



Supporting the integration of computing in physics education

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Department of Computational Mathematics,

Science, and Engineering

CREATE For STEM Institute

University of Oslo

Department of Physics

Centre for Computing in Science Education



What do I do with my physics degree?

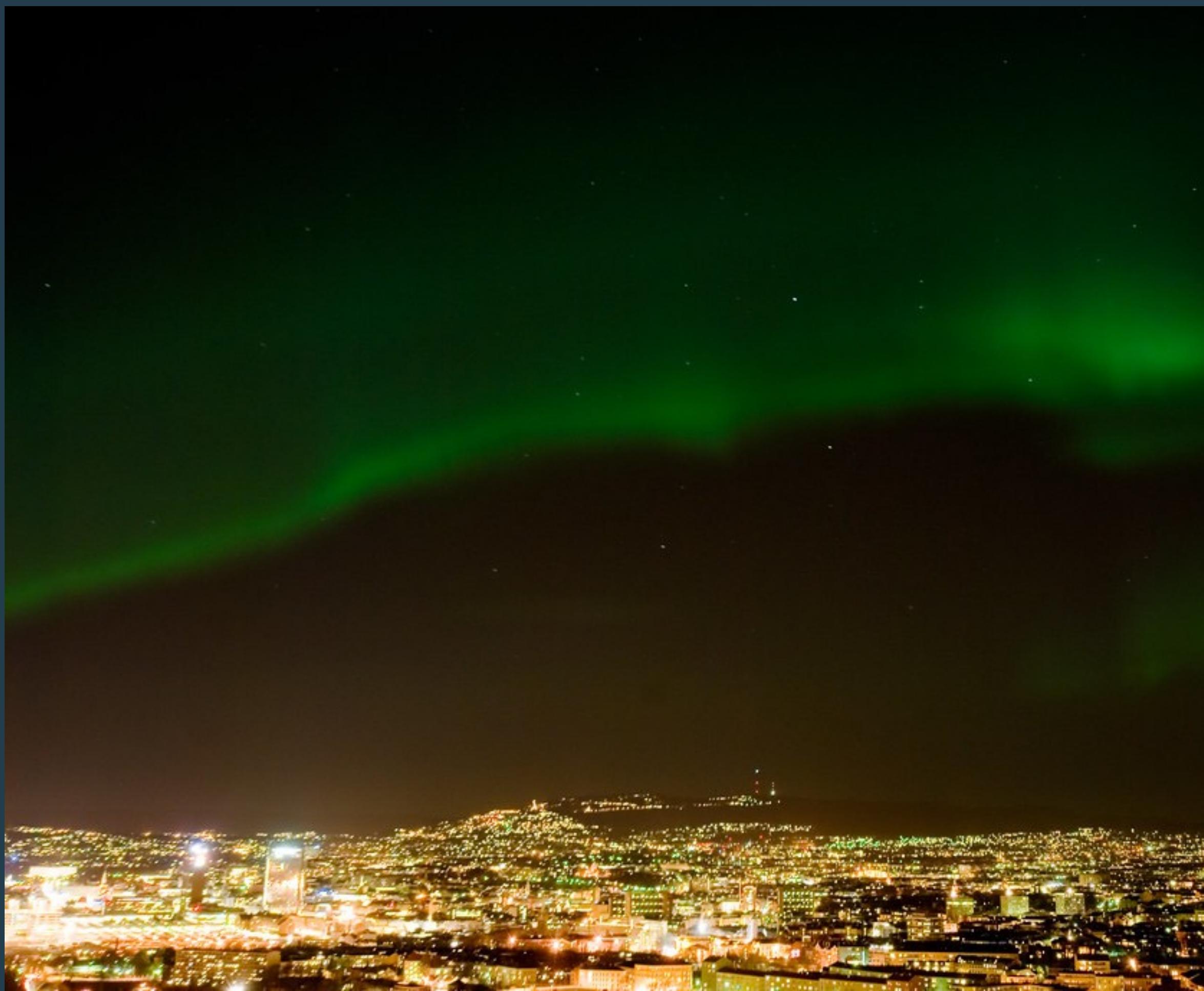
A few things...

- PhD in Physics from Georgia Tech;
Postdoc Physics Education at CU-Boulder
- Former high school physics teacher;
Atlanta Public Schools
- Professor of Physics and Computational
Science at MSU and UiO
- Co-direct two research labs (in Physics &
Computational Science Education)
- Labor Organizer for Union of Tenure
System Faculty-MEA



Danny Caballero
github.com/dannycab
Since November 2011
13 followers · 2 following
Michigan State University · East Lansing, MI
@physicstdanny





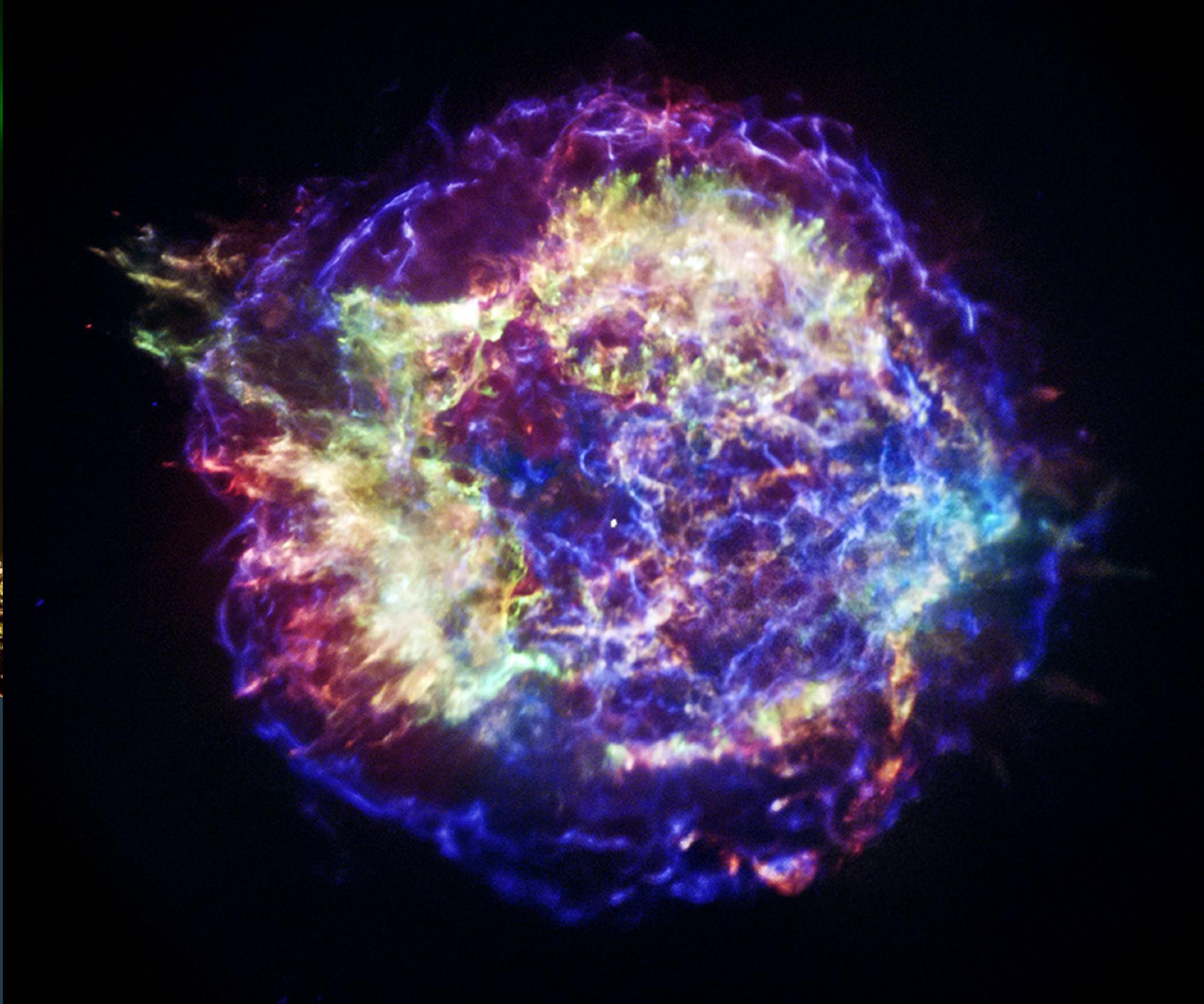
aurora borealis over oslo

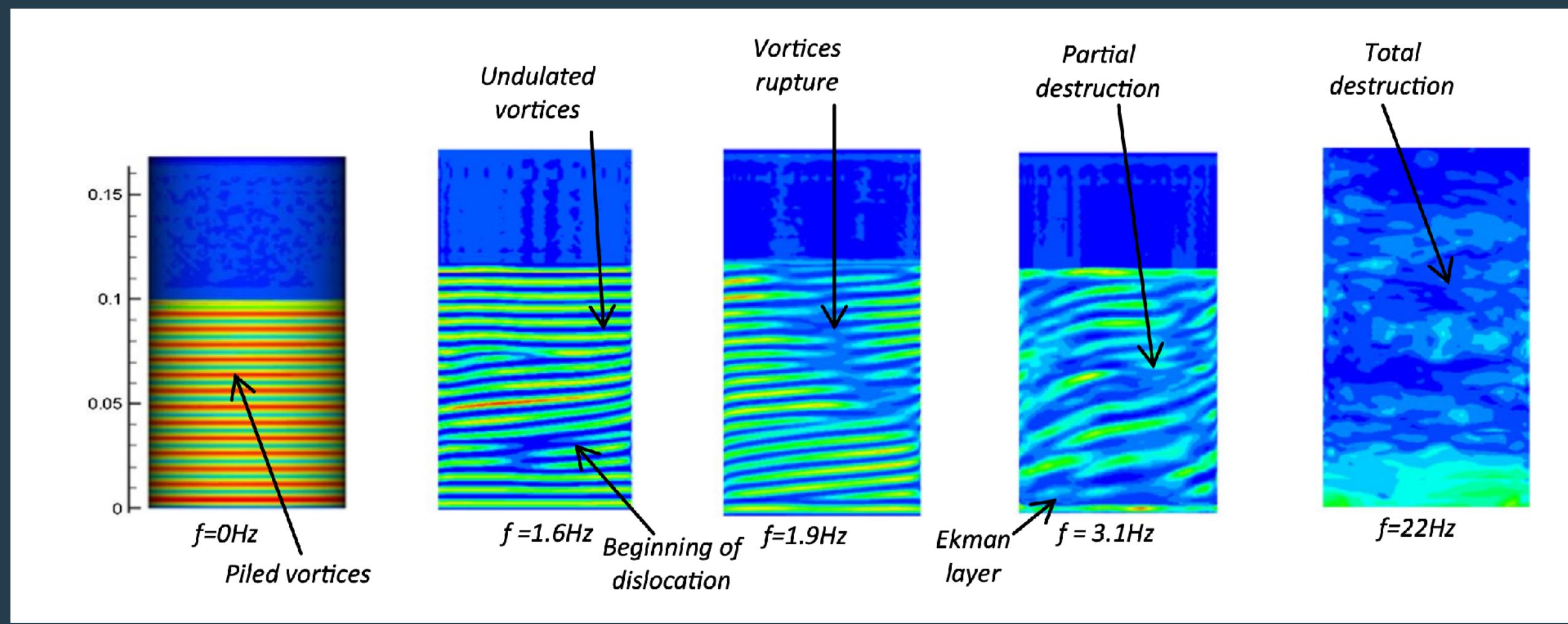
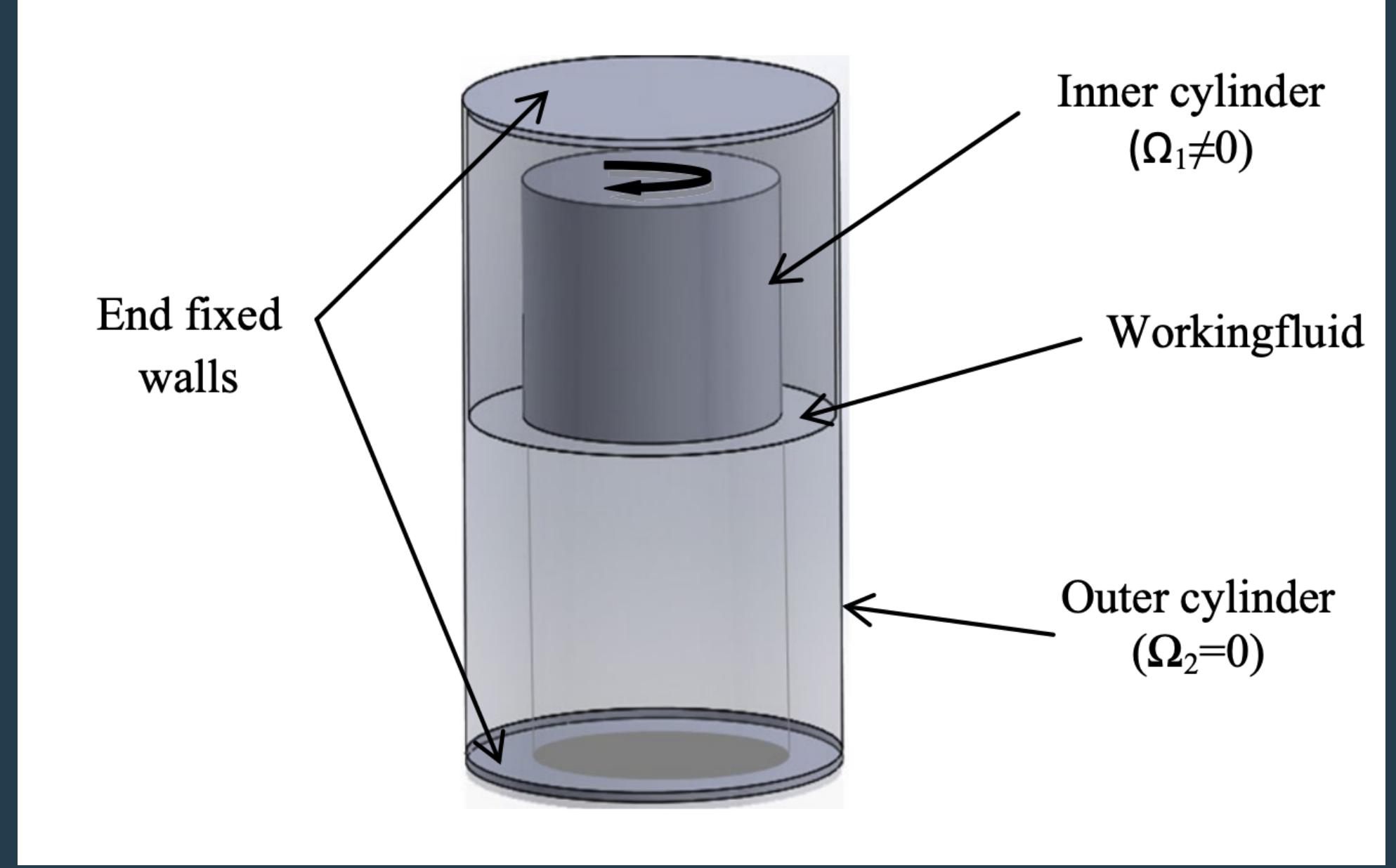
<https://www.flickr.com/photos/65218245@N00/326627830>

science can explain
natural phenomena

supernova remnant - cassiopeia a

https://www.nasa.gov/mission_pages/chandra/multimedia/exploring-cassiopeiaA.html





taylor-couette cylinder & transition to turbulence

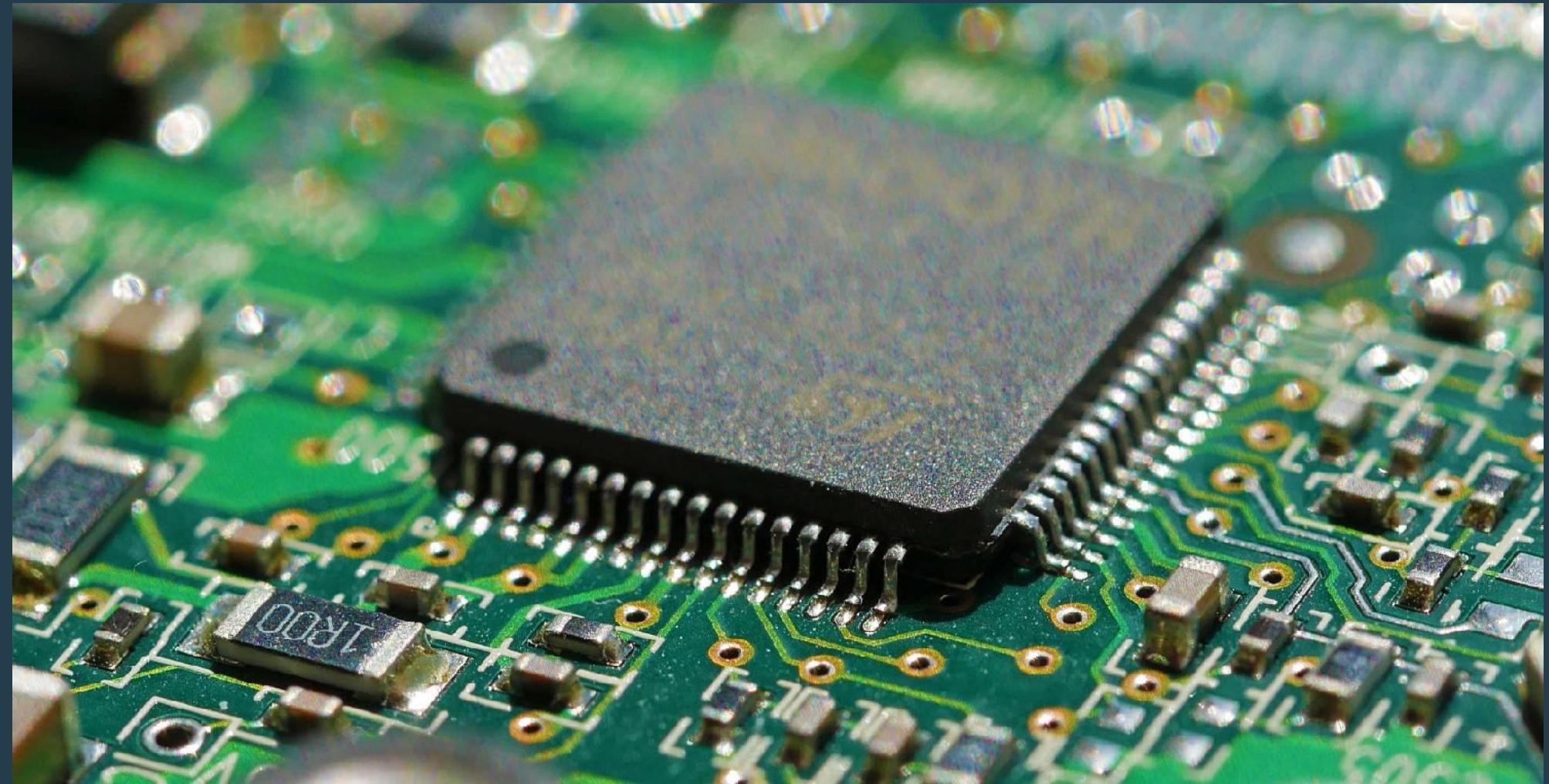
Abdelali, A., et al. *Journal of the Brazilian Society of Mechanical Sciences and Engineering* 41.6 (2019): 259.

natural transition to turbulent flow

<https://www.flickr.com/photos/22493175%40N02/50000447596>

science can satisfy
human curiosity

science can benefit society



framing my work

all folks can develop a deep understanding of science

all folks can develop a positive stance towards science

all folks can shape the work and practice of science

framing my work

all folks can develop a deep understanding of science

all folks can develop a positive stance towards science

all folks can shape the work and practice of science

we discover, design, and develop the
conditions and environments in which all folks
who are learning science can thrive

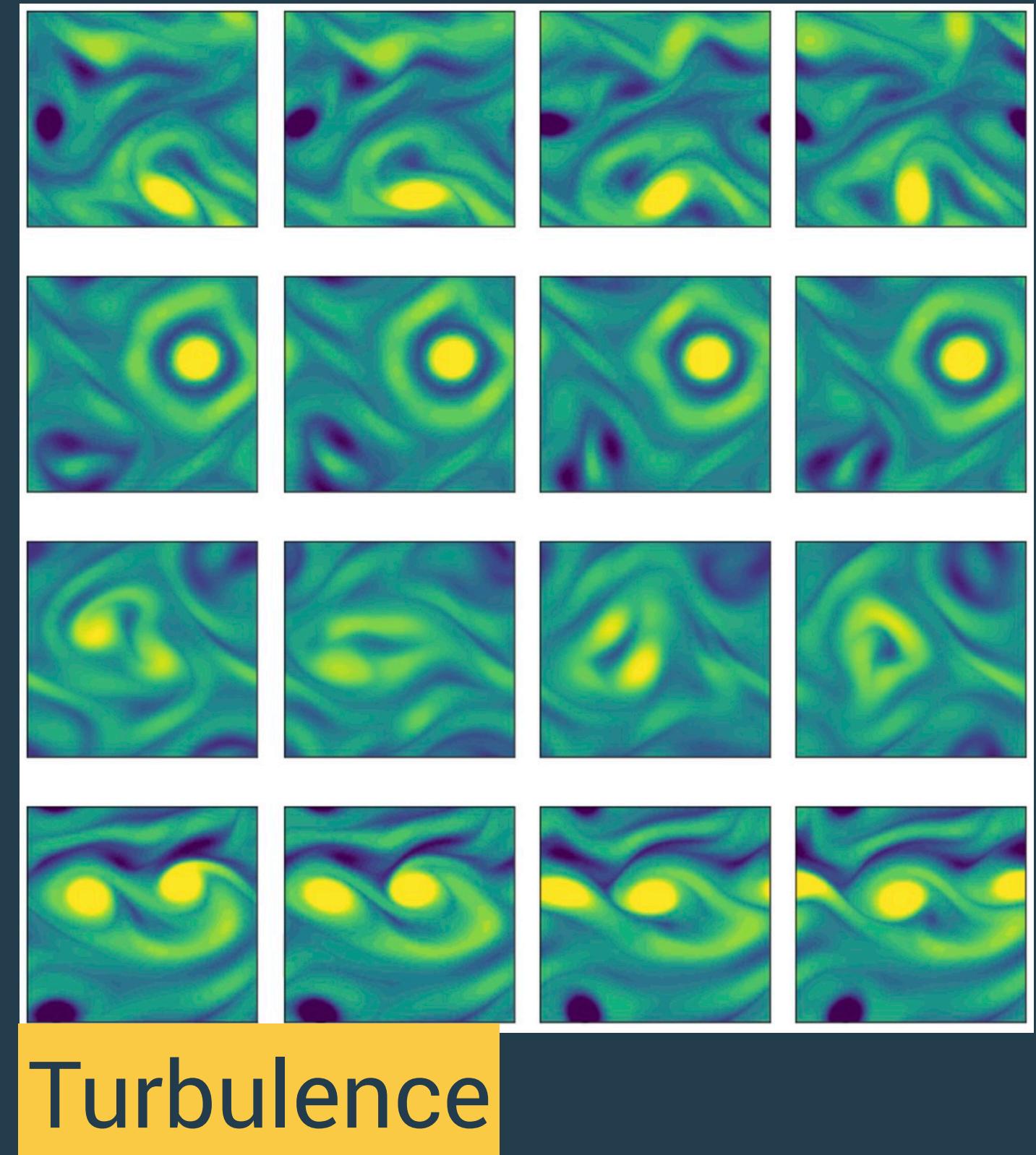
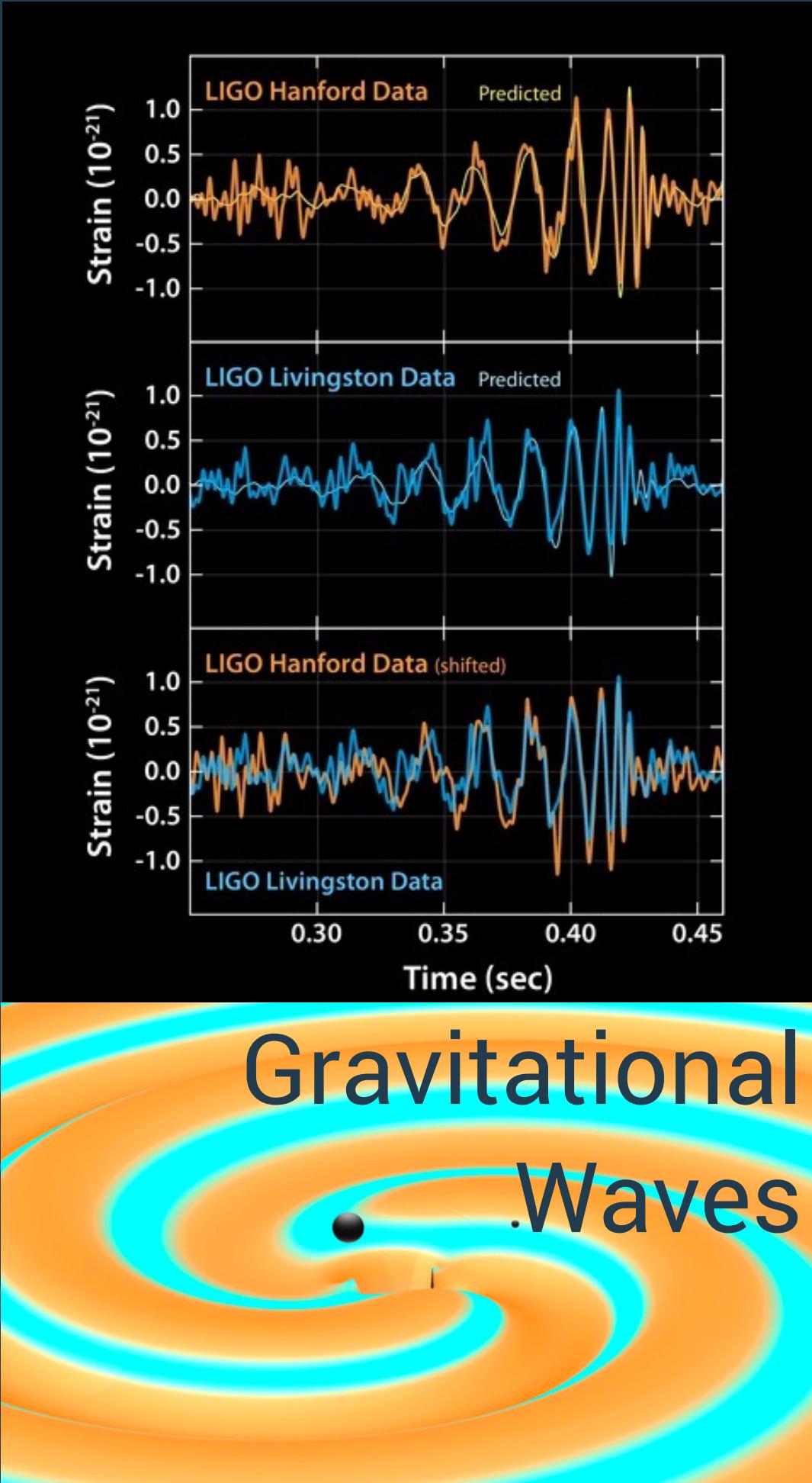
**more folks learn
science better
greater diversity
across all of
science**

A diagram illustrating a cyclical relationship. A curved orange arrow points from the bottom right text box up towards the top left text box. Another curved orange arrow points from the top left text box down towards the bottom right text box.

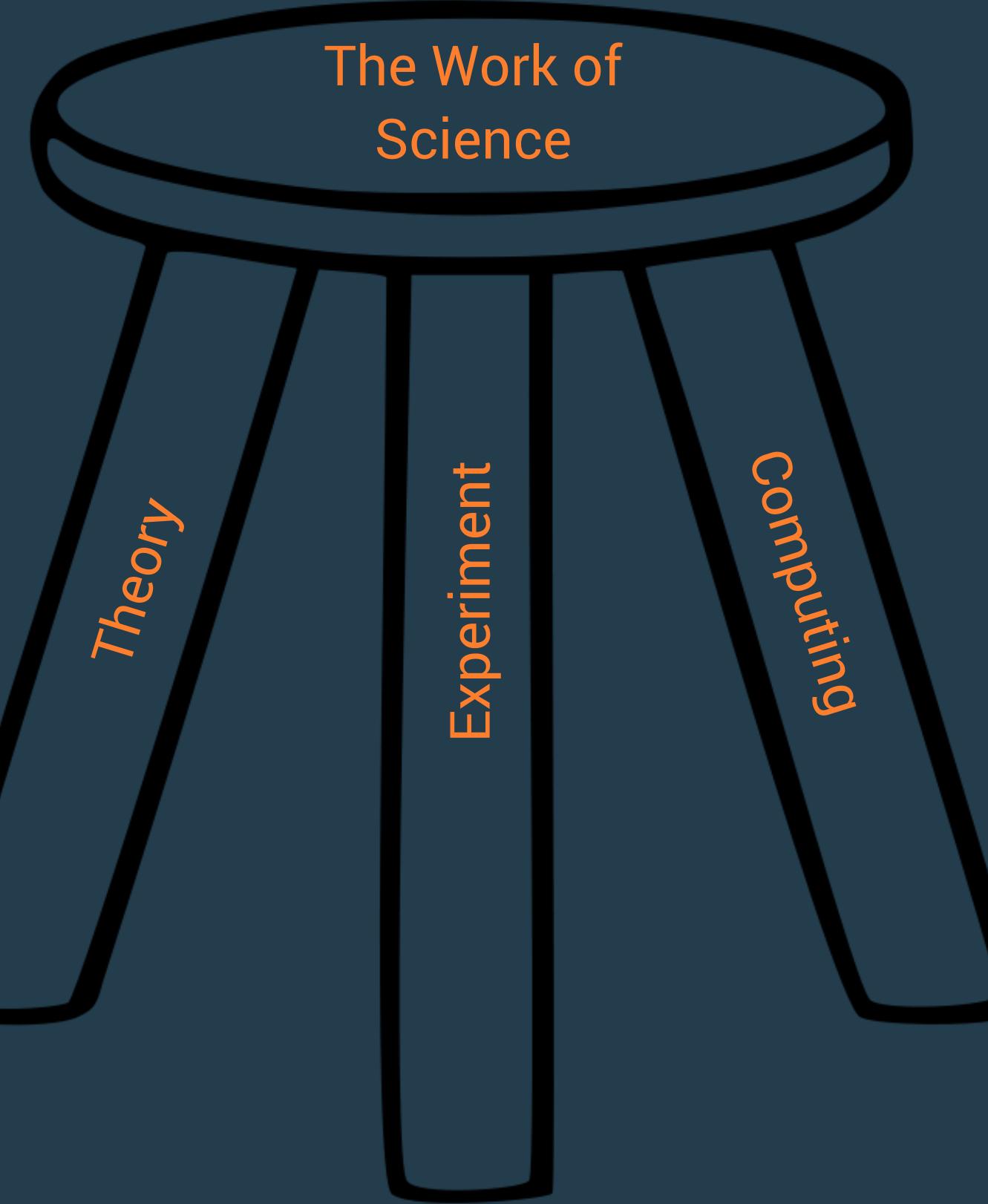
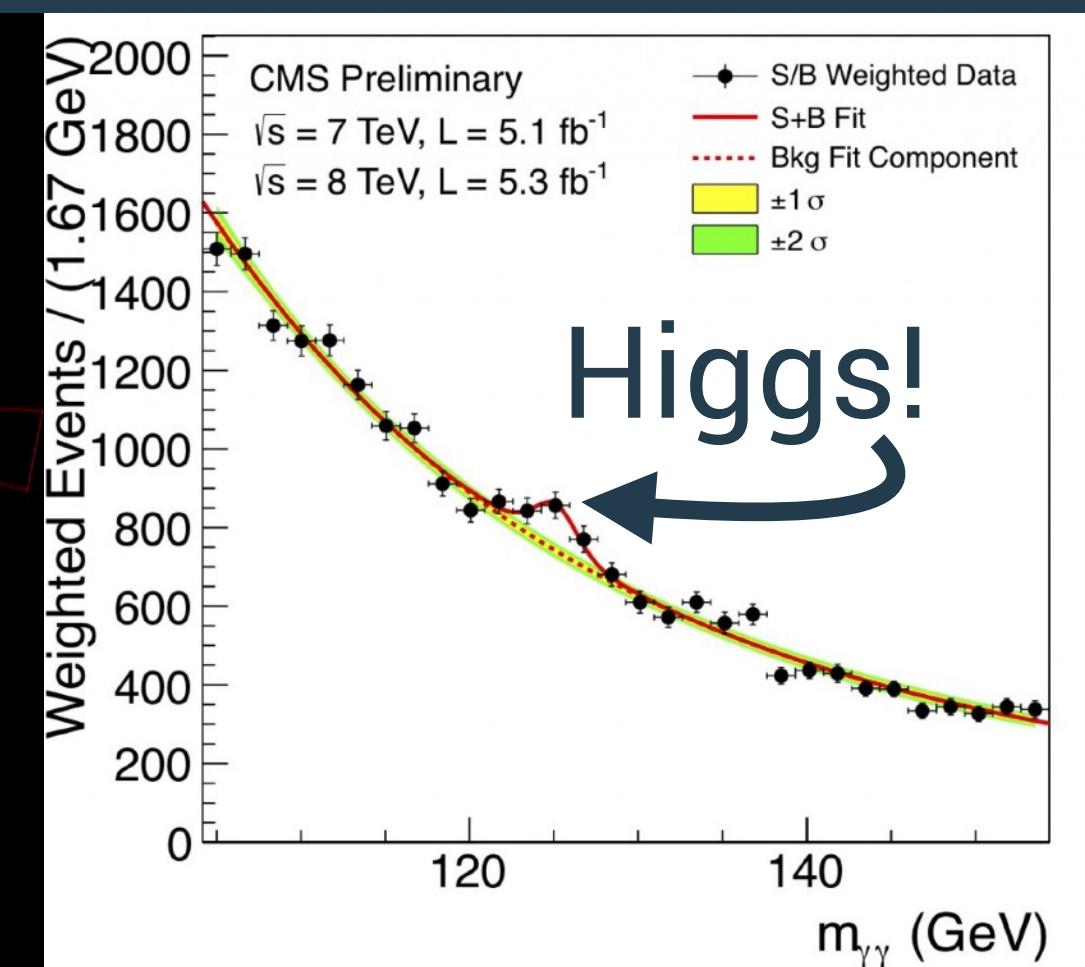
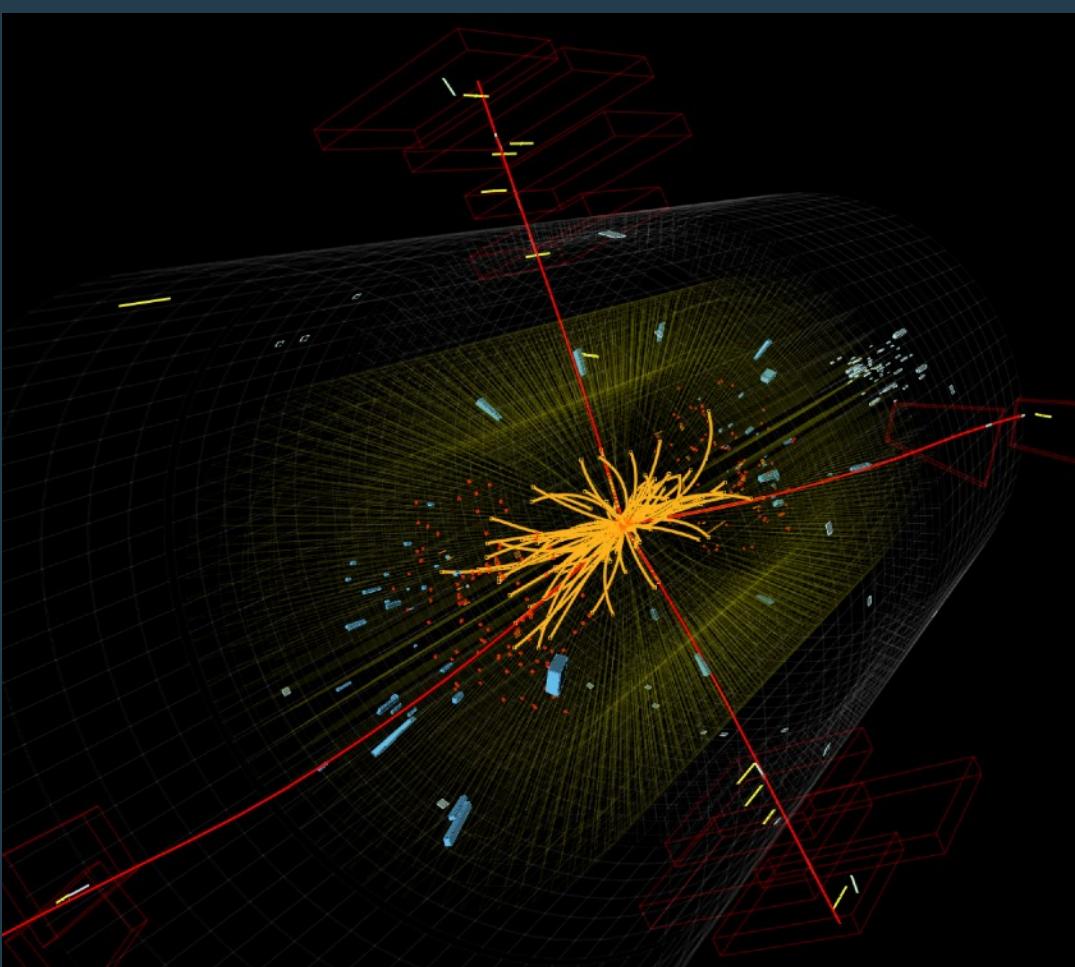
**A science that is more
representative of and
responsive to society**

**A society that deeply
values and strongly
supports science**

Computing is how science is done.



Aad, Georges, et al. *Physics Letters B* 716.1 (2012): 1-29.
Abbott, Benjamin P., et al. *PRL* 116.6 (2016): 061102.
Page, J., et al., *PNAS*, 121 (23) e23200712 (2024)



Students should be able to use computing in physics

<https://ep3guide.org/>

The screenshot shows the homepage of the EP3 Effective Practices for Physics Programs website. At the top, there's a navigation bar with links for FAQ, Events, Contact, and About. Below the navigation is a row of icons: Guide Overview (document icon), Get Started (play button icon), Map Your Program's Goals (graph icon), Help & Community (hand holding a speech bubble icon), and Search (magnifying glass icon). The main content area features a banner with a collage of physics-related images. Below the banner, the page title is "Guide to Computational Skills". To the left of the title is the text "Version 1. January 29, 2021" and a link to "Contributors and Reviewers". A horizontal menu bar below the title includes links for Description, Benefits, Effective Practices, Programmatic Assessments, Resources, Evidence, and Glossary.

Departments should strive to:

- Establish goals and a plan for providing students with computational skills
- Integrate opportunities to develop computational skills into the curriculum
- Provide students early and continuing opportunities to learn and apply computational skills
- Communicate the value of computation in physics and for a broad range of careers

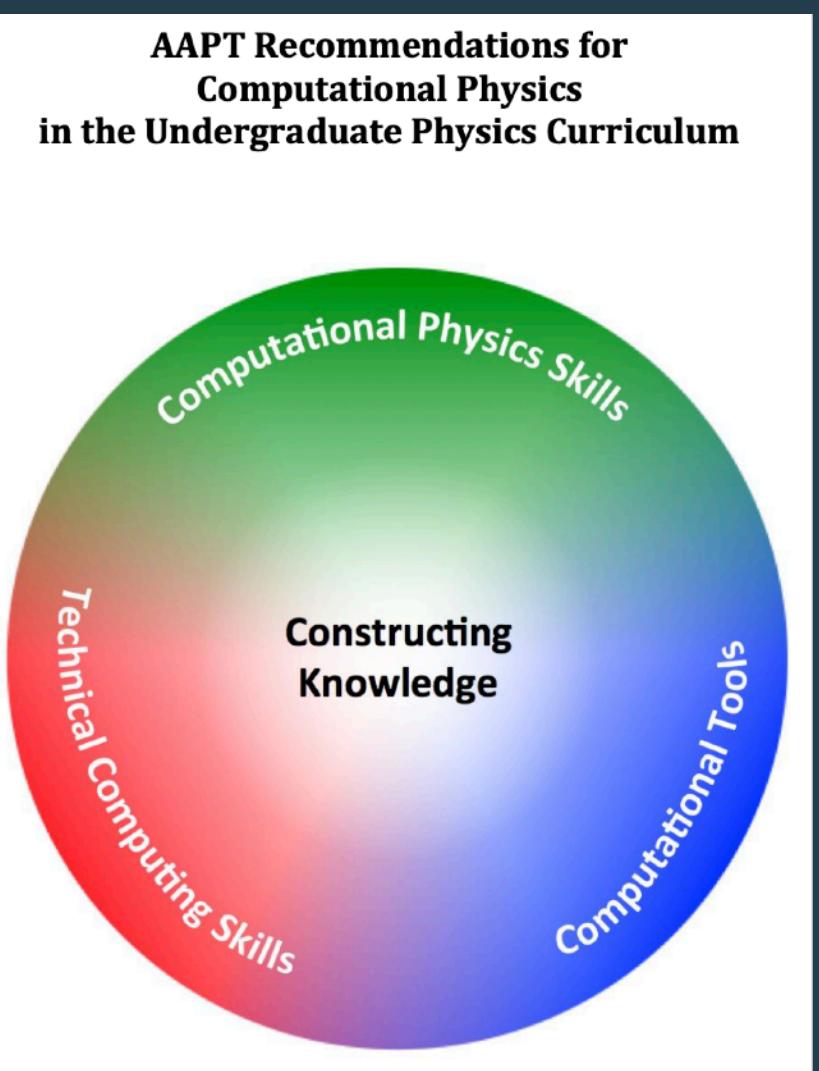
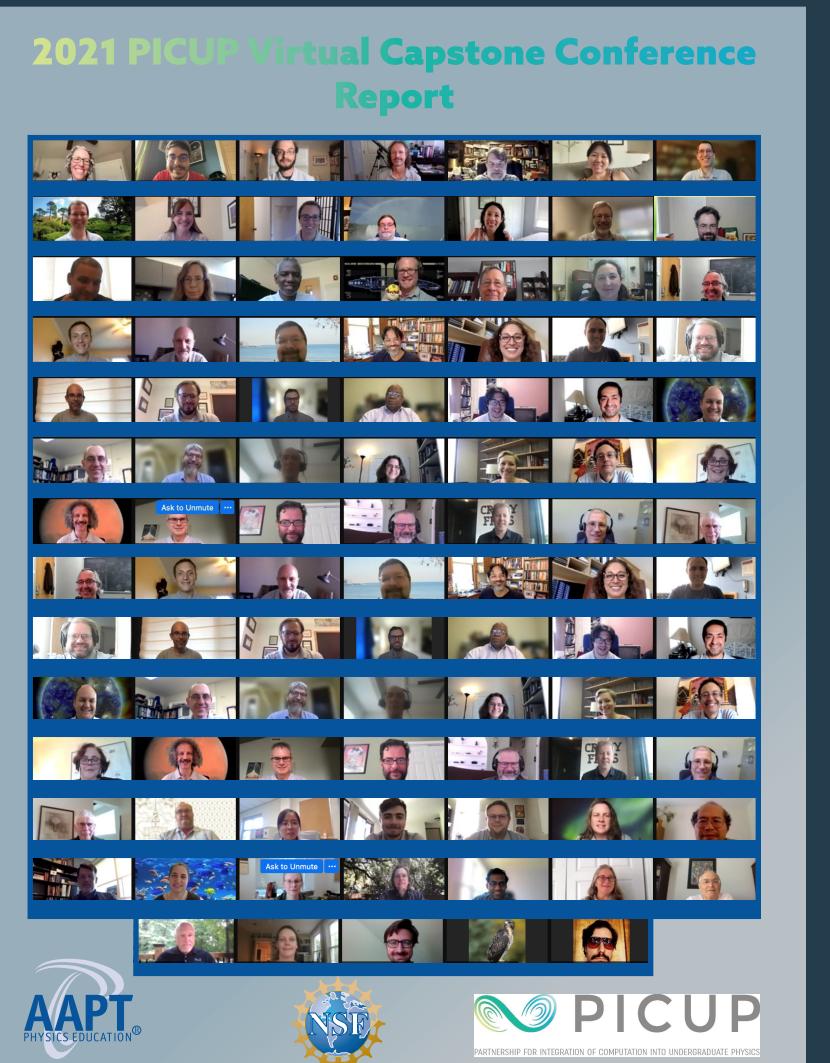
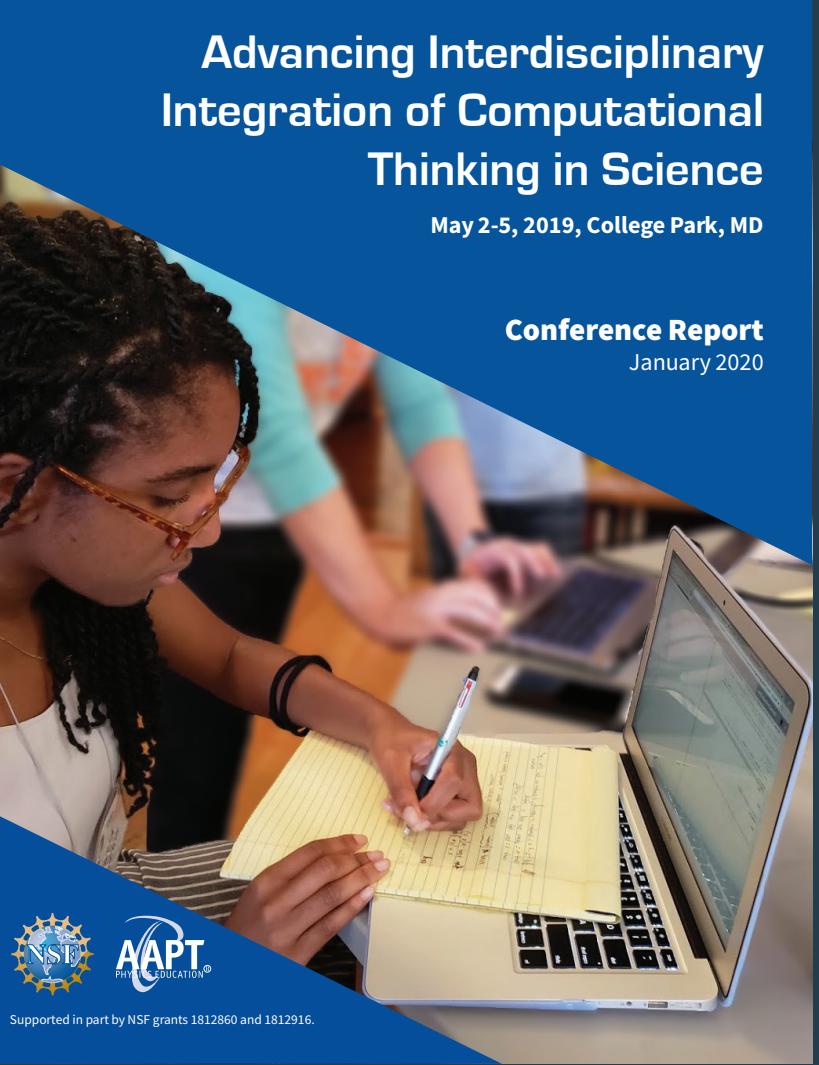
https://www.compadre.org/picup/events/pdfs/2021_PICUP_Capstone_Report_Final_Final_220502.pdf

https://www.aapt.org/Resources/upload/Computational_Thinking_Conference_Report_Final_200212.pdf

https://www.aapt.org/resources/upload/aapt_uctf_compphysreport_final_b.pdf

Advancing Interdisciplinary
Integration of Computational
Thinking in Science
May 2-5, 2019, College Park, MD

Conference Report
January 2020



$$\left| \uparrow \downarrow \right\rangle + \left(\frac{\partial Q}{\partial t} \right)$$

$$\left| \uparrow \downarrow \right\rangle = \frac{1}{\sqrt{2}} (\uparrow \downarrow + \downarrow \uparrow) \quad \left| \downarrow \uparrow \right\rangle = \frac{1}{\sqrt{2}} (\downarrow \uparrow + \uparrow \downarrow)$$

$$\left| \downarrow \downarrow \right\rangle = \underbrace{\downarrow \downarrow}_{\text{symmetric lower energy}}$$

$$\left| S m \right\rangle = \sum_{m_1+m_2=m}^{S_1, S_2} c_{m_1, m_2}^{\pm} |S_1 m_1\rangle |S_2 m_2\rangle$$

$$i\hbar \frac{\partial X}{\partial t} = H X, X(t) = aX + e^{i\omega_B t/2} + bX - e^{-i\omega_B t/2}, H = -\vec{\mu} \cdot \vec{B} = -\gamma \vec{S} \cdot \vec{B}$$

$$\det(A - \tilde{\lambda}I) = 0, H\Psi = E\Psi, X = aX_+ + bX_-$$

n=0,
l=0,
m_l=0
m_j=-1
m_j=-1

$$\Psi_n^0, \Psi_n^1 = \sum_{m \neq n} \frac{\langle \Psi_m^0 | H' | \Psi_n^0 \rangle}{(E_n^0 - E_m^0)} \Psi_m^0, E_n^2 = \sum_{m \neq n} \frac{|\langle \Psi_m^0 | H' | \Psi_n^0 \rangle|^2}{E_n^0 - E_m^0}, E_{\pm}^1 = \frac{1}{2} [W_{aa} + W_{bb} \pm \sqrt{(W_{aa} - W_{bb})^2 + 4|W_{ab}|^2}]$$

$\tilde{j} = (l+s),$

$$\begin{pmatrix} \alpha \\ \beta \end{pmatrix} = E_r \begin{pmatrix} \alpha \\ \beta \end{pmatrix}, W_{ij} = \langle \Psi_i^0 | H' | \Psi_j^0 \rangle$$

$$H_{hyd} = \frac{-\hbar^2}{2m} \nabla^2 - \frac{e^2}{4\pi\epsilon_0 r} \frac{1}{r}, T = \frac{P^2}{2m} = \frac{-\hbar^2}{2m} \frac{d^2}{dx^2}, H_r = \frac{-P^4}{8m^3 c^2}, E_r^1 = \frac{-1}{2mc^2} [E^2 - 2E]$$

$$\frac{n}{4} - 3], SO: H_{SO}^1 = \left(\frac{e^2}{8\pi\epsilon_0} \right) \frac{1}{m^2 c^2 r^3} \vec{S} \cdot \vec{L}, E_{SO}^1 = \frac{(E_n)^2}{mc^2} \left\{ \frac{n[\delta(j+1) - l(l+1) + 3/4]}{l(l+1/2)(l+1)} \right\}, E_{FS}^1 = E_r^1 + E_{SO}^1 = \frac{(E_n)^2}{2mc^2} \left(3 - \frac{4n}{j+1/2} \right)$$

$$mj: E_{nj} = \frac{-13.6 eV}{n^2} \left[1 + \frac{\alpha^2}{n^2} \left(\frac{n}{j+1/2} - \frac{3}{4} \right) \right], \alpha = \frac{e^2}{4\pi\epsilon_0 \hbar c}$$

$$\stackrel{?}{=} H_z^1 = \frac{e}{2m} (\vec{L} + 2\vec{S}) \cdot \vec{B}_{ext}, M_B = \frac{e\hbar}{2m}$$

$$, E_z^1 = \langle n, l, j, m_j | H_z^1 | n, l, j, m_j \rangle \Rightarrow E_z^1 = \mu_B \left[1 + \frac{\delta(j+1) - l(l+1) + 3/4}{l(l+1/2)(l+1)} \right] B_{ext} m_j. \leftarrow \textcircled{i} . E_{tot}(\text{one shell}) = \textcircled{i} + \textcircled{ii}$$

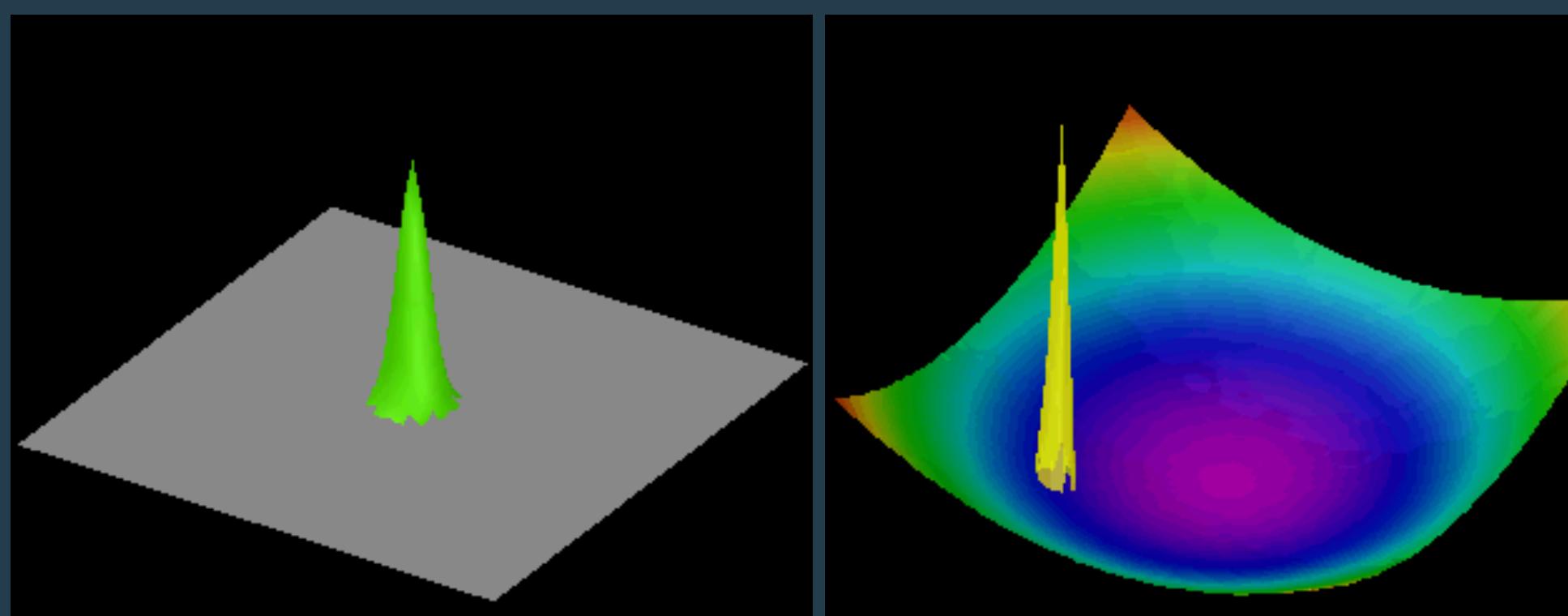
Physics education requires a computing education

$$E_{tot}(\text{sterk}) = \textcircled{iii} + \textcircled{iv}$$

$$e^{\pm i\theta} = \cos \theta \pm i \sin \theta$$

$$\cos \theta = \frac{1}{2}(e^{+i\theta} + e^{-i\theta})$$

$$\sin \theta = \frac{1}{2i}(e^{+i\theta} - e^{-i\theta})$$



Michielson and De Raedt, 2012

Construct visualizations; develop conceptual understanding

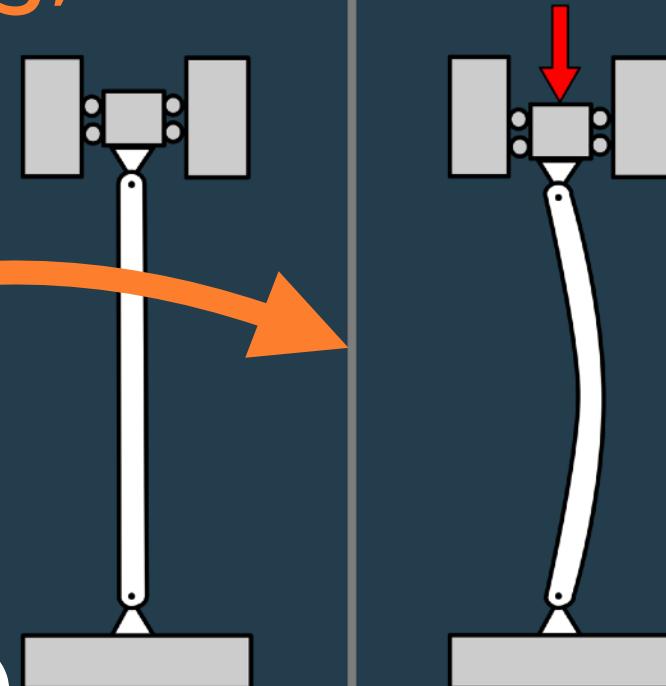
Teach necessary skills; prepare workforce

Graduate Study

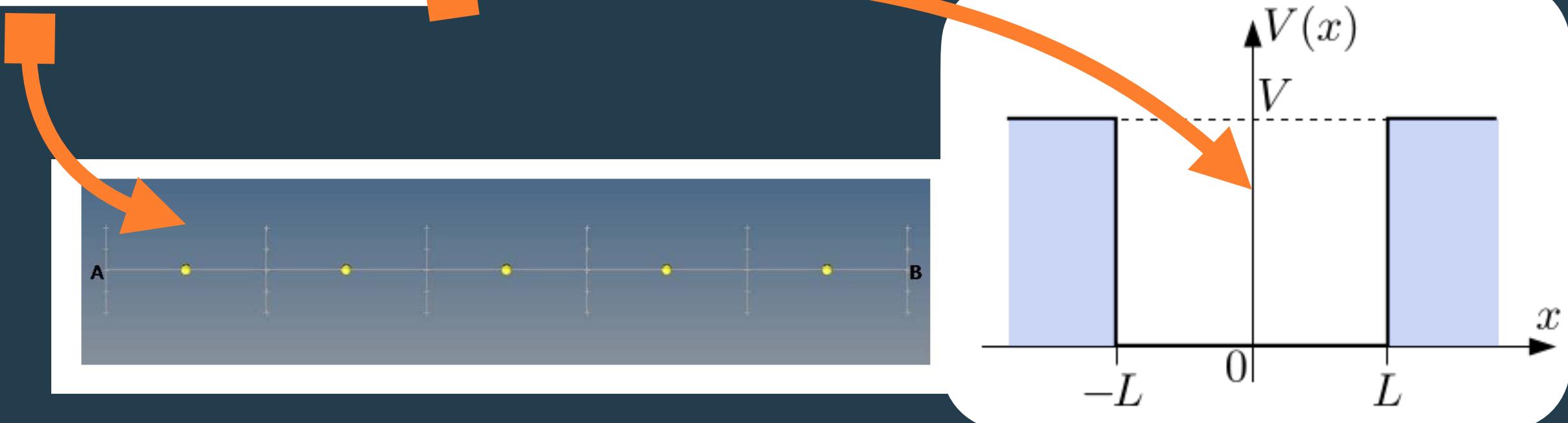
Workforce

Not Employed

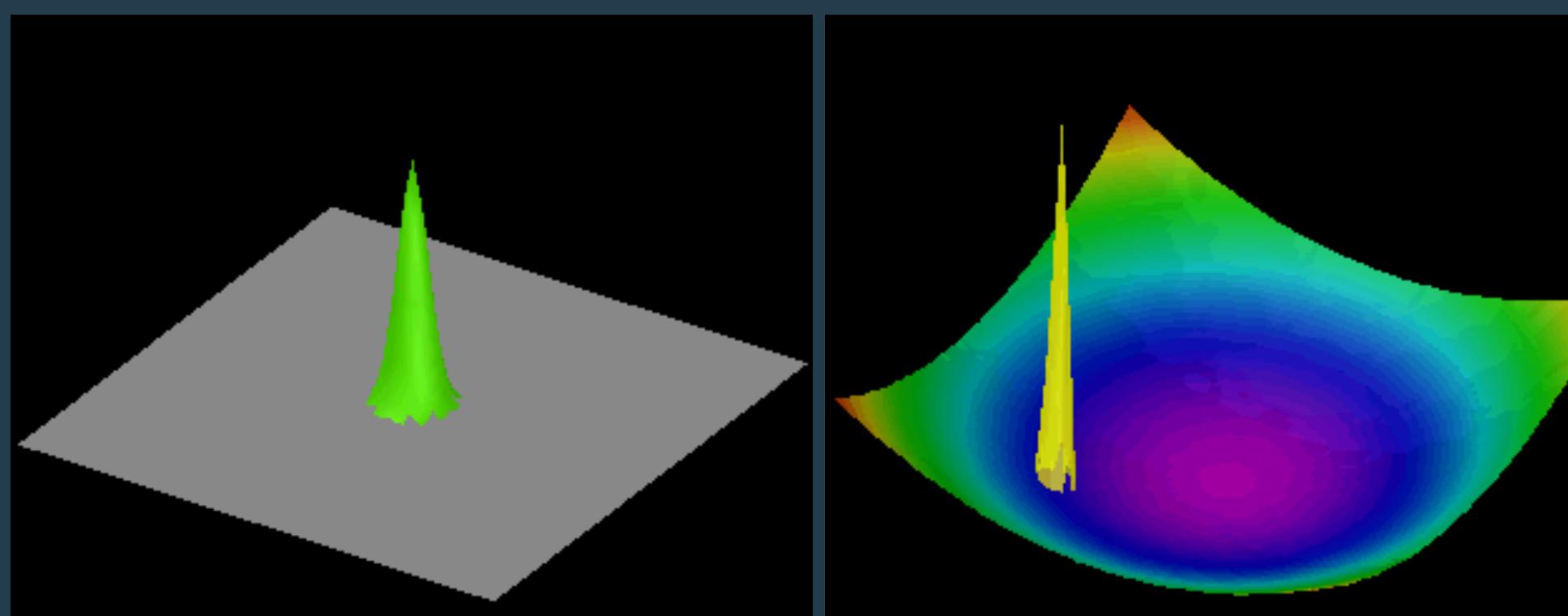
Apply algorithmic thinking;
generalize problem solving



$$A \frac{d^2 u(x)}{dx^2} = -B u(x)$$



Developing students' computational competencies



Michielson and De Raedt, 2012

Construct visualizations; develop conceptual understanding

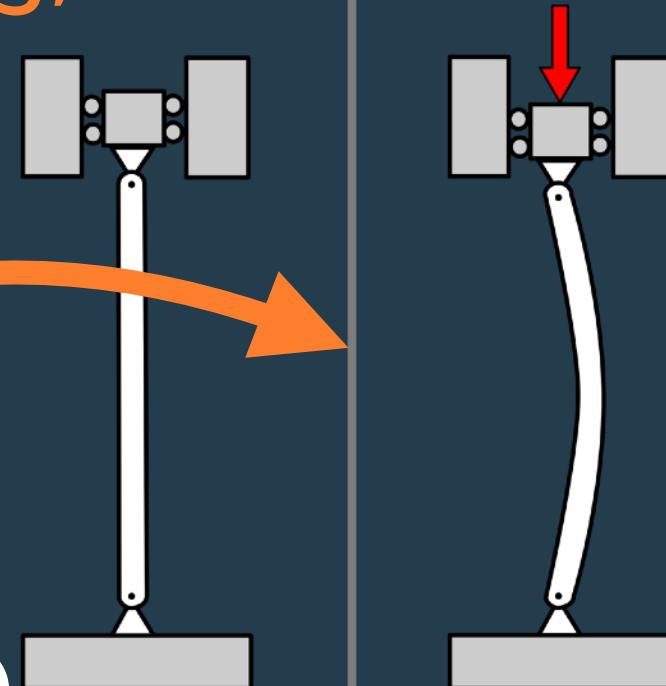
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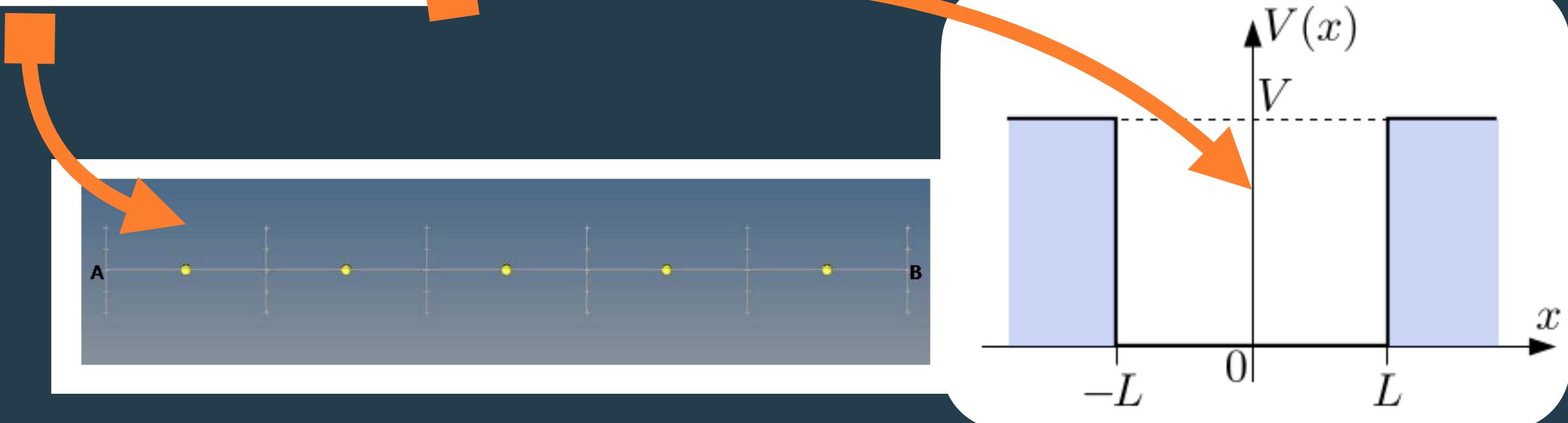
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Developing students' computational competencies

MICHIGAN STATE UNIVERSITY



Located in East Lansing, MI

Population (2024):

47,741 permanent residents

52,089 students (41k are undergrads)

5,703 academic staff (2k tenure stream)

Founded in 1855

Became first “land-grant” university in the USA: 1862

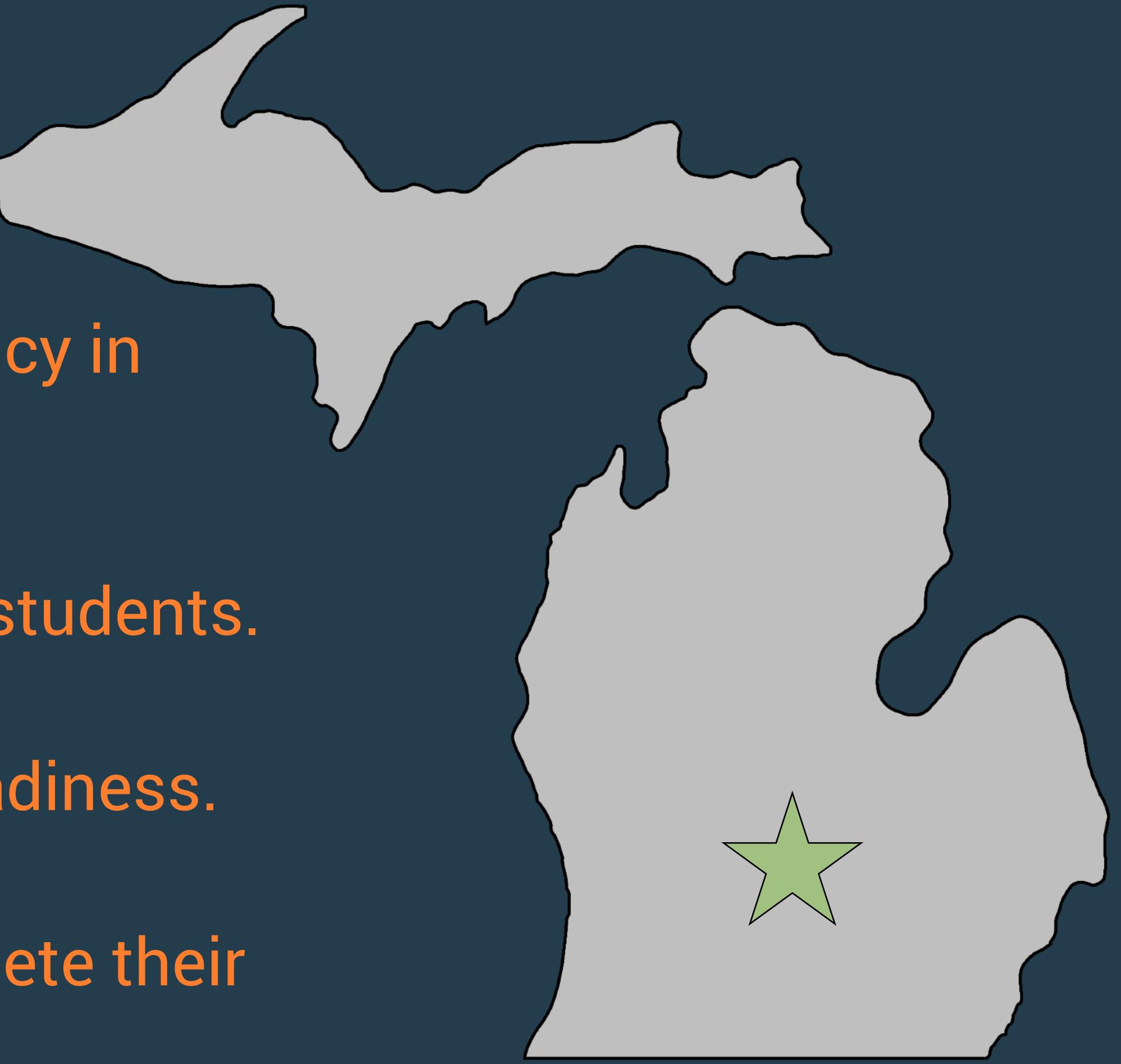
Historically, and “primarily” an agricultural school

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

- Many students in Michigan do not achieve proficiency in science and math.
- Advanced STEM courses are inaccessible to many students.
- Few high school graduates demonstrate college readiness.
- Few students who enroll in two-year colleges complete their degree programs.
- Students of color and those who are economically disadvantaged are disproportionately affected.
- Few women and students of color earn STEM degrees.



> 75% of MSU students
are Michiganders.

Michigan State Physics and Astronomy

~70 Academic and Teaching Staff
~400 majors
~300 PhD students

MSU Physics and Astronomy is a large, high research activity program.

Physics and Astronomy



NSCL/FRIB



Twin goals of our program

MICHIGAN STATE
UNIVERSITY



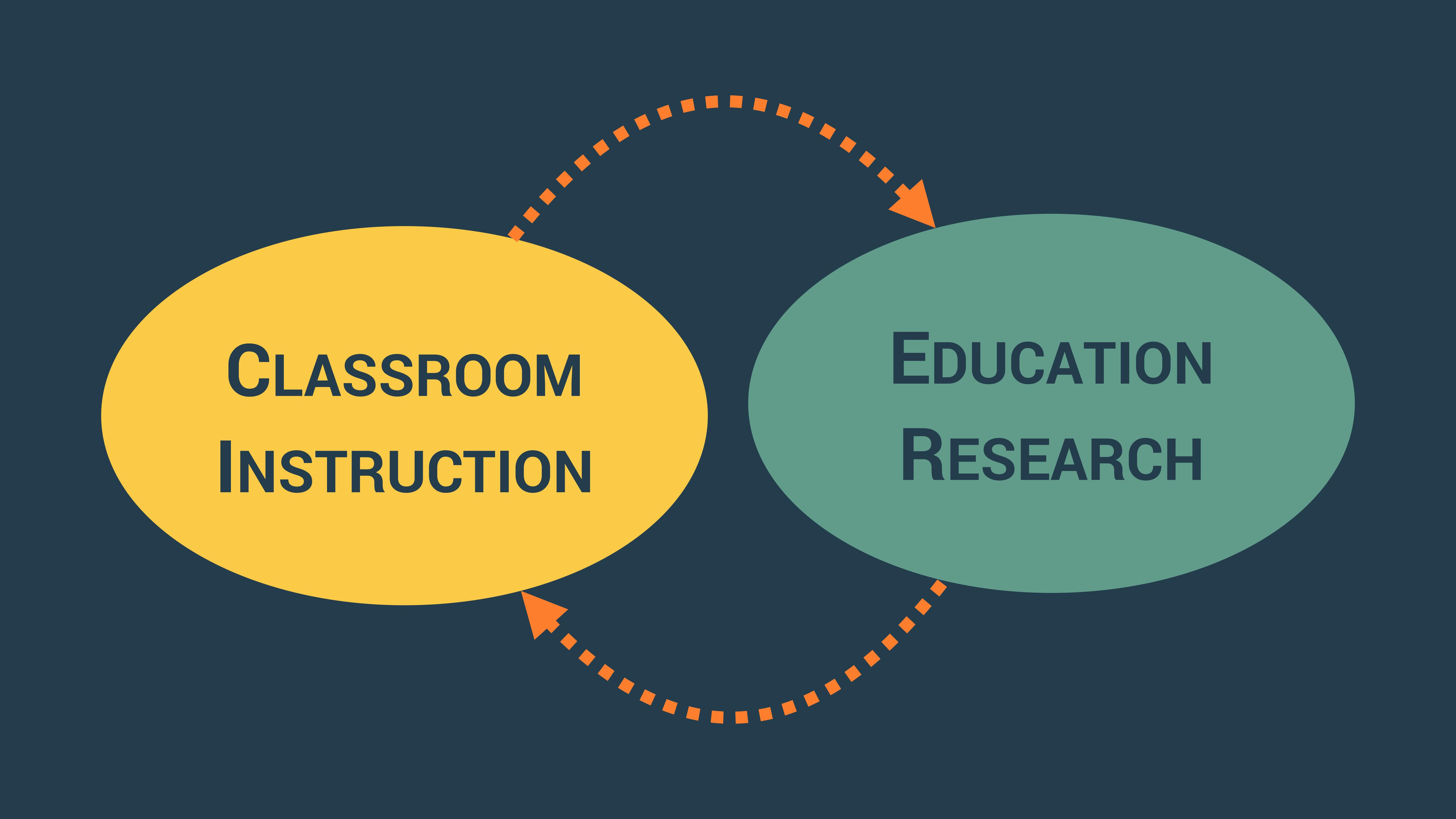
Conducting Original Research

Two students working on
an FRIB experiment



Educating the Next Generation

Students working on introductory physics
lab in Lyman Briggs College



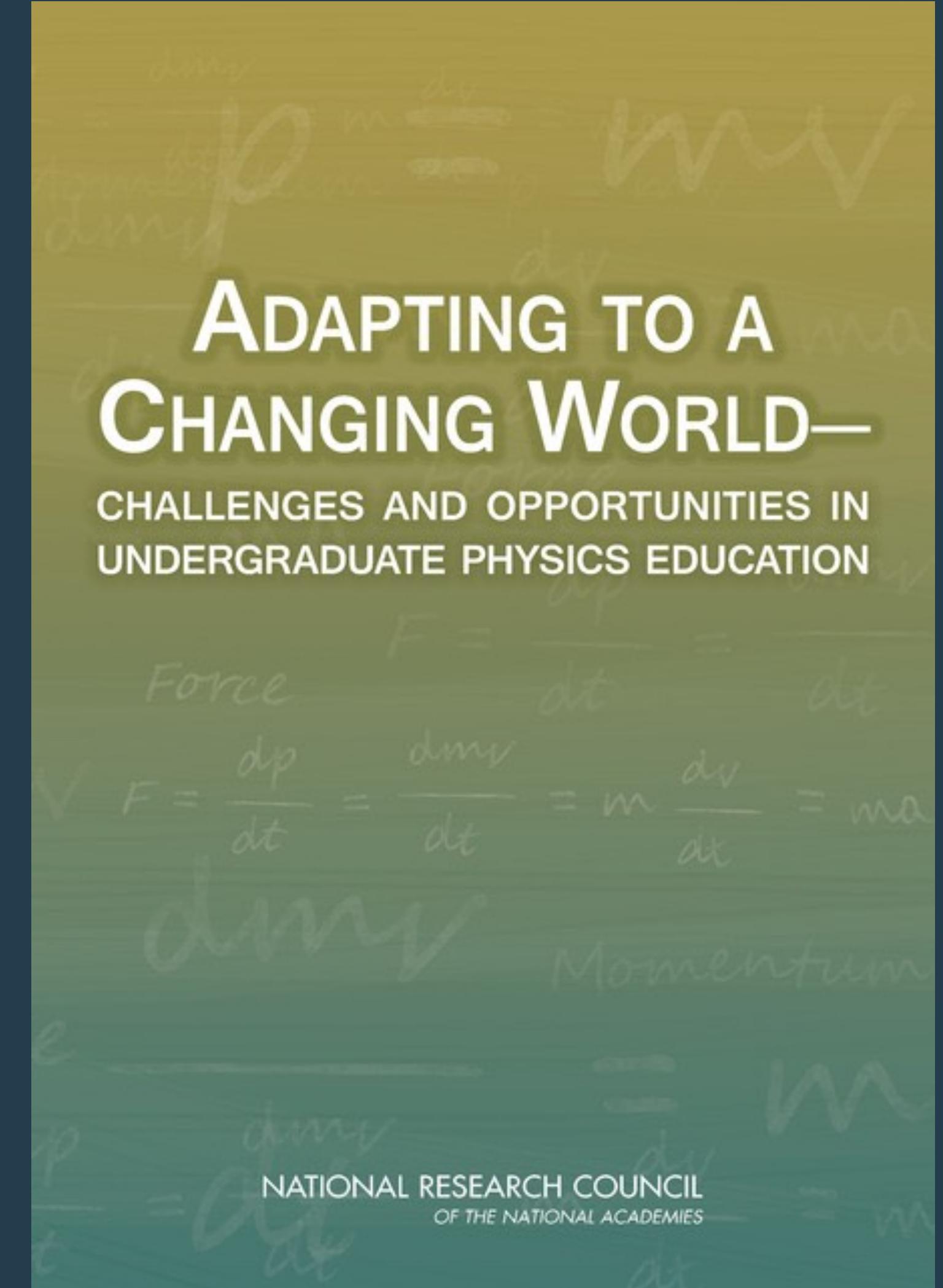
**CLASSROOM
INSTRUCTION**

**EDUCATION
RESEARCH**

Physics Education Research studies:

- student learning and engagement
- pedagogical and curricular impacts
- recruitment and retention of students
- diversity and inclusivity in physics
- faculty practice and decision making
- departmental culture and climate
- national landscapes surrounding physics

Theory, Experiment, and Applied



National Research Council, et al. "Adapting to a changing world: Challenges and opportunities in undergraduate physics education." (2013).

Challenges and Opportunities in Physics Education

Student learning is improved through peer collaboration and by using evidence-based techniques.

Discipline-Based Education Research (NRC, 2012); Adapting to a Changing World (NRC, 2013); Reaching Students (NRC, 2015); Freeman, Scott, et al., PNAS (2014). Matz, Rebecca L., et al., Science Advances (2018); Theobald, Elli J., et al., PNAS (2020). Cooper, Melanie M., et al. PLoS one (2024); and many others

Participation in physics has not kept pace with the growth with STEM.

Mulvey and Nicholson (AIP, 2012); Adapting to a Changing World (NRC, 2013); Nicholson and Mulvey (AIP, 2023)

Physics has actively, systematically, and unintentionally excluded certain groups from participating in it¹ – leading to historical and continued underrepresentation of these groups in physics.

Nicholson and Mulvey (AIP, 2011); White and Chu (AIP, 2014); Porter, Church, and Ivie (AIP, 2024)

Physics is changing; we are using new tools and new techniques

Kozminski et al (AAPT, 2014); Behringer et al (AAPT, 2016); Caballero et al (AAPT, 2020)

¹This is my position and we can disagree on that. But it also my experience, and that is not up for debate.



Computing in physics is:

PHYSICAL REVIEW SPECIAL TOPICS - PHYSICS EDUCATION RESEARCH 8, 020106 (2012)

Implementing and assessing computational modeling in introductory mechanics

Marcos D. Caballero,^{1,*} Matthew A. Kohlmyer,^{2,†} and Michael F. Schatz^{1,‡}

¹*Center for Nonlinear Science and School of Physics, Georgia Institute of Technology, Atlanta, Georgia 30332, USA*

²*Department of Physics, North Carolina State University, Raleigh, North Carolina 27695, USA*

(Received 26 July 2011; published 14 August 2012)

Using the computer as a tool to model, to simulate, and / or to visualize a physical problem.

High-level computing languages + Powerful computers

Some programming is necessary.

```
1 from __future__ import division
2 from visual import *
3
4 craft = sphere(pos = vector(10e7,0,0), color = color.white, radius = 1e6)
5 Earth = sphere(pos = vector(0,0,0), color = color.blue, radius = 6.3e6)
6 trail = curve(color = craft.color)
7
8 G = 6.67e-11
9 mcraft = 1500
10 mEarth = 5.97e24
11
12 vcraft = vector(0,2400,0)
13 pcraft = mcraft*vcraft
14
15 t = 0
16 deltat = 60
17 tf = 365*24*60*60
18
19 while t < tf:
20
21     r = craft.pos-Earth.pos
22     rhat = r/mag(r)
23     Fgrav = -G*mEarth*mcraft/mag(r)**2*rhat
24
25     pcraft = pcraft+Fgrav*deltat
26     craft.pos = craft.pos + pcraft/mcraft*deltat
27
28     trail.append(pos = craft.pos)
29     t = t + deltat
30
31 print 'Craft final position: ', craft.pos, 'meters.'
```

Initial Conditions

Force Calculation

Newton's Second Law

Position Update



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```

```
    craft.color = craft.color
```

2012

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```
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Force Calculation

Newton's Second Law
Position Update

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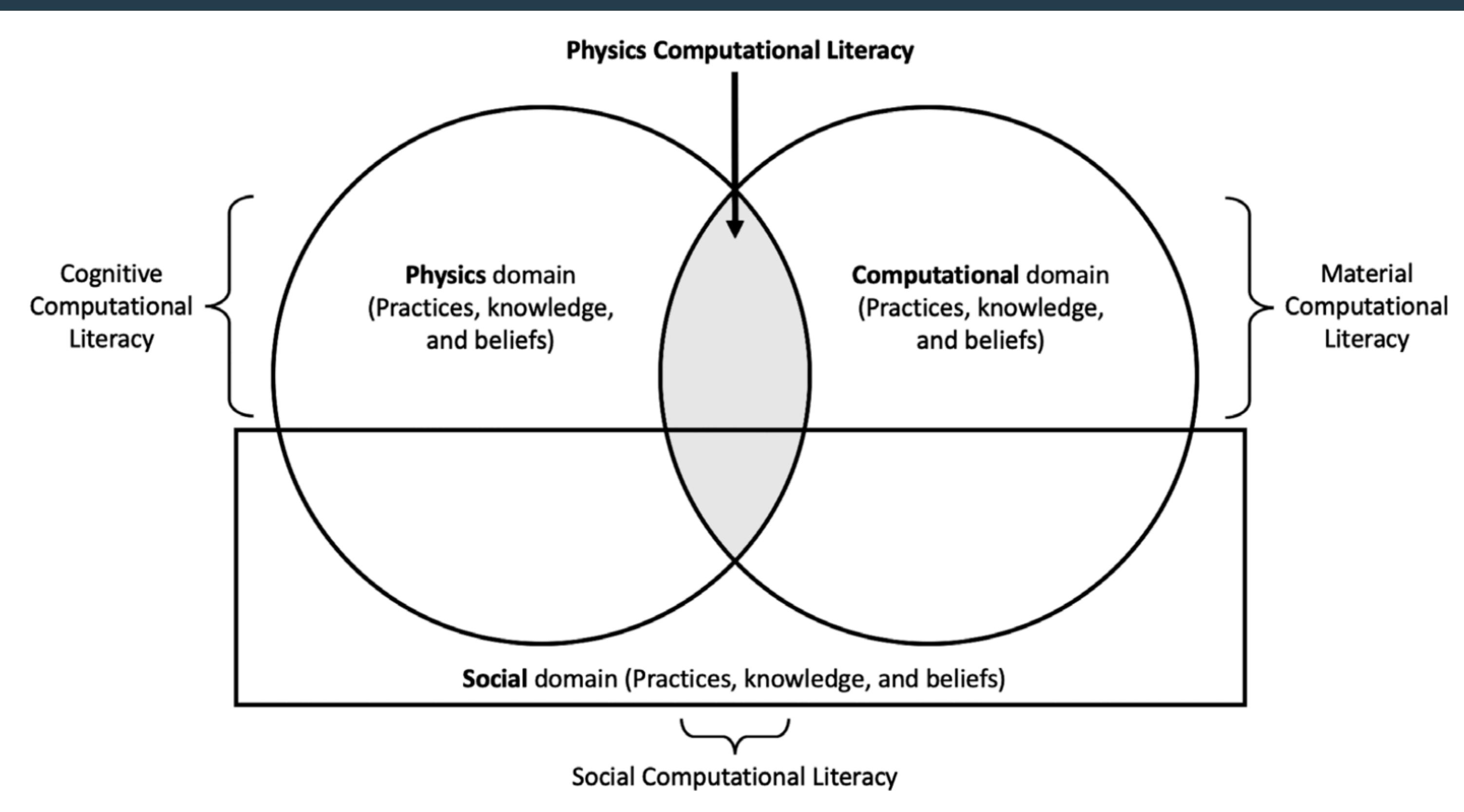
Physics computational literacy: An exploratory case study using computational essays

Tor Ole B. Odden¹, Elise Lockwood², and Marcos D. Caballero^{1,3}

¹*Center for Computing in Science Education, University of Oslo, 0316 Oslo, Norway*

²*Department of Mathematics, Oregon State University, Corvallis, 97331 Oregon, USA*

³*Department of Physics and Astronomy & CREATE for STEM Institute, Michigan State University, East Lansing, 48824 Michigan, USA*



Computational Literacy
involves cognitive, material,
and social literacies

Overlapping practices,
knowledge, and
beliefs

Requires further R&D

How Physics Students Develop Disciplinary Computational Literacy

Tor Ole B. Odden^{1*} and Benjamin Zwickl^{1,2}

[1] Center for Computing in Science Education, Department of Physics, University of Oslo, 0316 Oslo, Norway

[2] School of Physics and Astronomy, Rochester Institute of Technology, 84 Lomb Memorial Drive, Rochester, NY, 14607

*t.o.b.odden@fys.uio.no (corresponding author)

PCL is a model that informs activity development & pedagogy



The Research Council
of Norway



Prior Experience

- Year 1 intro to scientific programming
- Physics modeling
- Reluctant coders
- Used, but never written, Jupyter notebooks
- Interest in biophysics
- Prior biophysics homework problem

Embodiment

- Example simulations
- Suggested investigation questions
- Rubrics and guidelines
- Example computational essays
- Oral presentation

Mediating Processes

Ideation

- Seeking a realistic model
- Reviewing neuron example simulation
- Suggested investigation question on interatomic potentials

Model comprehension

- Understanding code in example simulation
- Researching physics background for model
- Choosing realistic parameters

Model refinement

- Struggling to modify example simulation, adding new lines of code
- Rubrics insufficient to allay worries that code was inadequate
- Puzzling over model results
- Revisiting length and time scales in model

Essay writing

- Using Jupyter notebook for presentation
- Considering audience background
- Answering investigation questions

Outcomes

Material DCL

- Developed experience reading code, but did not write many lines of code, which they felt was a weakness

Cognitive DCL

- Modeling practices
- Applying computation to physics

Social DCL

- Explanations of model
- Defining and answering investigation question

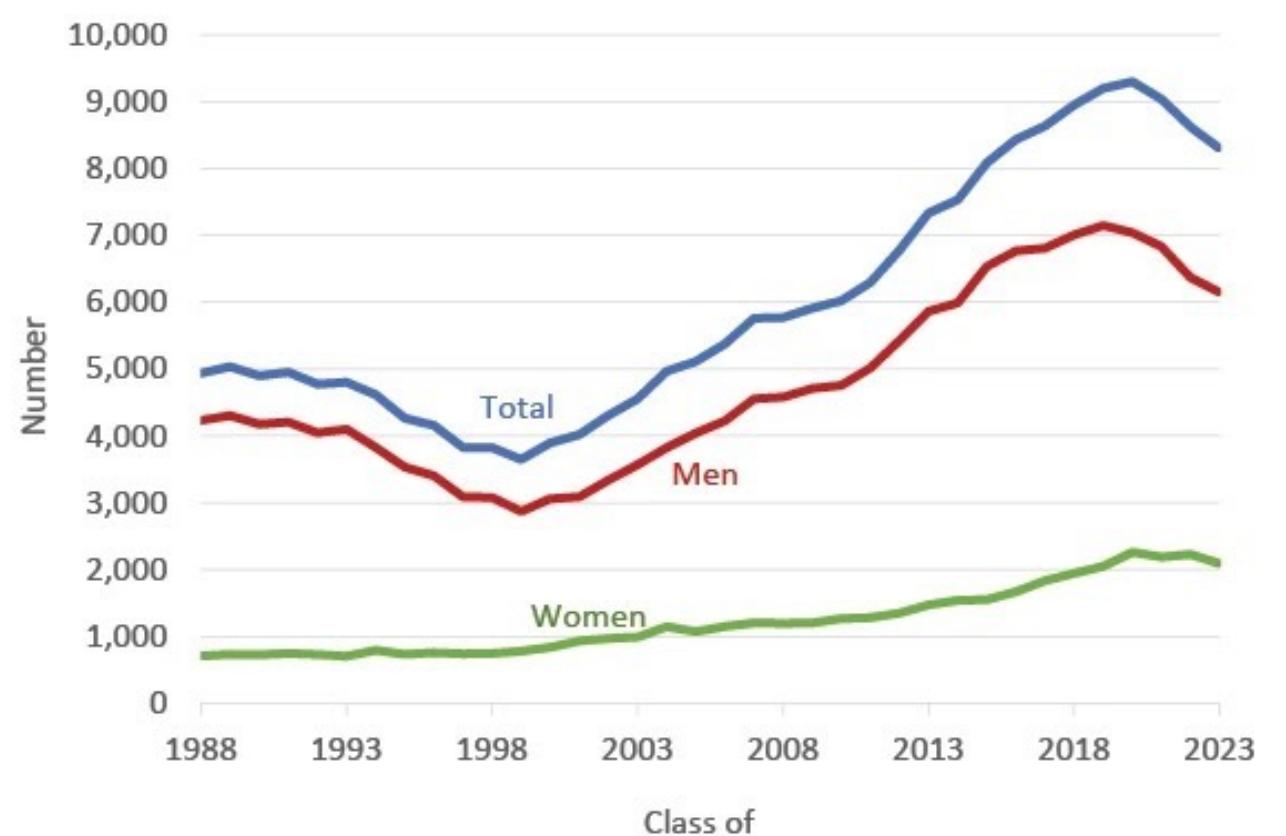
Disciplinary knowledge

- Physics of cells and atoms
- Little explicit electricity and magnetism content knowledge

Odden and Zwickl, ArXiv, 2024

Twelve years have past between this paper and the first.

Number of Bachelor's Degrees Earned in Physics, Classes 1988 through 2023

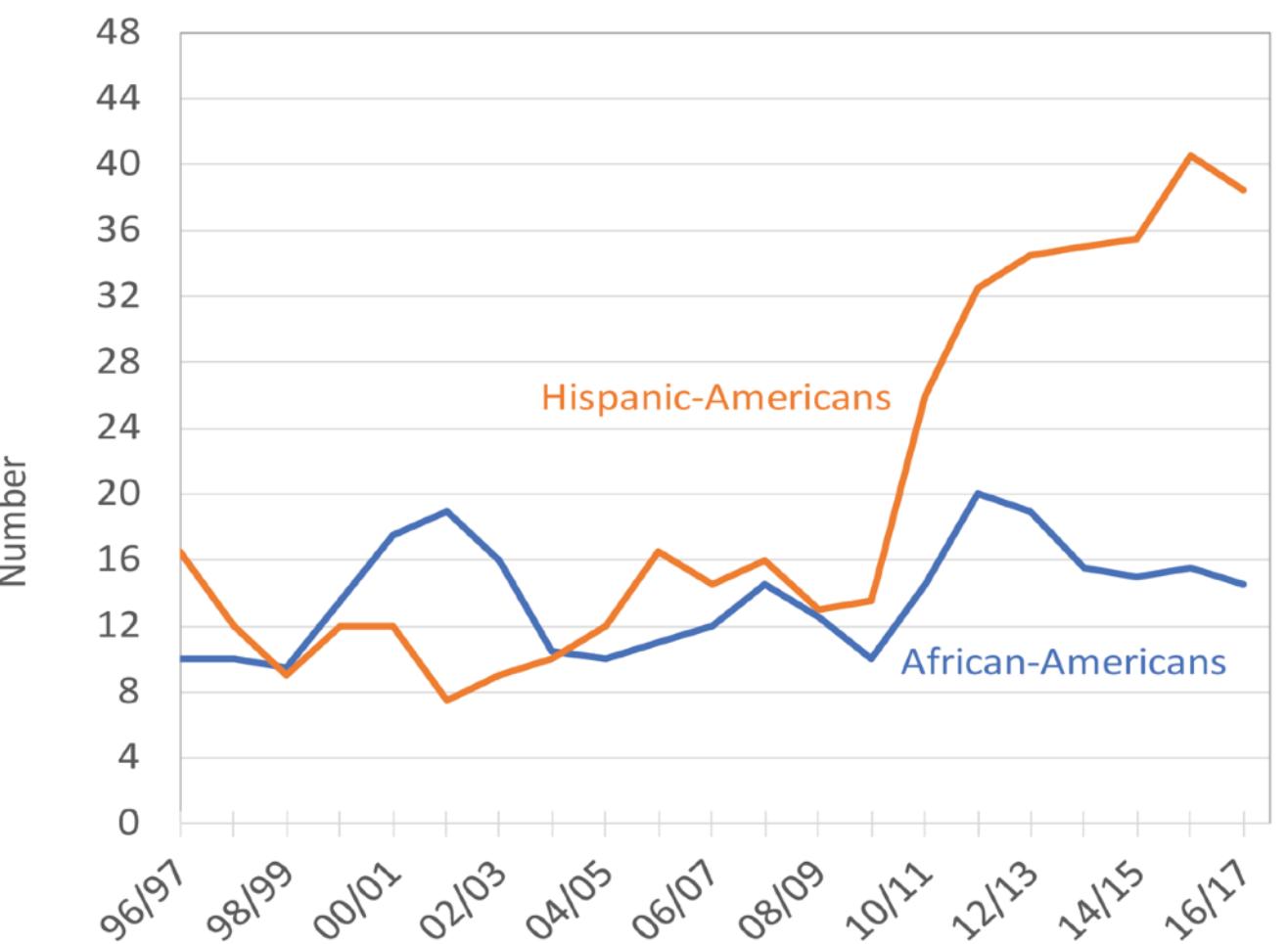


Physics departments reported <1% of their physics bachelor's degree recipients in the class of 2023 identify as a gender other than man or woman.

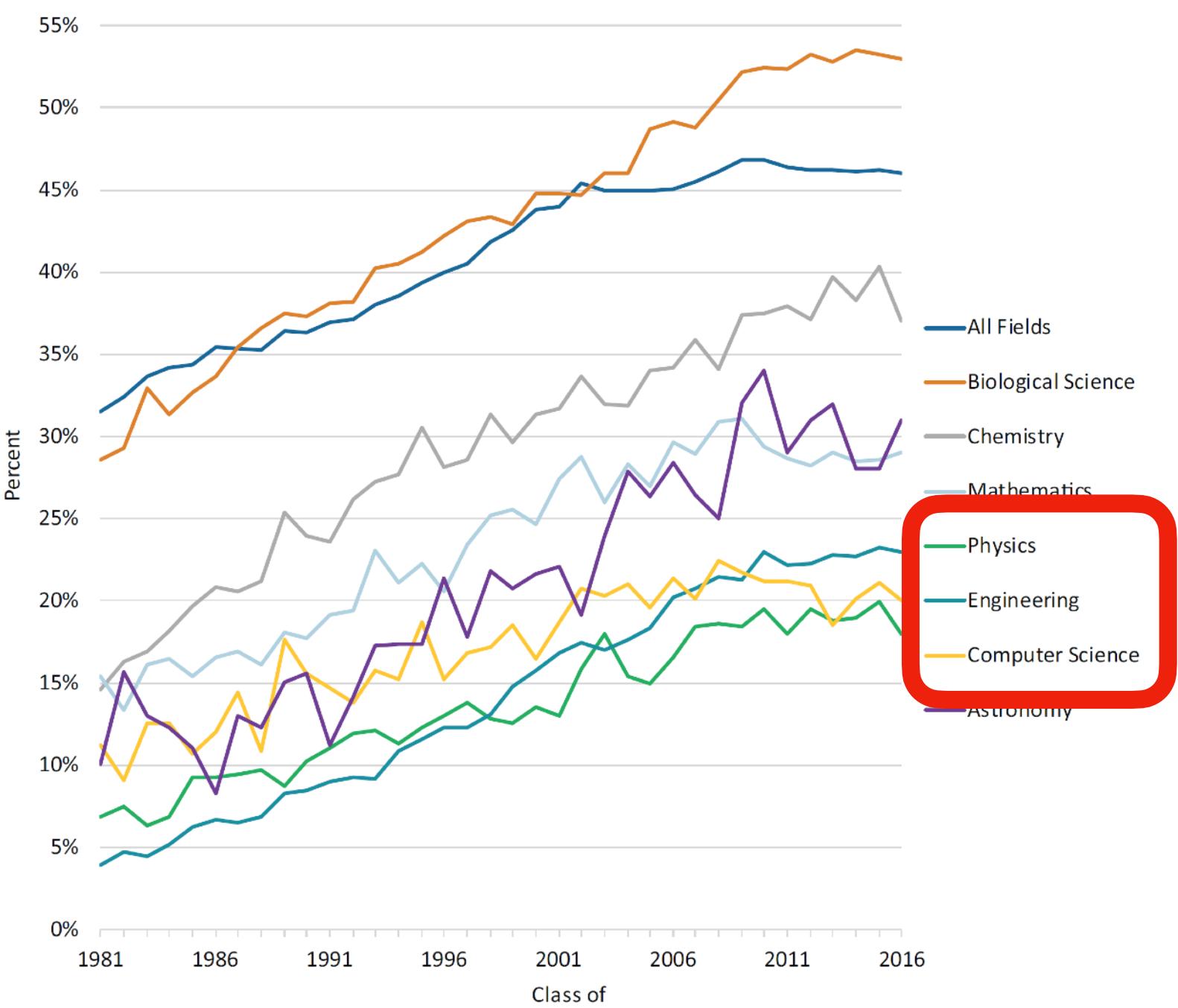


Our work does not exist in a vacuum

Number of Physics Doctorates Earned by African-Americans and Hispanic-Americans, Classes 1996 through 2017.

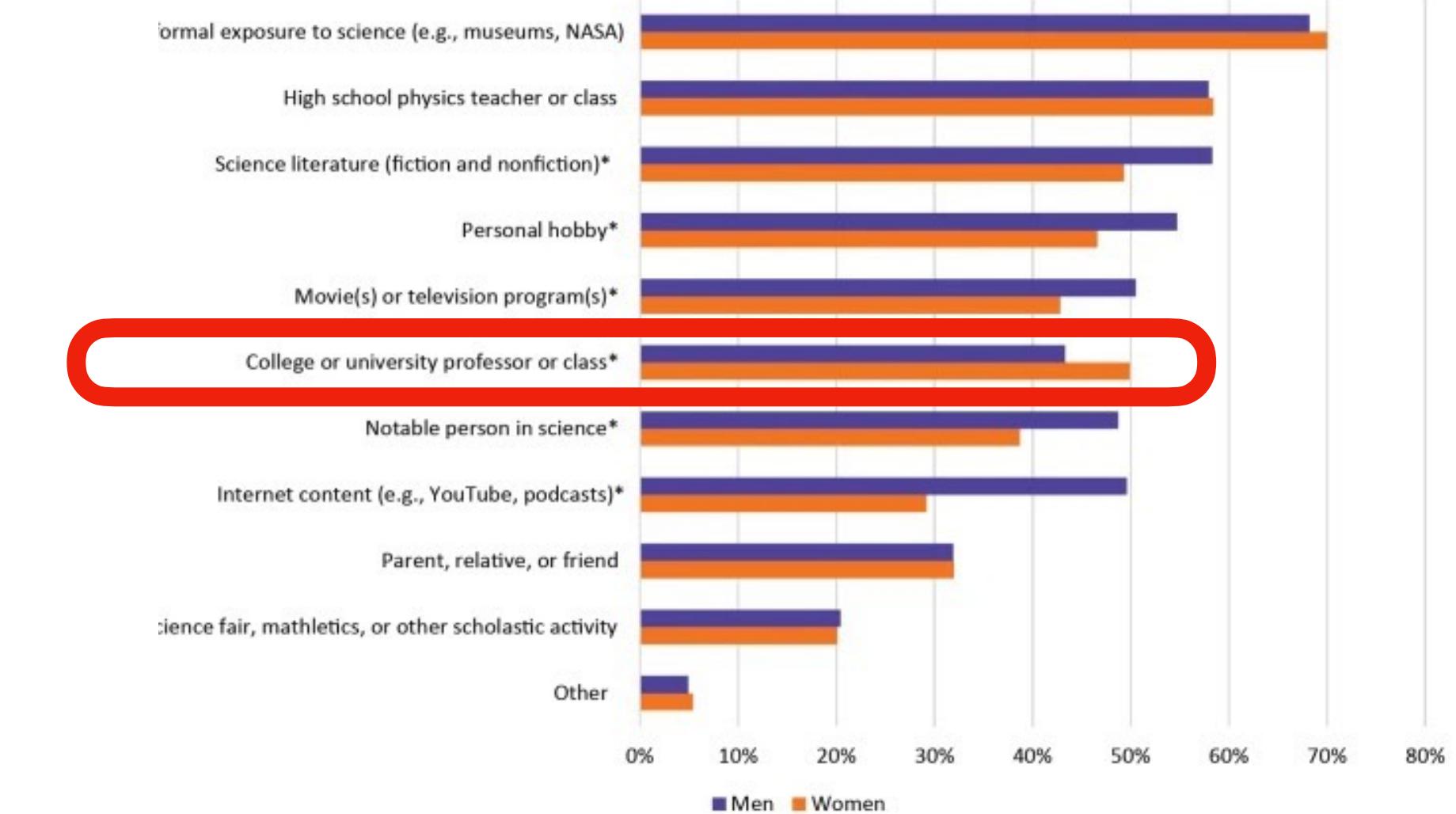


Percent of PhDs Earned by Women in Selected Fields, Classes of 1981 through 2016



Source: National Science Foundation, National Center for Science and Engineering Statistics. Data compiled by AIP Statistical Research Center.

Influences on Physics Bachelors Decision to Pursue Physics, Classes of 2021 and 2022 Combined



icates a statistically significant difference by gender.
respondents were asked, "Did any of the following influences inspire you to study physics?" Women selected a median of four influences, men selected a median of five influences.
percent of the degree recipients identified as a gender other than man or woman. They are not included in this figure.



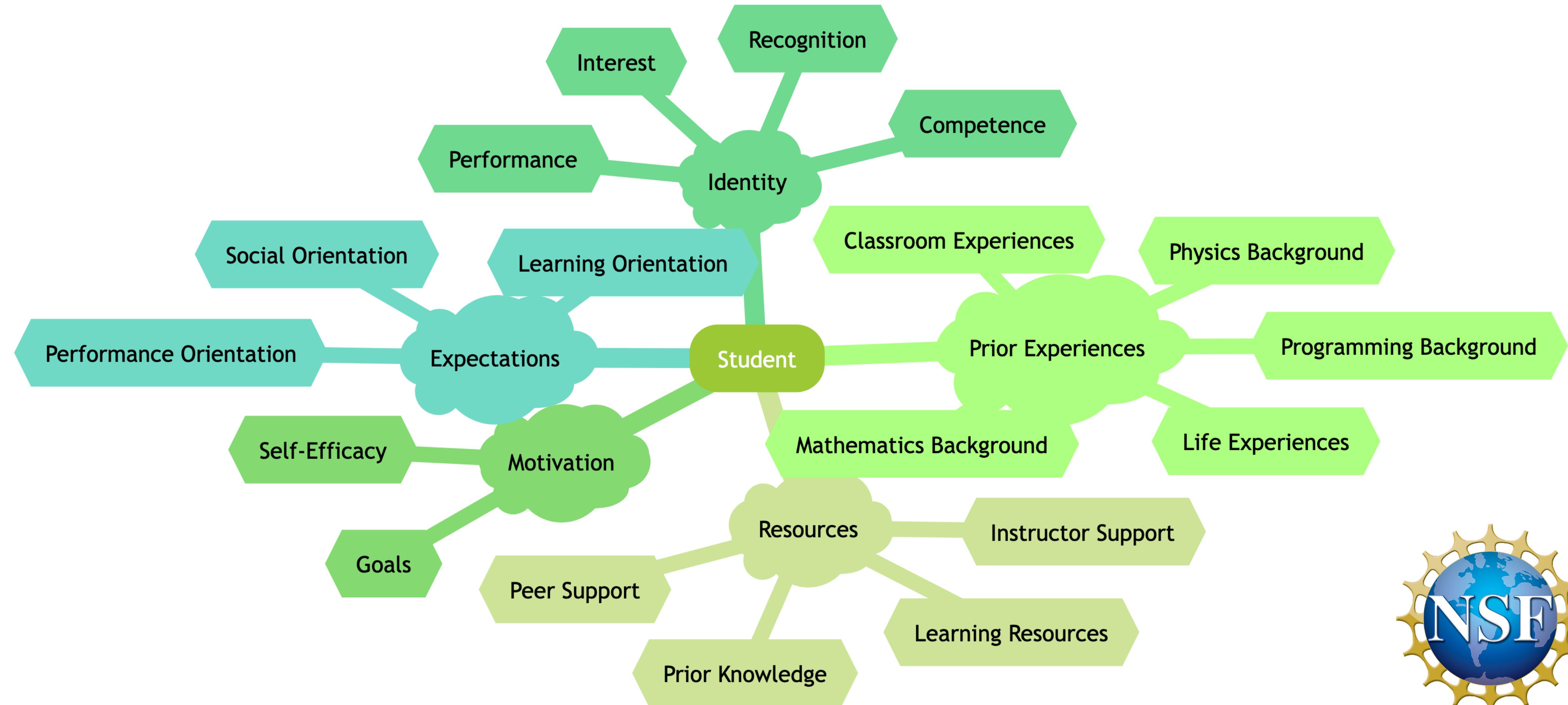
aip.org/statistics

Women, LGBTQIA+, folks of color, the disabled, veterans, first generation students, and folks with these and other intersecting identities have been systematically excluded from physics

Investigating Physics Computational Literacy



Student Dimension



Investigating Physics Computational Literacy



Student and Educator
Interviews



Actionable Feedback for Instructions

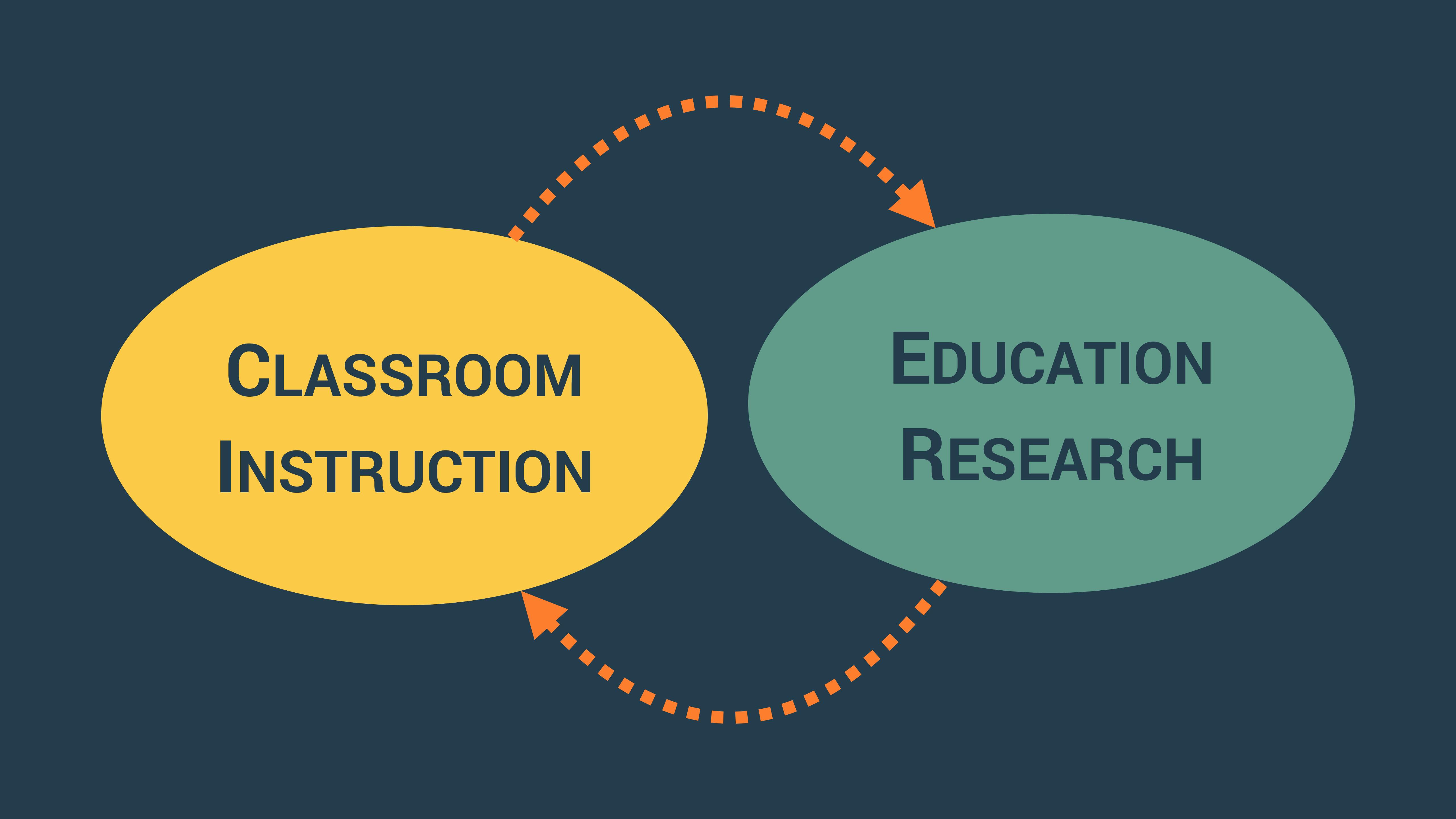


Survey of
Components



Survey of
Instruction

What can computational
instruction look like?



**CLASSROOM
INSTRUCTION**

**EDUCATION
RESEARCH**

Projects and Practices in Physics

The screenshot shows a web page titled "Projects & Practices in Physics" with a sub-page for "Project 3: Geosynchronous Orbit: Part A". The page includes a graph of velocity vs. time, navigation links like "Recent changes", "Media Manager", and "Sitemap", and a sidebar with download links for Python code and modules.

Project 3: Geosynchronous 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.

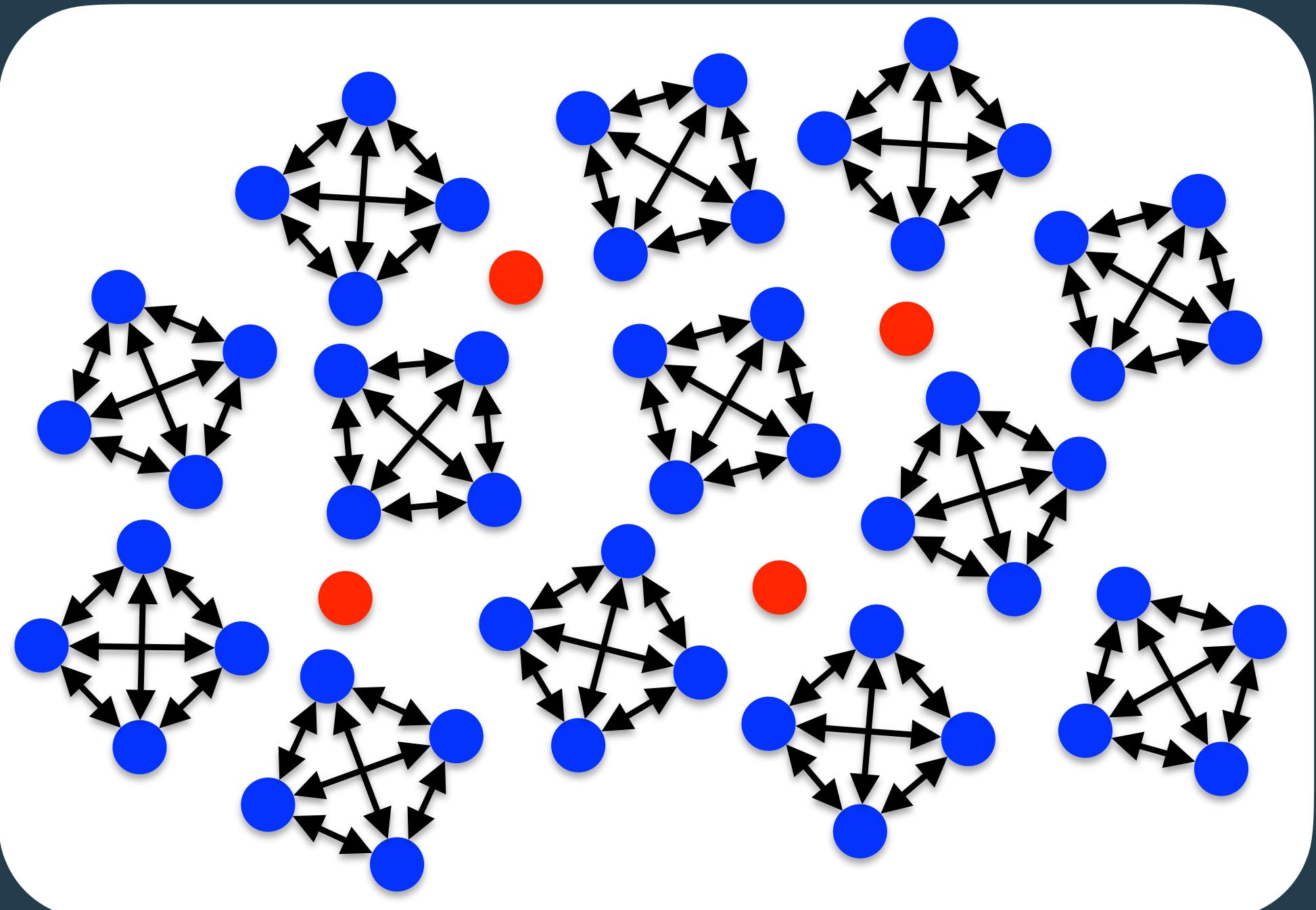
Project 3: Geosynchronous Orbit: Part B

Carver is impressed with your work, but remains unconvinced by your predictions. He has asked you to write a simulation that models the orbit 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 ones.

Code for Project 3:
[geosync.py](#)
[PhysUtil Module](#)

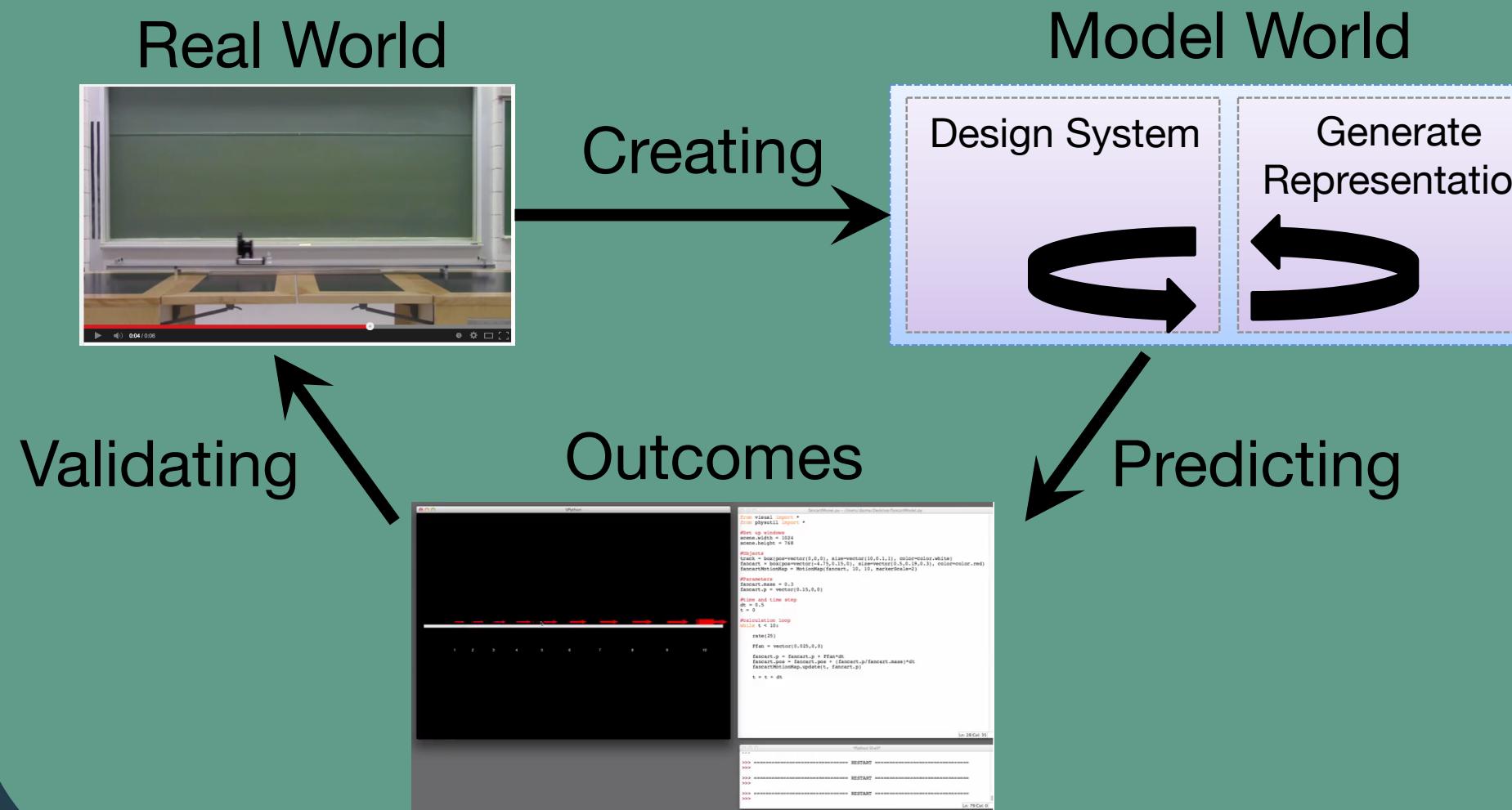
183_projects/project_3_2015_semester_1.txt · Last modified: 2015/01/29 12:42 by pwirving

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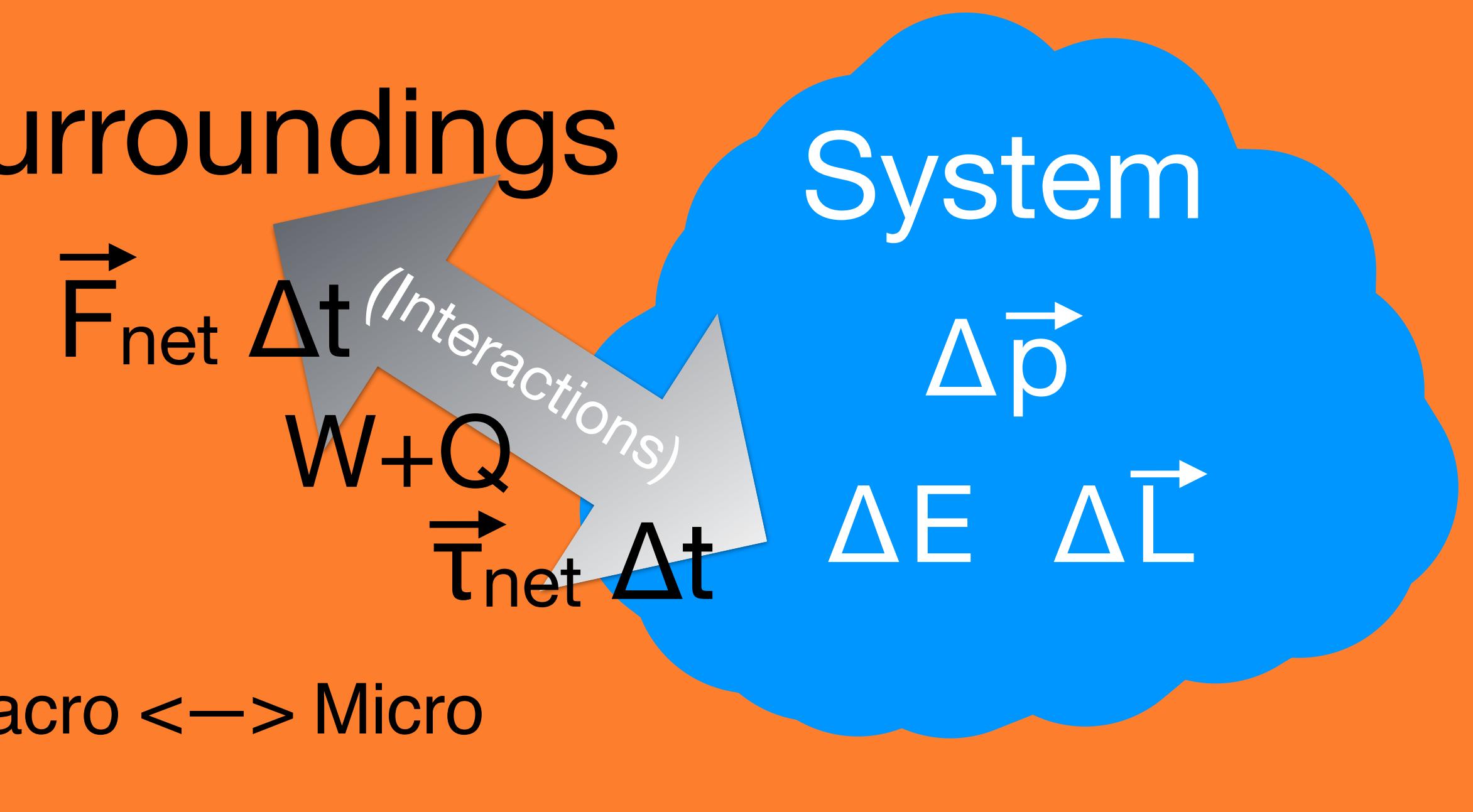
Projects and Practices in Physics

Modeling cycles



Course Narrative

Surroundings



Sample Learning Goals

Students should be able to develop computational models of mechanical systems using the Euler-Cromer method.

Students should be able to track the energies of mechanical systems over time and explain dynamics of the system using conservation of energy.

Students should be able to explain how the calculation loop predicts the motion of their chosen physical system

Learning Scaffolds

Marcos Caballero (Course Coordinator) PHY183 - Section 4, Fall 2014 - Messages Roles Help Logout Physics for Scientists and Engineers I

Main Menu | Contents | Course Editor | What's New | Grades | People | Settings | Public | Switch role |

Course Contents » ... » Pre-class HW 4 Notes Stored Links Evaluate Feedback Print Info

Functions Edit Content Grades Content Settings Edit Folder

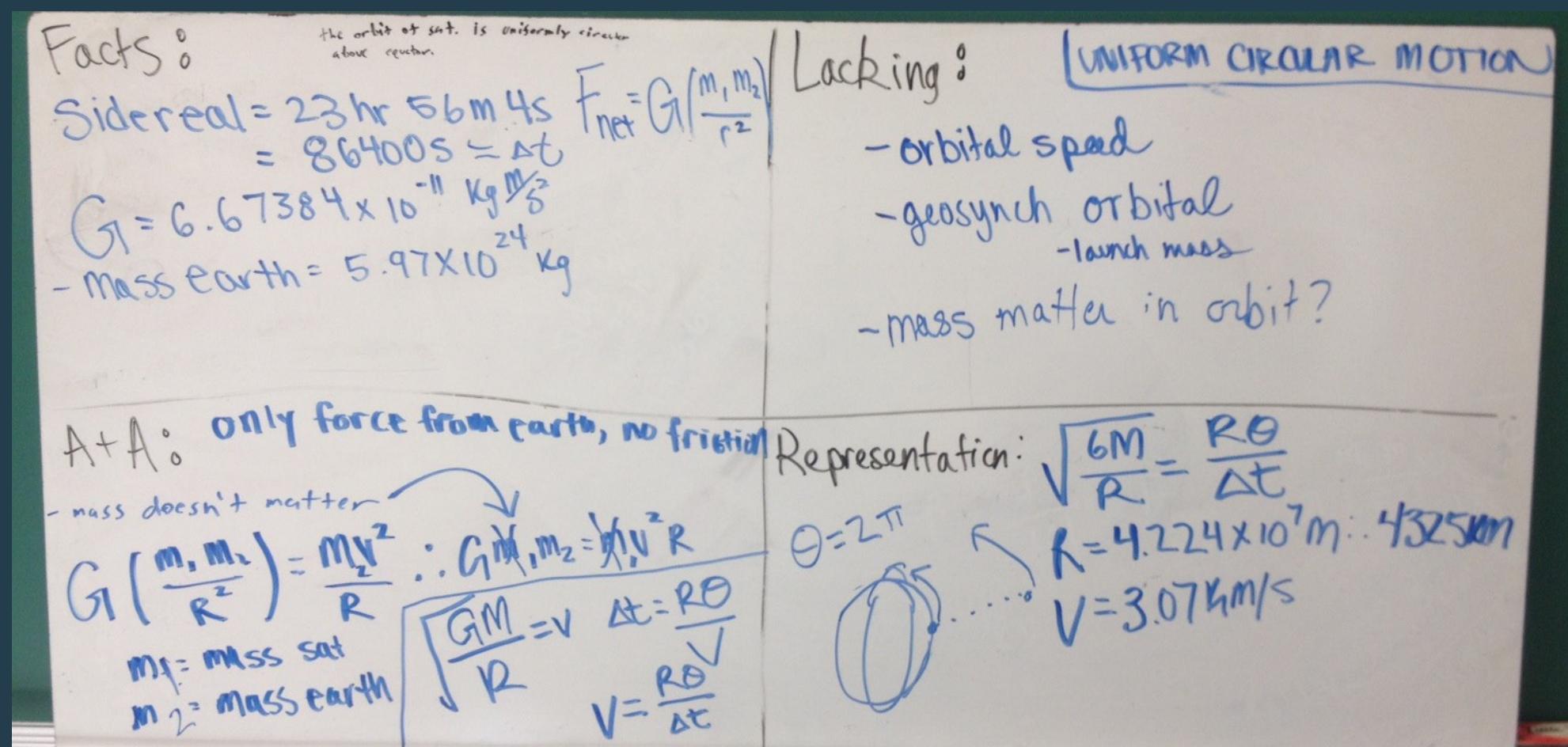
A hydrogen atom contains one electron of mass 9.00×10^{-31} kg and one proton of mass 1.90×10^{-27} kg which are separated by an average distance of 6.20×10^{-11} m. Calculate the magnitude of the gravitational force between the electron and the proton.

$|\vec{F}| = 2.967 \times 10^{-47}$ N

You are correct. Computer's answer now shown above. Your receipt no. is 156-9700

Previous Tries

Pre-class HW



4 Quadrants Whiteboard

```

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(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:
    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)

    Satellite.pos = Satellite.pos + pSatellite/mSatellite*deltat
    SatelliteMotionMap.update(t, pSatellite/mSatellite)

    t = t + deltat

```

Minimally Working Program

Tutor Questions

Two friends are having a conversation. Justine says a satellite in orbit is in free-fall because the satellite keeps falling toward Earth. Amy says a satellite in orbit is not in free-fall because the acceleration due to gravity is not 9.80 m/s^2 .

Who do you agree with and why?

Completed Code

Over the course of 2 hours...

```
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

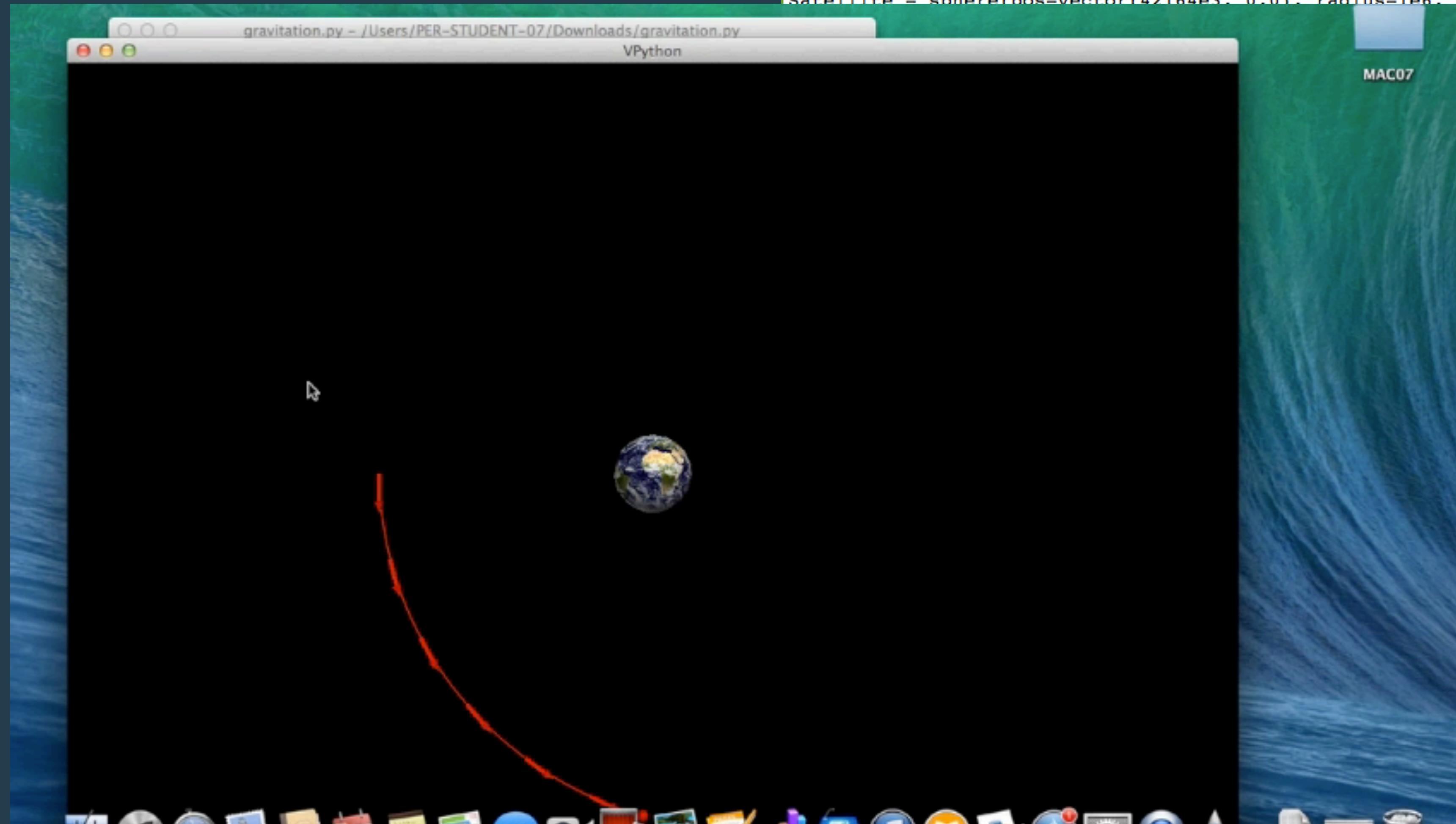
    SatelliteMotionMap.update(t, pSatellite/mSatellite)
    FnetMotionMap.update(t, Fnet)

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

    t = t +deltat
```

Completed Code

Over the course of 2 hours...



```
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)
```

```
scale=2000, labelMarkerOrder=False)
000, labelMarkerOrder=False)
```

```
S LINE
in=vector(0,0,0)) # IGNORE THIS LINE
```

```
cellite.pos)**3)
```

```
ite*deltat
```

Note: video is sped up a bit.

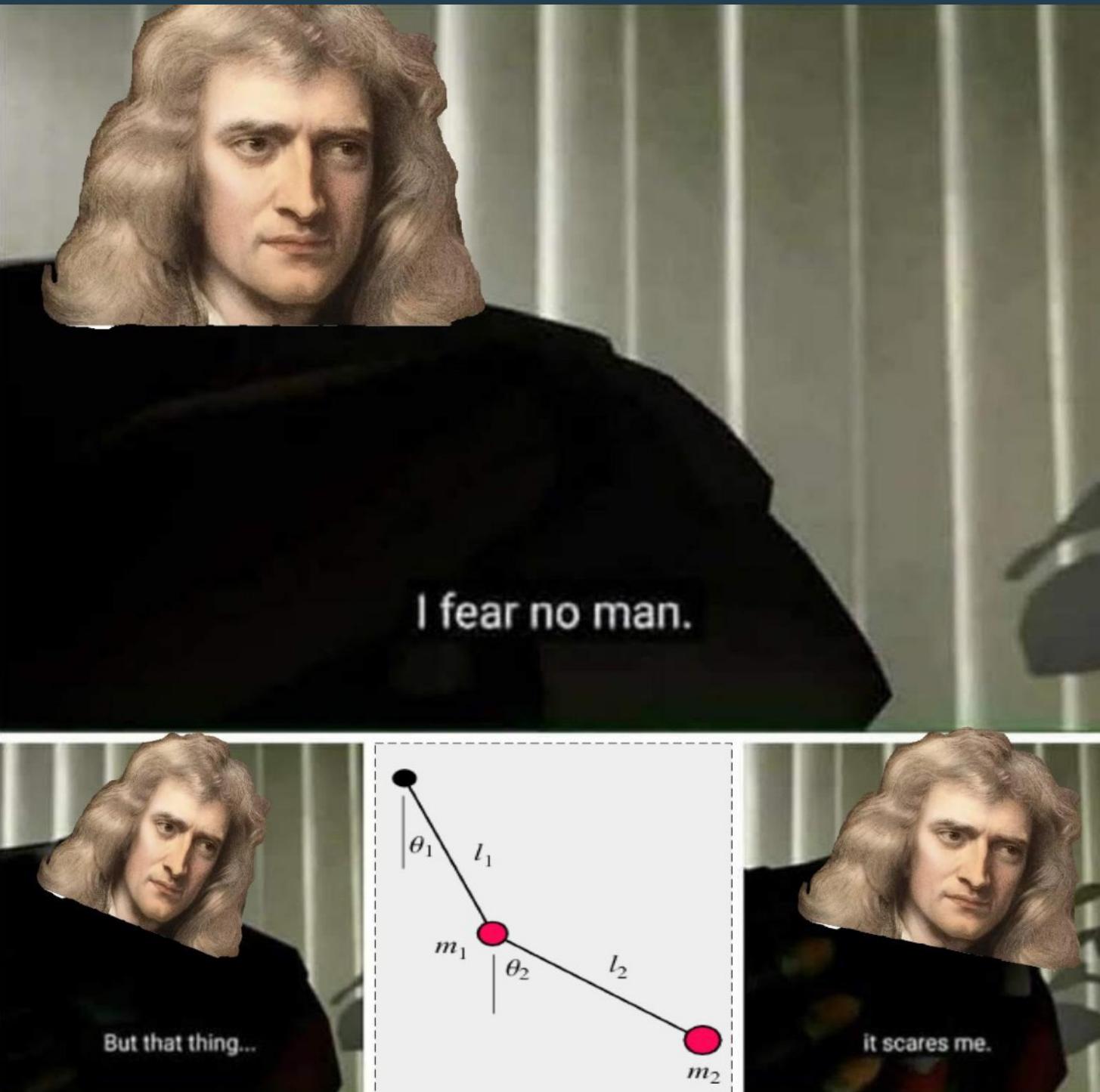
PHY 321: Classical Mechanics 1, Michigan State University, Spring 2025

This is the Jupyter-Book for the Classical Mechanics course at MSU



jupyter {book}

First major's course with advanced calculus
Makes use of evidence-based techniques
Emphasizes creativity, exploration, and agency



Computational Essays as a form of assessment

Narrative text

Title and Introduction

Pictures and Diagrams

Pictures and Diagrams

Computer Code

Introduction: What is a Railgun?

A railgun is a device that uses magnetic forces to accelerate a projectile to extremely high speeds. In the simplest case, it consists of two parallel, current-carrying rails (wires, essentially) with a moveable, conductive bar (the projectile launched by the railgun) between them. The bar, because it is a conductor, experiences a force due to the magnetic fields of the rails, which accelerates it.

The United States navy has recently debuted a 10-meter long railgun that can launch a 3.2 kg projectile at speeds up to 2500 m/s. Railguns are exciting, because theoretically they could represent a viable alternative to expensive chemical propulsion methods. While there are certainly many military applications to this type of system, one might also be able to use it for scientific purposes, such as launching satellites and supplies into orbit without the need for expensive, one-time-use rockets. However, how viable are railguns for these types of applications?

In this notebook, we aim to estimate how much current one would need in order to use such a railgun to launch a 1kg package of supplies to the ISS, which is approximately 405 km above the surface of the earth. We will create a simple simulation of this system, then add in some complicating factors to try to get a more accurate calculation.



The US Navy's Electromagnetic Railgun (From [popular mechanics](#))

Initial Simulation of the Railgun

First, we have to import our various libraries. We will be using sympy and numpy for the graphing, as well as matplotlib. We will also use VPython to do some visualization.

```
In [1]: import sympy as sp
import numpy as np
import matplotlib.pyplot as plt
```

Next, we define some parameters, including the current in the rails, the separation of the rails (which is also the width of the projectile), the lengths of the rails, and the mass of the projectile.

Using the [approximate dimensions](#) of the navy railgun as a guide, we set the length of the rails to 10m and the separation of the rails to 15cm (corresponding to a 150mm bore railgun). We will also define the mass of the projectile (1 kg) and the magnetic constant for use in magnetic force calculations later on.

```
In [2]: D = .15 #separation of the rails and width of the bar. Set to 15cm
w = 0.1 #width of the rails. Set to 10cm each
L = 10 #length of the rails. Set to 10m
m = 1 #set mass to 1kg
I = 10000 #starting current. Set to 10000 Amps
```

Importing packages

Model parameters

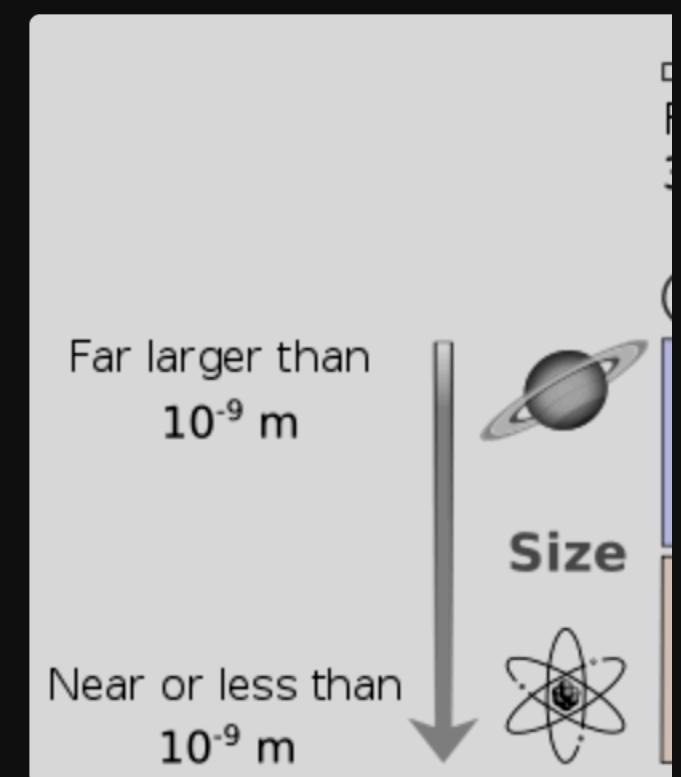
Week 1 - Overture: What is Classical Physics?

There are many different fields of what kinds of physical systems there based on the system's size and sp

- Classical physics: large, slow
 - Statistical and quantum mech
 - General relativity: large, fast
 - Quantum field theory: small,

These are not hard and fast rules, complex problems. For example, particle physics use physical models that depend on how we define field by size and speed is a useful thus far. The figure below shows that behaviors are both fluid drag, but

The first form ($F \sim v^2$) describes a baseball thrown through the air. But moving through the ocean. These forces, which can result in damage,



Source: [Wikipedia](#)

Week 4 - Why does fluid drag complicate things?

As an object moves through the fluid, it experiences a drag force. This collision changes the momentum of the fluid particles, but the average effect of all those collisions is to change the direction of the object's velocity, $F(v)$. In some cases, they might approach the object, and in other cases, they might move away from it. These behaviors are both fluid drag, but they have different names.

The first form ($F \sim v^2$) describes baseball thrown through the air. By moving through the ocean. Through forces, which can result in damage and focus on the way this form of

This form of air resistance cannot fluid. Objects moving a speeds th changes in density, pressure, and flying at supersonic speeds.

Week 7 - Nonlinear Dynamics

We have now built enough tools to tackle some challenging physical systems that have nonlinear equations

Week 10 - Chaotic Dynamics

Chaos theory is a branch of science that focuses on the study of systems that exhibit chaotic behavior.

These systems are quite sensitive

Nonlinear dynamics is the science of systems that exhibit nonlinearity. This can include crystals and other optical systems, in fluid dynamics, plasma physics, and with nonlinear dynamics. Nonlinear systems are often characterized by their sensitivity to initial conditions, which means that small changes in the starting point can lead to vastly different outcomes over time. This sensitivity can also lead to complex behaviors like chaos. The study of nonlinear dynamics requires a combination of mathematical tools such as differential equations, numerical simulations, and statistical methods to predict and understand the behavior of these systems.

where the Hamiltonian is nonlinear
chaotic systems.

We will focus on classical chaos,
There is no inherent randomness
but this is not required for a system
sensitivity to initial conditions, ch

Nonlinear Differ

Differential equations are the language we use to investigate how things evolve over time. They are often used to model real-world phenomena, giving a good overview of what different variables of the system do over time.

Differential equations

Sensitive Dependence

One of the hallmark features of climate change is that it creates
differences in the starting state of the system. In some cases this means that we cannot
make accurate short-term predictions. For example, if a butterfly flapping its wings in Brazil can cause
reaching effects. But it is true that

“Textbook”: Interactive JupyterBook

- Derivations & Examples
 - Code & Resources
 - Videos & Links

Week 12 - The Principle of Least Action

Newtonian Mechanics is an incredibly useful model of the natural world. In fact, it wasn't until the mid 1970s that we were able to truly test Einstein's gravity as a true replacement for Newton. That being said, for most terrestrial situations (macroscopic objects moving at low speeds), Newton's mechanics is very good.

- 1. We must be able identify each interaction on the object or model an average behavior from many smaller interactions (e.g., models of friction vs. detailed E&M forces)
 - 2. We must be able to mathematically describe the size and direction of the interaction at all times we want to model
 - 3. We must be able to vectorially add the interactions to produce the net force $\sum_i \vec{F}_i = \vec{F}_{net}$.

k In many cases, we can do this. But consider a bead sliding inside a cone. How would you write down the contact force between the cone and the bead for all space and time?

This is where [Lagrangian Mechanics](#) comes in. It is a powerful and elegant way to describe the motion of particles and systems. It is based on the [Calculus of Variations](#), a field of mathematics that is concerned with finding the path that minimizes or maximizes (called "extremization") a certain quantity. In the case of Lagrangian Mechanics, the quantity we are extremizing is the action.

The video below discusses the concept of the Principle of Least Action, which is the foundation of Lagrangian Mechanics.

60-100 Students take PHY 321

Interactive Lecture with Clickers

Clicker Question 31-1

We completed this derivation with the following mathematical statement:

$$\int_{s_1}^{s_2} \eta(x) \left[\frac{\partial f}{\partial y} - \frac{d}{dx} \left(\frac{\partial f}{\partial y'} \right) \right] dx = 0$$

where $\eta(x)$ is an arbitrary function. What does this imply about the term in square brackets?

1. The term in square brackets must be a pure function of x .
2. The term in square brackets must be a pure function of y .
3. The term in square brackets must be a pure function of y' .
4. The term in square brackets must be zero.
5. The term in square brackets must be a non-zero constant.

5 / 9

Clicker Question 6-2

Assuming a **linear model** for Air Resistance $\sim bv$, we obtained this EOM for a falling ball:

$$\ddot{y} = -g + \frac{b}{m}\dot{y}$$

What happens when $\ddot{y} = 0$?

1. The ball stops moving ($v = 0$).
2. The ball reaches a velocity of mg/b .
3. The ball reaches a terminal velocity.
4. I'm not sure.

9 / 13

Clicker Question 34-1

For this plane pendulum, the mathematical statement

$$\frac{d}{dt} \left(\frac{\partial \mathcal{L}}{\partial \dot{x}} \right) = \frac{d}{dt} (m\dot{x}) = 0$$

is equivalent to what statement? Is it true?

1. Conservation of energy. True.
2. Conservation of energy. False.
3. Conservation of linear momentum. True.
4. Conservation of linear momentum. False.

7 / 10

60-100 Students take PHY 321

Group Activities

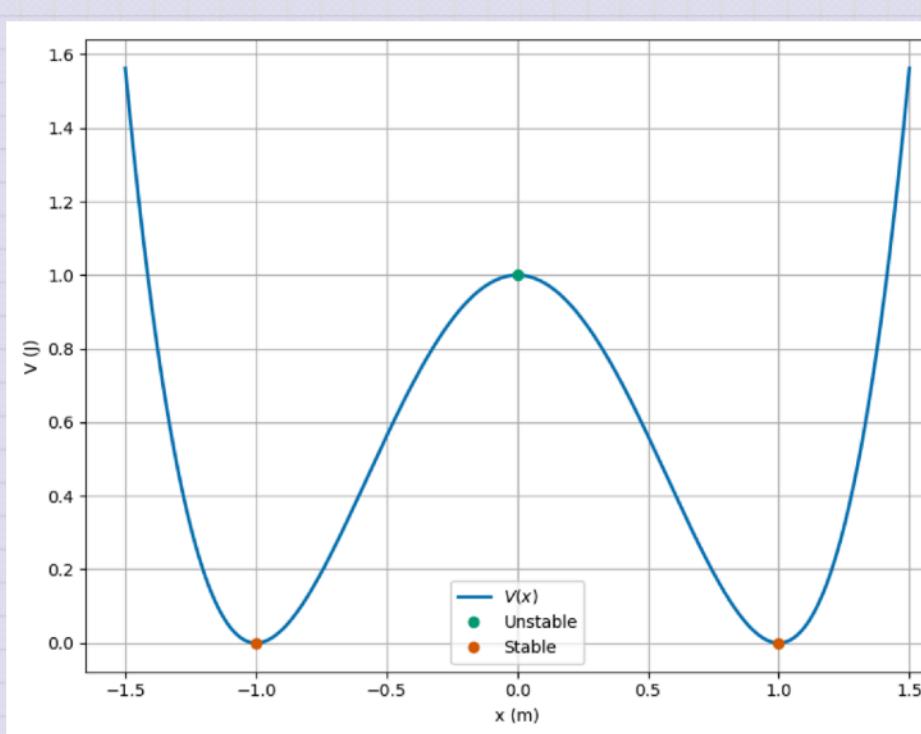
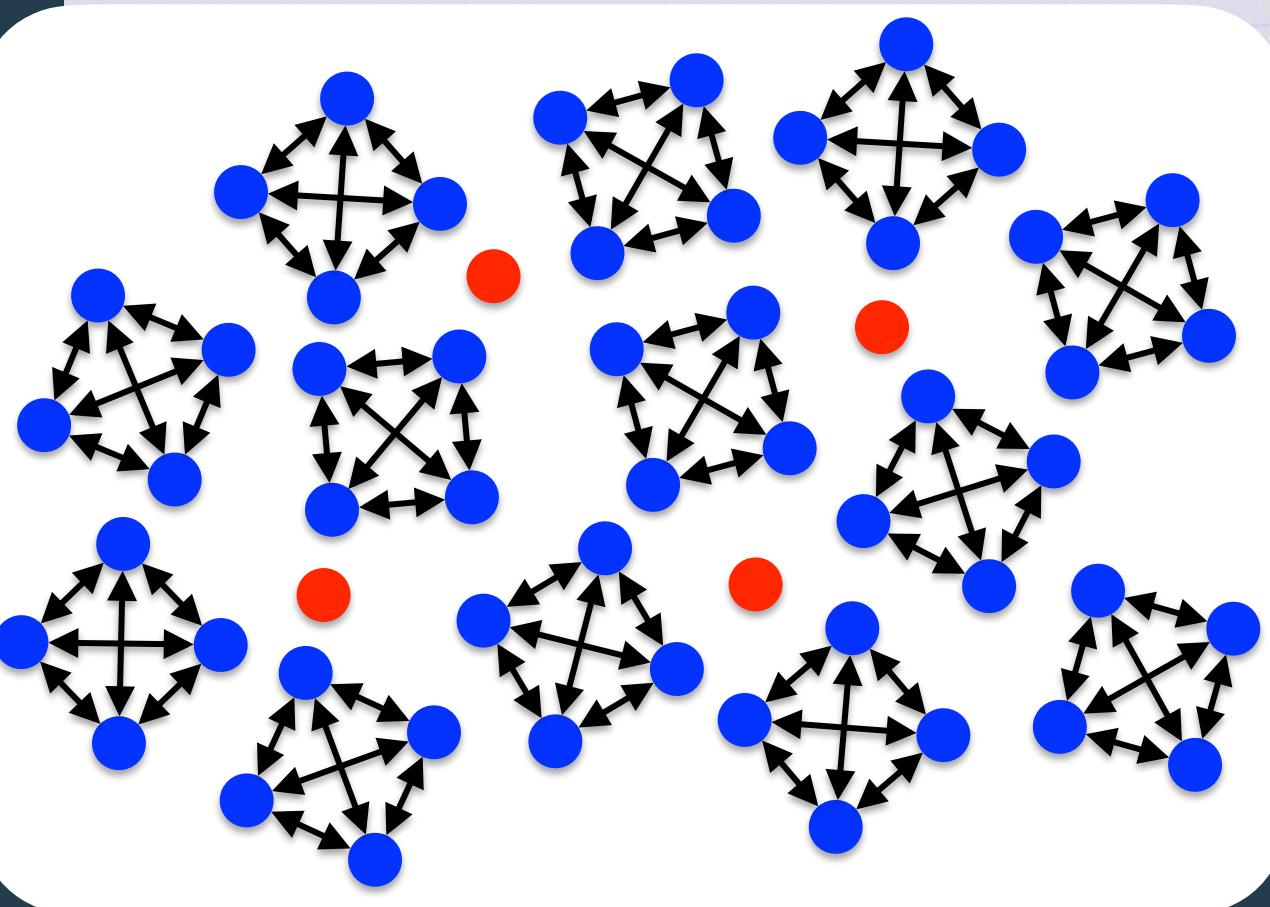
Clicker Question 15-5

Here's a graph of the potential energy function $U(x)$ for a double-well potential.

Describe the motion of a particle with the total energy, $E =$

1. 0.4 J, < barrier height
2. 1.2 J, > barrier height
3. 1.0 J, = barrier height

Click when done.



Clicker Question 18-4

Consider now the differential equation $\dot{x} = x^3 - x$. To find $t(x)$, we can integrate:

$$t(x) = \int_{x_0}^x \frac{dx'}{x'^3 - x'}$$

That yields the following solution (😺😺😺):

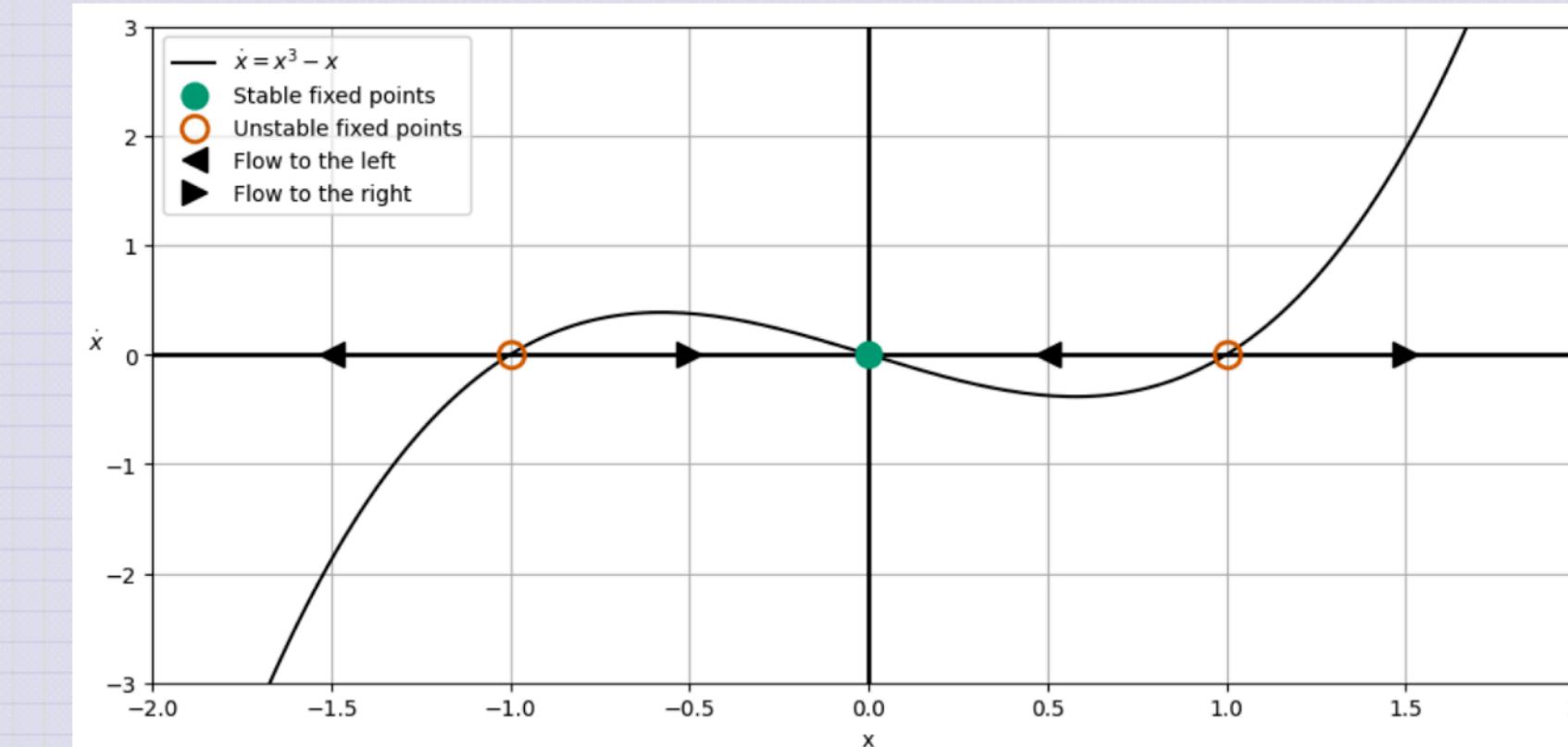
$$t(x) = \left(\frac{1}{2} \ln(1 - x^2) - \ln(x) \right) - \left(\frac{1}{2} \ln(1 - x_0^2) - \ln(x_0) \right)$$

1. Find the equilibrium points (x^*) of the system.
2. Sketch the differential equation $\dot{x} = x^3 - x$ in the phase space x vs. \dot{x} .
3. What can you say about the stability of the critical points? Add these to your plot.

Click when you and your table are done.

14 / 17

Phase Space Diagram for $\dot{x} = x^3 - x$



15 / 17

Midterms help develop agency

Midterm 1 (Due 28 Feb)

Spring 2025

```
import numpy as np
from math import *
import matplotlib.pyplot as plt
import pandas as pd
%matplotlib inline
plt.style.use('seaborn-v0_8-colorblind')
```

Part 1, Particle in a one-dimensional potential (60 points)

We consider a particle (for example an atom) of mass m moving in a one-dimensional potential,

$$V(x) = \frac{V_0}{d^4} (x^4 - 2x^2d^2 + d^4).$$

We will assume all other forces on the particle are small in comparison, and neglect them in our model. The parameters V_0 and d are known constants.

- (5pt) Sketch or plot the potential and find the equilibrium points (stable and unstable) by requiring that the first derivative of the potential is zero. Make an energy diagram (see for example Malthe-Sørensen chapter 11.3) and mark the equilibrium points on the diagram and characterize their stability. The position of the particle is x .
- (5pt) Choose two different energies that give two distinct types of motions, draw them on the energy diagram, and describe the motion in each case.
- (5pt) If the particle starts at rest at $x = 2d$, what is the velocity of the particle at the point $x = d$?
- (5pt) If the particle starts at $x = d$ with velocity v_0 , how large must v_0 be for the particle to reach the point $x = -d$?

Same Tasks Student selected system

Part 2, model your own system (50 points)

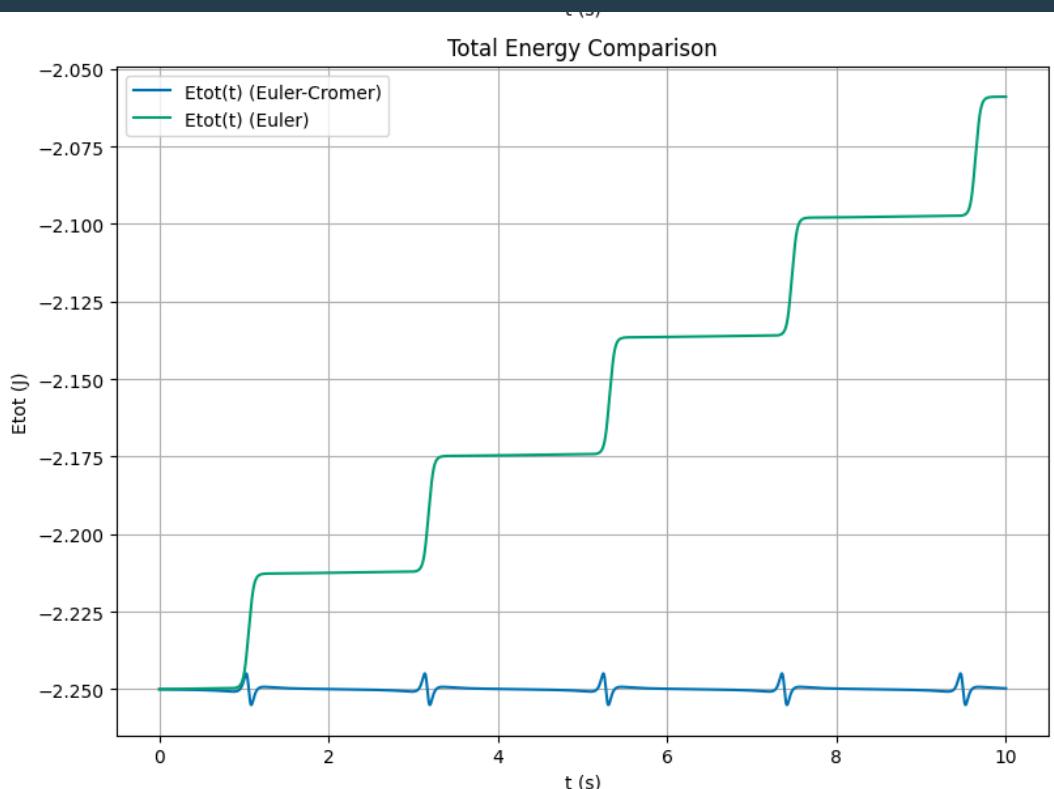
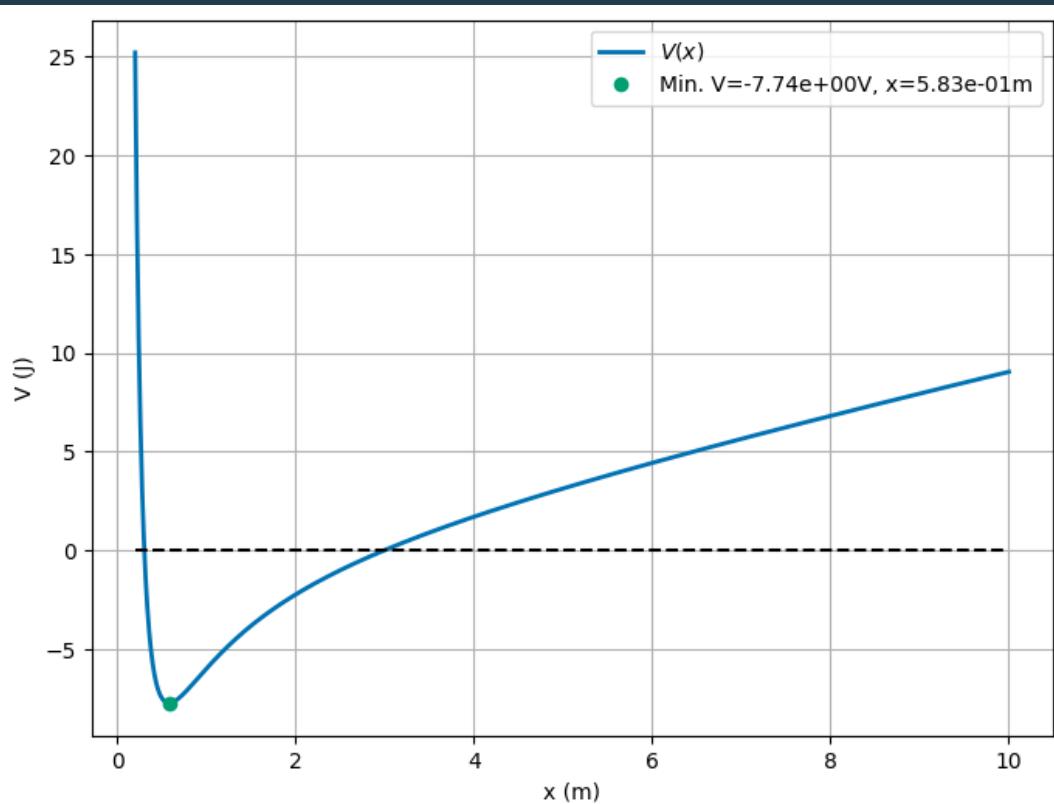
In this problem, you will choose a one dimensional system of your own. You may choose a known potential, or you may invent your own. Your potential must:

- Have at least one stable equilibrium point.
- Have at least one unstable equilibrium point, or some other interesting feature (e.g., asymptotic behavior).
- For some choice of total energy, it should have oscillatory motion (i.e., classical turning points).
- Produce a non-linear and conservative force.
- Be continuous and differentiable over the range of interest.

For this problem, you will need to perform the following tasks:

- (5pts) Write down the potential and start to demonstrate that it meets the above criteria. **Make sure it is conservative and that the force is nonlinear before proceeding.**
Sketch or plot the potential and find the equilibrium points. You need to show you can compute the equilibrium points and characterize their stability. For some choices of potential, you may need to use a numerical method to find the equilibrium points and conceptual arguments to determine their stability.
- (10pts) Pick a total energy that gives rise to oscillatory motion. Show this by sketching or plotting the energy diagram and describing the motion. Are there any other kinds of motion that can occur for other choices of total energy?
- (20pts) Write a numerical algorithm to find the position and velocity of the particle (it's trajectories) for the choice of total energy where the motion is oscillatory. Here you must use two methods: (1) the standard forward Euler, and either (2) the Euler-Cromer or the [Velocity Verlet](#) algorithms. You will need to pick the time step Δt and the total time t_{\max} for your simulation. Compare the results of the two algorithms. Which one is better? Justify your answer. **You might find this [numerical integration resource](#) helpful.**
- (10pts) Use your program to plot the energy of the particle (T), the potential energy (V), and the total energy (E) as a function of time. Discuss the behavior of the energy between each choice of algorithm. Is energy conserved in your simulations?

1D quark confinement model



Midterms help develop agency

In-class Modeling Activity

The Lorenz model is given by:

$$\frac{dx}{dt} = \sigma(y - x)$$

$$\frac{dy}{dt} = x(\rho - z) - y$$

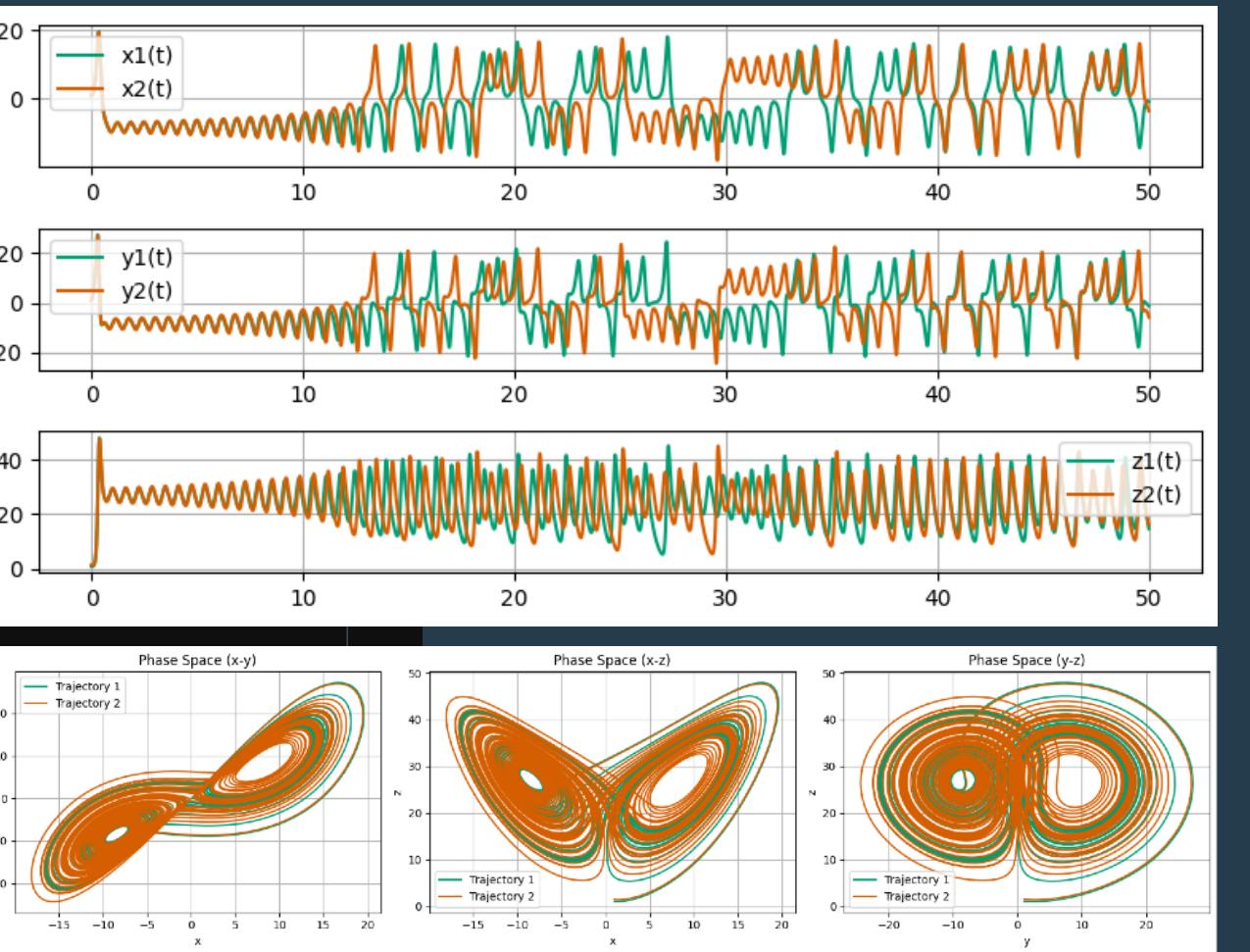
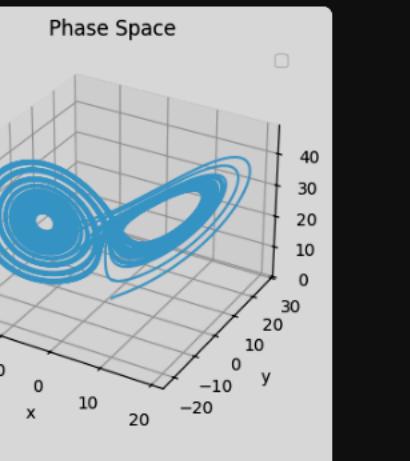
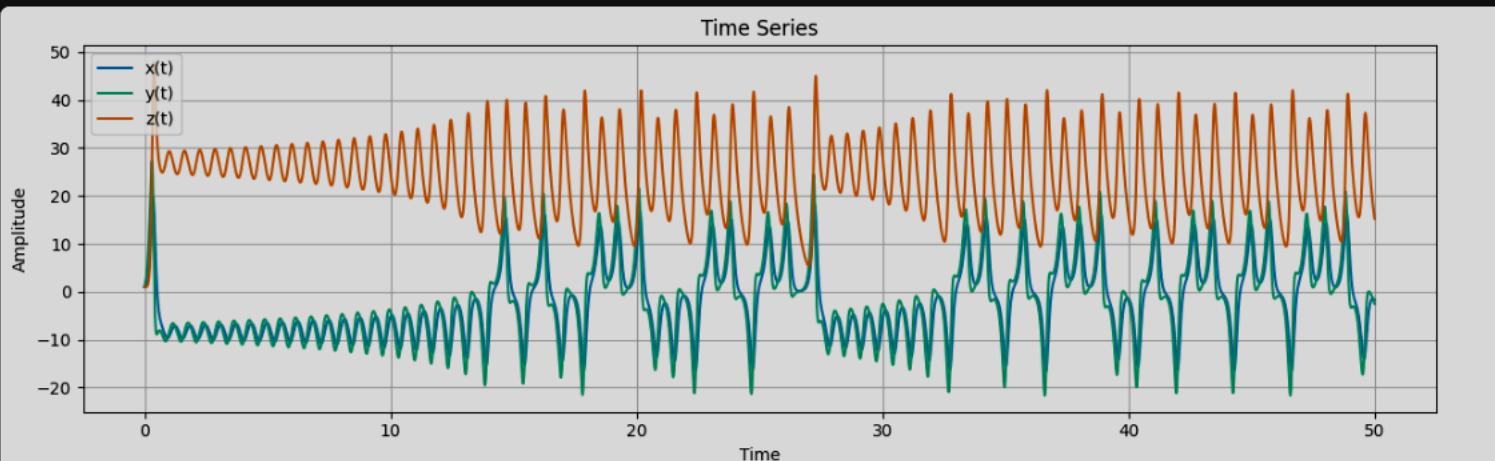
$$\frac{dz}{dt} = xy - \beta z$$

Where σ , ρ , and β are system parameters. The canonical values are $\sigma = 10$, $\rho = 28$, and $\beta = \frac{8}{3}$.

Numerically Integrate the Lorenz Attractor

In the cells below, we scaffold some of the code to simulate the Lorenz attractor. You will need to fill in the missing pieces. Once you plot the solution, you should be able to produce time series, and phase space plots of the Lorenz attractor. **Note that the phase space for the Lorenz attractor is 3D (x,y,z), so you will need to use a 3D plotting function or plot projections.**

For the parameters, we will use the canonical values of $\sigma = 10$, $\rho = 28$, and $\beta = \frac{8}{3}$. Choose initial conditions of $x = 1$, $y = 1$, and $z = 1$ and simulate for 50 time units. If you do, your solution will look like the one below.



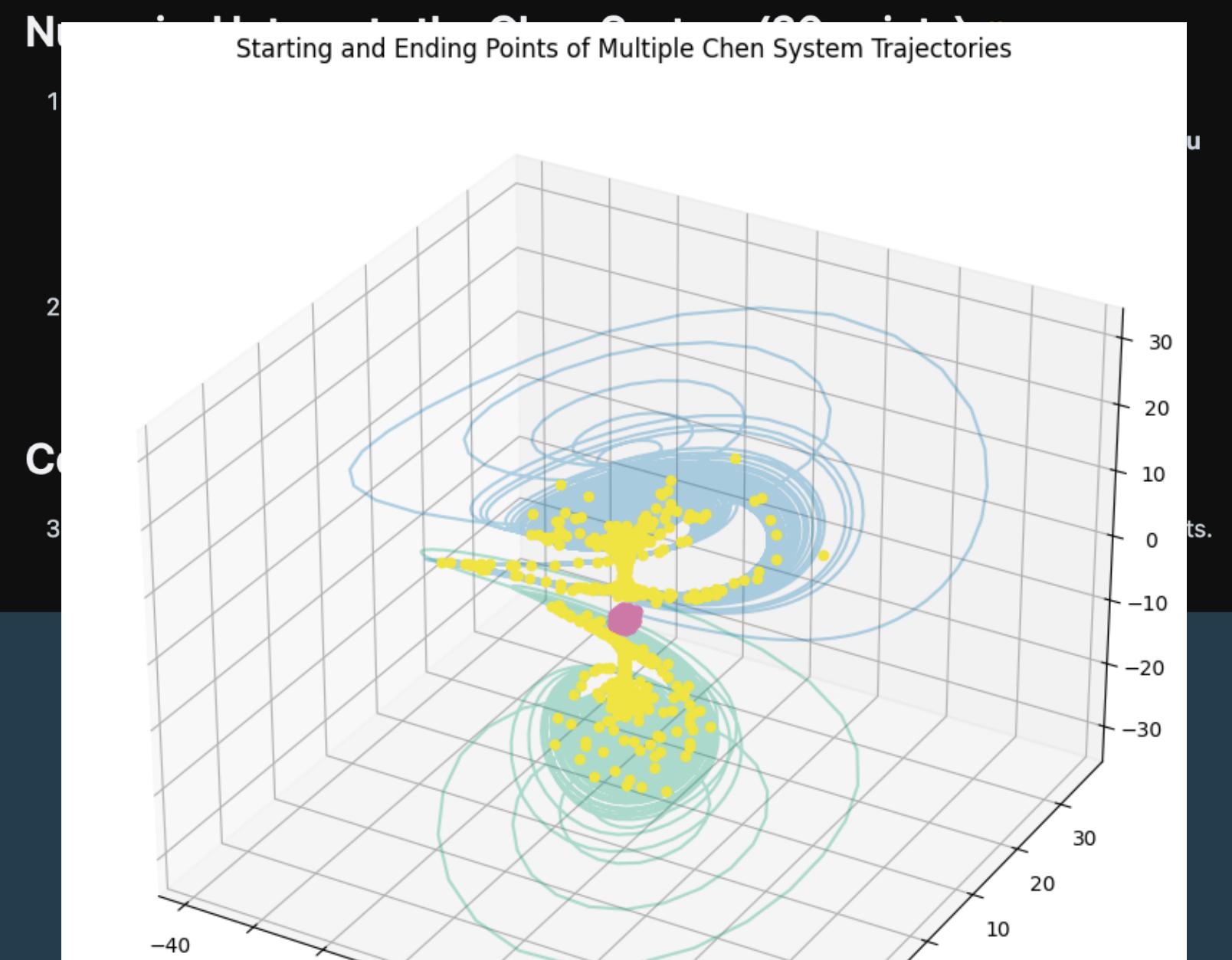
Part 2, Strange Attractor (40pt)

We learned about [Strange Attractors](#) when modeling the [Lorenz system](#) in class. In this part of the exam, we will explore the [Chen system](#), which is another example of a system that exhibits chaotic behavior and has a strange attractor. The Chen system is given by the following set of ordinary differential equations:

$$\begin{aligned}\dot{x} &= \alpha x - yz, \\ \dot{y} &= \beta y + xz, \\ \dot{z} &= \delta z + xy/3,\end{aligned}$$

where α , β , and δ are constants that determine the behavior of the system. For this problem, we will use the following values:

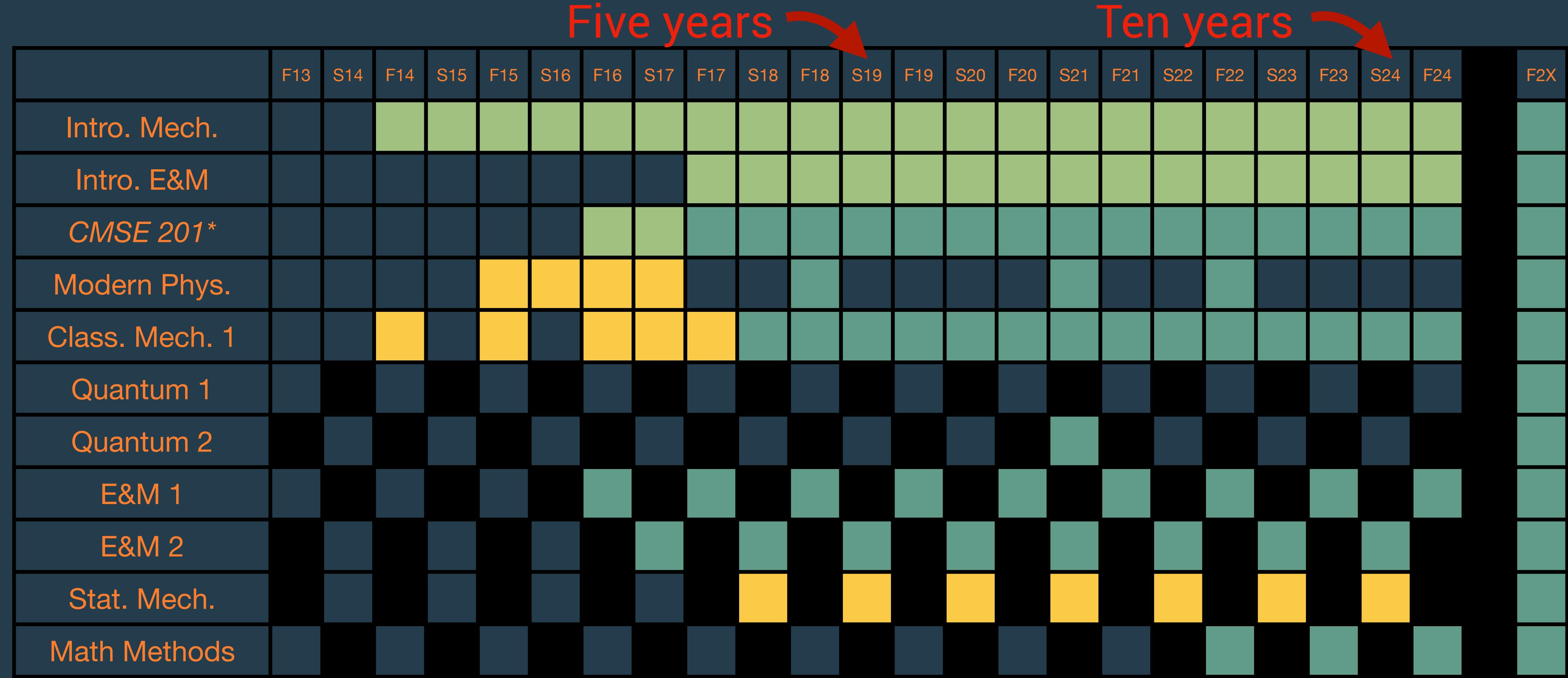
Parameter	Value
α	5.0
β	-10.0
δ	-0.38



Student's illustration of initial condition sensitivity

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

Five years ↗

Ten years ↗

We are 11 years into a five year plan. 😅

Timeline of Integrating Computation at MSU

Typical Course Progression



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

Instruction in computation (some sections)

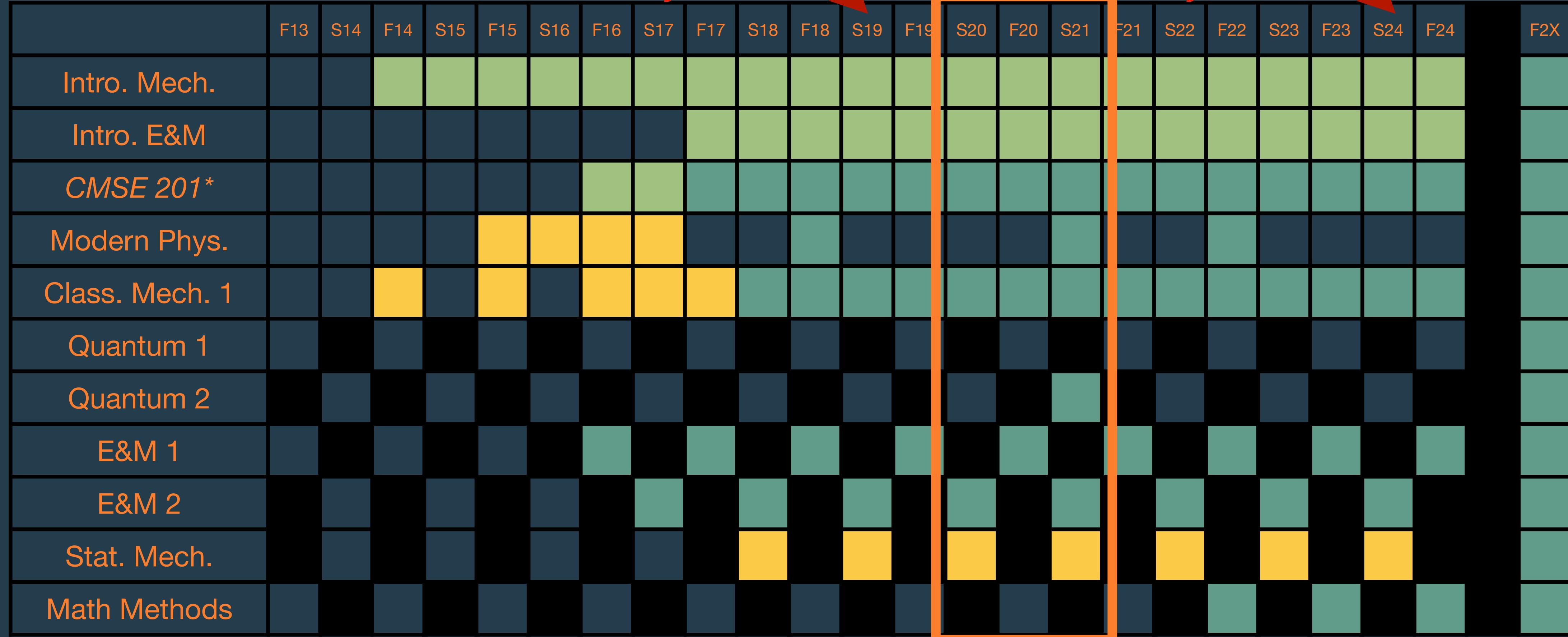
Instruction in computation



Not offered

Five years ↗

Ten years ↗



COVID-19
Pandemic

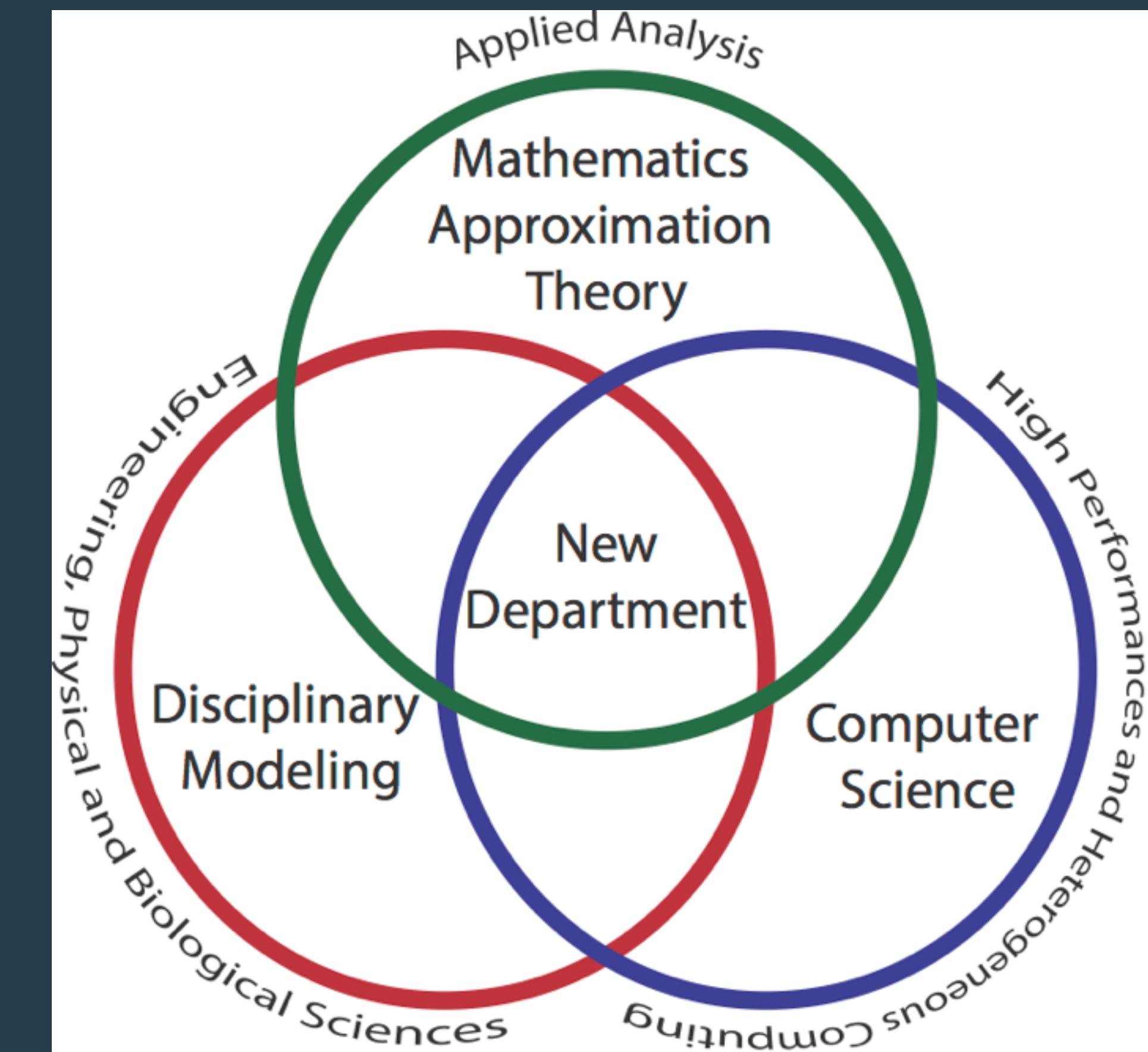
We are 11 years into a five year plan. 😅

External support can help
accelerate the process of
integration.

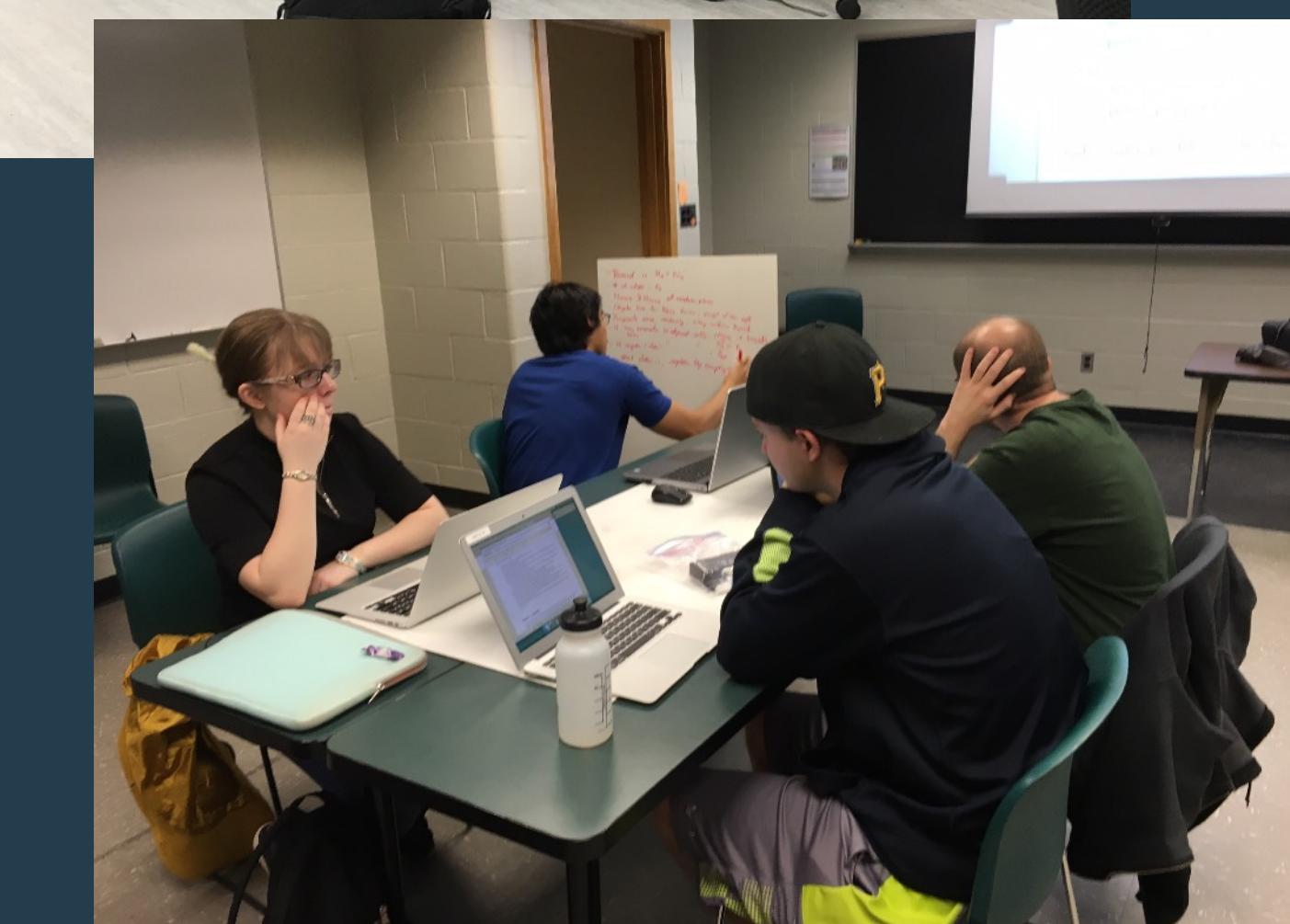
Computational science: using computers to analyze and solve scientific and engineering problems.

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

BS, MS, and PhD granting department



We teach computational and data science



From the articles:

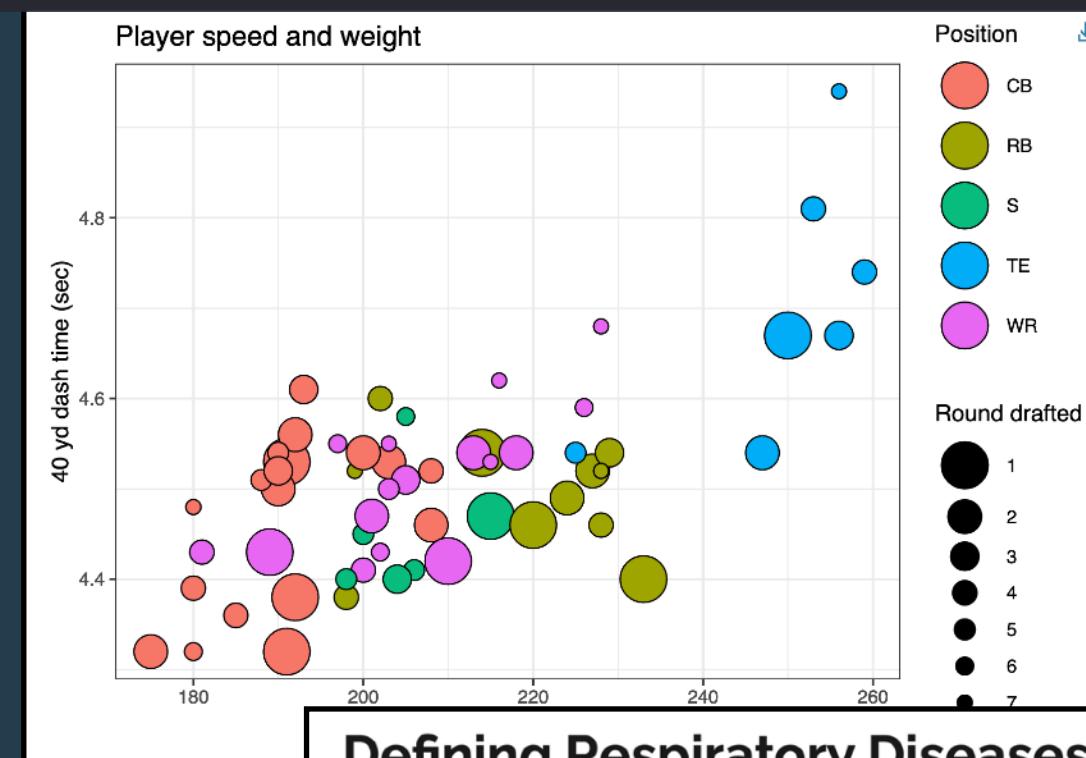
Summarize the main points of the article you read. You had your choice of three linked on D2L (around 250–500 words).

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?

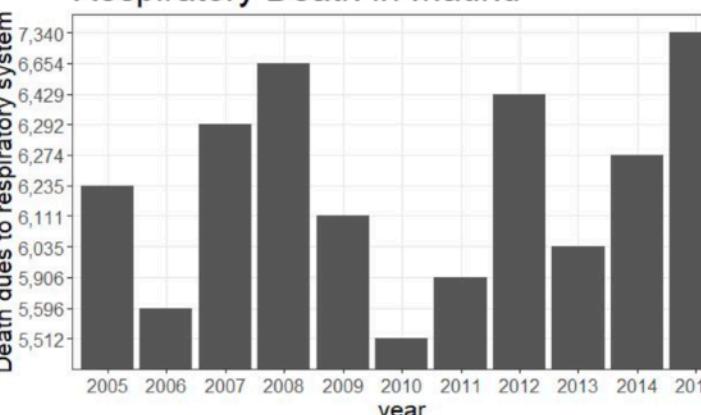
What do data ethics mean to you?



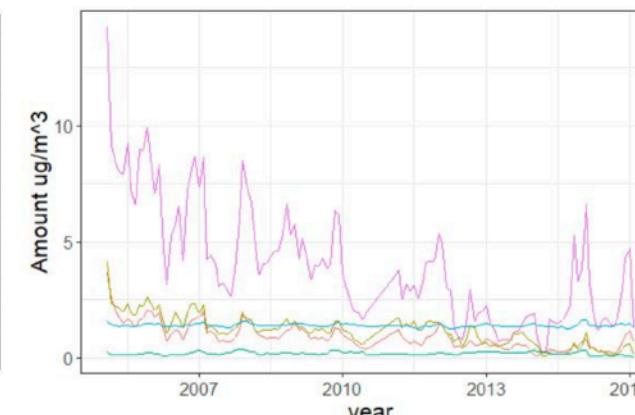
Defining Respiratory Diseases

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

Respiratory Death in Madrid



Pollutants in the Air in Madrid



Basic Numerical Integration: the Trapezoid Rule

A simple illustration of the trapezoid rule for definite integration:

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

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)+95

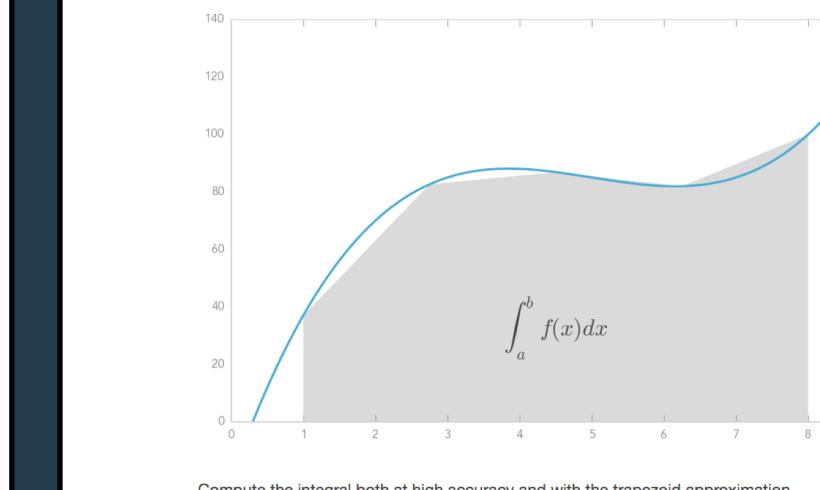
x = np.linspace(0, 10, 200)
y = f(x)
```

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

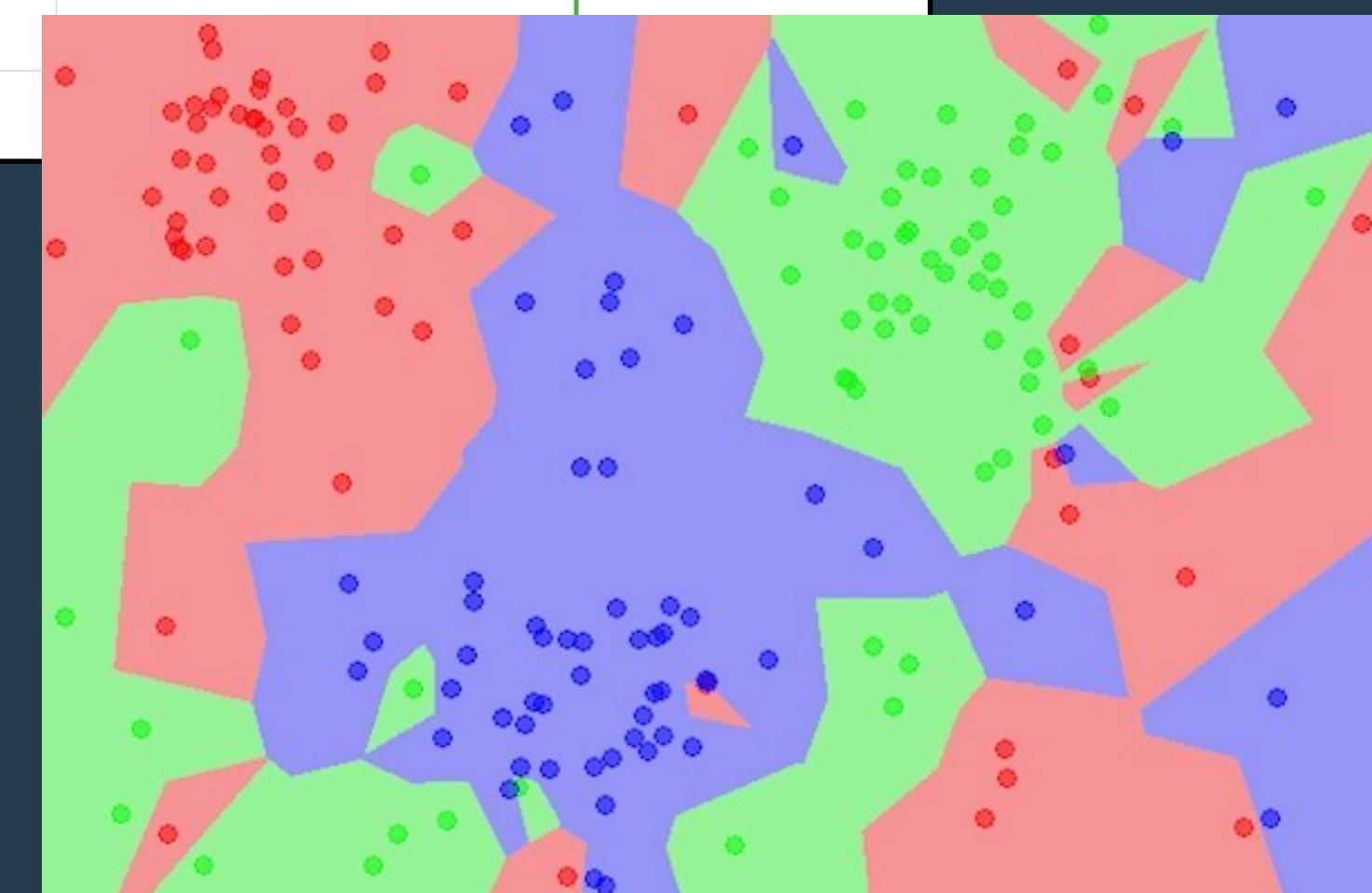
```
In [3]: a, b = 1, 8 # the left and right boundaries
N = 5 # the number of points
xint = np.linspace(a, b, N)
yint = f(xint)
```

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

Introductory Computational Science

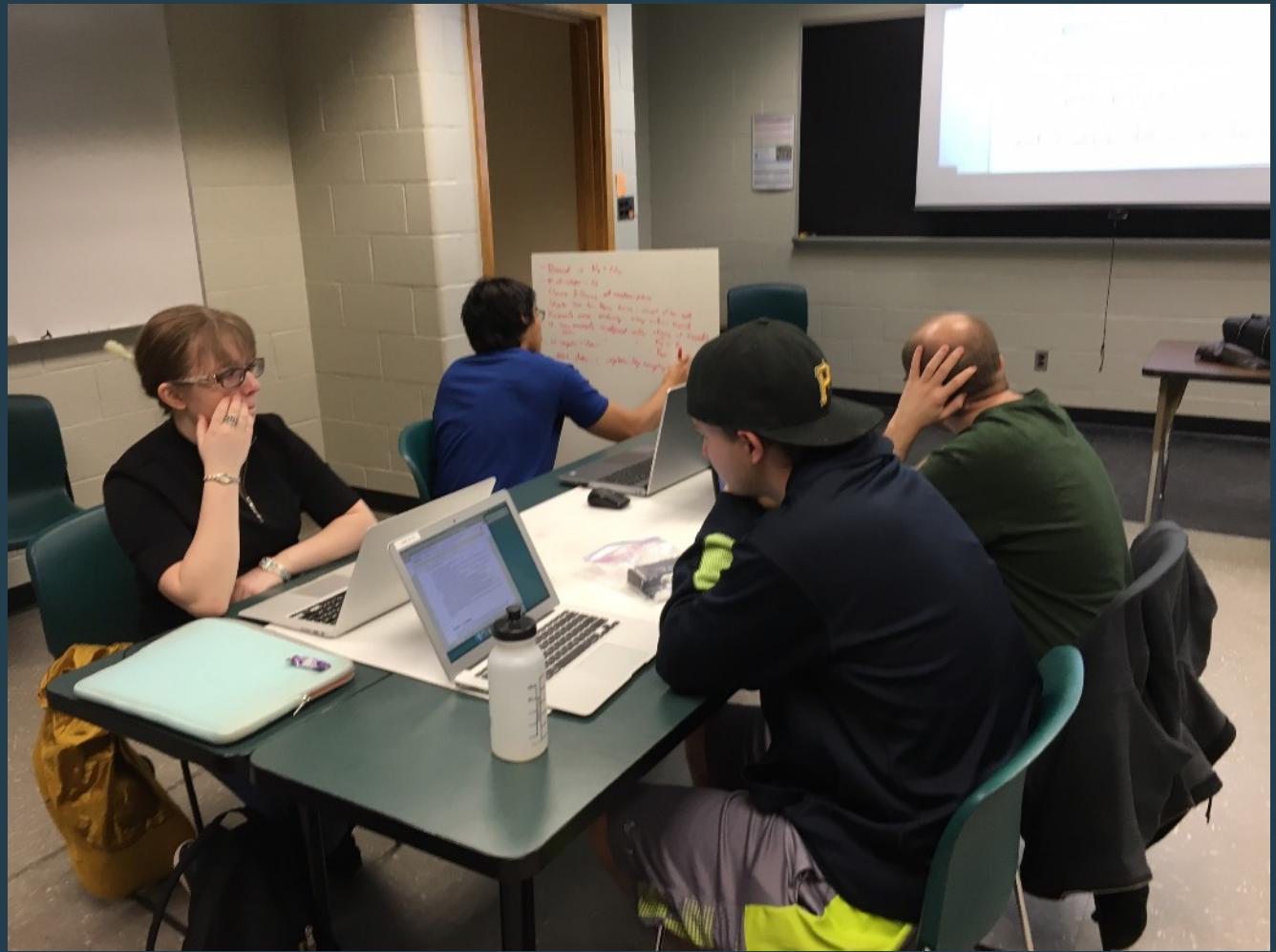
Learning Goals for CMSE 201



1. Gain insight into physical, biological, and social systems through the use of computational algorithms and tools.
2. Write programs to solve common problems in a variety of disciplines.
3. Identify salient features of a system that can be codified into a model.
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.

For any STEM major - pre-req: Calculus 1

Intro. Comp. Modeling (CMSE 201)



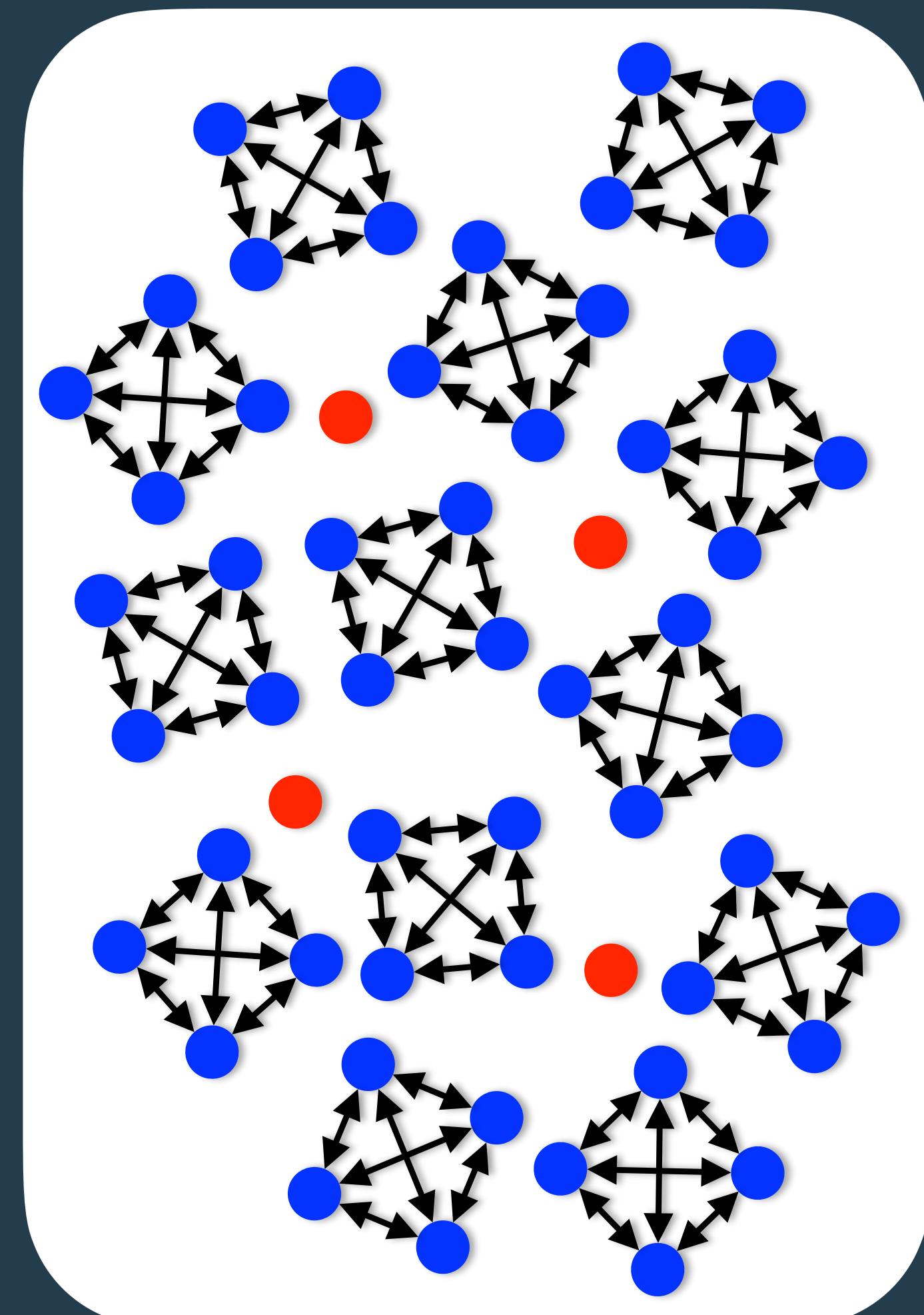
Introductory course in data analysis and modeling
Taken by STEM majors (Calc 1 pre-req)
Required for Physics and Astronomy majors

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



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

50-70 students/section



Integrated Progression

Modeling, Context, and Programming work together

Time ↓	Modeling/Data Analysis Concept	Context/Application	Programming Practices/Tools
	Order of magnitude estimation	Varied (e.g. estimating population)	Variable definition, 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...

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



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:

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

Part 2: The falling skydiver meets air resistance

Part 3: Opening the parachute

Part 4: Modeling a bungee jumper

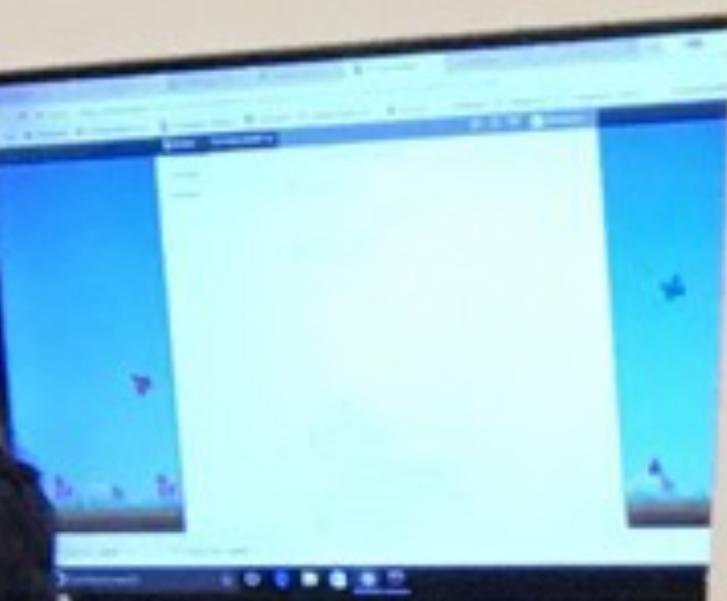
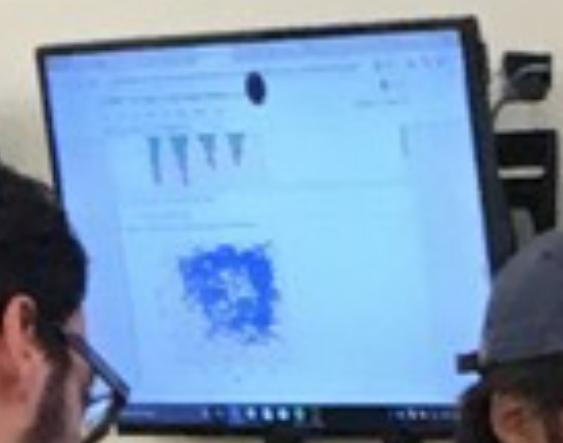
Required for PA majors
before Classical Mechanics

MICHIGAN STATE
UNIVERSITY

4

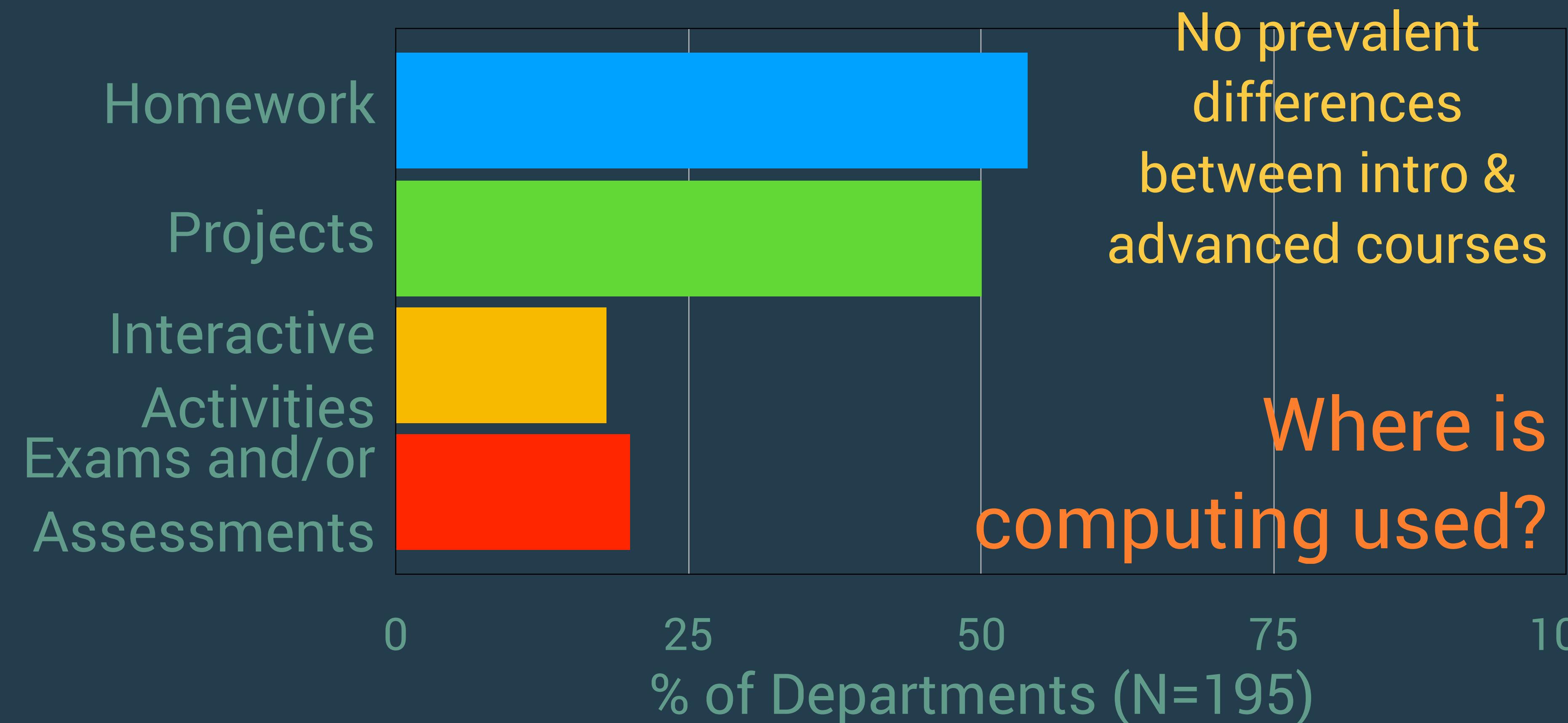


2018-2019
bar, legal (total)



Who teaches computing in physics?

>50% departments report experience with teaching computing in physics
Computational instruction is more prevalent than in the past¹



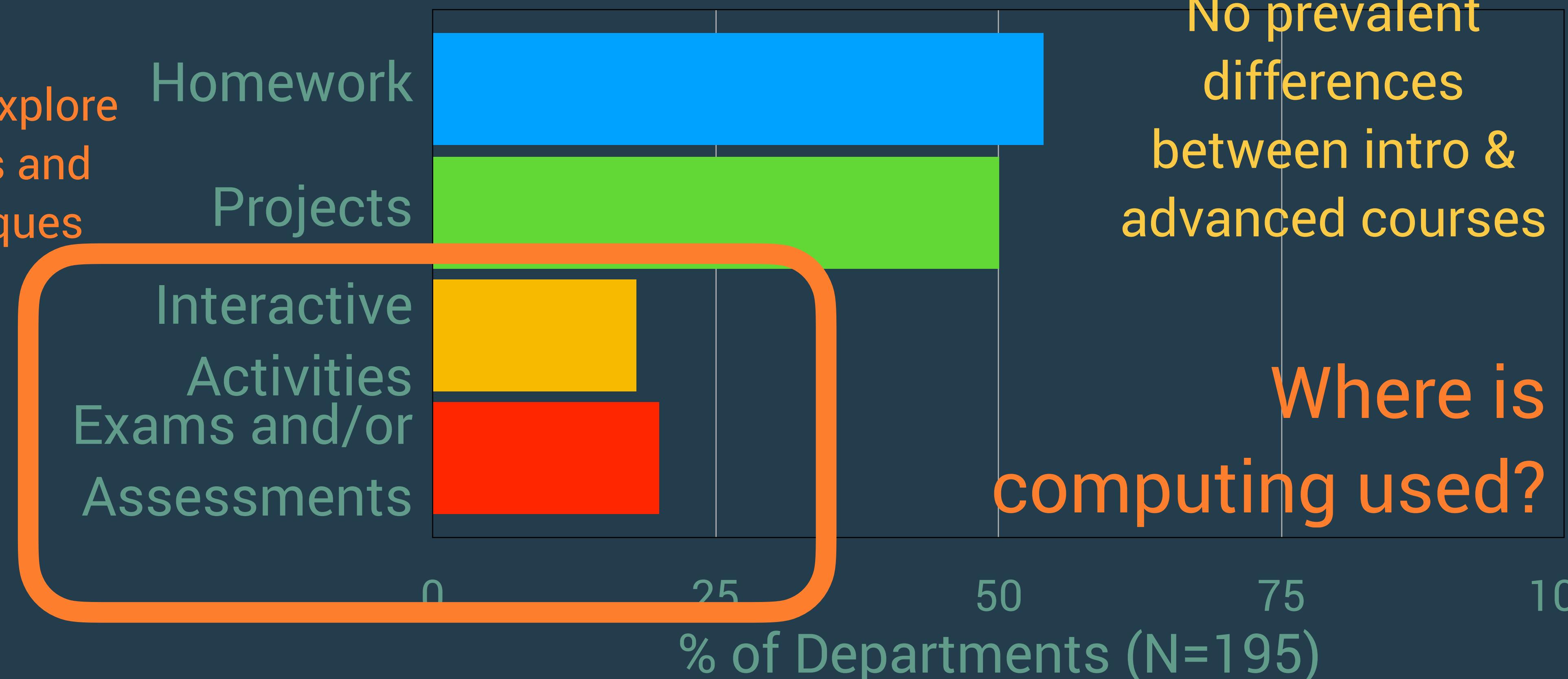
PICUP

¹Chonacky and Winch, Am. J. Phys., 2008
Caballero & Merner, Phys. Rev. PER, 2018

Who teaches computing in physics?

>50% departments report experience with teaching computing in physics
Computational instruction is more prevalent than in the past¹

There is a need to explore interactive methods and assessment techniques for computation



No prevalent differences between intro & advanced courses

Where is computing used?



PICUP

¹Chonacky and Winch, Am. J. Phys., 2008
Caballero & Merner, Phys. Rev. PER, 2018

But “who” teaches computation?



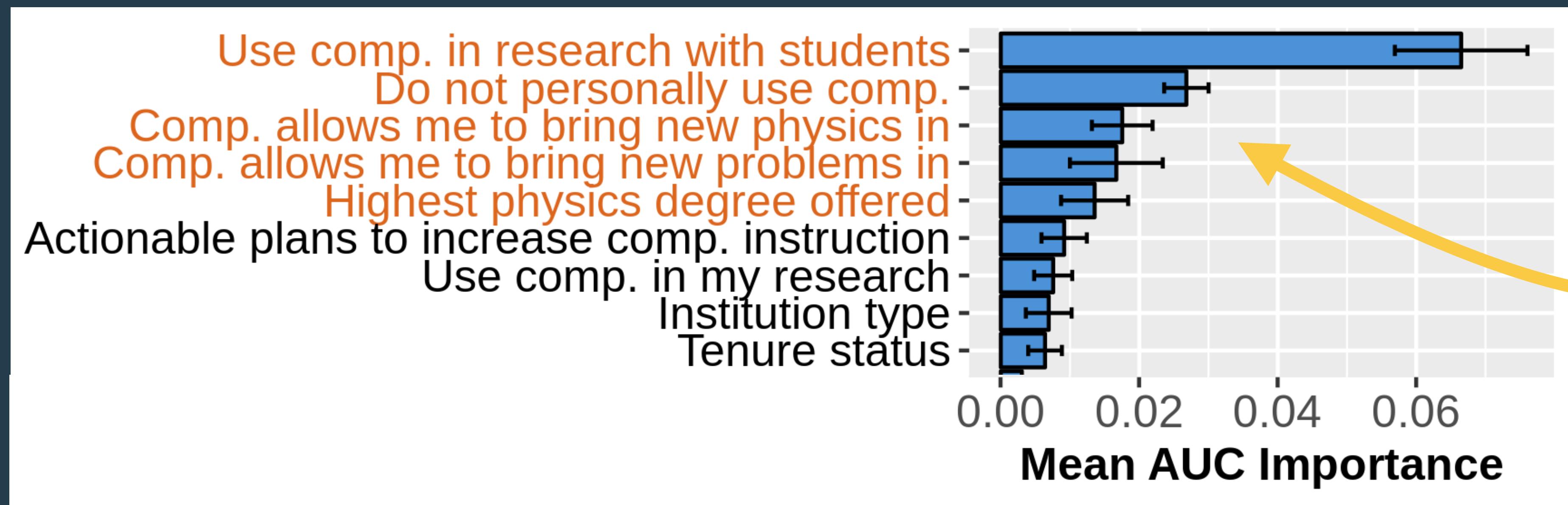
Rate on a scale of 1 (Strongly Agree) to 7 (Strongly Disagree)

Computational physics is hard to teach in the classroom.

My department rewards me for teaching computation.

Computation allows me to bring new physics into the classroom that I otherwise couldn't.

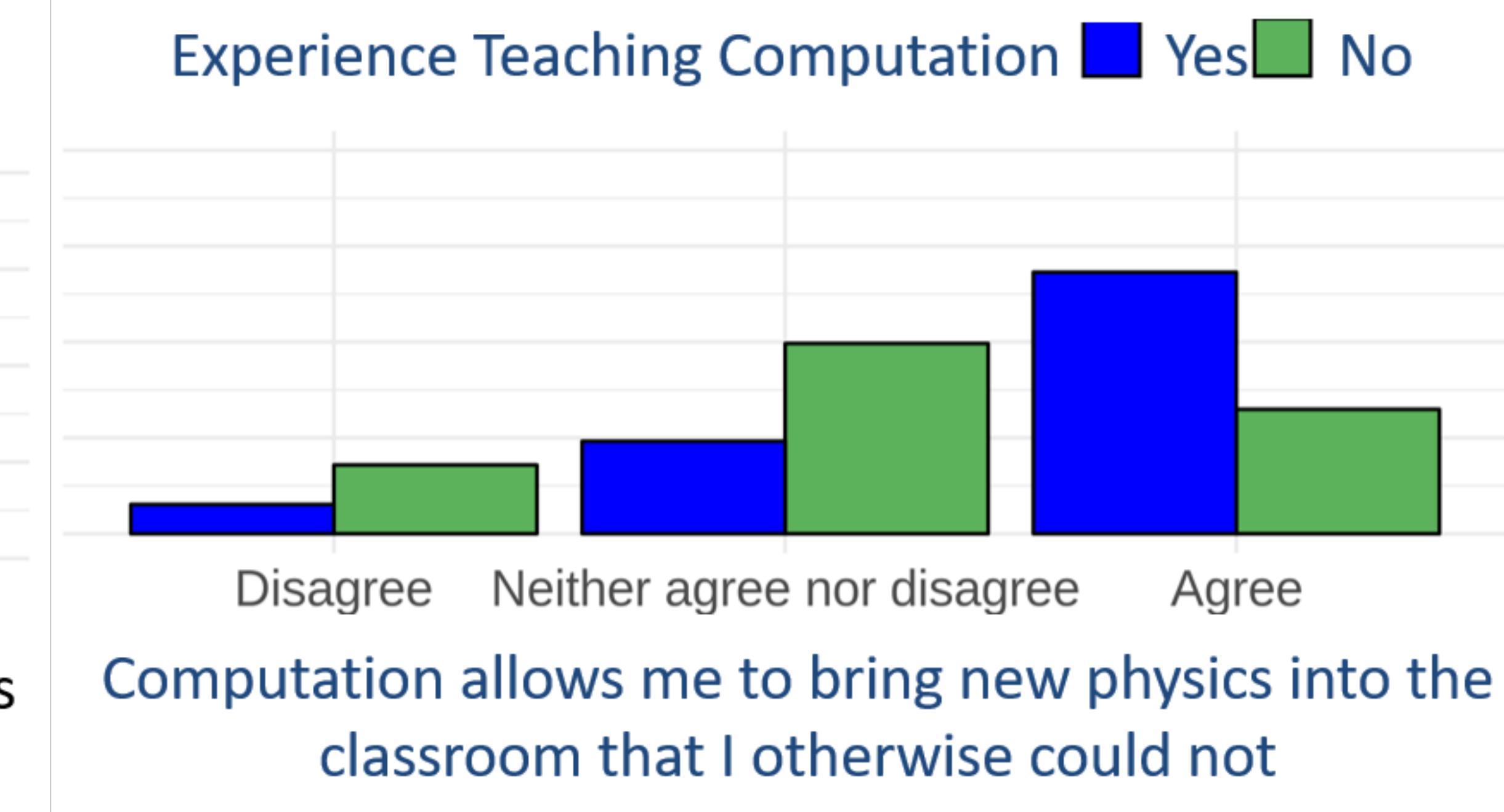
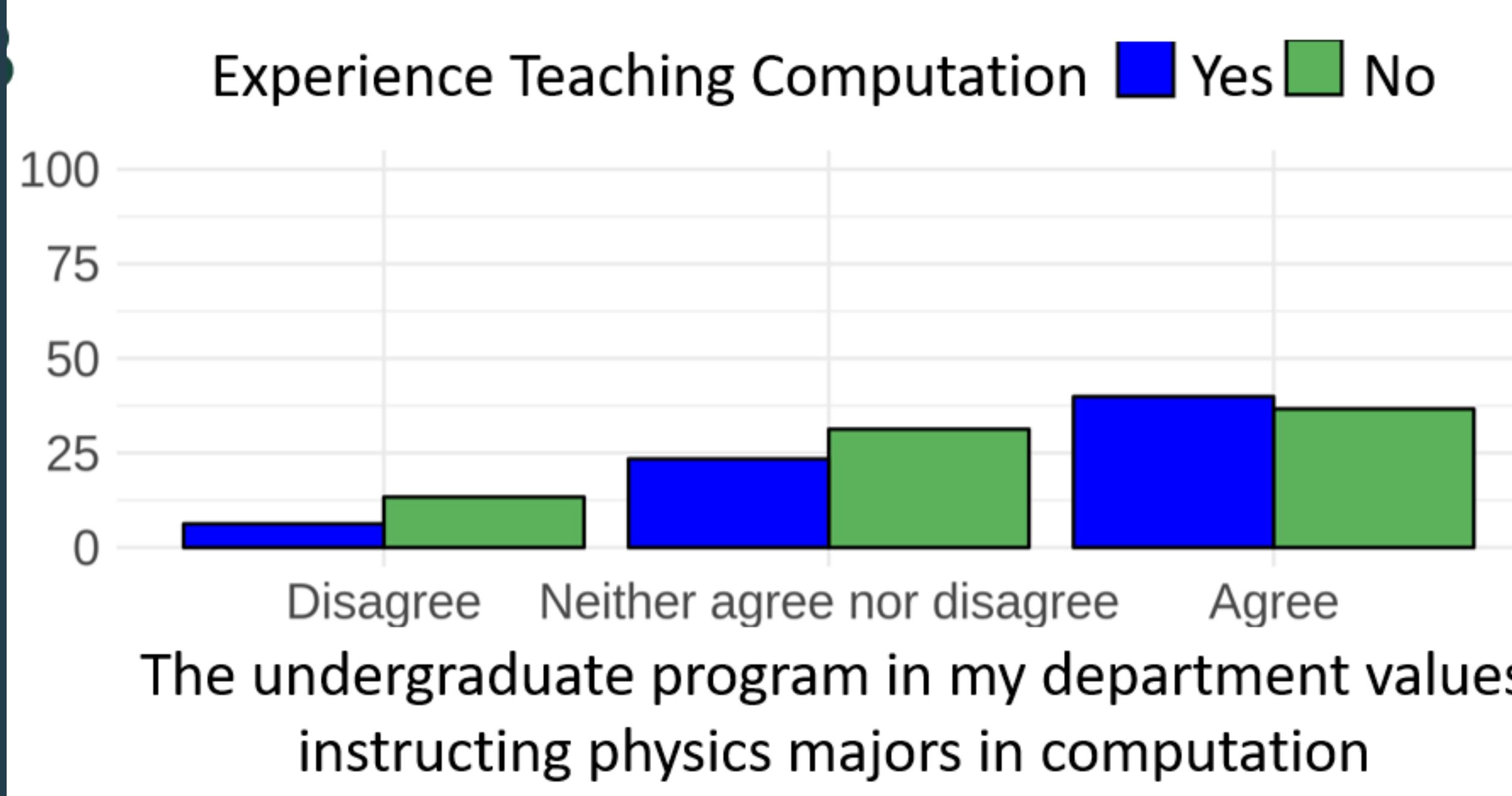
...



Random Forest
Classification

Most important
factors in model

Do these factors make sense? ✓



(At that moment)

Faculty that teach computation tend to:

- Use computation in their research with students or some other way outside of the classroom
- Believe computation brings new physics and problems into the curriculum
- Teach at institutions that offer at least a physics bachelor's degree

Faculty treat teaching computation as an individual choice



PICUP

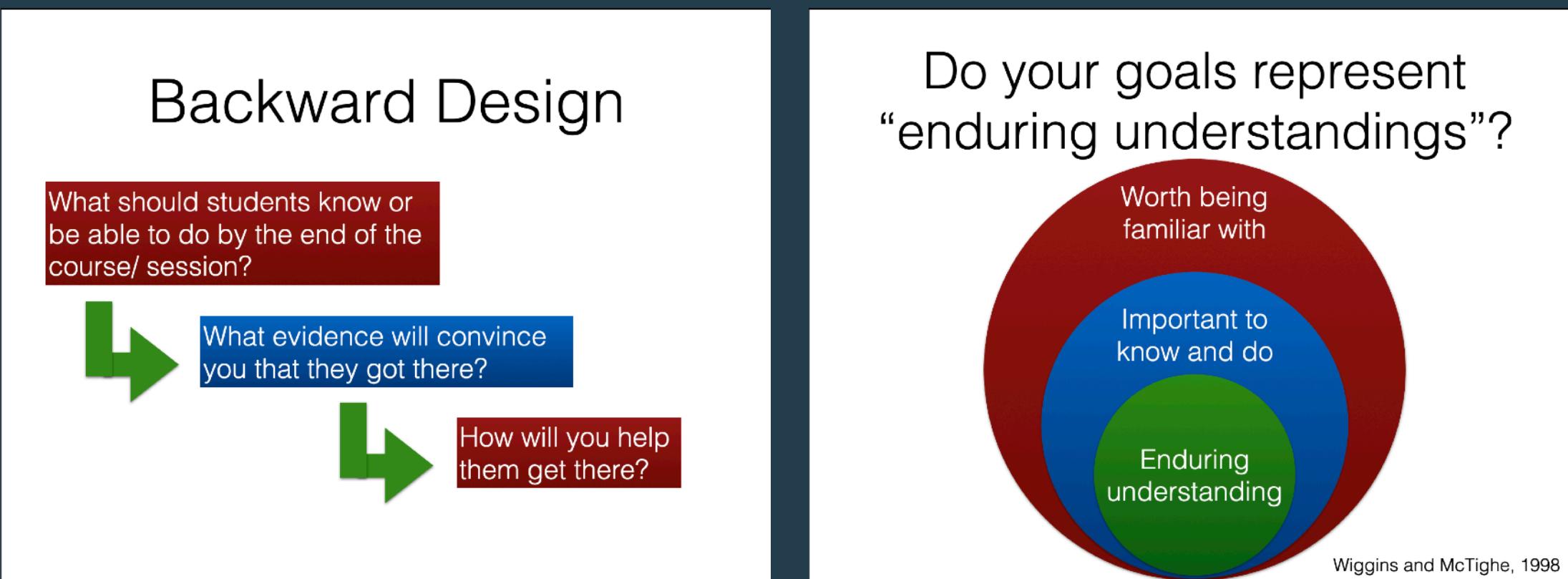
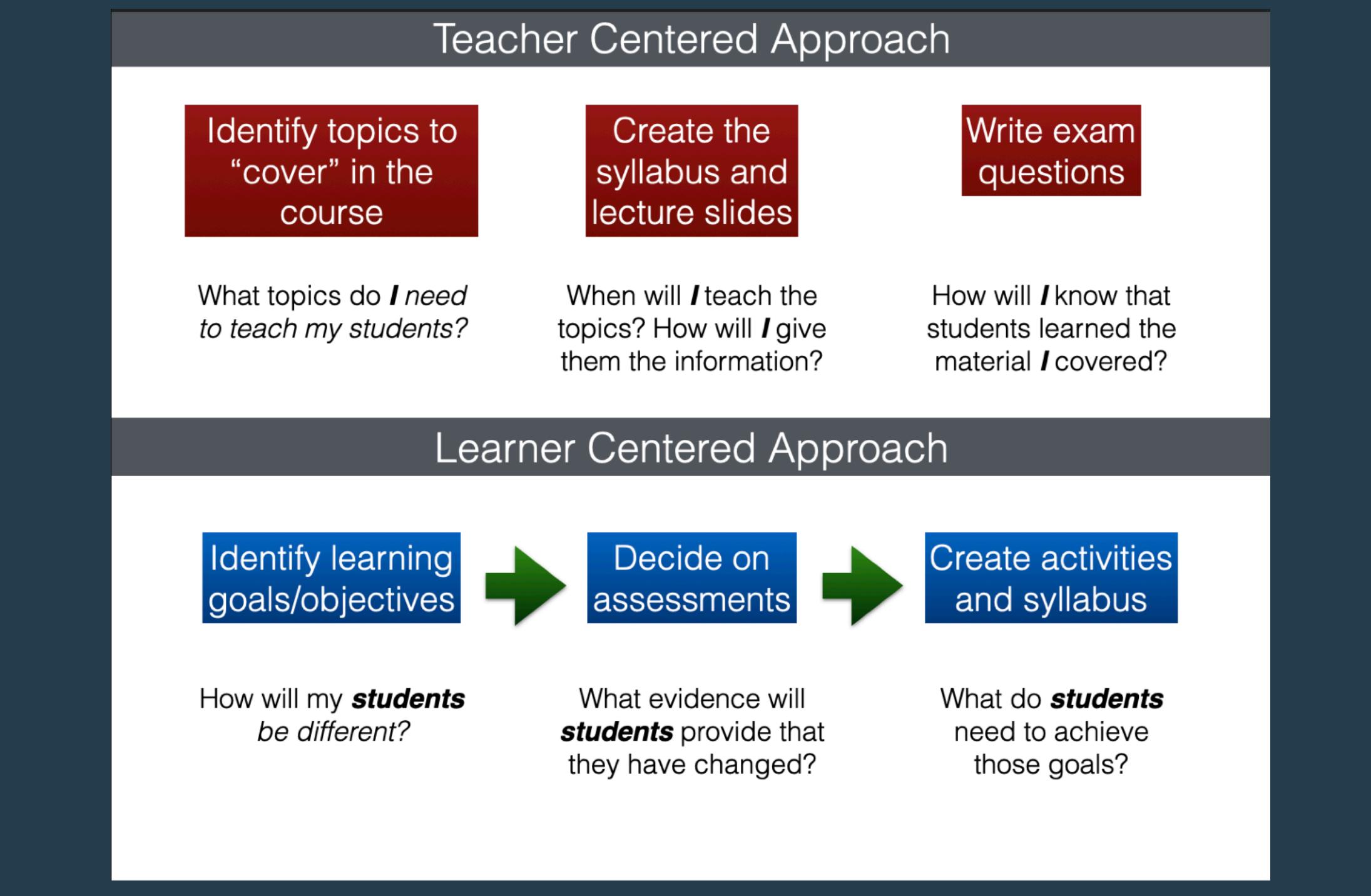


PARTNERSHIP FOR INTEGRATION OF COMPUTATION INTO UNDERGRADUATE PHYSICS



PICUP Professional Dev

gopicup.org



rooster 2:50 PM
@channel 2025 Los Angeles Area PICUP Workshop on Integrating Computation into High School and Undergraduate Physics
All you who dwell in the Los Angeles area (and beyond, depending on your willingness to drive a little for a big gain!) are invited to participate in the inaugural LA Area PICUP Workshop, a day-long event to be held on Saturday, May 17 from 8:30am to 4:30pm at Riverside City College in Riverside, CA. This PICUP workshop is intended for those who desire to energize their physics courses at all levels, and the scope is appropriate for physics teachers from high schools, 2-year colleges, and 4-year colleges and universities. Workshop details and registration information can be found here: <https://www.compadre.org/PICUP/events/LA2025/>
Please note that this workshop is intended to be the first in a series of annually occurring PICUP workshops in the LA area, and we urge you to be involved. We are looking to develop a working, supportive community of like-minded instructors who teach computation in their physics classes, and to grow this southern California-based effort into a thriving, self-sustaining community that supports computation in physics into the future and beyond! Please spread the word to other faculty you may know that could benefit from this experience, and do your best to join us on May 17.

PICUP
LA Area PICUP Workshop 2025 (21 kB) ▾

1 1 2 1

In-person & virtual

PICUP Community

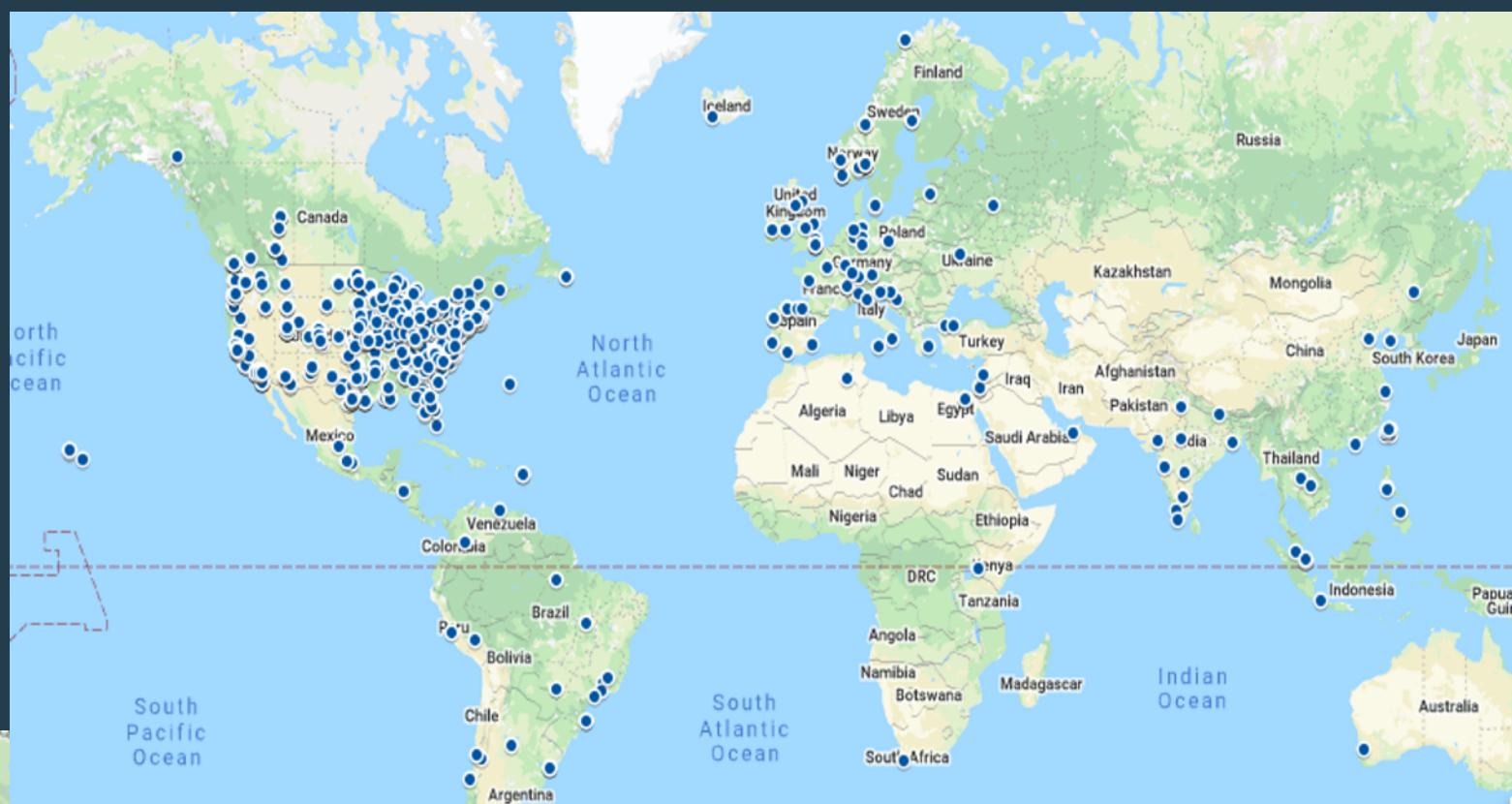
gopicup.org



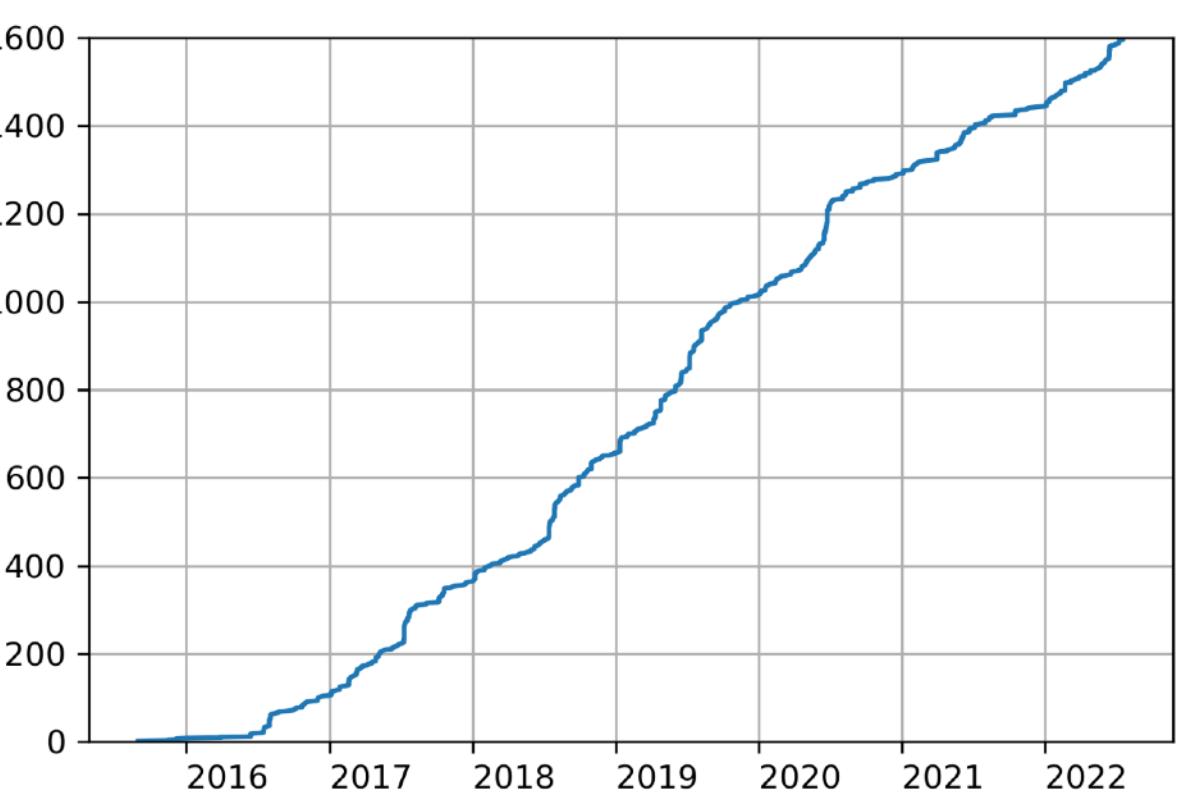
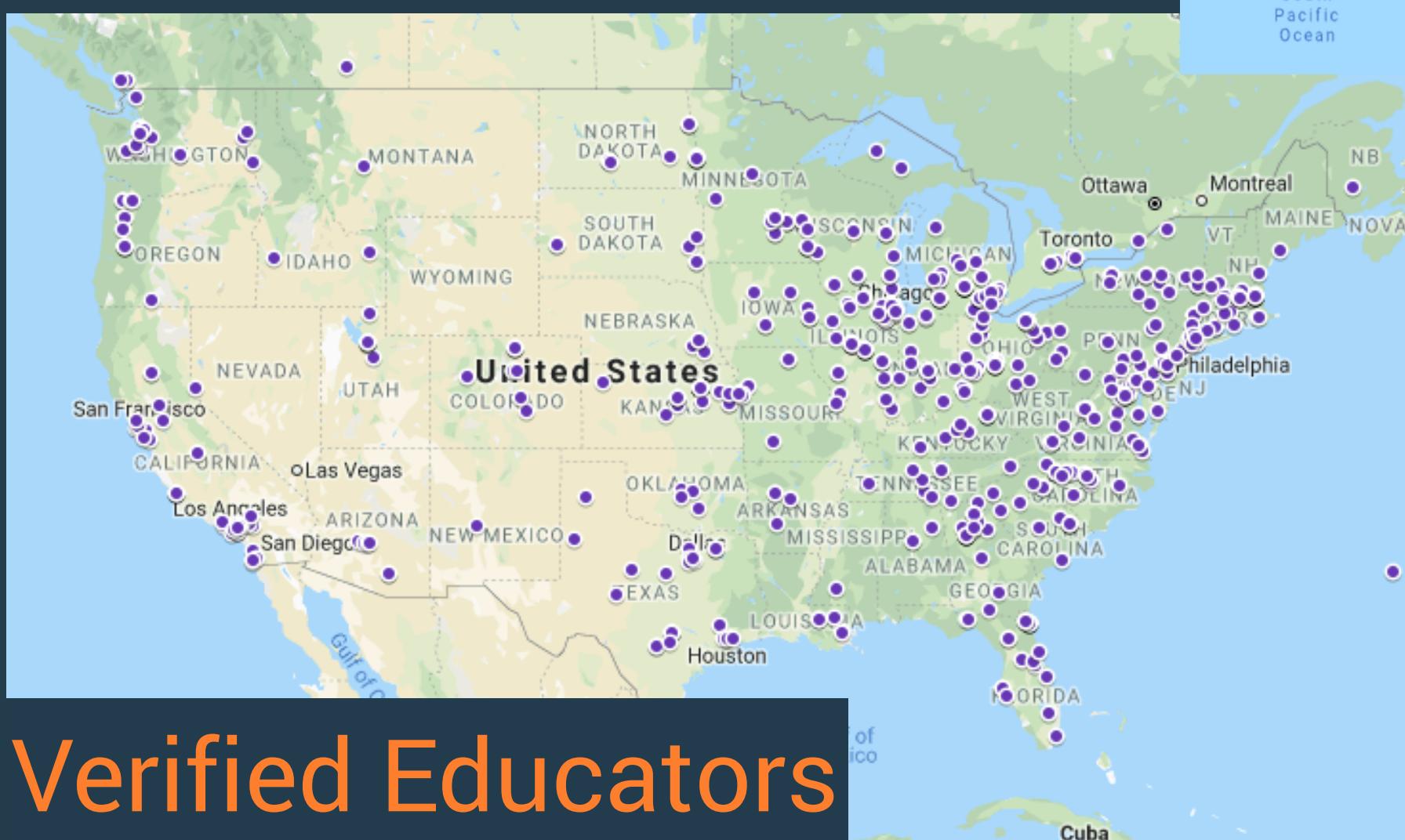
FDW Participants

Verified educators submit
academic documentation
to gain access to:

Solutions & Source Codes
Implementation Guides
Additional Materials



The screenshot shows the PICUP website interface. At the top, there's a navigation bar with links for Home, Exercise Sets, Faculty Commons, Resources, Community, Events, and About PICUP. The AAPT logo is also present. Below the navigation, a specific exercise titled "A Rigid Three-bar Pendulum" is displayed. This exercise was developed by E. Behringer and published on July 31, 2016. The page includes a color scale plot, download options (Word document), a variation creation section, credits (Attributed to E. Behringer, "A Rigid Three-bar Pendulum," Published in the PICUP Collection, July 2016.), and licensing information (Creative Commons Attribution-NonCommercial-ShareAlike 4.0 license). The footer contains a Creative Commons BY-NC-SA license logo.



Verified Educators

Summer Leadership Institute

June 23-27, 2025 @ University of Wisconsin-River Falls



PARTNERSHIP FOR INTEGRATION OF COMPUTATION INTO UNDERGRADUATE PHYSICS

Monday	Tuesday	Wednesday		Thursday		Friday
Arrival to MSP airport or drive to River Falls, WI	Working Breakfast	Working Breakfast		Working Breakfast		Working Breakfast
	Morning meeting	Morning meeting		Morning meeting		Morning meeting
	PICUP Panel: past accomplishments, current work, and future goals	Case Studies Q&A: Successful and Ongoing Transformation Efforts		Working time	Strategic Planning Round Tables	Debrief, progress reports, and future work
	Coffee break	Coffee break		Coffee break		Coffee break
	Poster session (group 1, group 2, discussion)	Barriers and Opportunities		Group Discussion	Strategic Planning Round Tables	Closing Remarks
	Working Lunch	Working Lunch		Working Lunch		Working Lunch
	Individual Goal Setting and Sharing of Goals	Working time	Models and Incentives	Mini workshop	DICE coordinator meeting	Check out and departure shuttle to MSP airport
	Break + Team Building	Break + Team Building		Break + Team Building		
	What support do you / your department need to integrate computation? Set topics for mini-workshops	Working time	Supporting Others, Growing Networks	Working time	DICE coordinator meeting	
	Shuttle from MSP airport to UW-River Falls	Working time	DICE info session	Group Discussion	Mini workshop	Mini workshop
Break		Break		Break		
Working Dinner: Welcome		Working Dinner		Working Dinner		



Seemingly necessary but not sufficient conditions for change

How was this effort to integrate computing in physics done?

- Define goals and scope collectively
- Build professional development and community
- Respect institutional factors and diversity
- Acknowledge the complexity of the problem
- Collect data on experience and progress
- Share successful cases openly and transparently

Must happen in
disciplinary contexts

Needs scientists, educators,
& ed. researchers

Computing in Physics Education Book

Published by Institute of Physics (Summer 2025)



AUTHORS

K. Svensson and U. Erickson

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B. Lunk and S. Weatherford

M. Hamilton

PRELIMINARY CHAPTER TITLE

Teachers' approach to computation in physics classrooms analyzed using social semiotics and variation theory of learning

Integrating computation into a physics bachelor's laboratory curriculum

Agency and Making in Computational Learning Environments

Computing in General Education Physics

Departmental Emphasis on Computation for the Physics Major: Successes and Failures of a multi-tier curricular redesign

Teaching Scientific Writing using Computational Essays

Resources for Integrating Computation into Physics Courses: Exercise Sets, Workshops, and a Supportive Community

Integration of computation across the curriculum at Bridgewater College

Student Engagement with Computational Models and the Development of the "Minimally Working Program" Instructional Tool

Integrating Computation in Physics: From High School Internships to Graduate Studies at Marshall University

How might we better support
students in our computationally
enabled STEM courses?

K-5



K-5



K-5



6-8



9-12



K-5



6-8

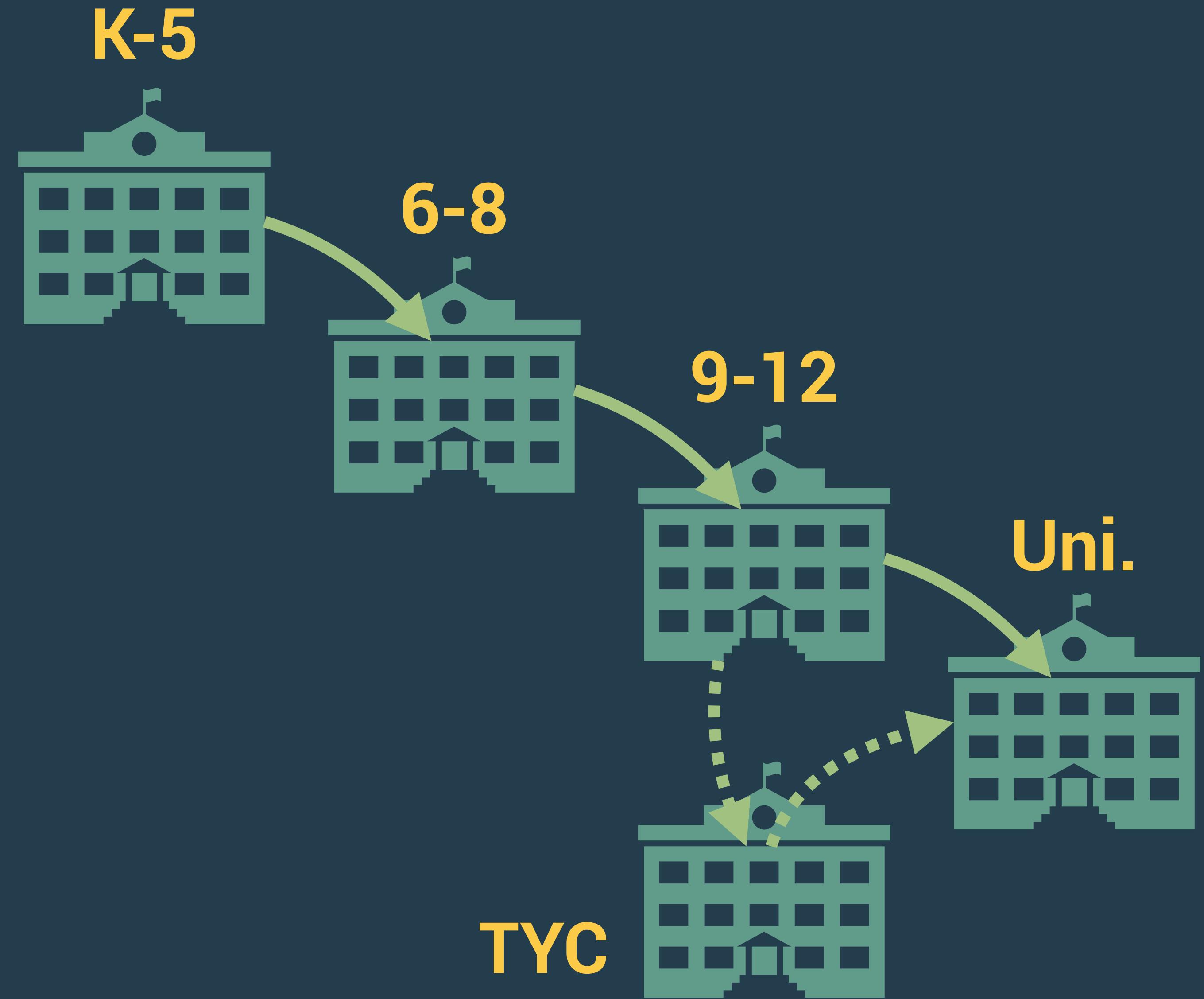


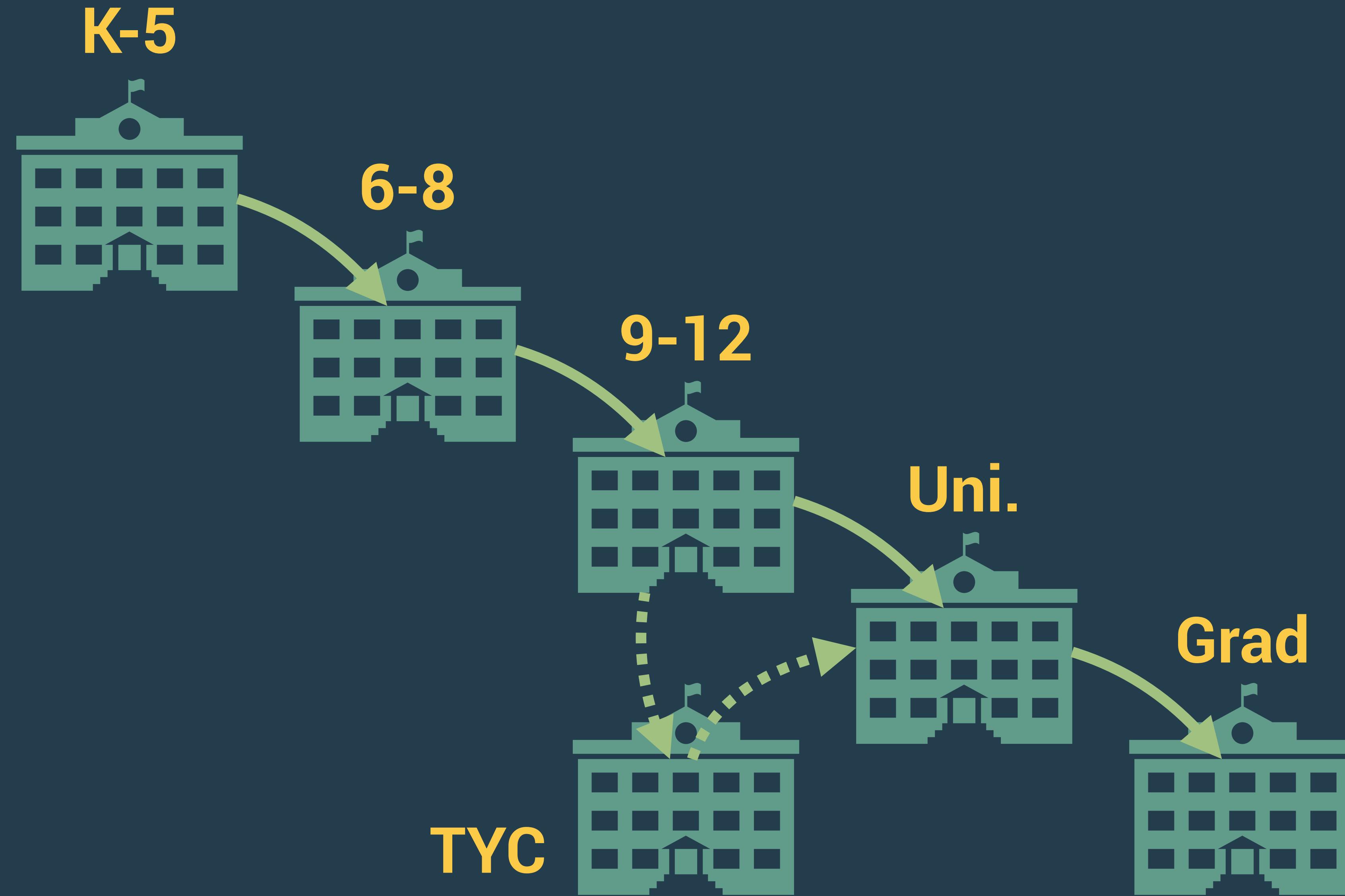
9-12



Uni.







K-5



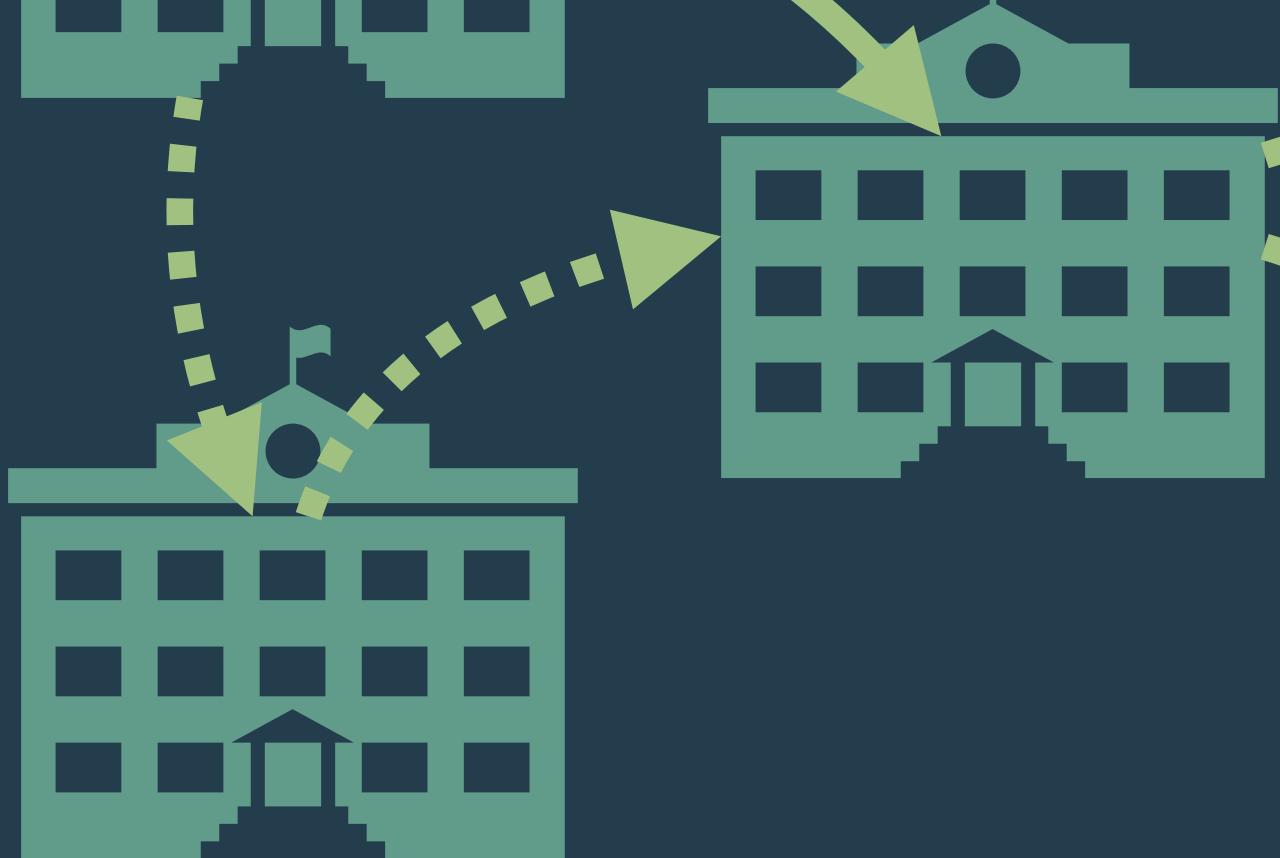
6-8



9-12

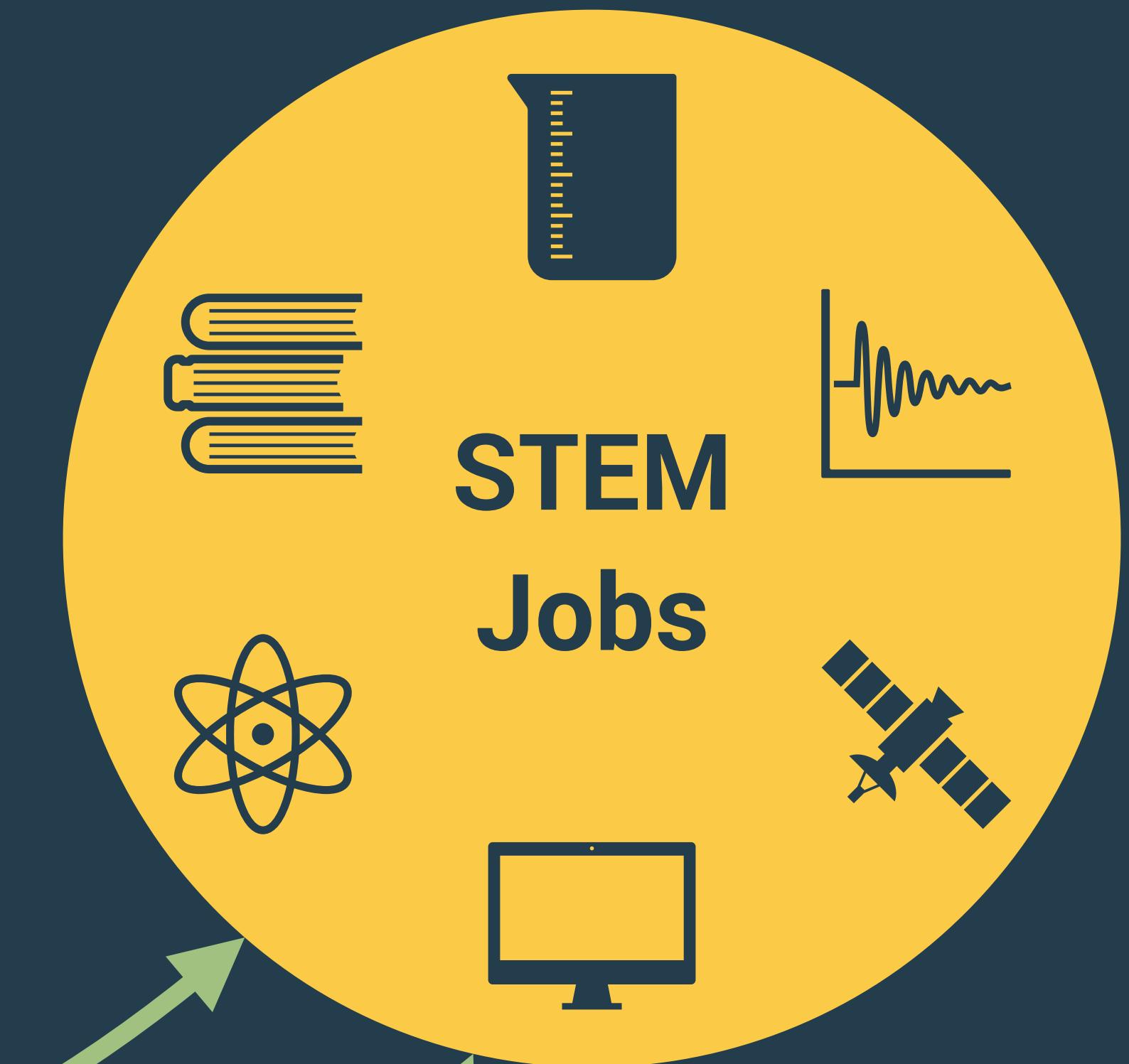


Uni.



TYC

Grad



K-5



6-8

9-12

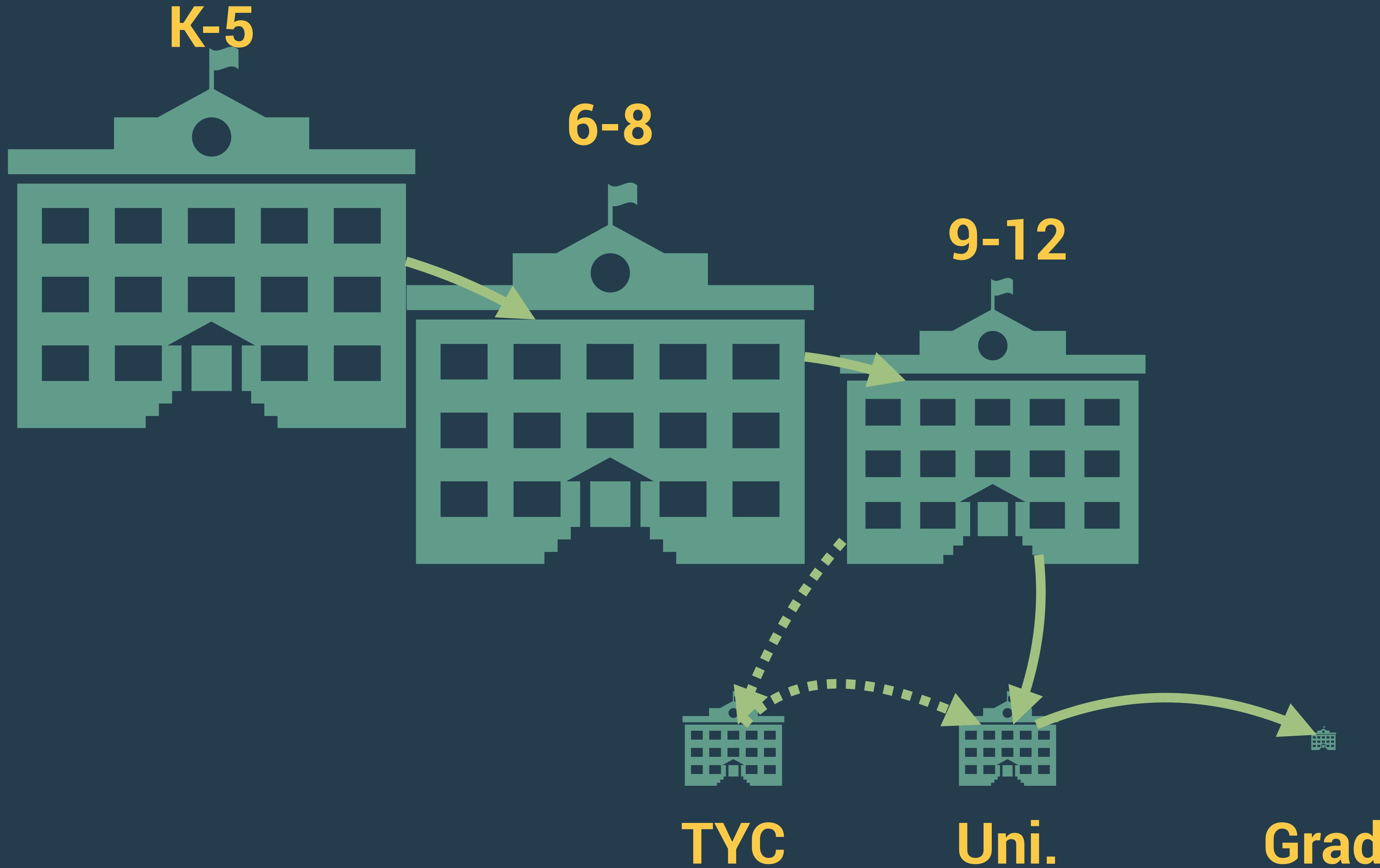
TYC

Uni.

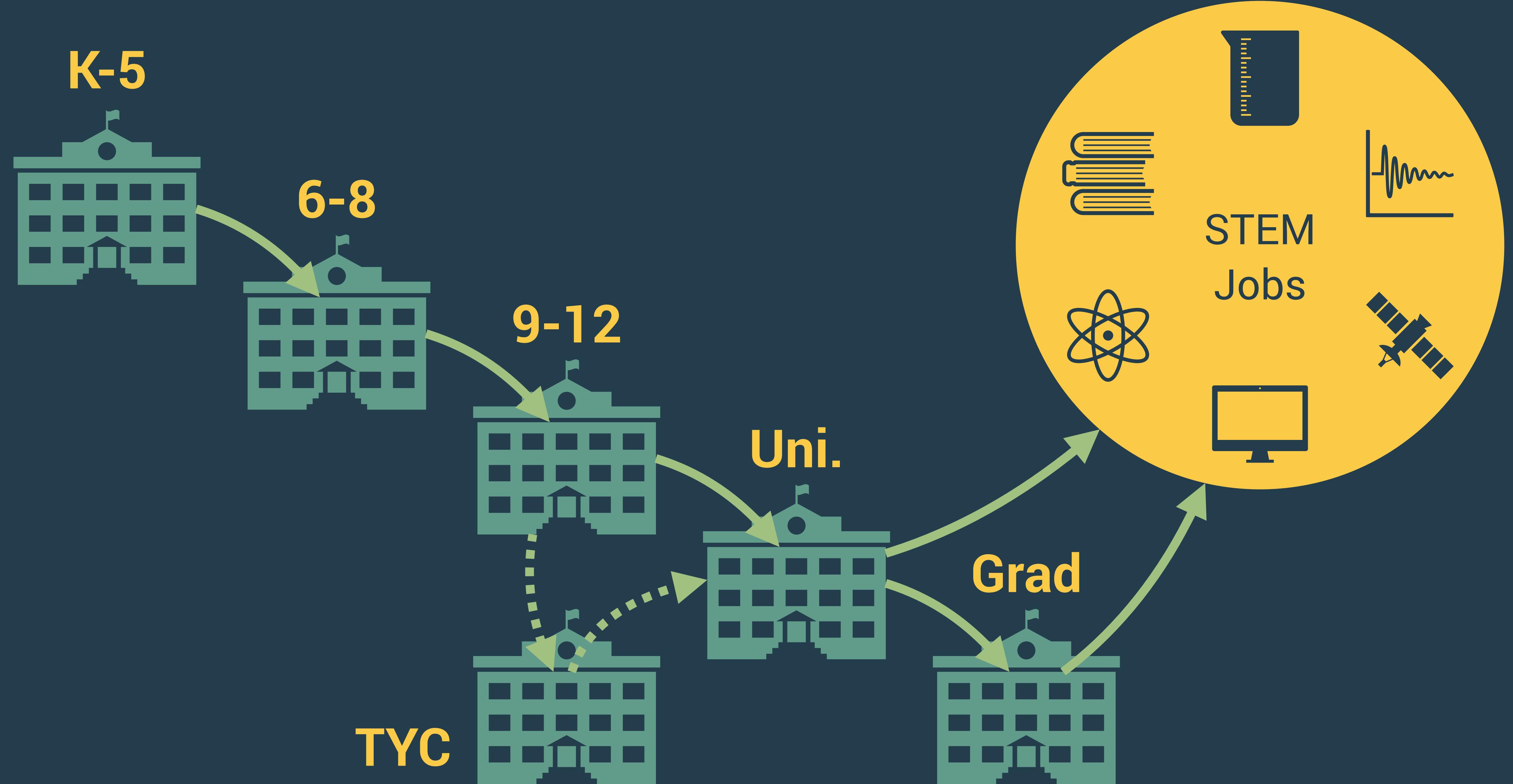
Grad



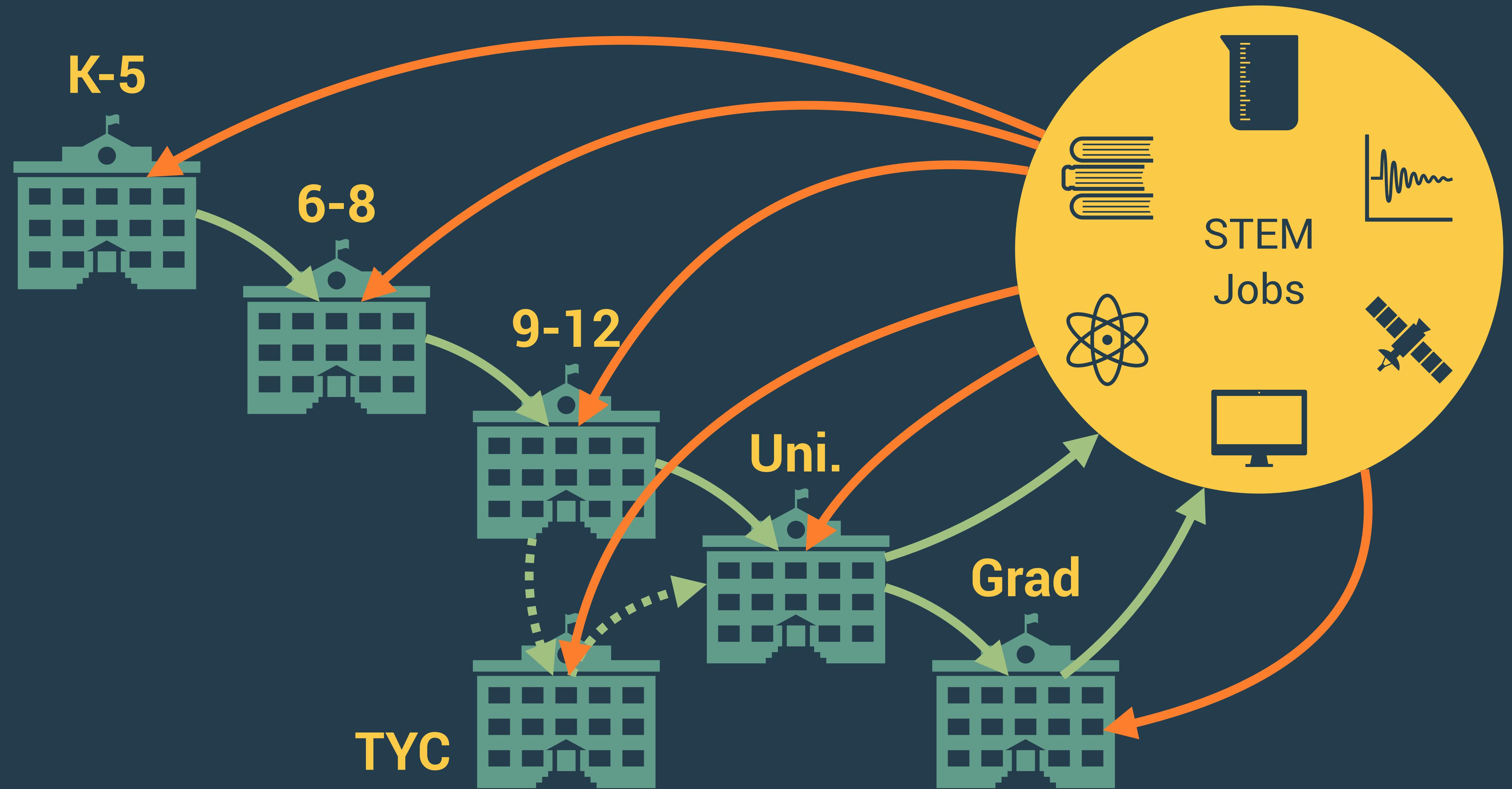
How my university sees things



How numbers of students are distributed



There's feedback in the system



There's feedback in the system

Integrating Computing in Science Across the Mitten



Michigan K-12 Standards
Science



November 2015



<https://www.michigan.gov/mde/services/academic-standards>

Create a **computational model** to calculate...
Use mathematical and/or **computational representations** to support explanations of factors...
Use mathematical or **computational representations** to predict the motion...



ICSAM Workshop



Weeklong Summer Camp for High School Teachers

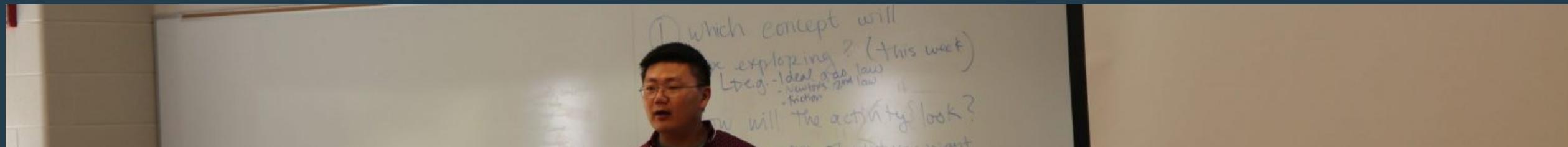
- Introduce computing
- Develop materials
- Grow community
- Focus on equity



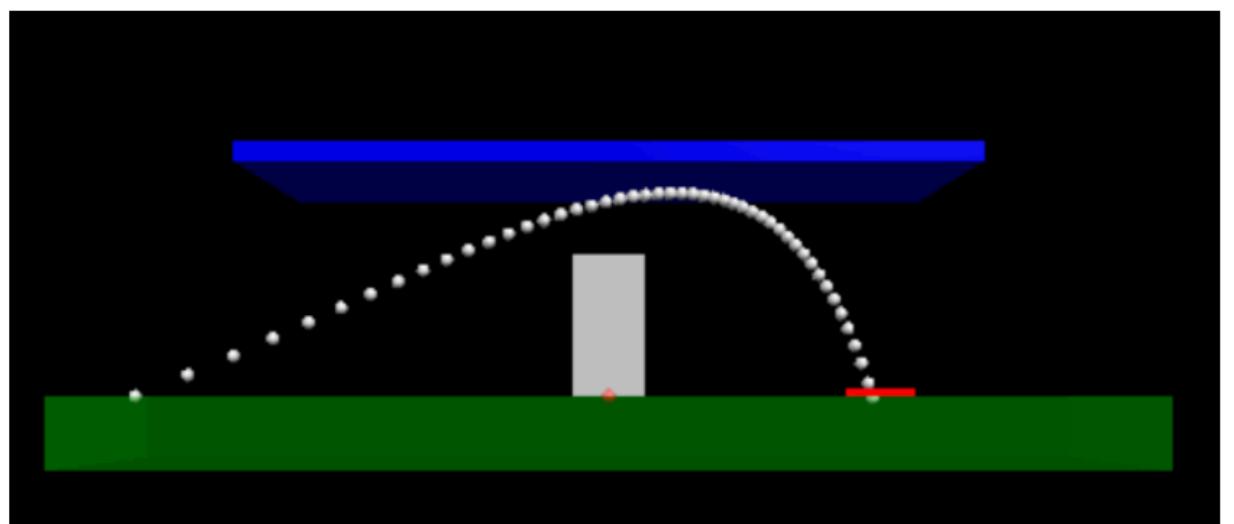
Return to MSU (virtual during COVID)

- Addressing problems of practice
- Community building

ICSAM Workshop



Marshmallow Launch



Activity Information

Learning Goals

- Create and modify a computational model to describe a given system
- Use Newton's second law to relate the acceleration of a marshmallow with the forces acting on it ([HS-PS2-1](#))



Weeklong Summer Camp for High School Teachers

- Introduce computing
- Develop materials
- Grow community
- Focus on equity

Return to MSU (virtual during COVID)

- Addressing problems of practice
- Community building

Many teacher-developed materials!

ICSAM is also a research lab

PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **18**, 020109 (2022)

Editors' Suggestion

Students' perspectives on computational challenges in physics class

Patti C. Hamerski^a,¹ Daryl McPadden,¹ Marcos D. Caballero,^{1,2} and Paul W. Irving¹

¹Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA
²Department of Physics and Center for Computing in Science Education, University of Oslo, N-0316 Oslo, Norway

PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **18**, 020106 (2022)

Development and illustration of a framework for computational thinking practices in introductory physics

Daniel P. Weller^b,^{1,2} Theodore E. Bott,¹ Marcos D. Caballero^a,^{1,3,4} and Paul W. Irving¹

¹Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA
²School of Mathematical and Physical Sciences, University of New England, Biddeford, Maine 04005, USA
³Department of Computational Mathematics, Science, and Engineering and CREATE for STEM Institute, Michigan State University, East Lansing, Michigan 48824, USA
⁴Department of Physics and Center for Computing in Science Education, University of Oslo,

COMPUTER SCIENCE EDUCATION
2020, VOL. 30, NO. 3, 254–278
<https://doi.org/10.1080/08993408.2020.1805285>

Routledge
Taylor & Francis Group

Check for updates

Racial hierarchy and masculine space: Participatory in/equity in computational physics classrooms

Niral Shah^a, Julie A. Christensen^b, Nickolaus A. Ortiz^c, Ai-Khanh Nguyen^a, Sunghwan Byun^b, David Stroupe^b and Daniel L. Reinholtz^d

^aCollege of Education, University of Washington, Seattle, USA; ^bCollege of Education, Michigan State University, East Lansing, MI, USA; ^cCollege of Education & Human Development, Georgia State University, Atlanta, GA, USA; ^dCollege of Sciences, San Diego State University, San Diego, CA, USA

ABSTRACT
Background and Context: Computing is being integrated into a range of STEM disciplines. Still, computing remains inaccessible to many minoritized groups, especially girls and certain people of color. In this mixed methods study, we investigated racial and

ARTICLE HISTORY
Received 31 October 2019
Accepted 31 July 2020

KEYWORDS

Tracking Inequity: An Actionable Approach to Addressing Inequities in Physics Classrooms

Julie Christensen, Michigan State University, East Lansing, MI
Niral Shah, University of Washington, Seattle, WA
Nickolaus Alexander Ortiz, Georgia State University, Atlanta, GA
David Stroupe, Michigan State University, East Lansing, MI
Daniel L. Reinholtz, San Diego State University, San Diego, CA

Recent studies reveal people from marginalized groups (e.g., people of color and women) continue to earn physics degrees at alarmingly low rates.^{1–3} This phenomenon is not surprising given reports of the continued perception of physics as a masculine space^{4,5} and the discrimination faced by people of color and women within the field.^{6–8} To realize the vision of an equitable physics education, fully open to and supportive of marginalized groups, teachers need ways of seeing equity as something that is concrete and actionable on an everyday basis. In our work, teachers have found value in intentionally reflecting on their instruction and their students explicitly in terms of race, gender, and other social markers. We find they are then better positioned to build equitable physics classrooms. Without a focus on specific social markers, common obstacles such as color-evasiveness emerge, which obstruct the pursuit of equity in classrooms.⁹

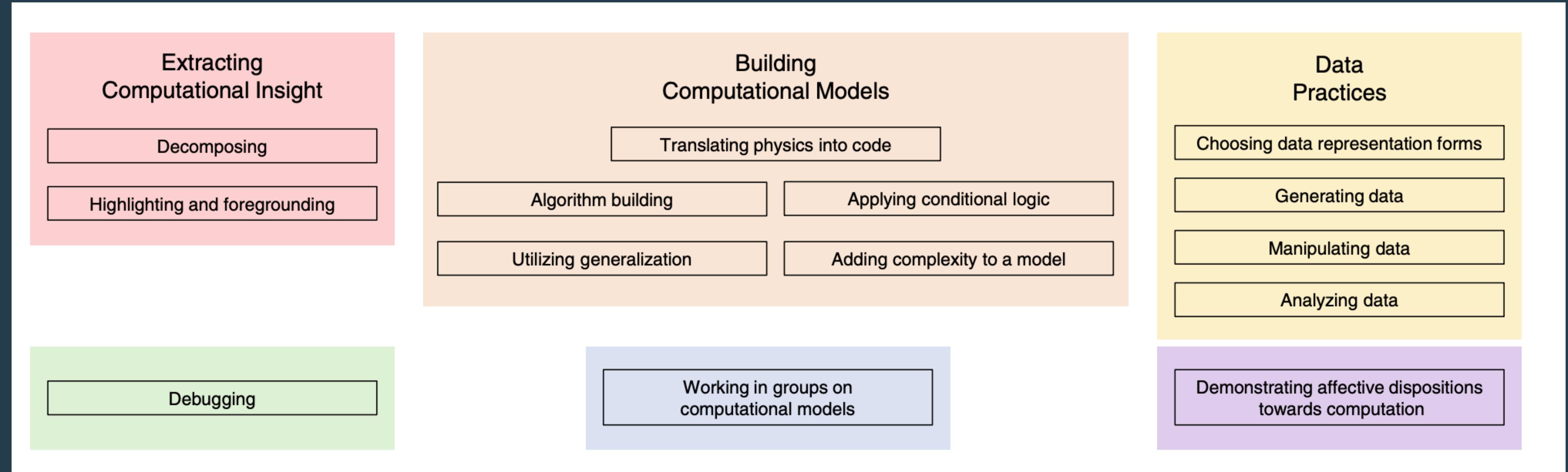
learners.^{12,13} Therefore, we encourage teachers to consider past and contemporary forms of marginalization when determining standards of fairness. In other words, we recommend a “reparations-type” view when defining equity.

In this article, we present a three-step process involving a classroom observation tool called EQUIP (<https://www.equip-ninja/>), which teachers can use to identify and attenuate patterns of discourse inequity. We begin by describing EQUIP and how its design supports physics teachers in thinking about equity in terms of social marker patterns in typical teaching and learning situations. Then, we illustrate how our partner teachers used EQUIP in action, especially as they sought to build equitable spaces for collaborative computation-based high school physics.

EQUIP: Equity QUantified In Particular



Analysis Framework for Computing Practices



Analysis Framework for Computing Practices

TABLE XVI. Summary of codes emerging in the analysis of Michael's classroom.^a

Practice	P1	P2	R1	R2	S1	S2
Decomposing			2	1	2	1
Highlighting and foregrounding			2	3	5	4
Translating physics into code			2		6	4
Algorithm building	2		5	3	1	
Applying conditional logic	1	1	1	1	2	
Utilizing generalization					1	2
Adding complexity to a model					2	
Debugging	2	3	4	6	8	6
Intentionally generating data					1	
Choosing data representation form					2	
Manipulating data					2	
Analyzing data	1	1			7	
Demonstrating constructive dispositions	2			2		
Working in groups		1		1	1	

^a P1=Projectile activity, group 1; P2=Projectile activity, group 2; R1=River crossing activity, group 1; R2=River crossing activity group 2; S1=Spring energy activity, group 1; S2=Spring energy activity, group 2.



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Manipulating data					2	
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Intentionally generating data					1	
Choosing data representation form					2	
Manipulating data					2	
Analyzing data	1	1			7	
Demonstrating constructive dispositions	2			2		
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Analysis Framework for Computing Practices

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Utilizing generalization					1	2
Adding complexity to a model					2	
Debugging	2	3	4	6	8	6
Intentionally generating data					1	
Choosing data representation form					2	
Manipulating data					2	
Analyzing data	1	1			7	
Demonstrating constructive dispositions	2			2		
Working in groups		1		1	1	

^a P1=Projectile activity, group 1; P2=Projectile activity, group 2; R1=River crossing activity, group 1; R2=River crossing activity group 2; S1=Spring energy activity, group 1; S2=Spring energy activity, group 2.



Analysis Framework for Computing Practices

TABLE XVI. Summary of codes emerging in the analysis of Michael's classroom.^a

Practice	P1	P2	R1	R2	S1	S2
Decomposing			2	1	2	1
Highlighting and foregrounding			2	3	5	4
Translating physics into code			2		6	4
Algorithm building	2		5	3	1	
Applying conditional logic	1	1	1	1	2	
Utilizing generalization					1	2
Adding complexity to a model					2	
Debugging	2	3	4	6	8	6
Intentionally generating data					1	
Choosing data representation form					2	
Manipulating data					2	
Analyzing data	1	1			7	
Demonstrating constructive dispositions	2			2		
Working in groups		1		1	1	

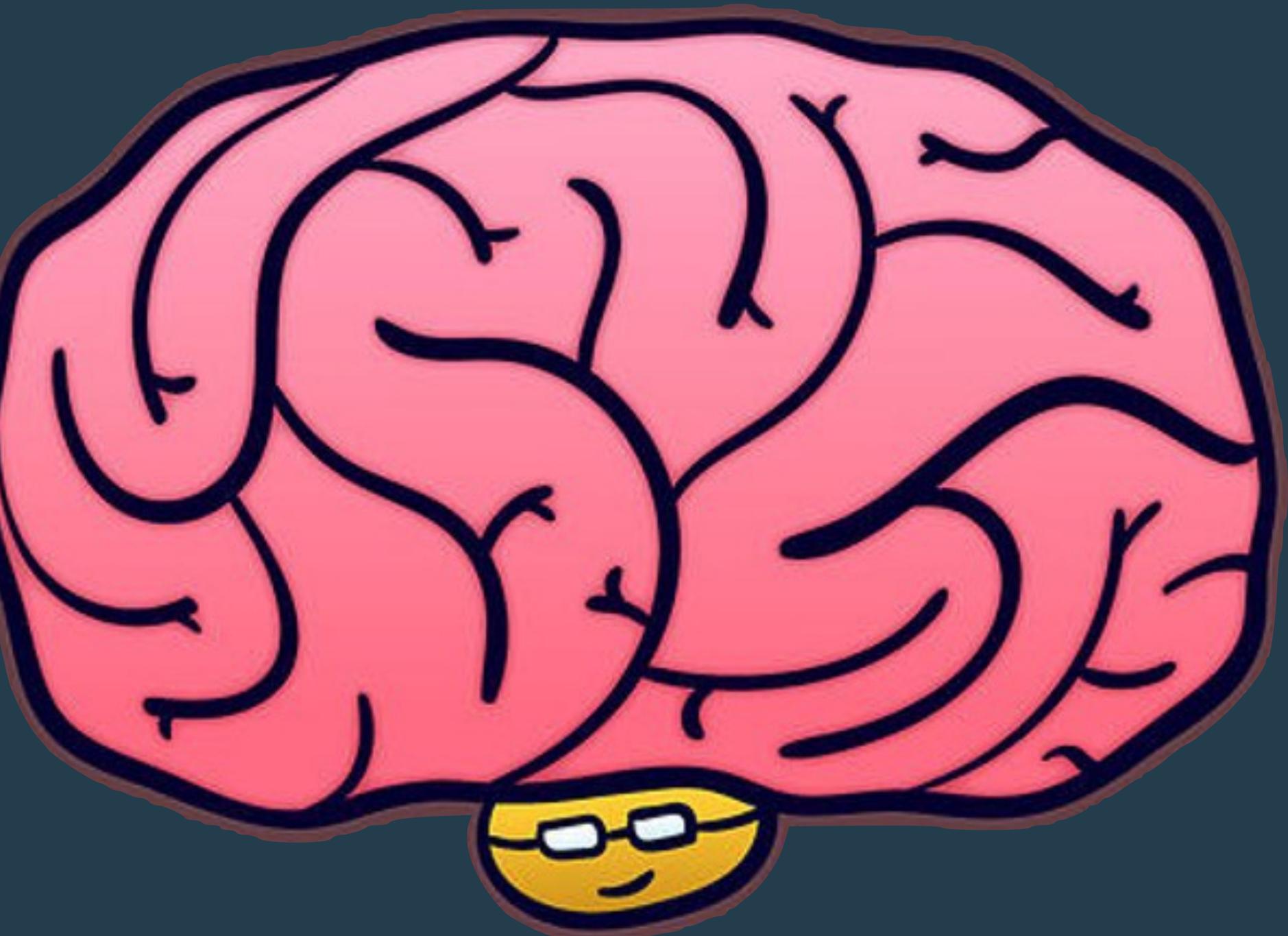
^a P1=Projectile activity, group 1; P2=Projectile activity, group 2; R1=River crossing activity, group 1; R2=River crossing activity group 2; S1=Spring energy activity, group 1; S2=Spring energy activity, group 2.



AND NOW FOR
SOMETHING
COMPLETELY
DIFFERENT



What is the relationship
between education in
science and artificial
intelligence?



It's Time

Artificial Intelligence has “arrived”

And it will “disrupt” education

● January 05, 2024

How Will AI Disrupt Higher Education in 2024?

Last year was when generative AI infused higher education. What can we expect in this new year?

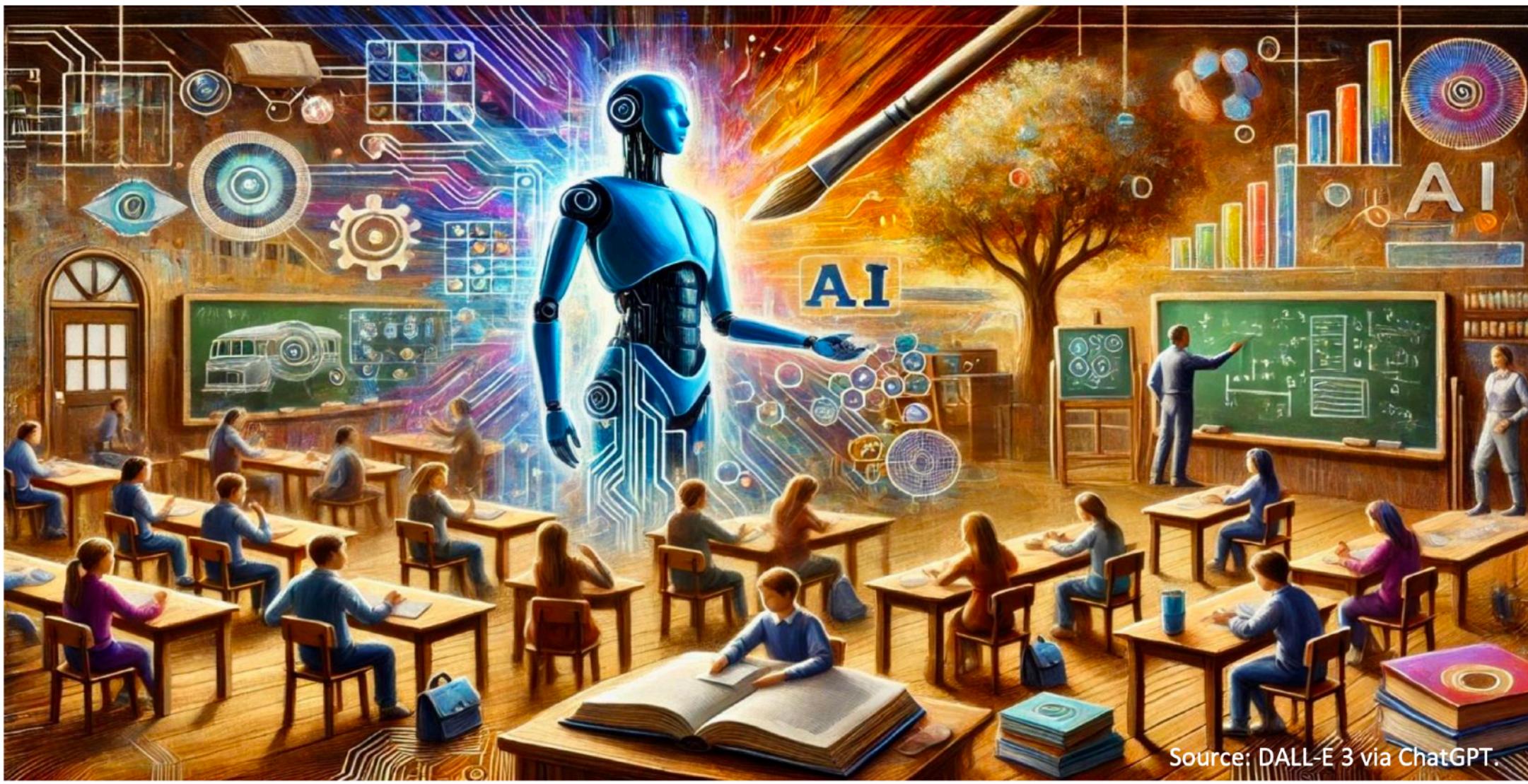
No. 10 | 2024 13 August 2024

By Ray Schroeder

AI is Disrupting Education – For Better or Worse

Challenges and Strategies for Sustainable Learning and Institutional Resilience

Anselm Küsters



Source: DALL-E 3 via ChatGPT.

Forbes

FORBES > LEADERSHIP > LEADERSHIP STRATEGY

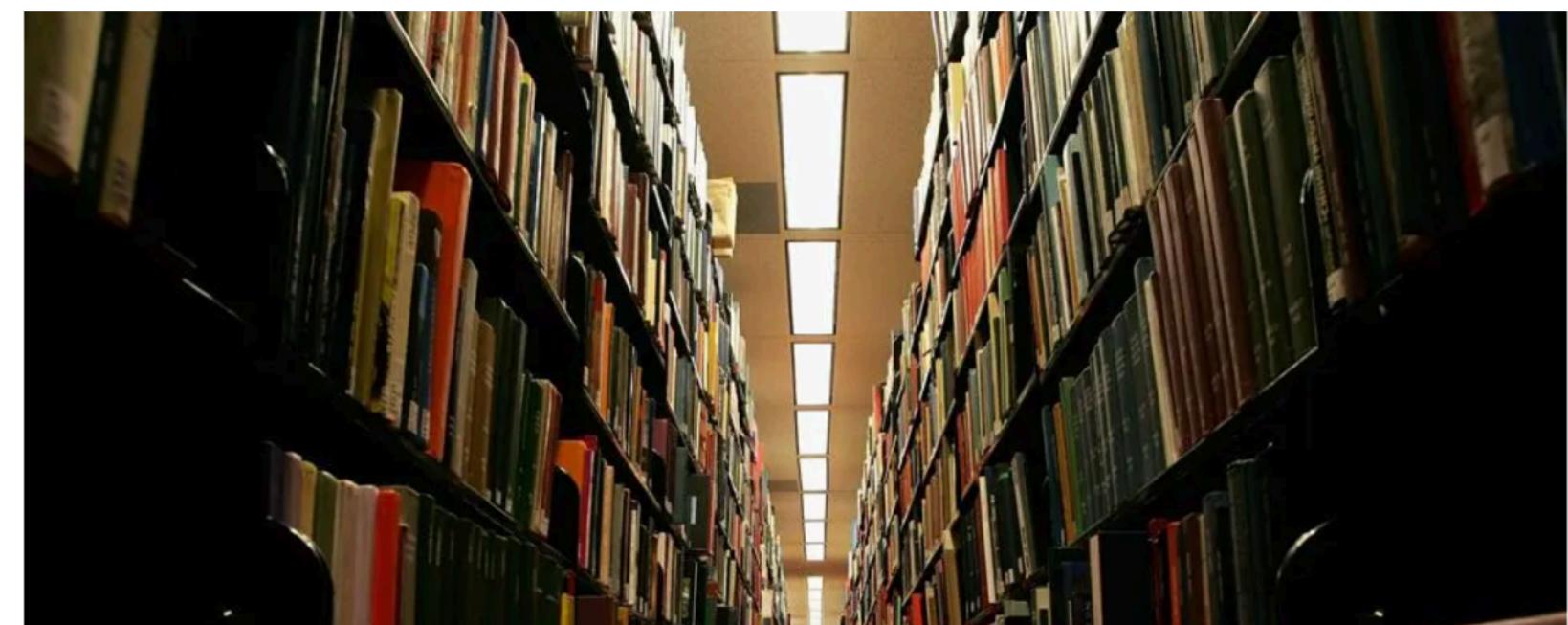
The Future Of Education - Disruption Caused By AI And ChatGPT: Artificial Intelligence Series 3/5

Nicole Serena Silver Contributor ⓘ
Nicole Serena Silver covers entrepreneurship and the future of work.

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Jun 5, 2023, 09:25pm EDT

Updated Jun 20, 2023, 01:29am EDT



What is being discussed?

AI has several potential benefits

Benefits

- Personalized Learning
- Supporting Educators & Reducing Administrative Burden
- Enhancing Student Engagement
- Improving Learning Analytics
- Expanding Access to Education
- Supporting Students with Different Needs
- Enhanced Collaboration & Communication

What is being discussed?

AI has several potential benefits & numerous concerns:

Benefits

- Personalized Learning
- Supporting Educators & Reducing Administrative Burden
- Enhancing Student Engagement
- Improving Learning Analytics
- Expanding Access to Education
- Supporting Students with Different Needs
- Enhanced Collaboration & Communication

Concerns

- Algorithmic Bias & Automating Inequality
- Dehumanization of Education
- Threats to Academic Integrity
- Data Privacy & Security
- Deprofessionalization of Teaching & Job Losses
- Over-reliance on Technology
- Ethics Issues & Lack of Transparency

Framing the AI issue

No single frame is used exclusively in practice. All have value in context.

Technological Solutionism:
tech can provide the necessary
solutions

- dealing with issues of scale
- addressing funding & efficiency
- emphasize personalization
- take advantage of new tech

*Sal Khan, Clayton Christensen,
Sugata Mitra, Eric Hanushek, Michelle
Rhee, Daphne Koller, Sebastian Thrun*

Human-centered Education:
social relationships are
paramount

- emphasize critical thinking,
- leverage experiential learning
- promote socioemotional development
- center humans in tech

*John Dewey, Nel Noddings, Seymour
Papert, Andrea DiSessa, Pasi
Sahlberg*

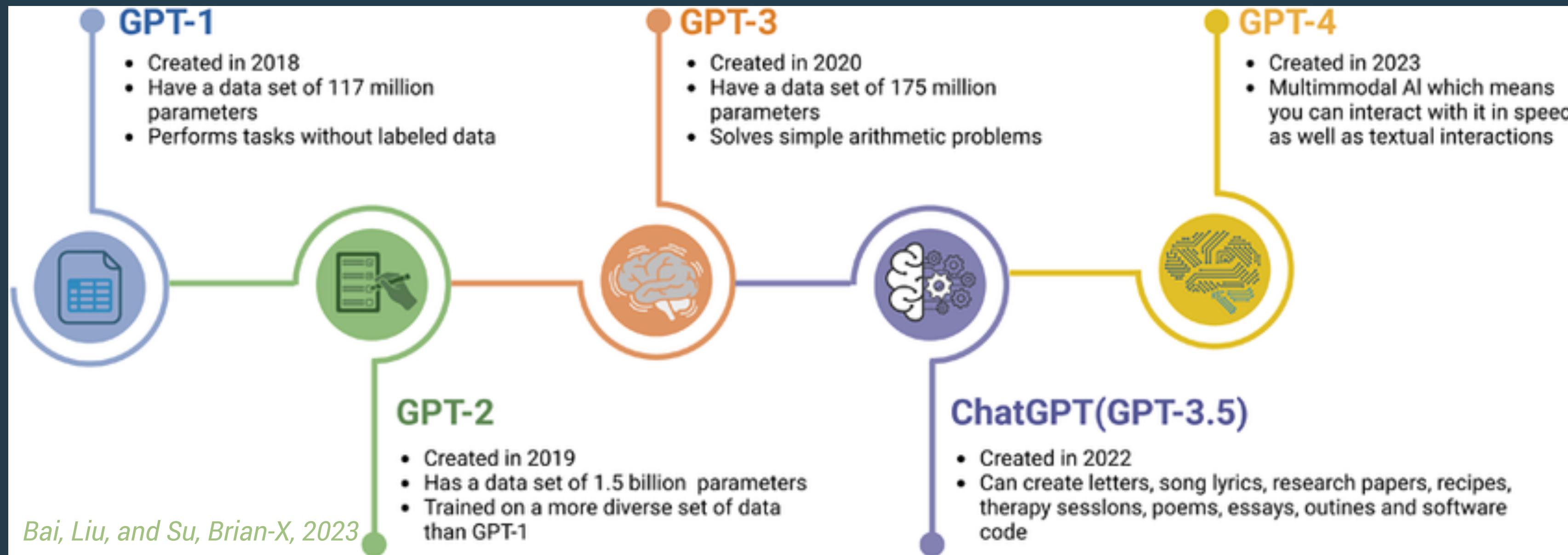
Education as a tool for Justice
education is a political act of
liberation

- promote diversity & equity
- emphasize social justice and
liberation
- educational systems perpetuate
inequality

*Paulo Freire, bell hooks, Angela
Valenzuela, Henry Giroux, Ruha
Benjamin, Gloria Ladson-Billings,*

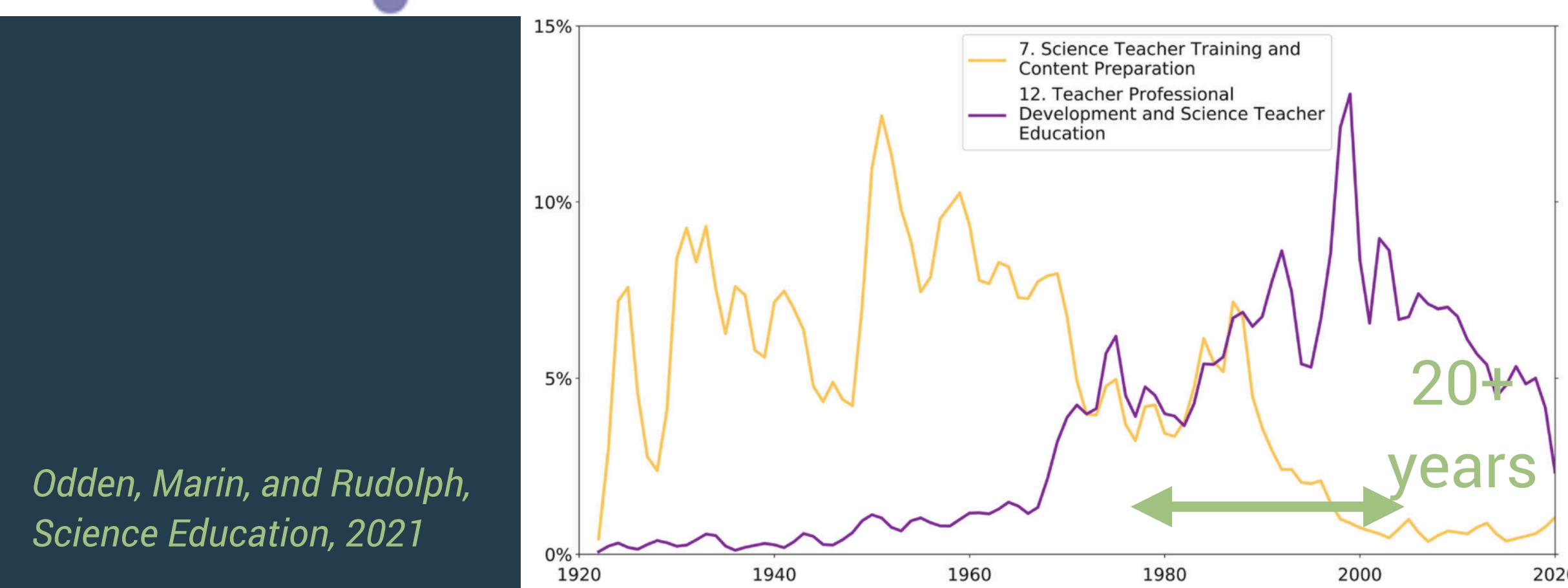
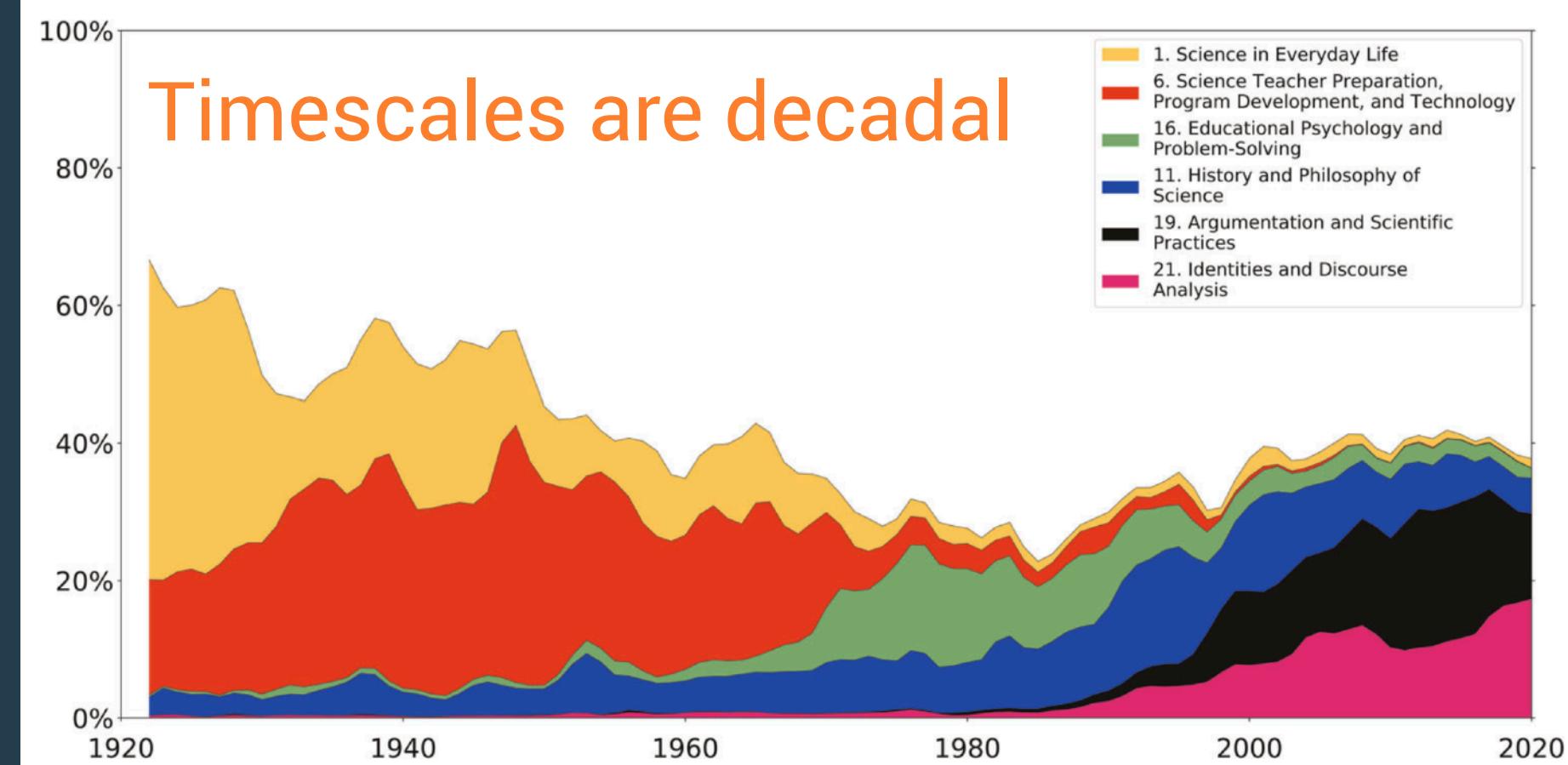
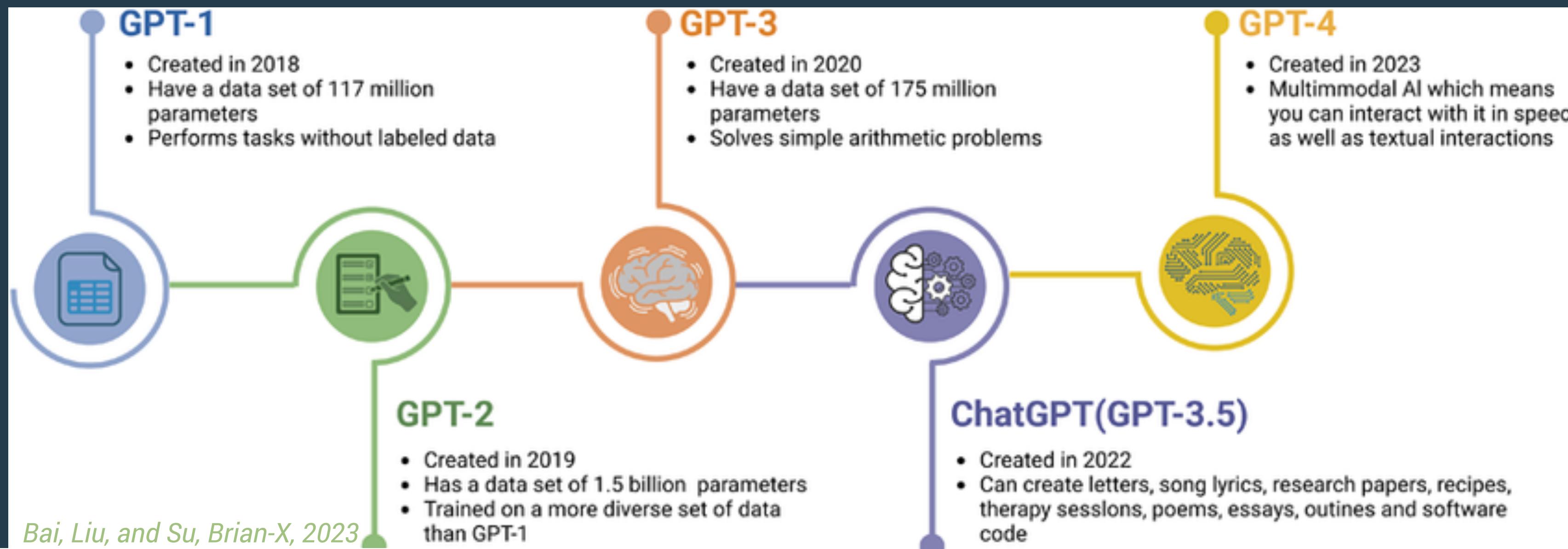
Rapid development

Development is too rapid for education research capacity and pace



Rapid development

Development is too rapid for education research capacity and pace



Computing Education Research Lab

CMSE Research Program

- How do students develop an understanding of modeling, data science, machine learning, and artificial intelligence?
- How do students' expectations, experiences, and sentiments shape their learning and participation in computational and data science?
- How are different pedagogical and curricular elements (including including artificial intelligence tools) useful for learning data science and machine learning?



The CERL squirrels

Two Concerns (for now)

i'm taking introductory computational science; can you give me three example questions for using functions for plotting? we use python with numpy and matplotlib.

Memory updated

Here are three example questions and Matplotlib:

1. Plotting a Sine Wave Function

- Write a Python function that plots a sine wave with values between 0 and 2π on the x-axis and the sine of those values on the y-axis.

Certainly! Variable scope in Python refers to the region where a variable is accessible. There are two main scopes to consider:

1. **Local scope:** Variables declared inside a function are local to that function.
2. **Global scope:** Variables declared outside of any function can be accessed globally, including inside functions, unless overridden.

Here's a working example where variable scope is handled correctly:

Working Example

```
python
import numpy as np
import matplotlib.pyplot as plt

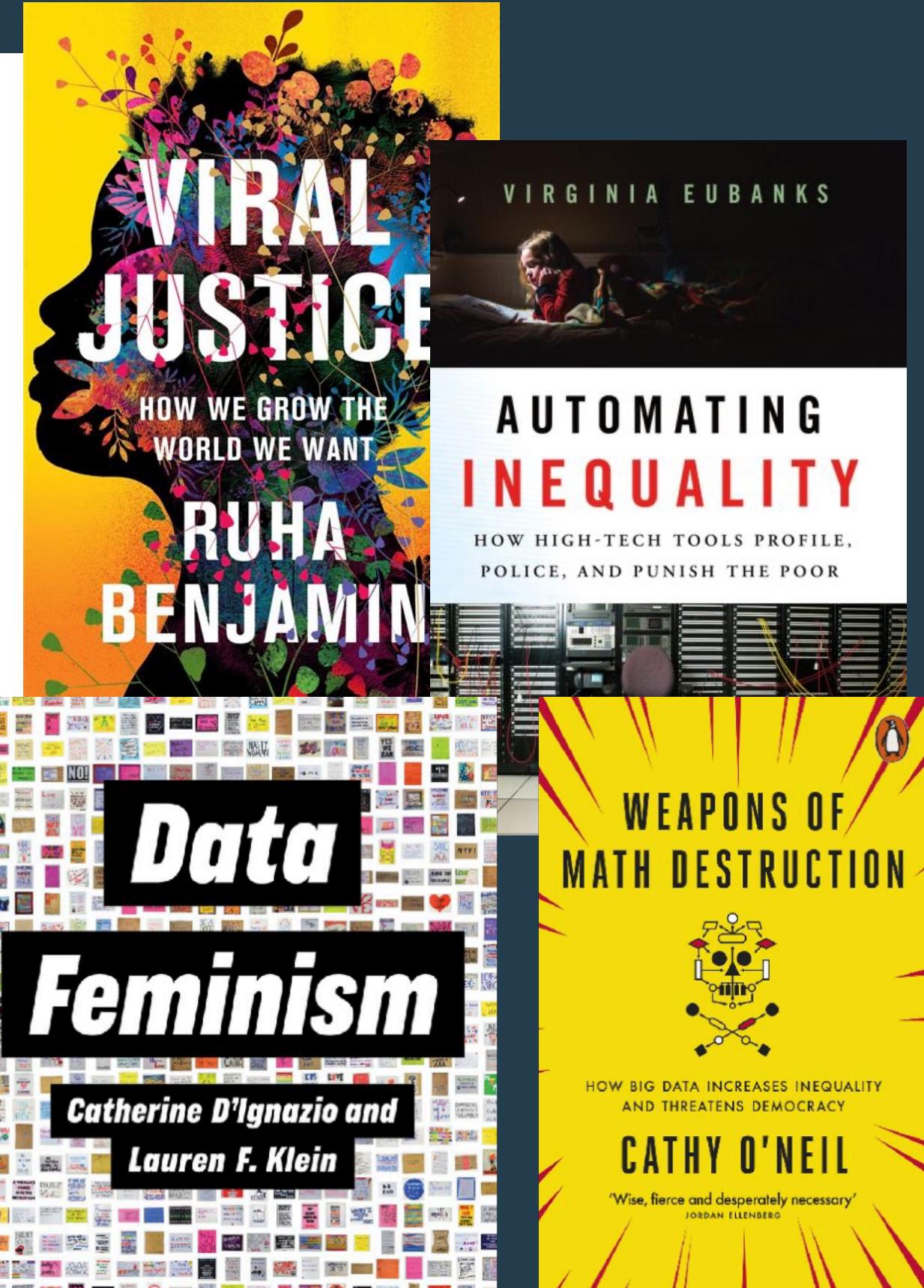
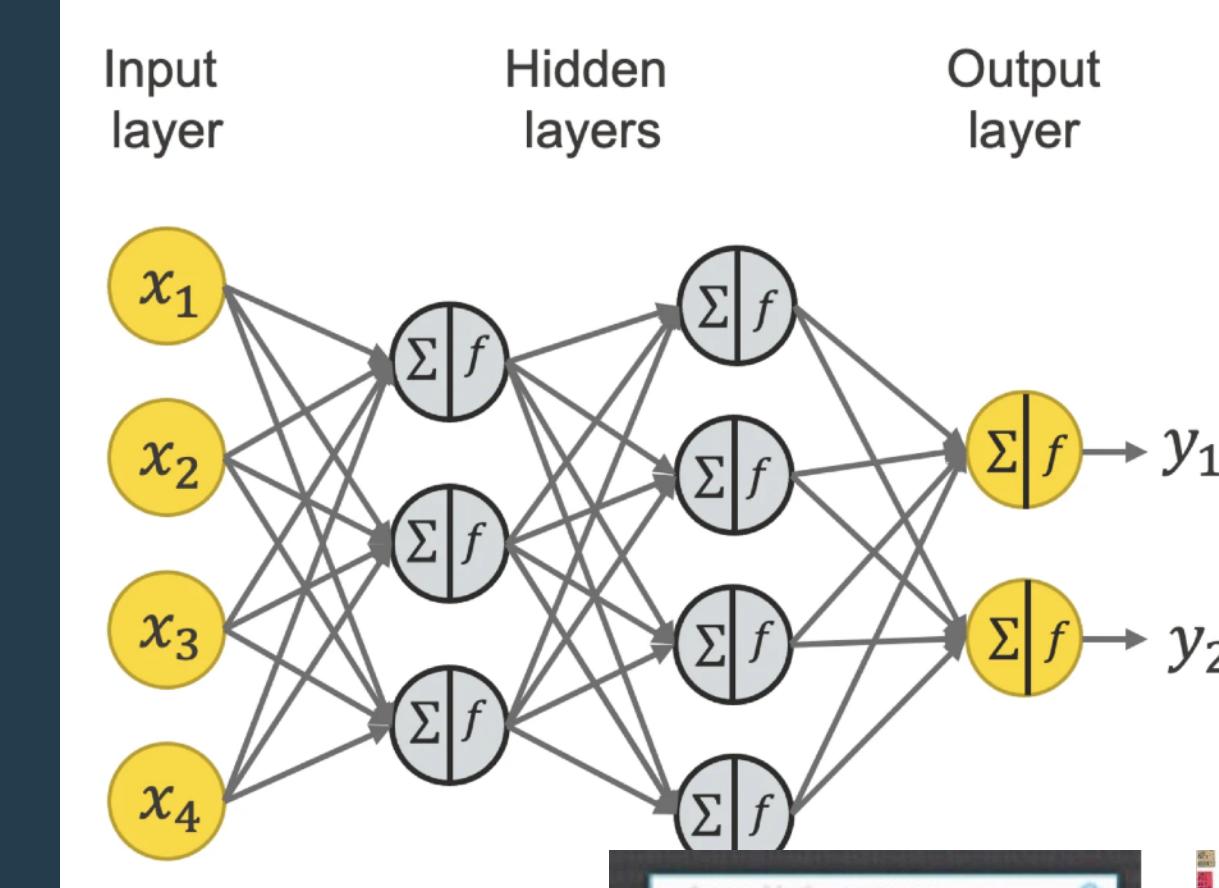
def plot_sine_wave():
    x = np.linspace(0, 2 * np.pi)
    y = np.sin(x)
    plt.plot(x, y)
    plt.title("Sine Wave")
    plt.xlabel("x (radians)")
    plt.ylabel("sin(x)")
    plt.show()

plot_sine_wave()
```

Output:

The Use of AI in CMSE classrooms

Let's test it out



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

ORIGINAL PAPER

Racial Justice Amidst the Dangers of Computing Creep: A Dialogue

Niral Shah¹ · Aman Yadav²

Educating students for a world with ML & AI

AI in my classes

Co-designed policy

Generative AI

Generative AI is a type of artificial intelligence that can generate new data from existing data.

- It is an **extractive** technology that has mined a vast data set.
- It is a **probabilistic** technology that uses statistical models to generate new data.
- It is **not a creative** technology that can generate new ideas, concepts, or products.
- It is **not a truthful** technology that can generate new data that is intrinsically true.

The "Grow At Any Cost" approach to generative AI is destroying communities, violating federal and international laws, upending climate progress, and consolidating power in the hands of a few.

And yet,

- Generative AI can be used productively.
- Generative AI can support accessibility.
- Generative AI can support creativity.
- Generative AI can support learning.

The complexity and tension of these issues are why we need to develop a policy together.

I will not live with the consequences of Generative AI, but y'all will, so this policy must be yours.



Set aside class time for discussion

AI in my classes

Co-designed policy

Creating a Generative Artificial Intelligence Policy

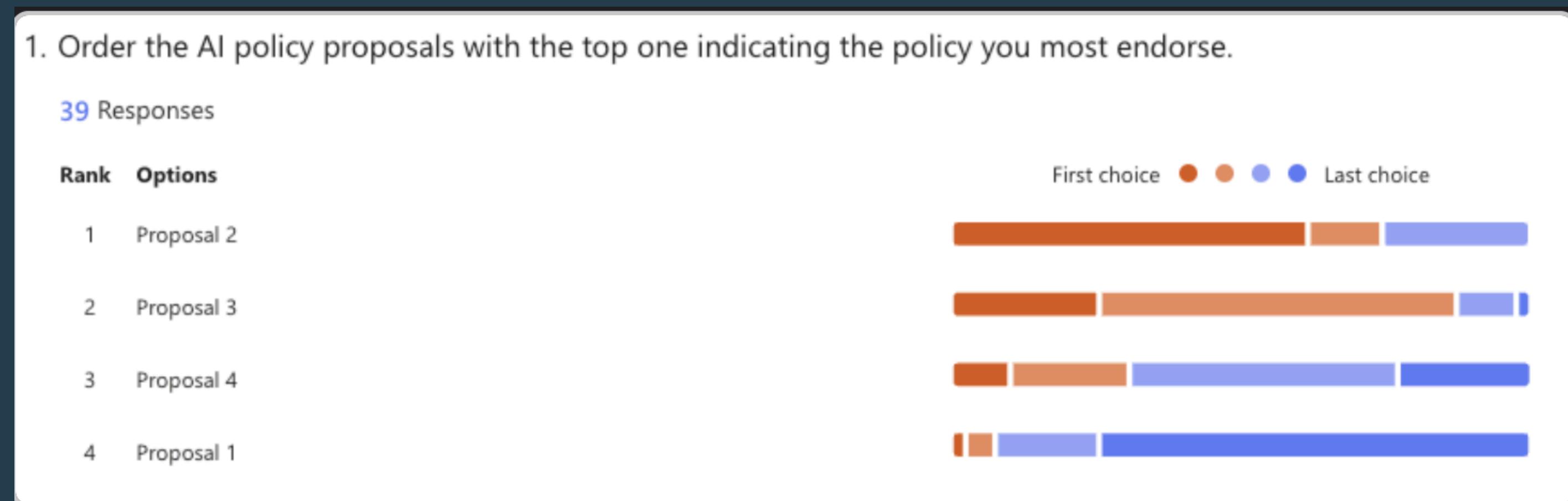
We define **productivity** as the ability to use Generative AI to deepen your understanding of Classical Mechanics.

Take five minutes to answer the following for yourself:

1. What are ways that you think that AI can be used productively in our classroom?
2. What are ways that you think that AI can be used unproductively in our classroom?
3. What do you think are acceptable uses of AI in our classroom?
4. What do you think are unacceptable uses of AI in our classroom?
5. How should we document the use of AI in our classroom?
6. Once we define a policy, how should we collectively enforce it?

11 / 12

Have students think about their values and experiences; share with others



Proposal 2: We adopt a policy that allows AI use for brainstorming, help, and editing.

- AI cannot be used for direct answers or completion of assignments.
- We expect documentation of AI use, but it can be informal.
- Violations are discussed with Danny; the first violation requires a redo of the assignment, and repeated violations result in a failing grade.

Final Takeaways

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- It's quite possible to integrate computing into a wide variety of learning environments. It's hard to do it sustainably.

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Final Takeaways

- It's quite possible to integrate computing into a wide variety of learning environments. It's hard to do it sustainably.
- It's critical that we work collectively across contexts to integrate computing. Local factors and resources are important.
- It's important that we engage with AI and science education. It will require an authentic and collective effort.
- It's gonna be a lot of work. But a lot of fun, too.

**more folks learn
science better
greater diversity
across all of
science**

A diagram illustrating a cyclical relationship. A curved orange arrow points from the bottom right text box back up to the top left text box. Another curved orange arrow points from the top left text box down to the bottom right text box.

**A science that is more
representative of and
responsive to society**

**A society that deeply
values and strongly
supports science**

Thank y'all!

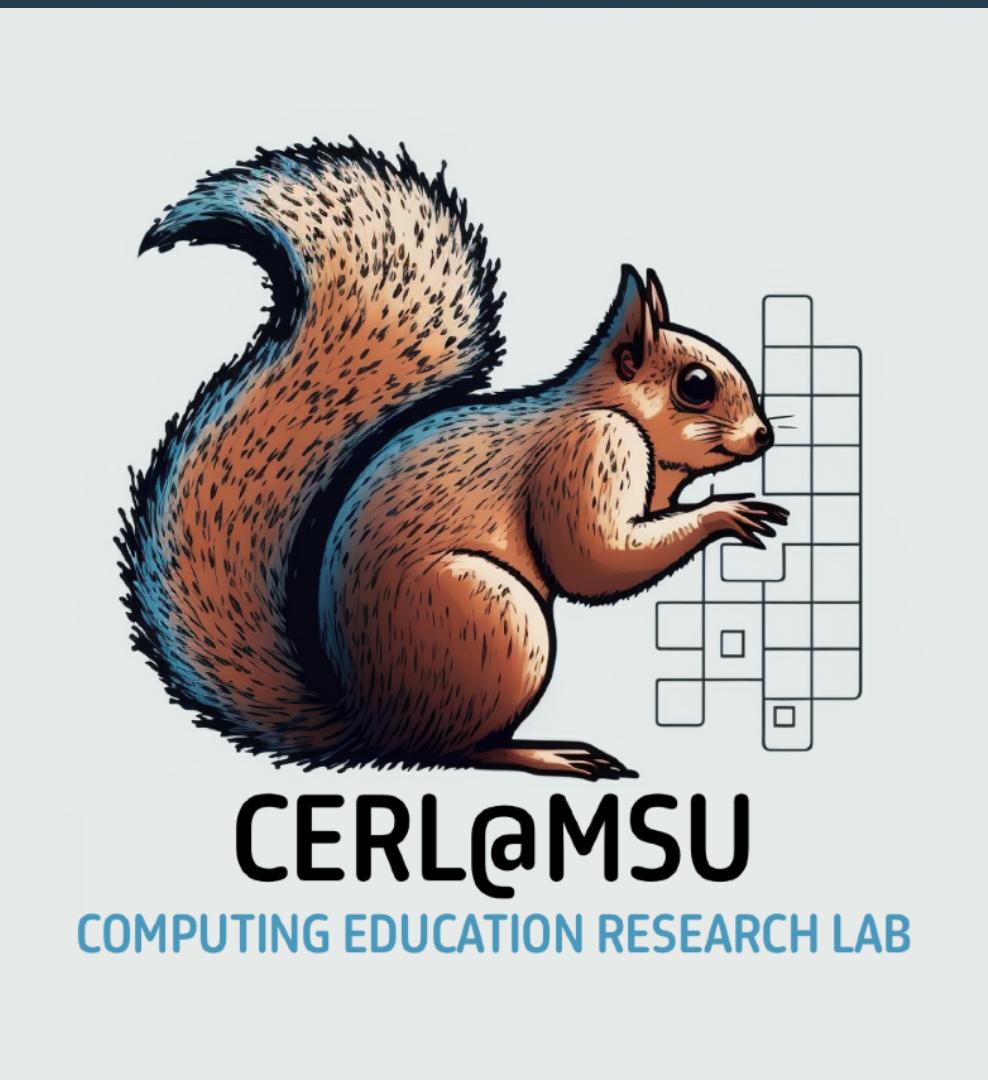


Questions?

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Extra Slides

