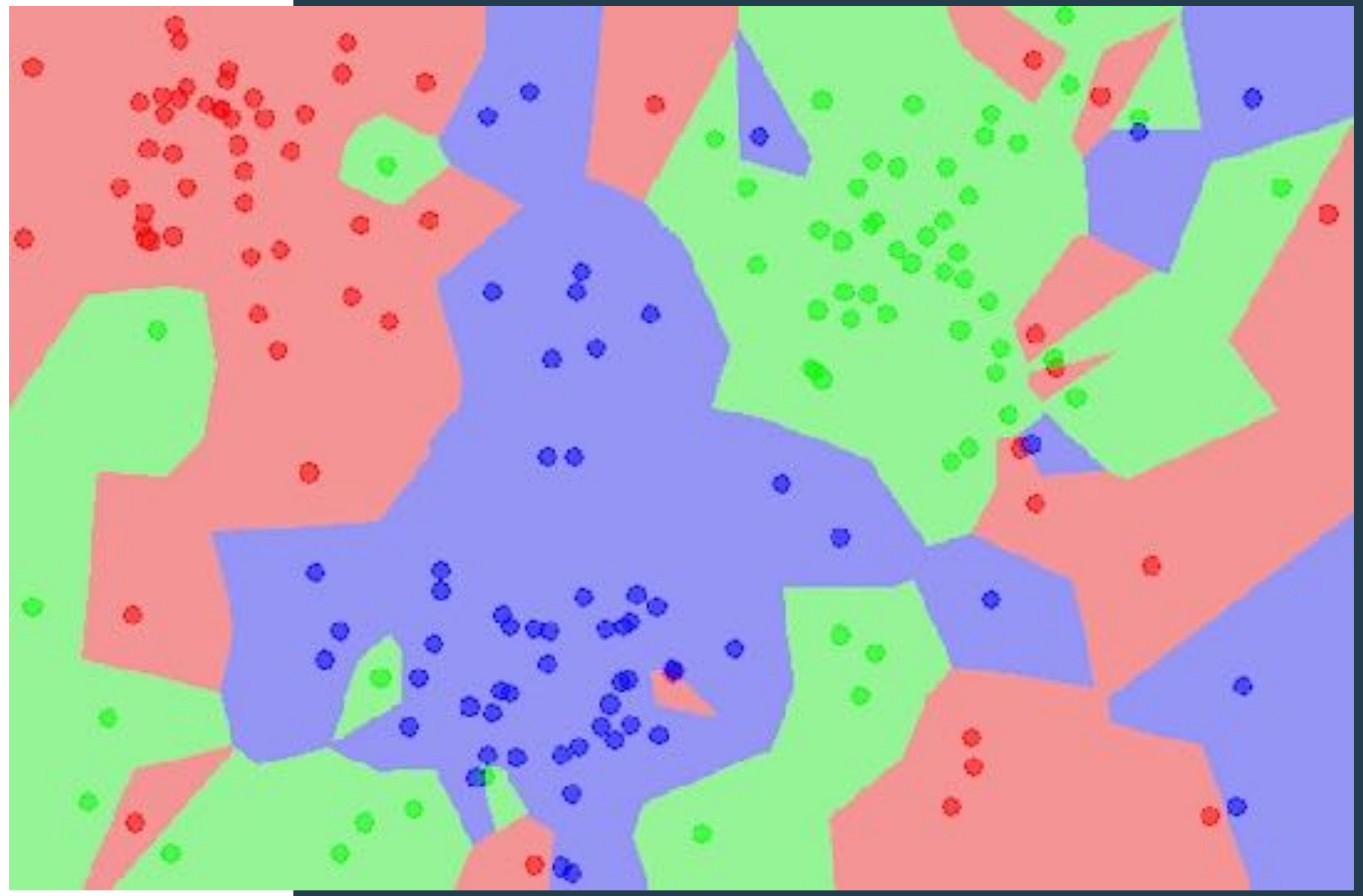
What do data ethics mean to you?

Data Ethics





ML



Final Projects

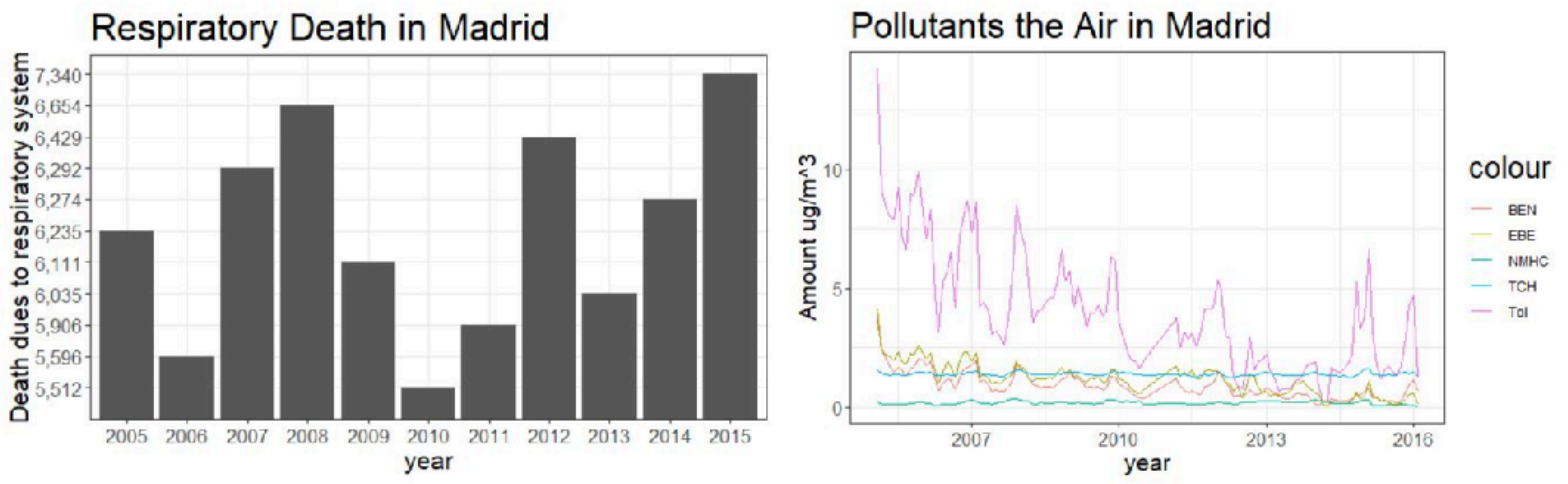
Students synthesize their skills in a single group project

- Develop questions for your data
- Generate justifiable claims illustrated with data analysis, visuals, and modeling
- Present those claims publicly

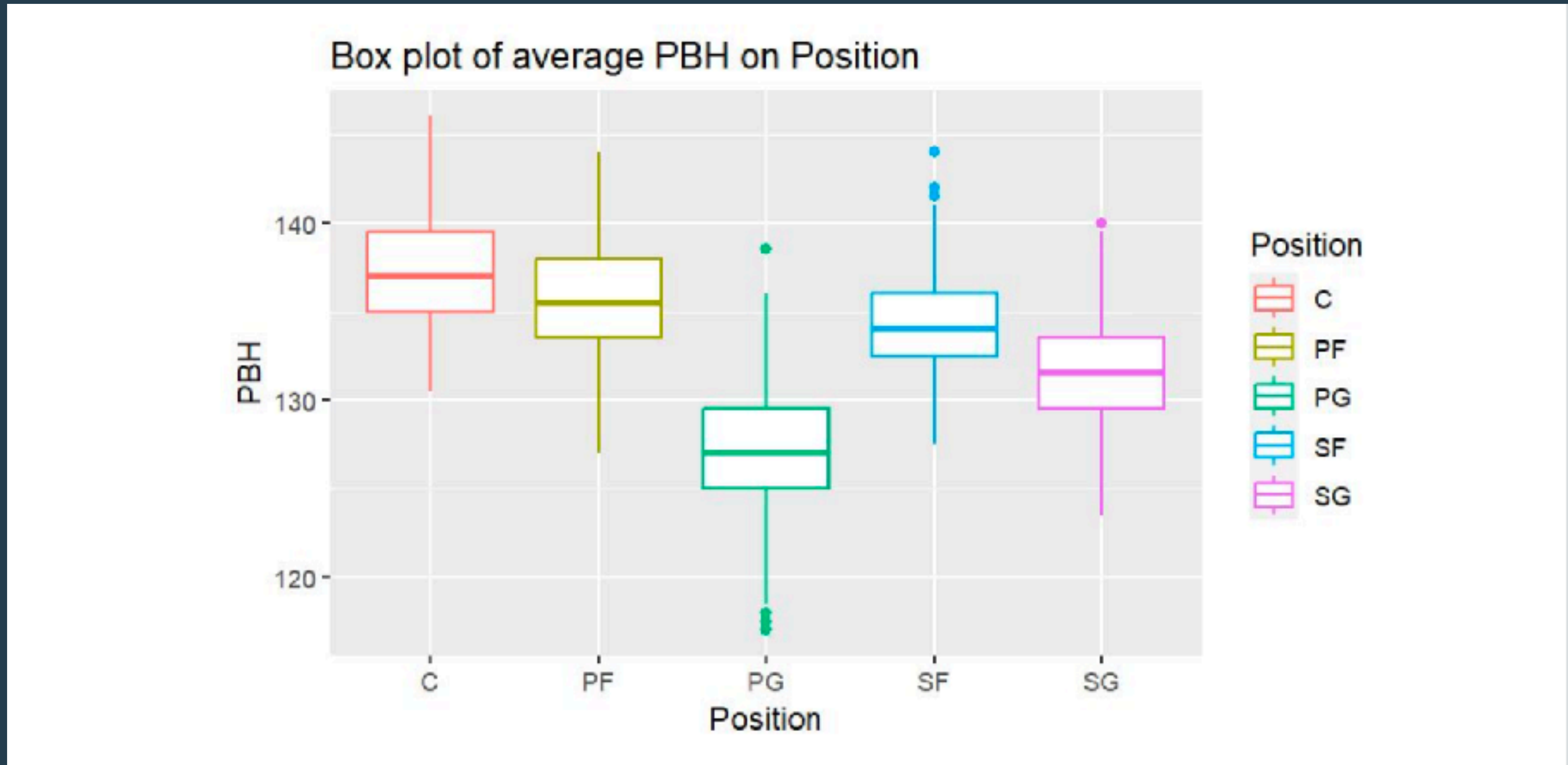
Air Quality and Pollutants

Defining Respiratory Diseases

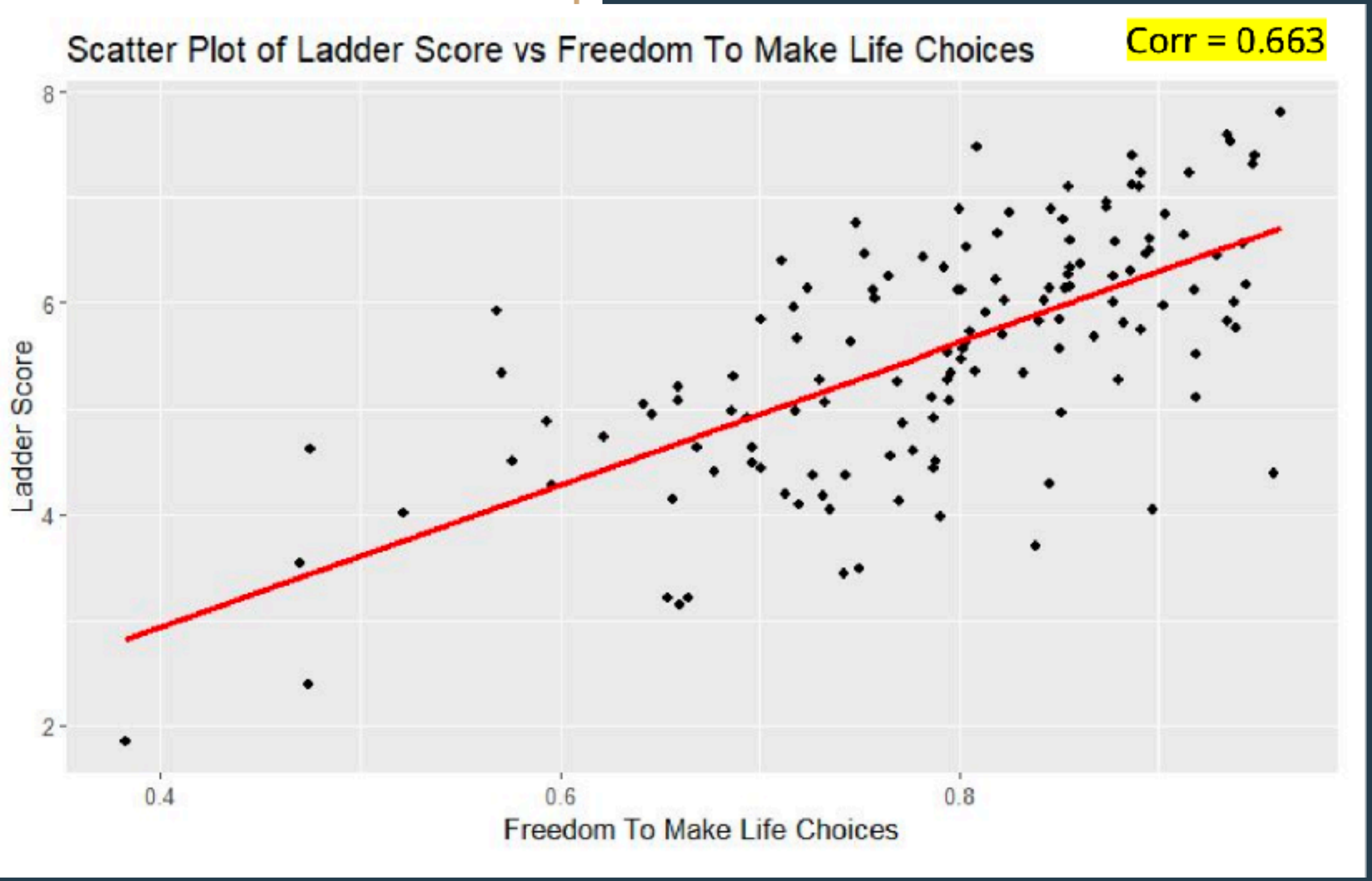
National Cancer Institute defines respiratory diseases as asthma, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis, pneumonia, and lung cancer.



Wide variety of contexts

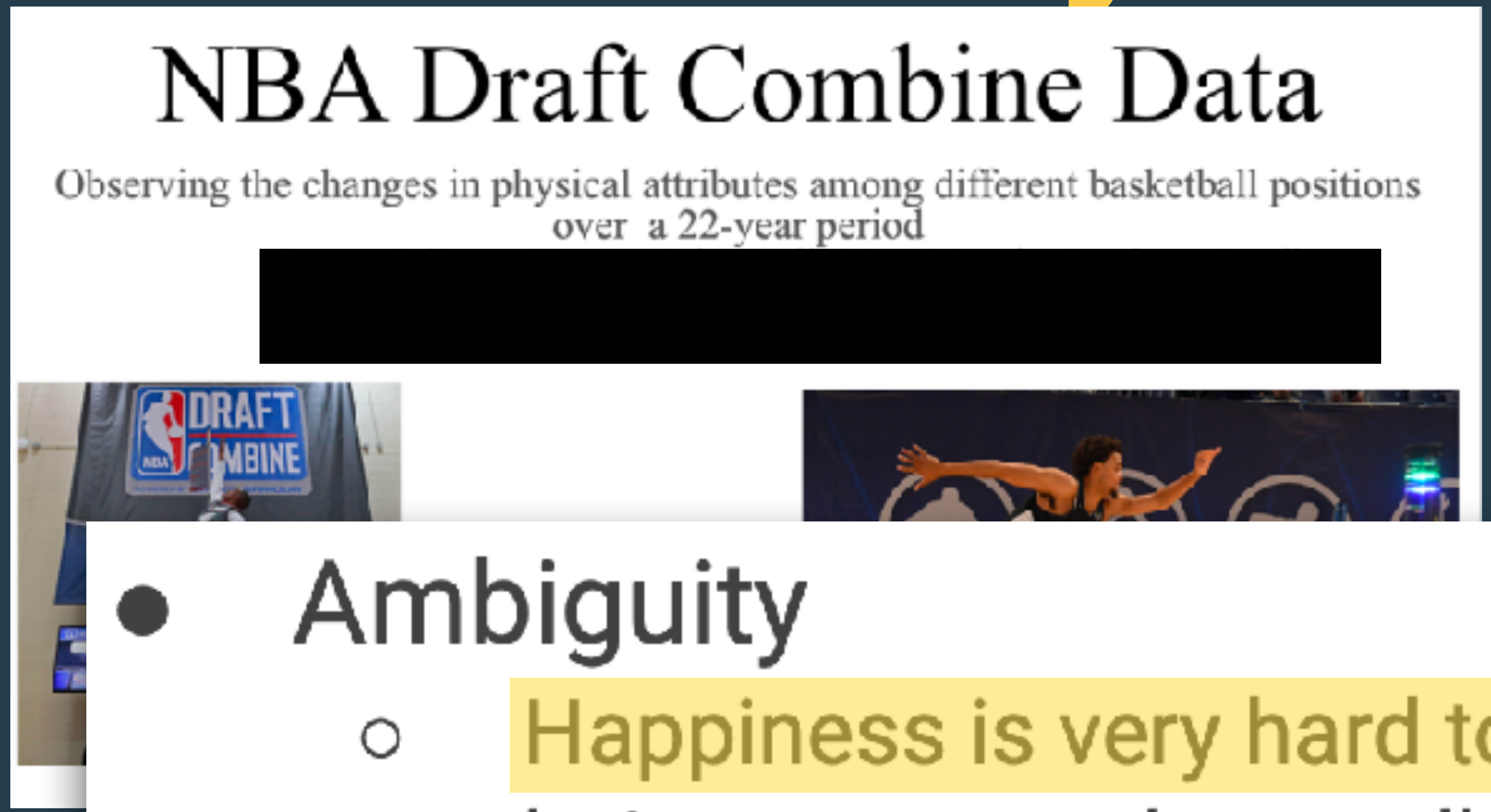


"PBH" is Standing reach + Standing Vertical. The "Point Guard" position has the lowest boxplot by far on this combined graph, but had the highest standing vertical out of any position. This shows how much "Point Guards" lack standing reach in comparison to other positions.

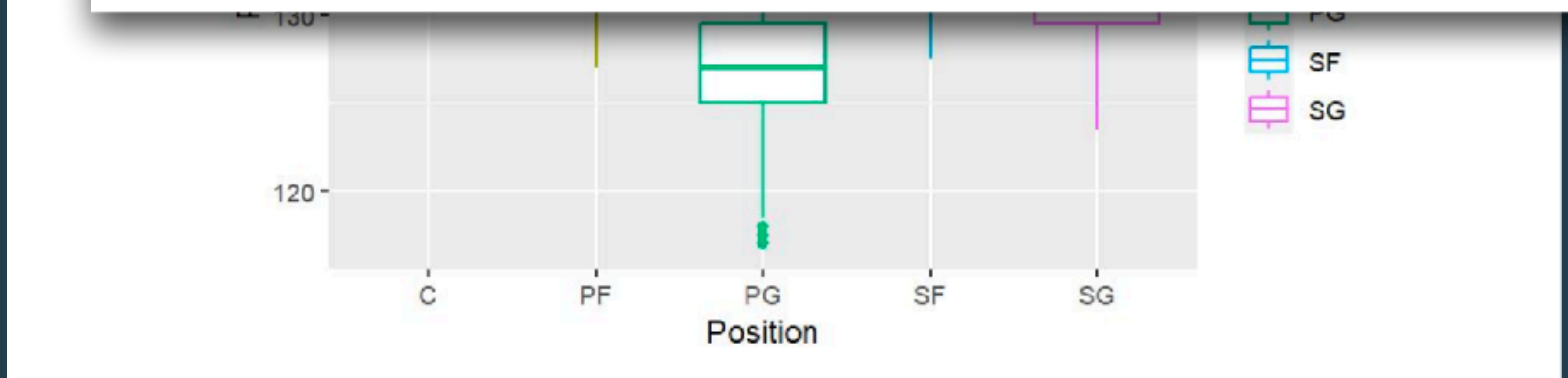


In collaboration with Patti Hamerski

Wide variety of contexts



- Ambiguity
  - Happiness is very hard to quantify and the dataset isn't clear on how the ladder scores are being generated, as well as the representative sample they are being generated from
- Conflation
  - Many of the values in the dataset show the values of a western researcher asking about personal ideological values. Thus, a country can score high on many of these points if they are westernized, as shown by the countries at the top of the list



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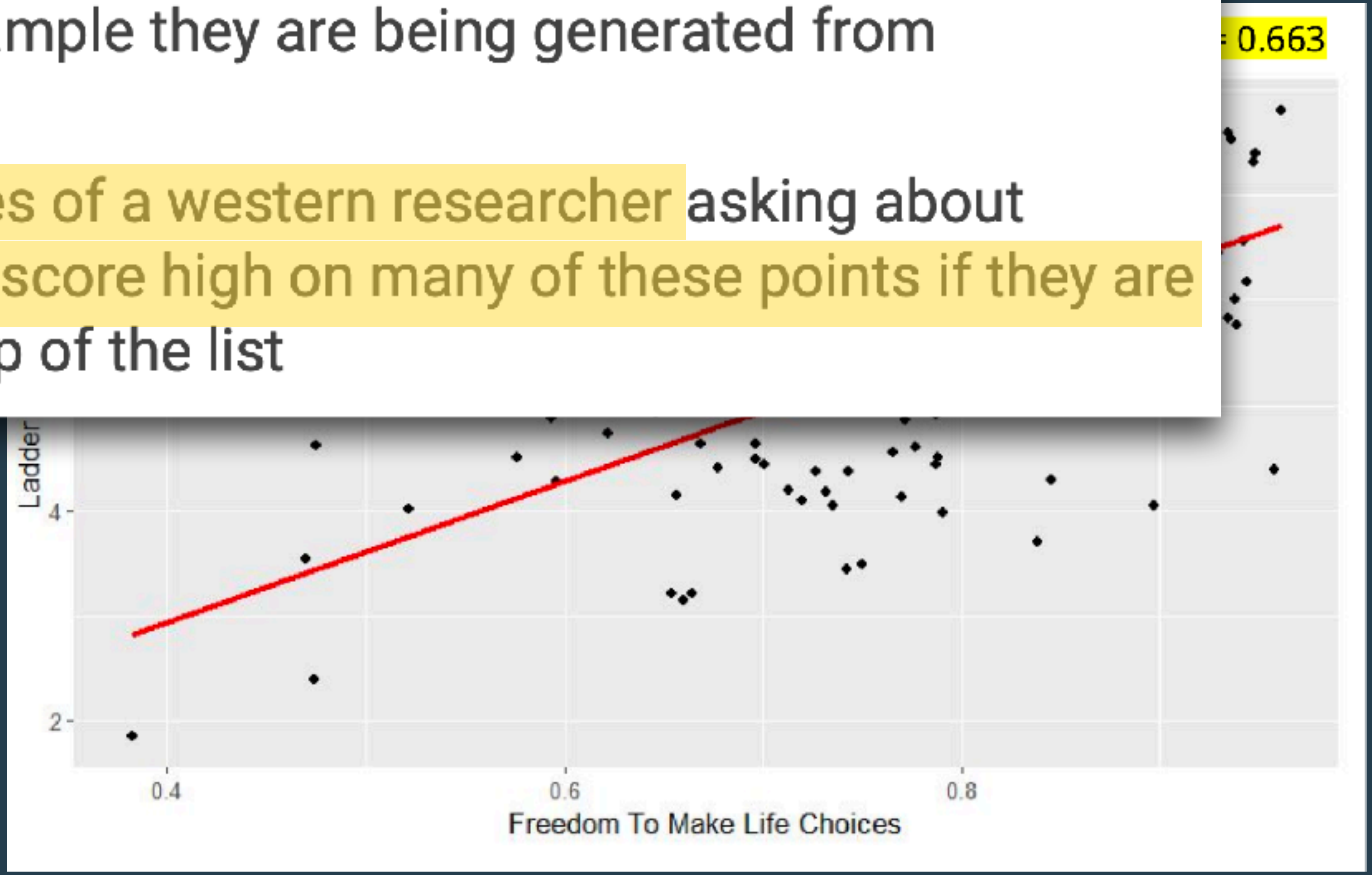

Critical Components

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- *Section coordination (counts as a teaching assignment)*
- *Integrated approach using modeling practices, different contexts, and introductory programming tasks*
- All instruction is facilitated by RMarkdown notebooks
- Assessments use final projects & presentations
- Focus on student interests

Parting thoughts

Computing education at MSU is supported by:

- flipped classes that focus on learning through in-class activities,
- appropriately scaffolded activities and assessments,
- learning assistants who have weekly professional development opportunities,
- section coordination by expert and dedicated instructional staff,
- integrated approaches where computing is just another way of doing science,
- constant formative assessment, and
- summative assessments that embrace students’ interests

Thanks, y’all

Questions?