slides?

Supporting the integration of computing in physics education

danny caballero (he/they)

Michigan State University
Department of Physics and Astronomy,
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…

- BS in Physics from Texas; MS & PhD in Physics from Georgia Tech; Postdoc Physics Education at CU-Boulder
- Copy shop manager; Kinko's (later, Fedex)
- High school physics teacher; Atlanta Public Schools
- Professor of Physics and Computational Science at MSU and UiO
- Co-direct two research labs at MSU (in Physics & Computational Science Education)
- Labor Organizer and Negotiator for Union of Tenure System Faculty-MEA
- Over 40 skateboard gang; avid cyclist

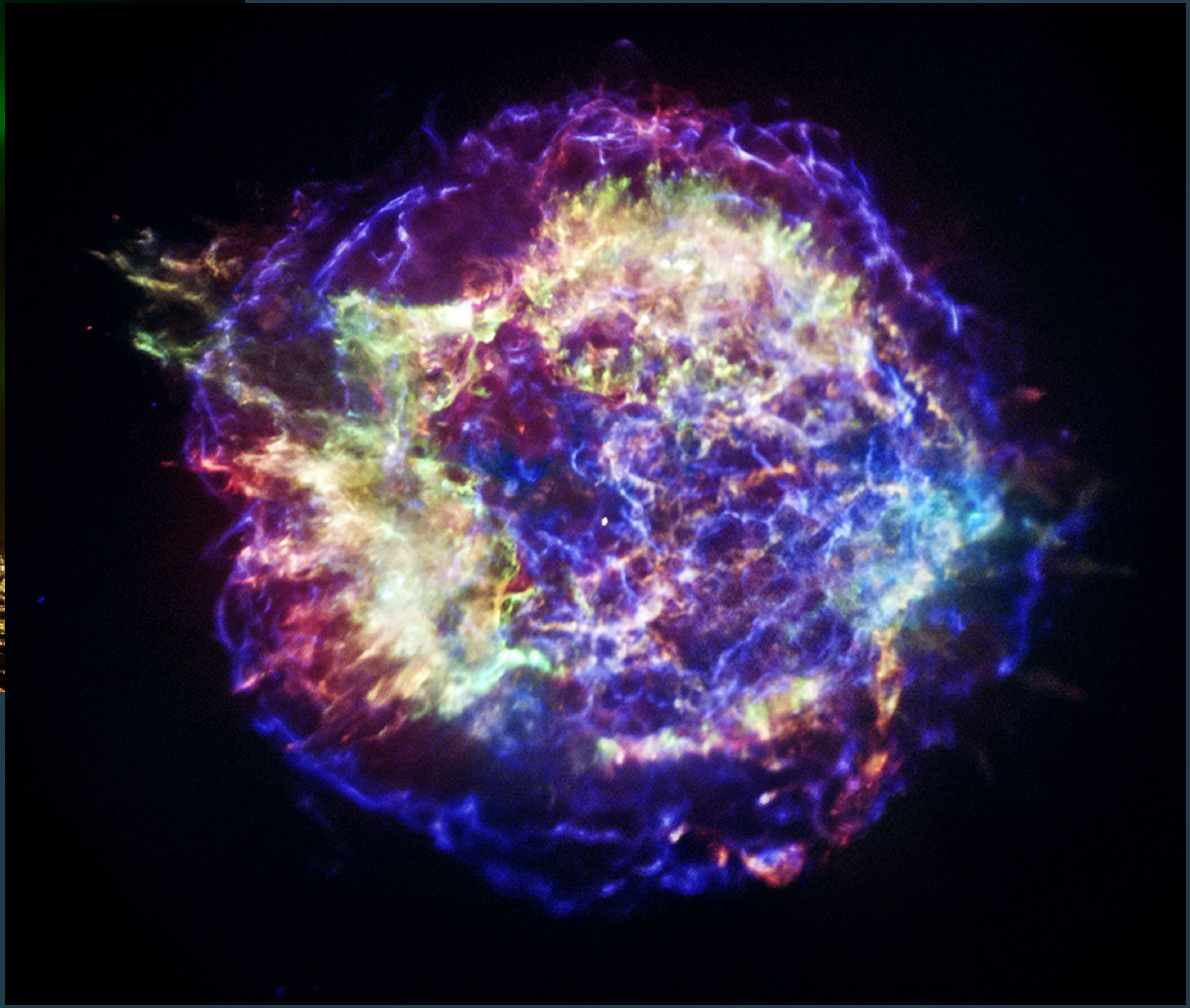
UTSF MICHIGAN STATE UNIVERSITY UNION OF TENURE SYSTEM FACULTY

aurora borealis over oslo

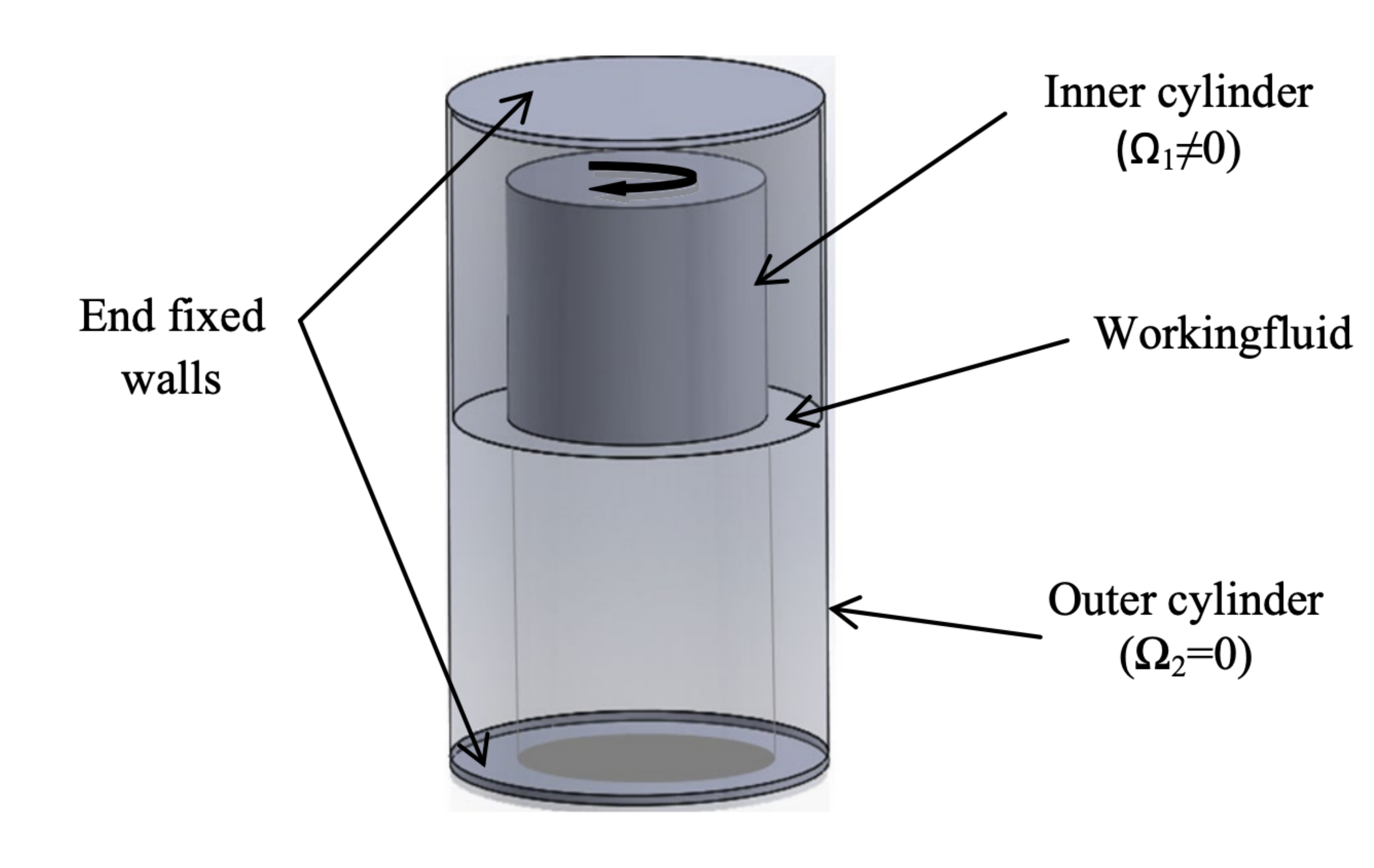
https://www.flickr.com/photos/65218245@N00/326627830

supernova remnant - cassiopeia a

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

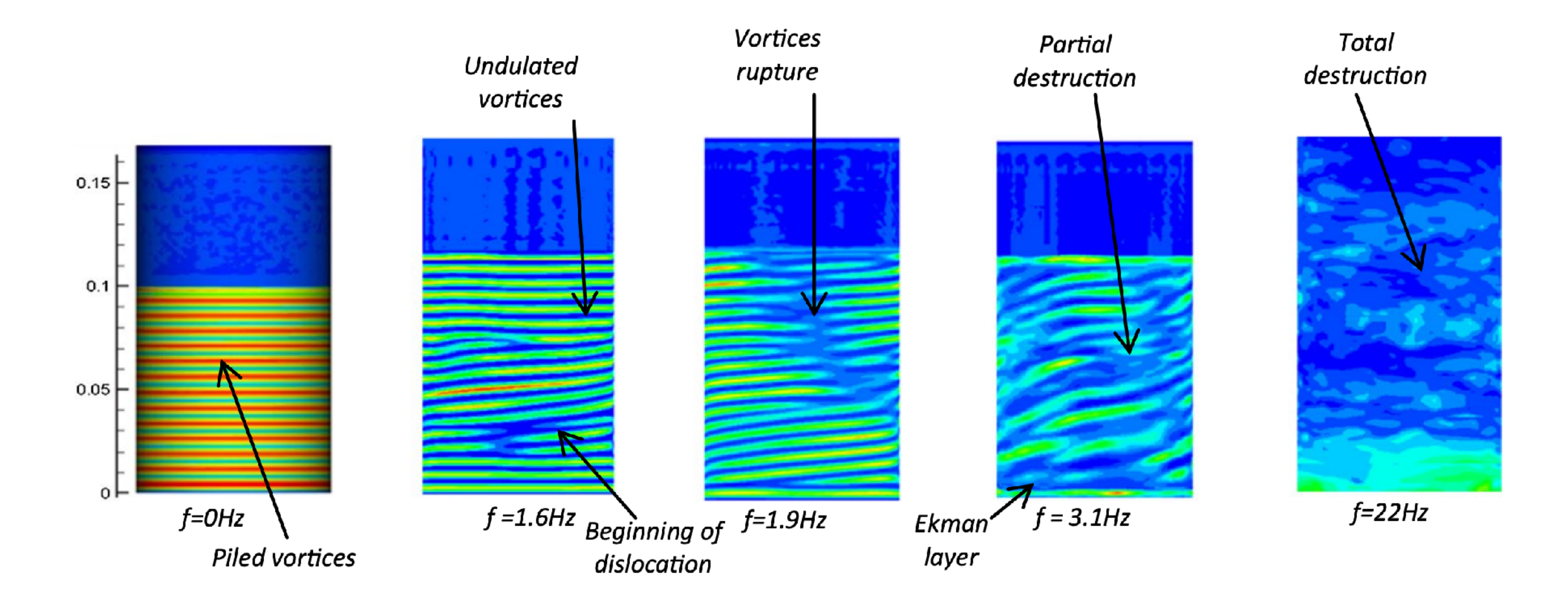


science <u>can</u> explain natural phenomena



natural transition to turbulent flow

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

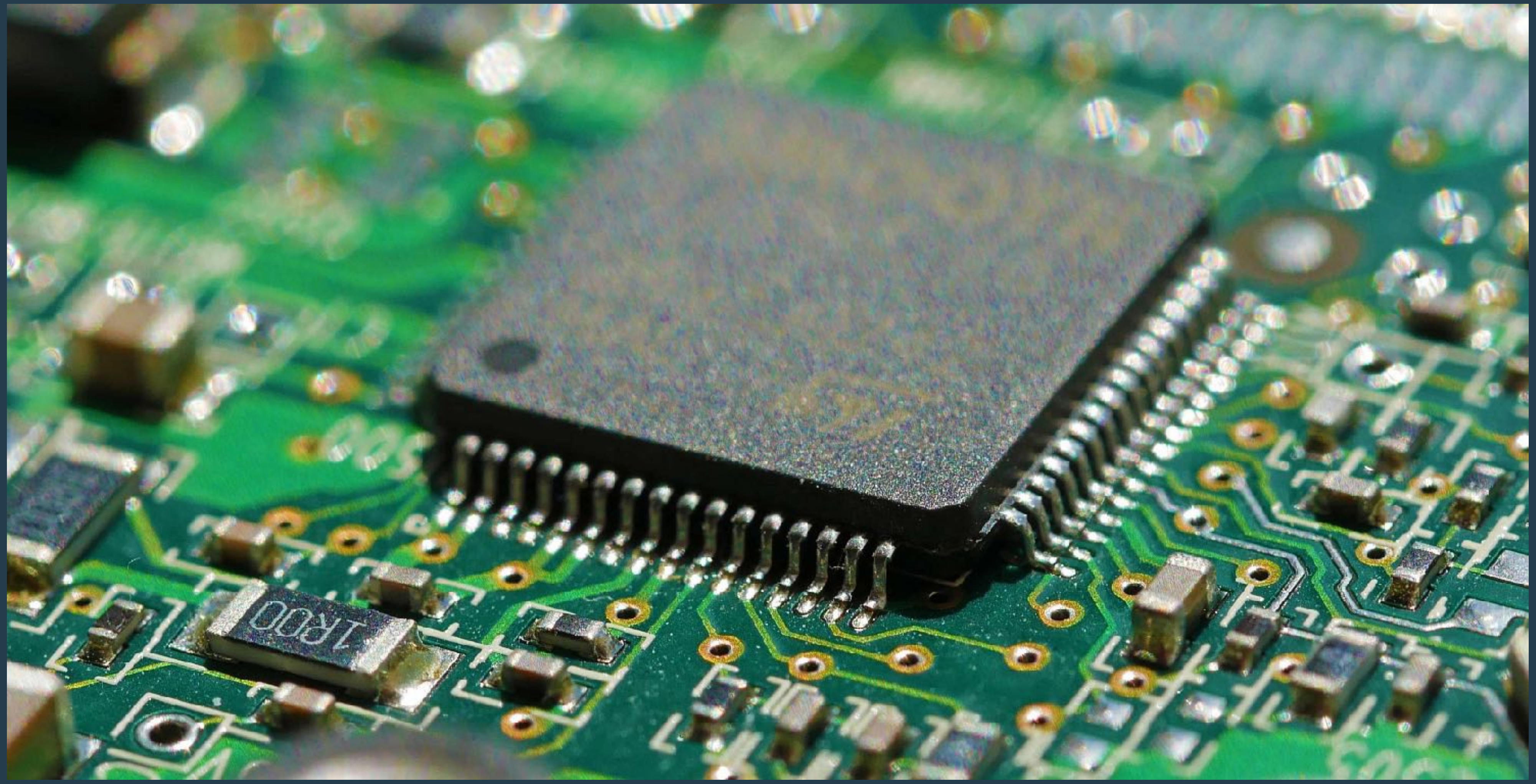


taylor-couette cylinder & transition to turbulence

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

science <u>can</u> satisfy human curiosity

science can benefit society



framing my work

all folks <u>can</u> develop a deep understanding of science

all folks <u>can</u> develop a positive stance towards science

all folks <u>can</u> 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

PERL @MSU

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

CERL@MSU
COMPUTING EDUCATION RESEARCH LAB

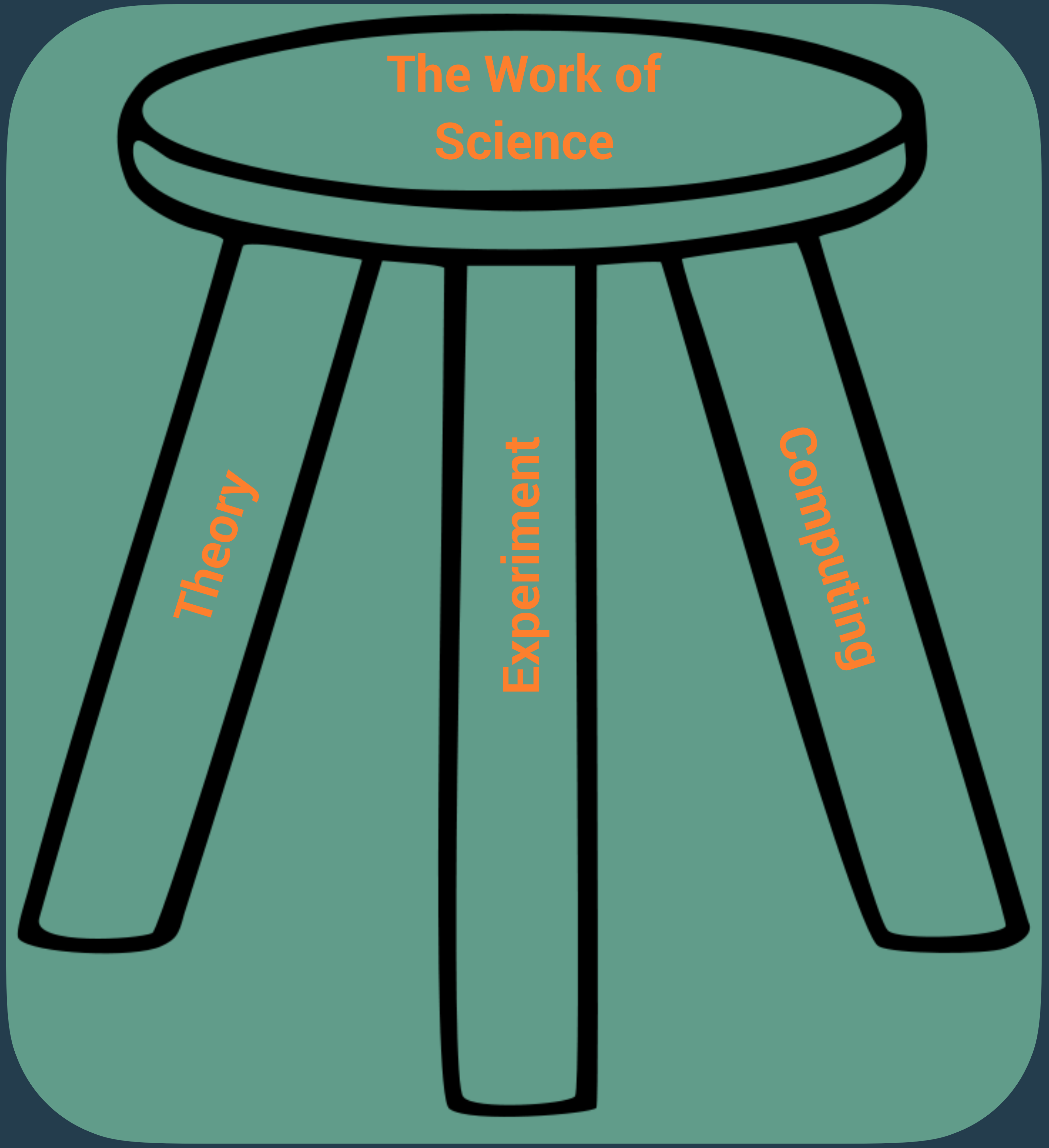
more folks learn science better

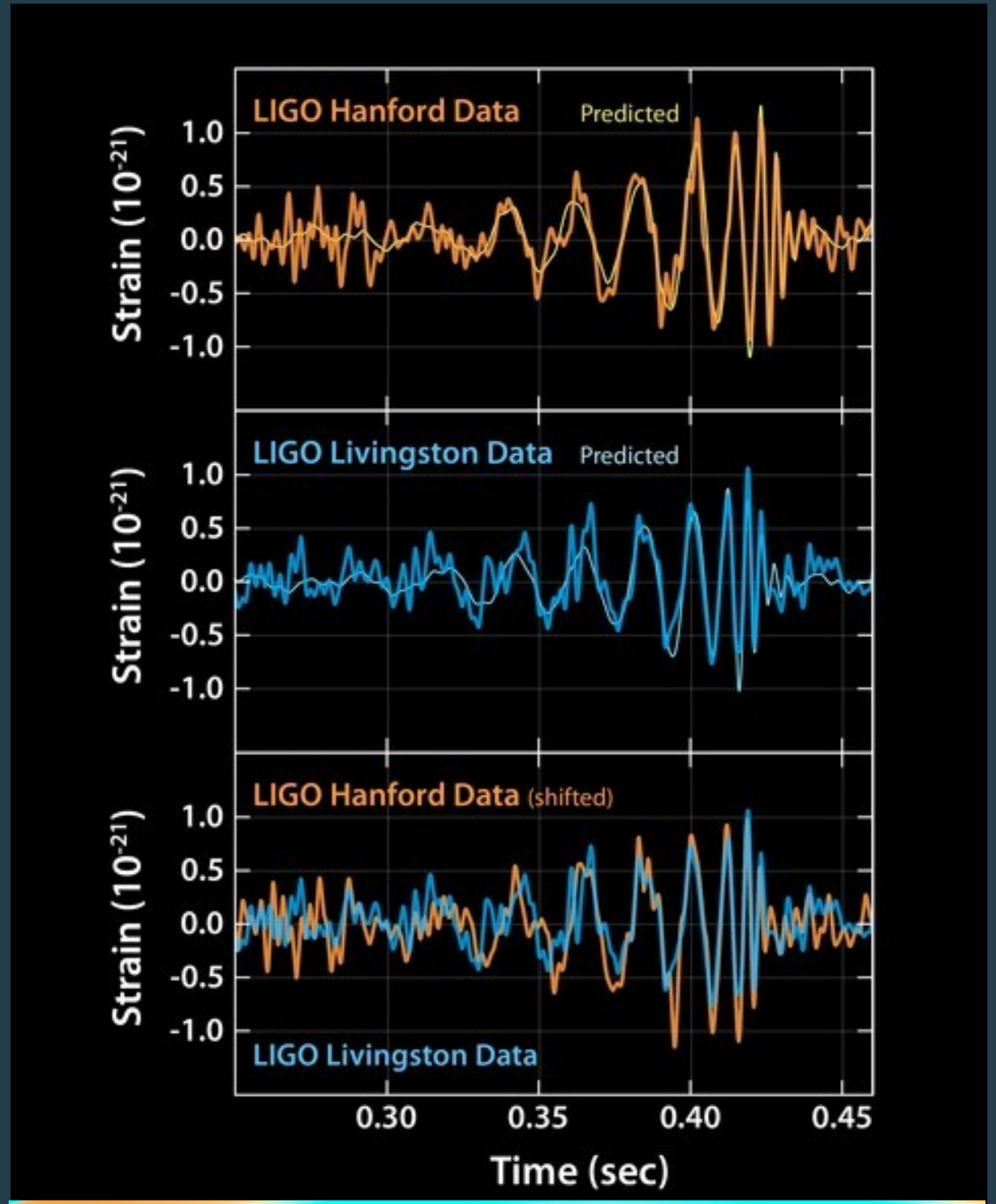
greater diversity across all of science

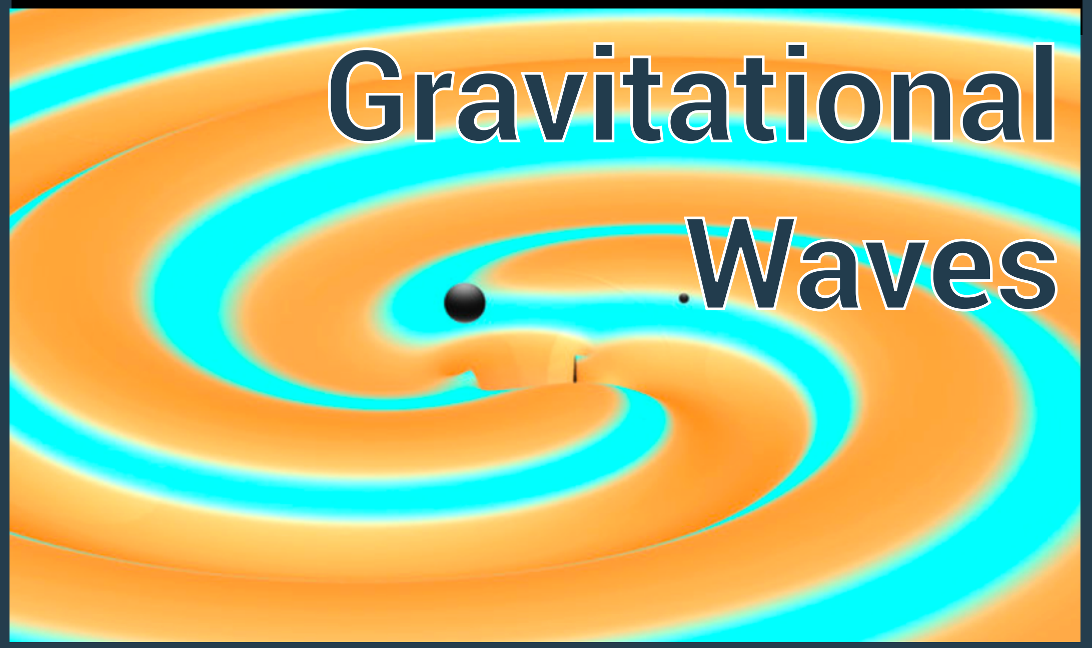
a science that is more representative of and responsive to society

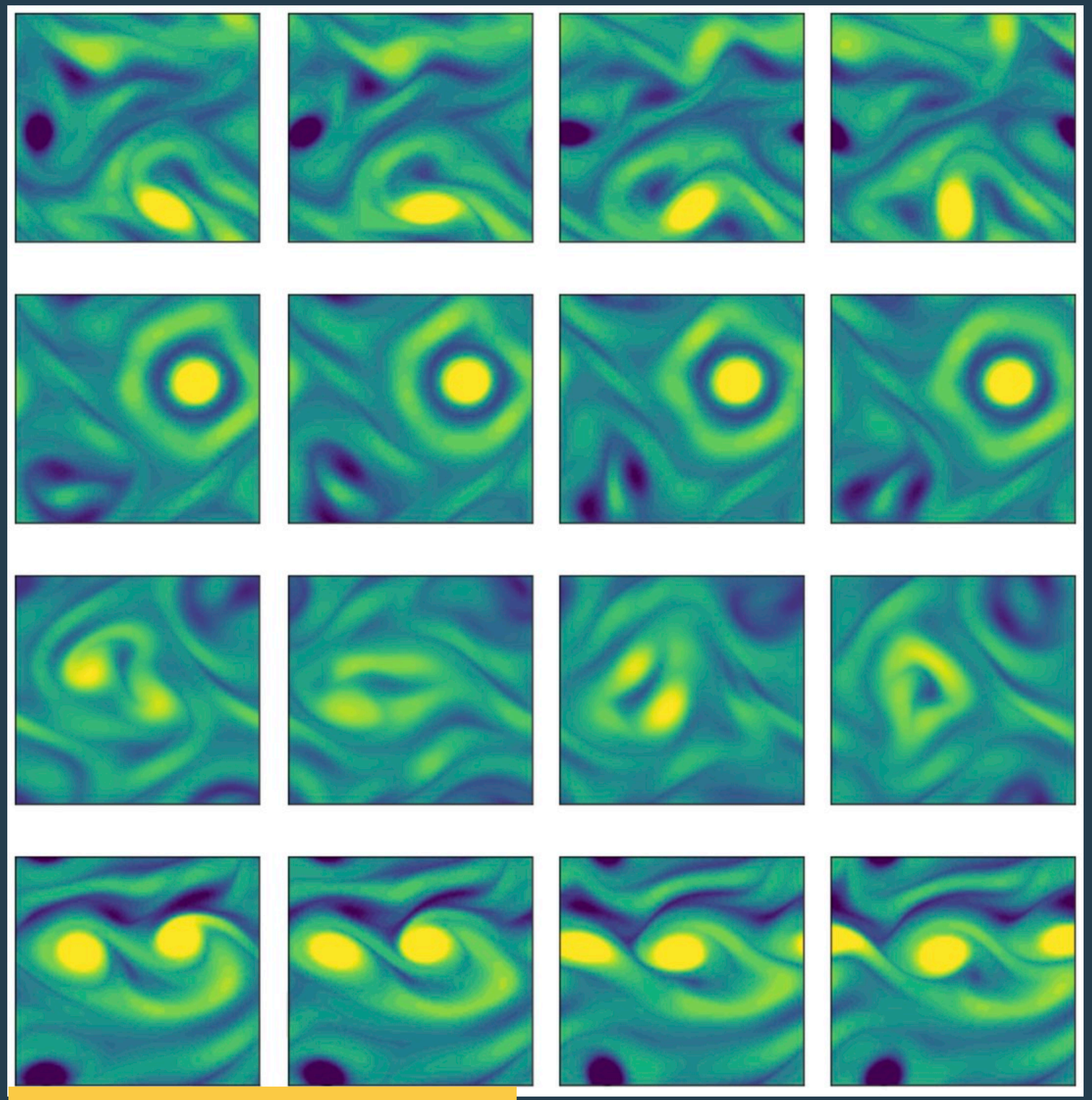
a society that deeply values and strongly supports science

computing is how science is done.

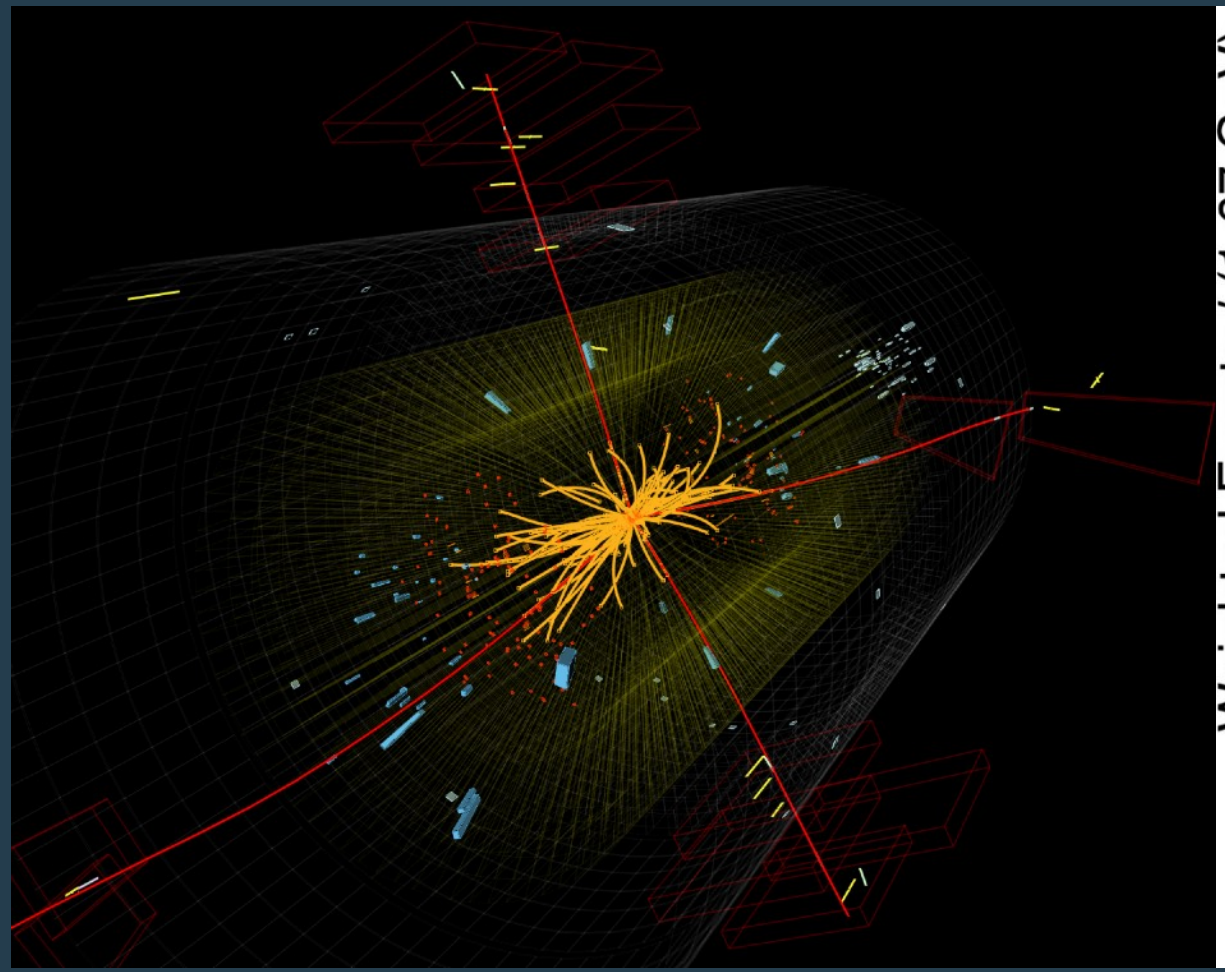


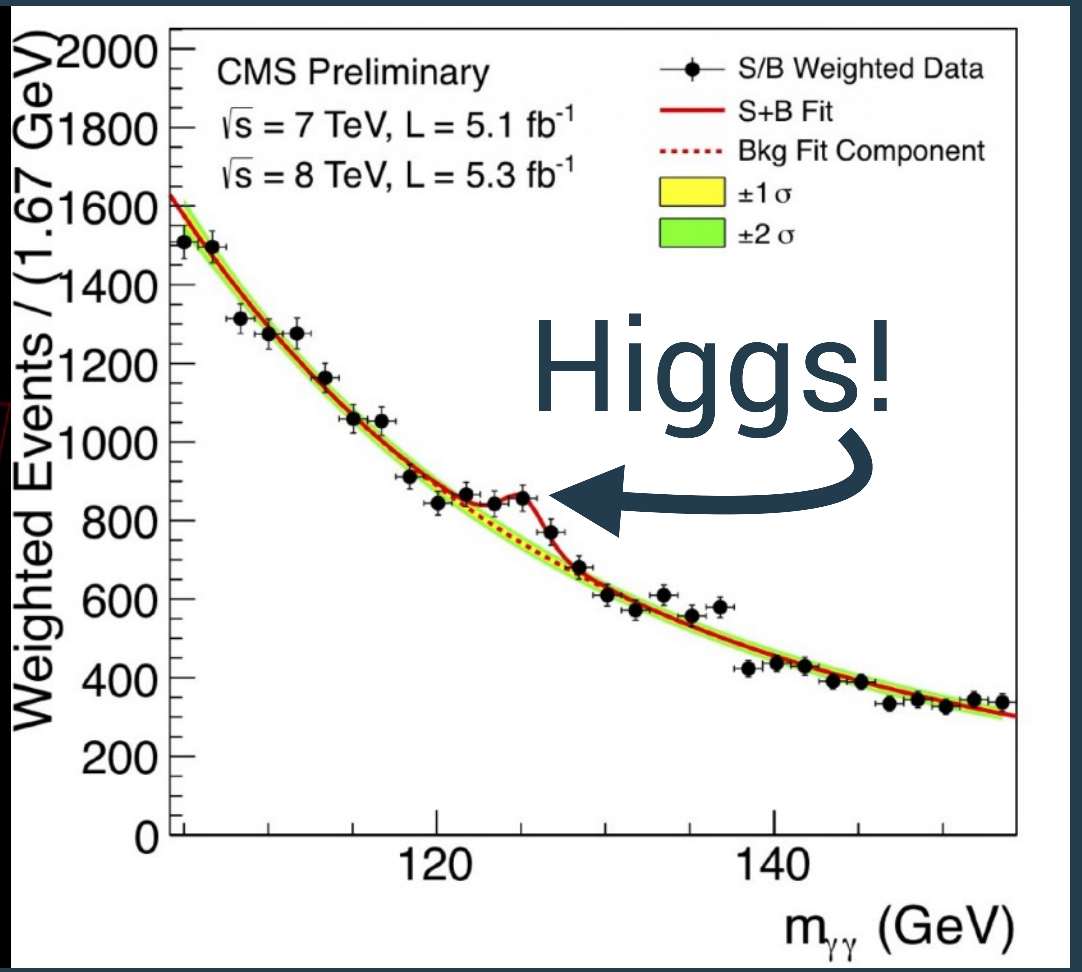






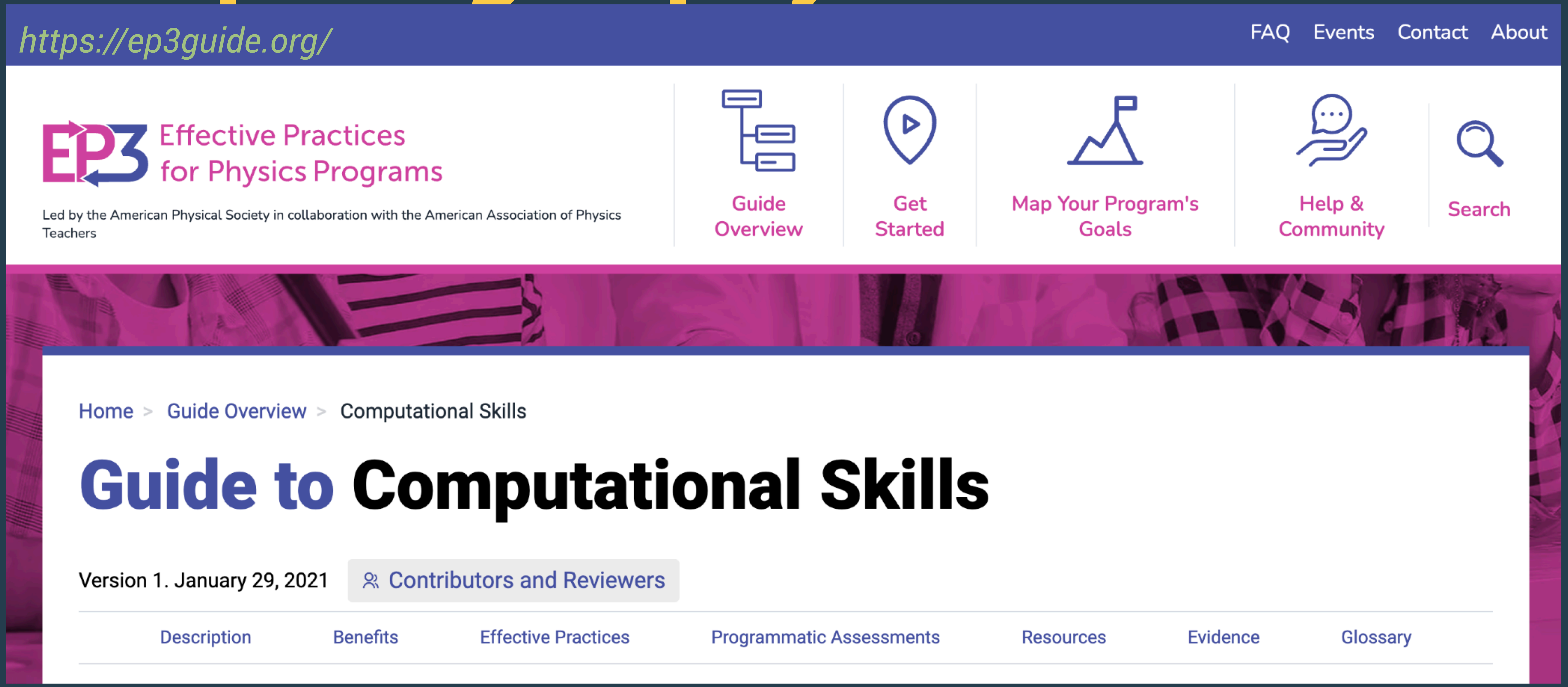
Turbulence

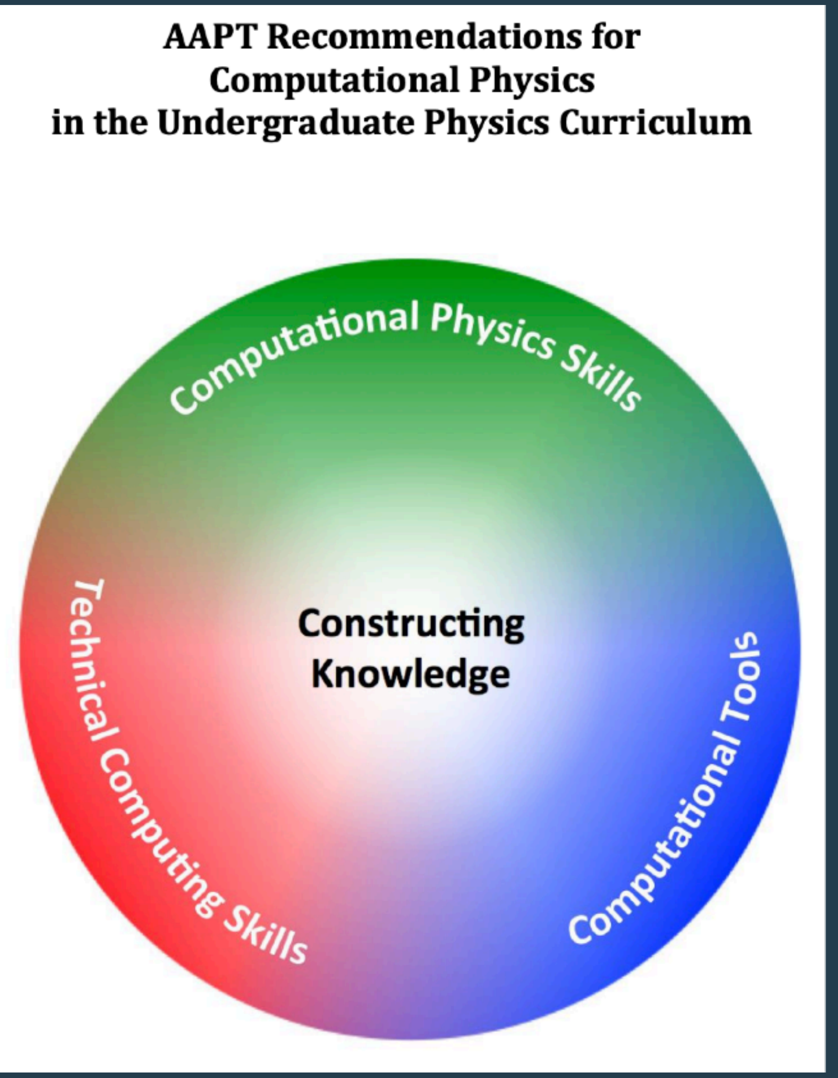




Aad, Georges, et al. Physics Letters B 716.1 (2012): 1-29.
Abbott, Benjamin P., et al. PRL 116.6 (2016): 061102.
Page, J., et al., PNAS, 121 (23) e232000712 (2024)

students should be able to use computing in physics



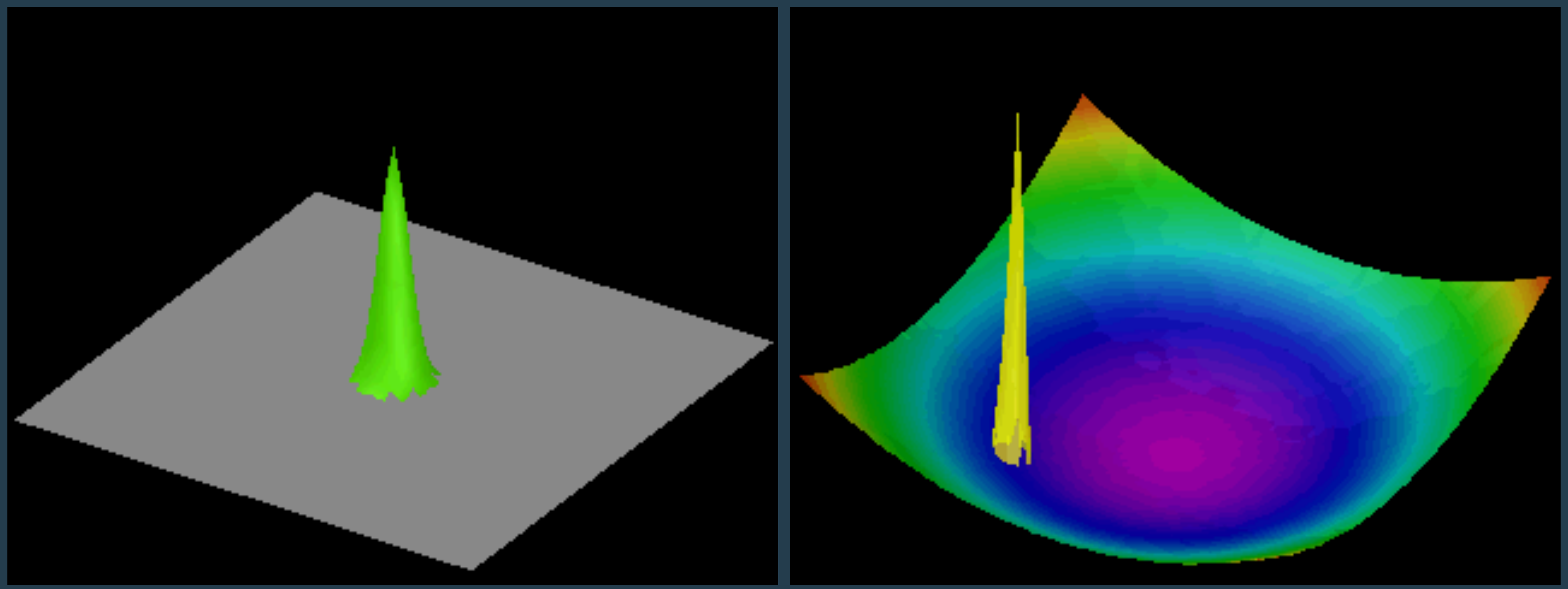


Departments should strive to:

- 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

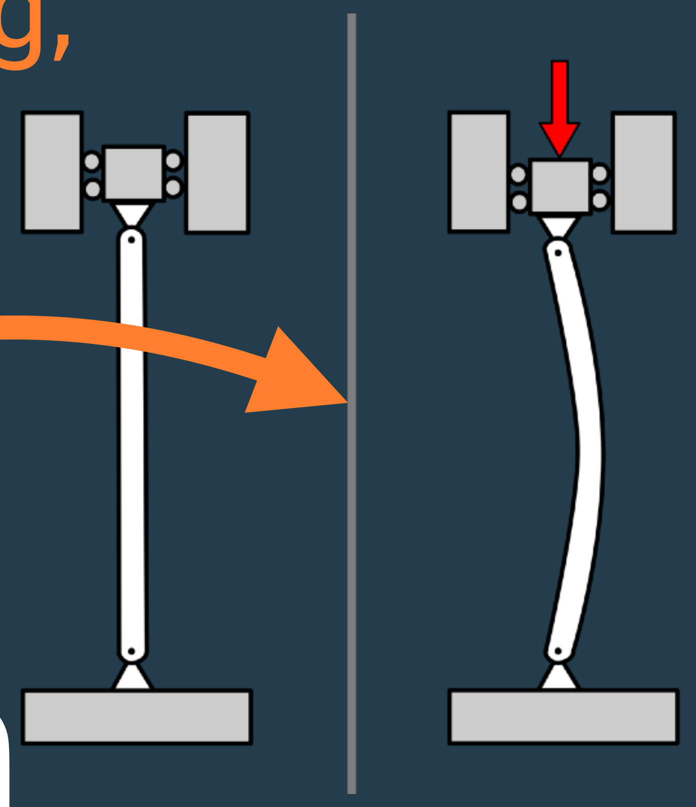
a physics education requires
a computing education

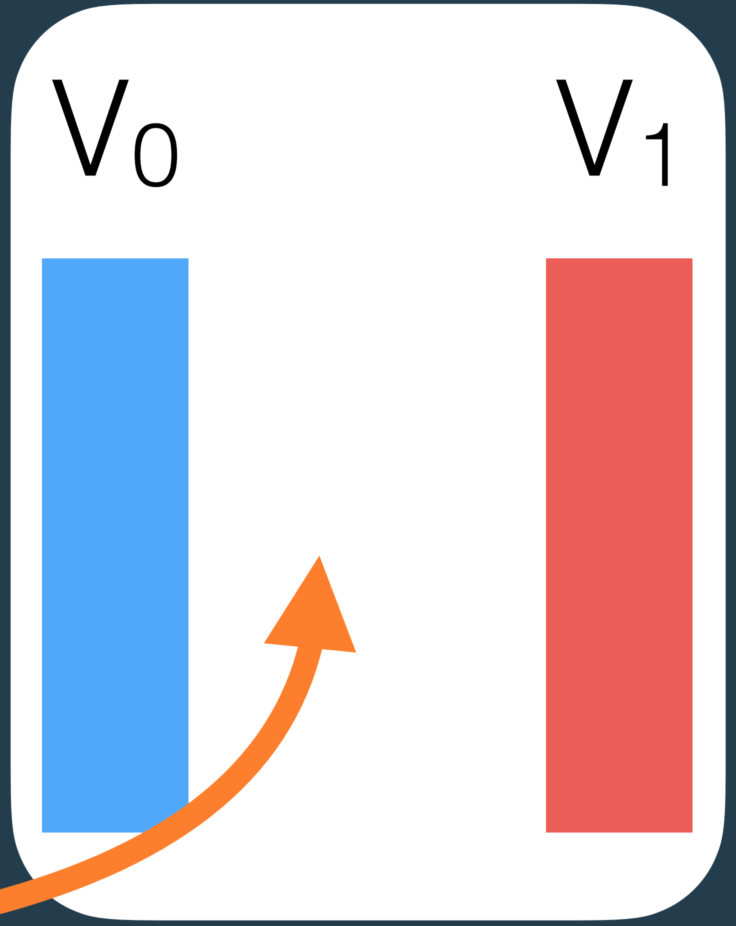


Michielson and De Raedt, 2012

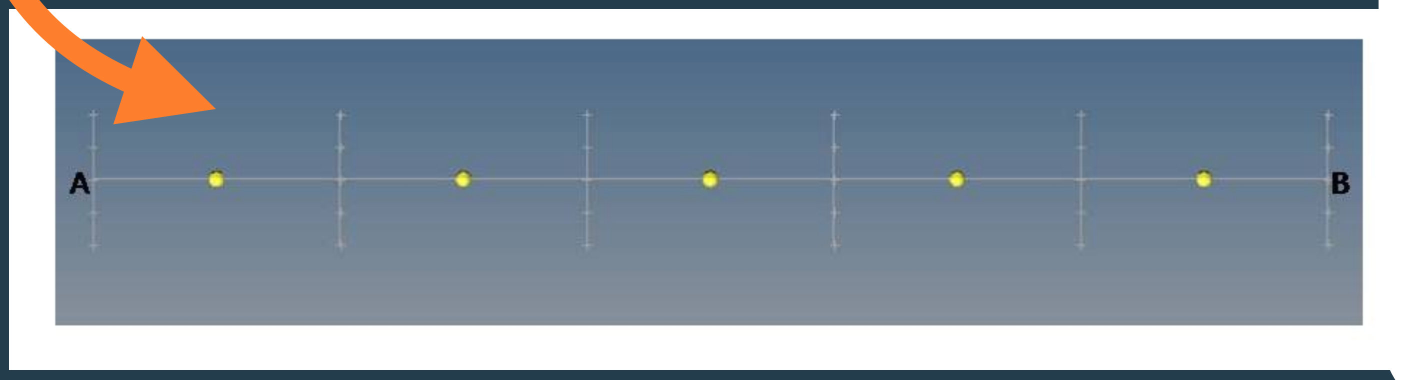
Construct visualizations; develop conceptual understanding

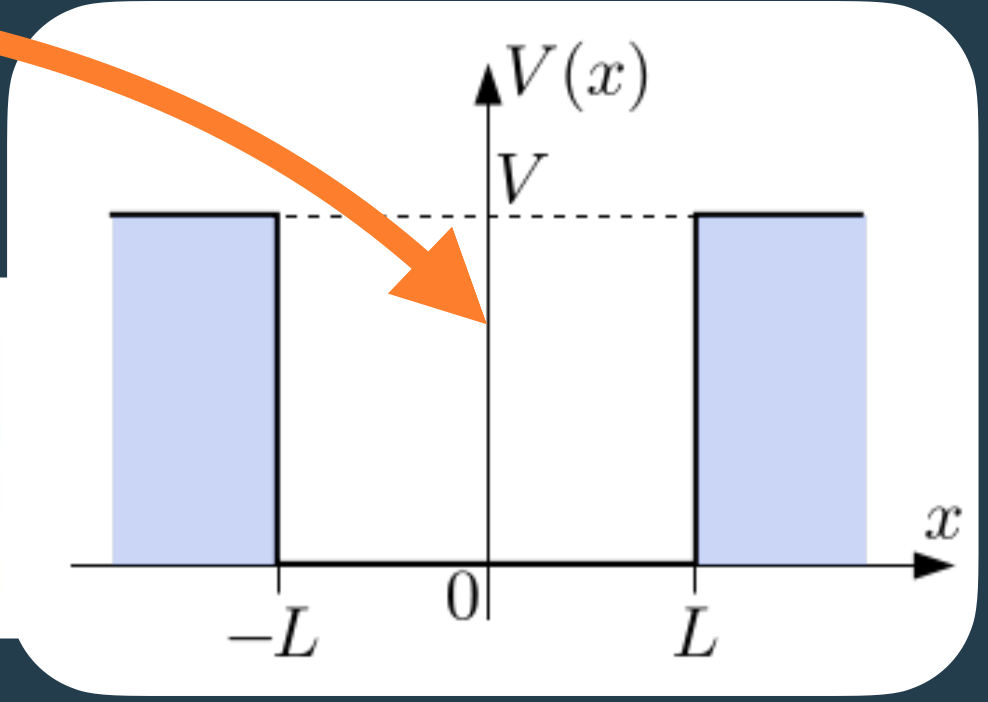
Apply algorithmic thinking; generalize problem solving





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

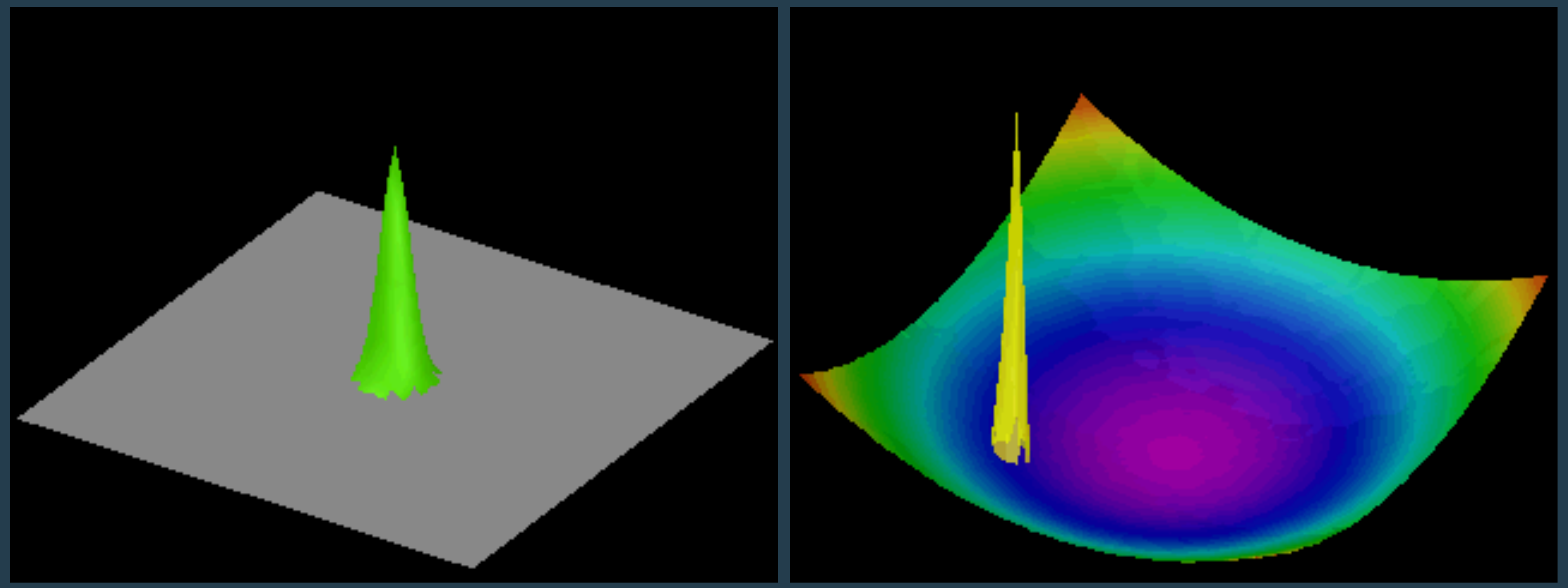




Teach necessary skills; prepare workforce

2022, AIP (2019 & 2020 classes; one year after graduation)

developing students' computational competencies



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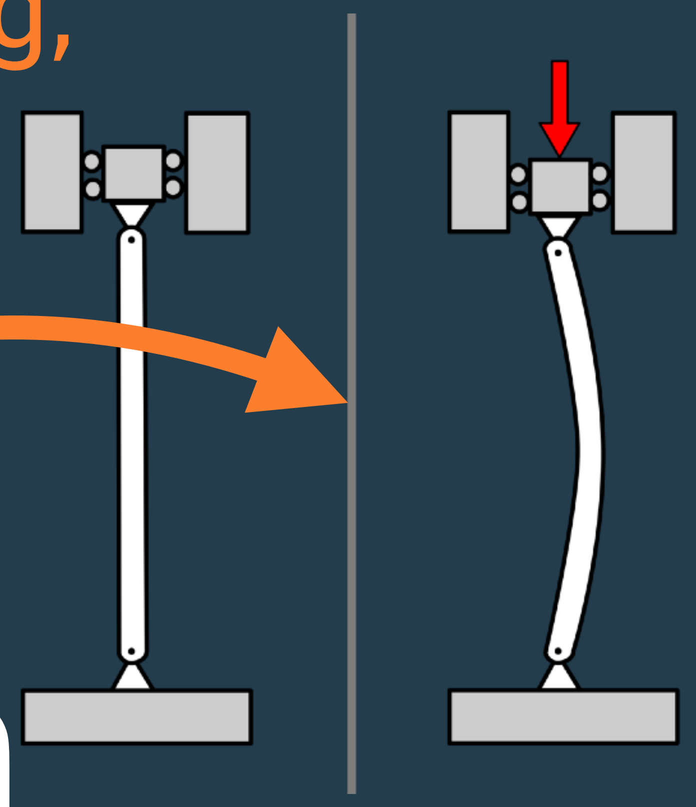

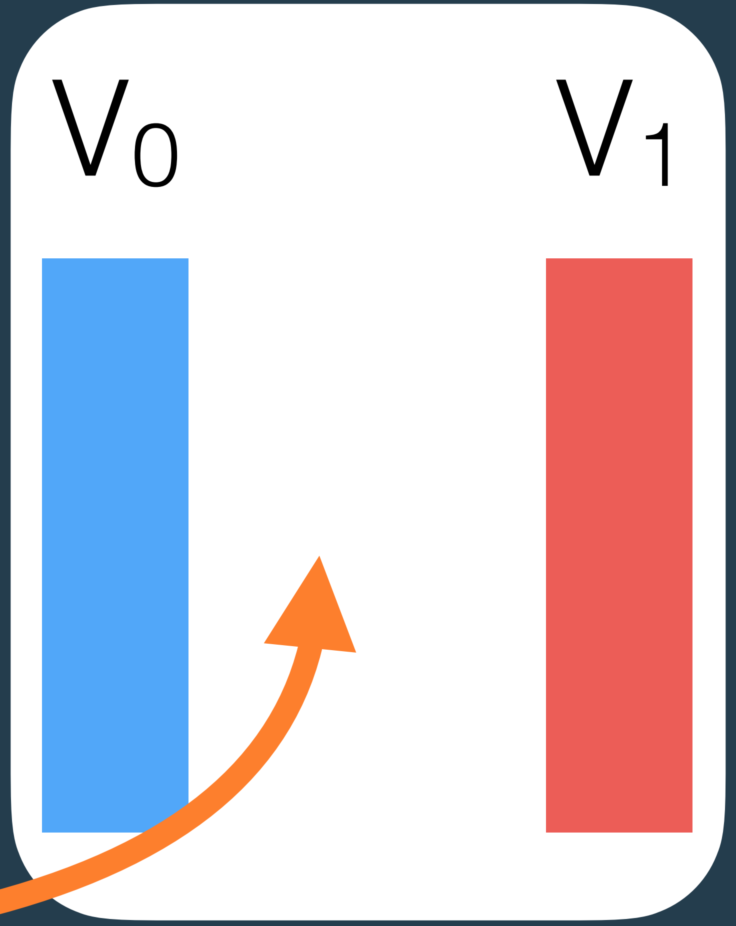

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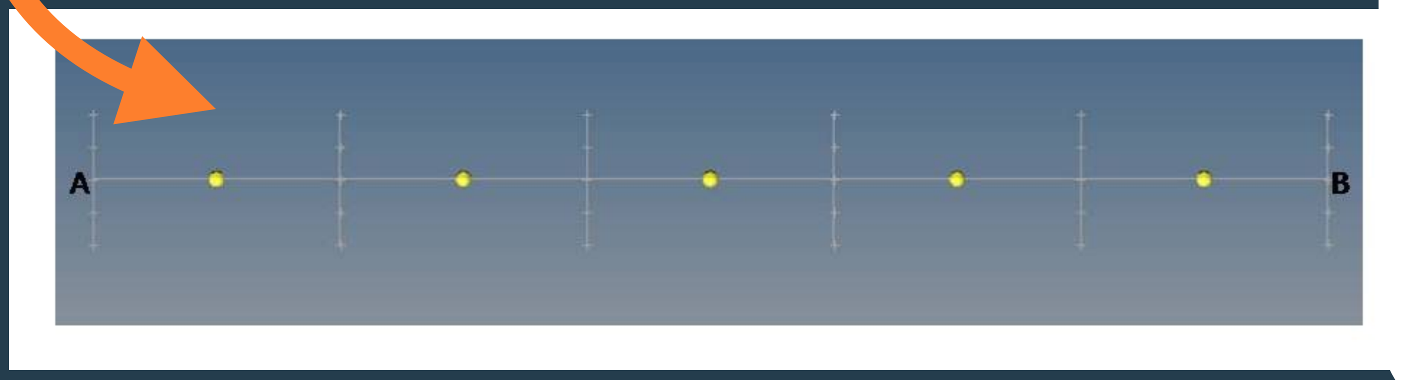

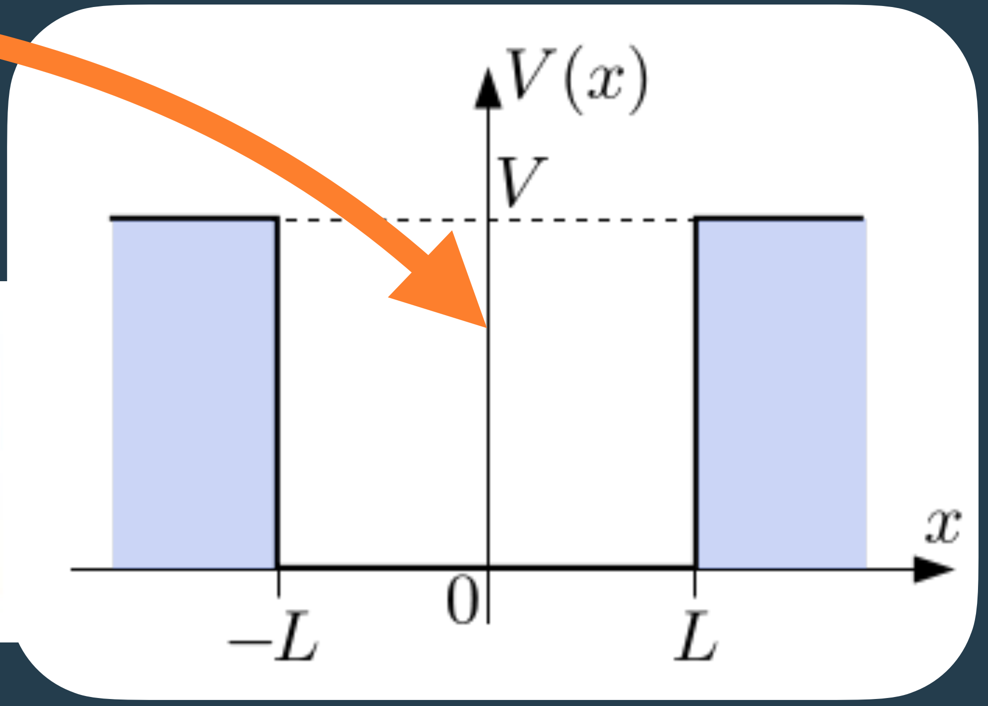

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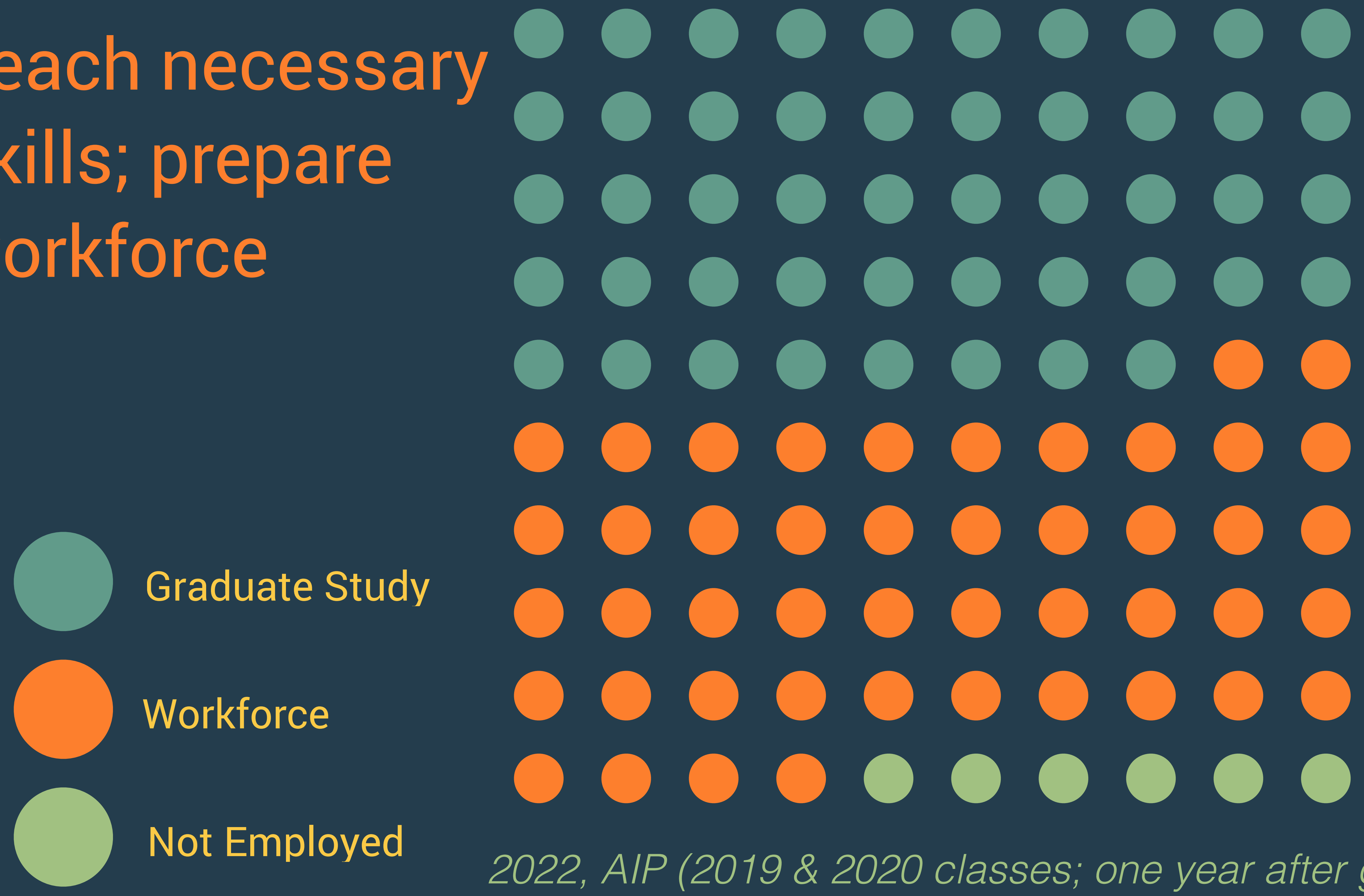


2022, AIP (2019 & 2020 classes; one year after graduation)

developing students' computational competencies

State of Michigan

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)**

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*)

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

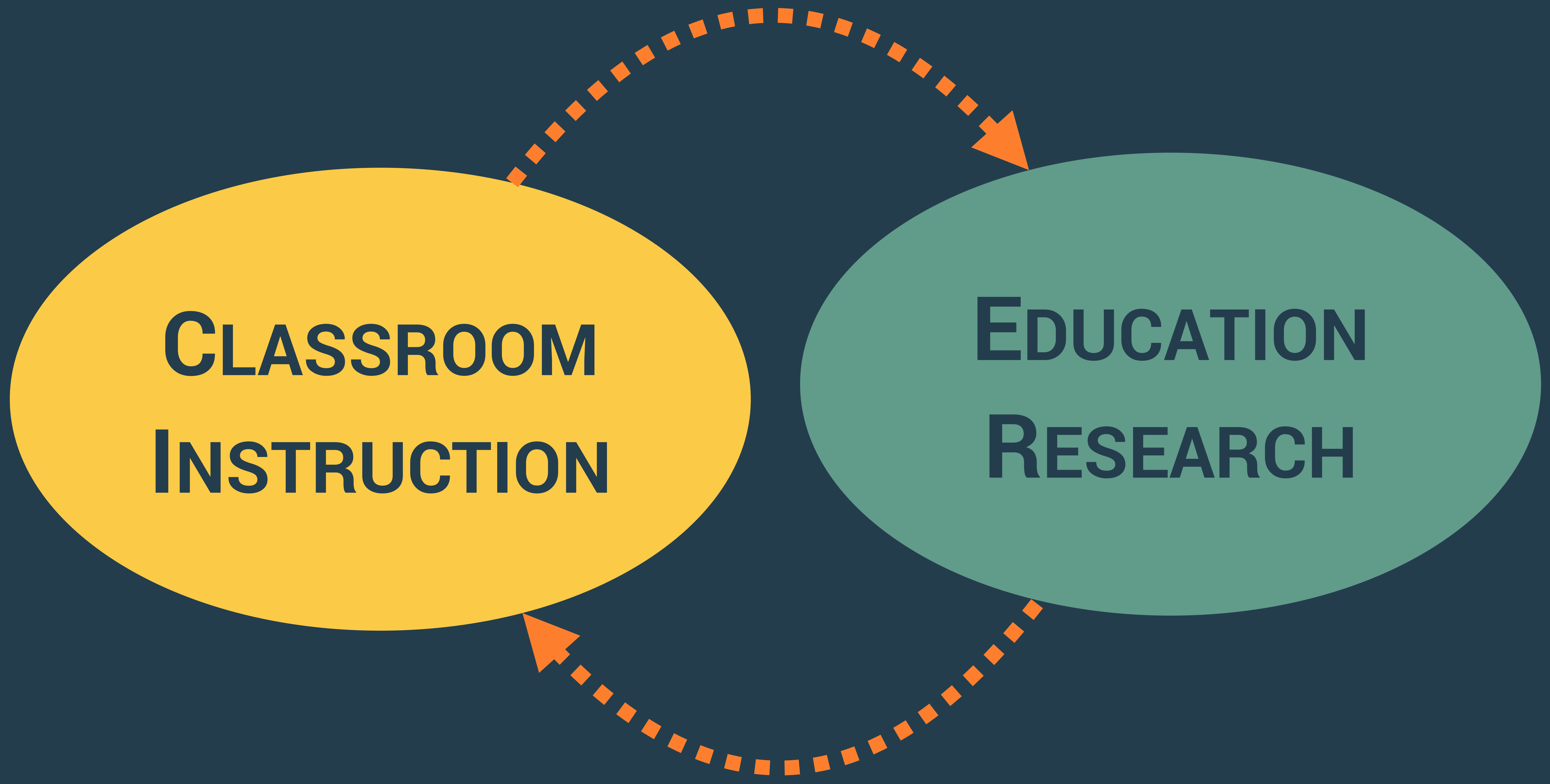
twin goals of our program

Conducting Original Research

Two students working on
an FRIB experiment

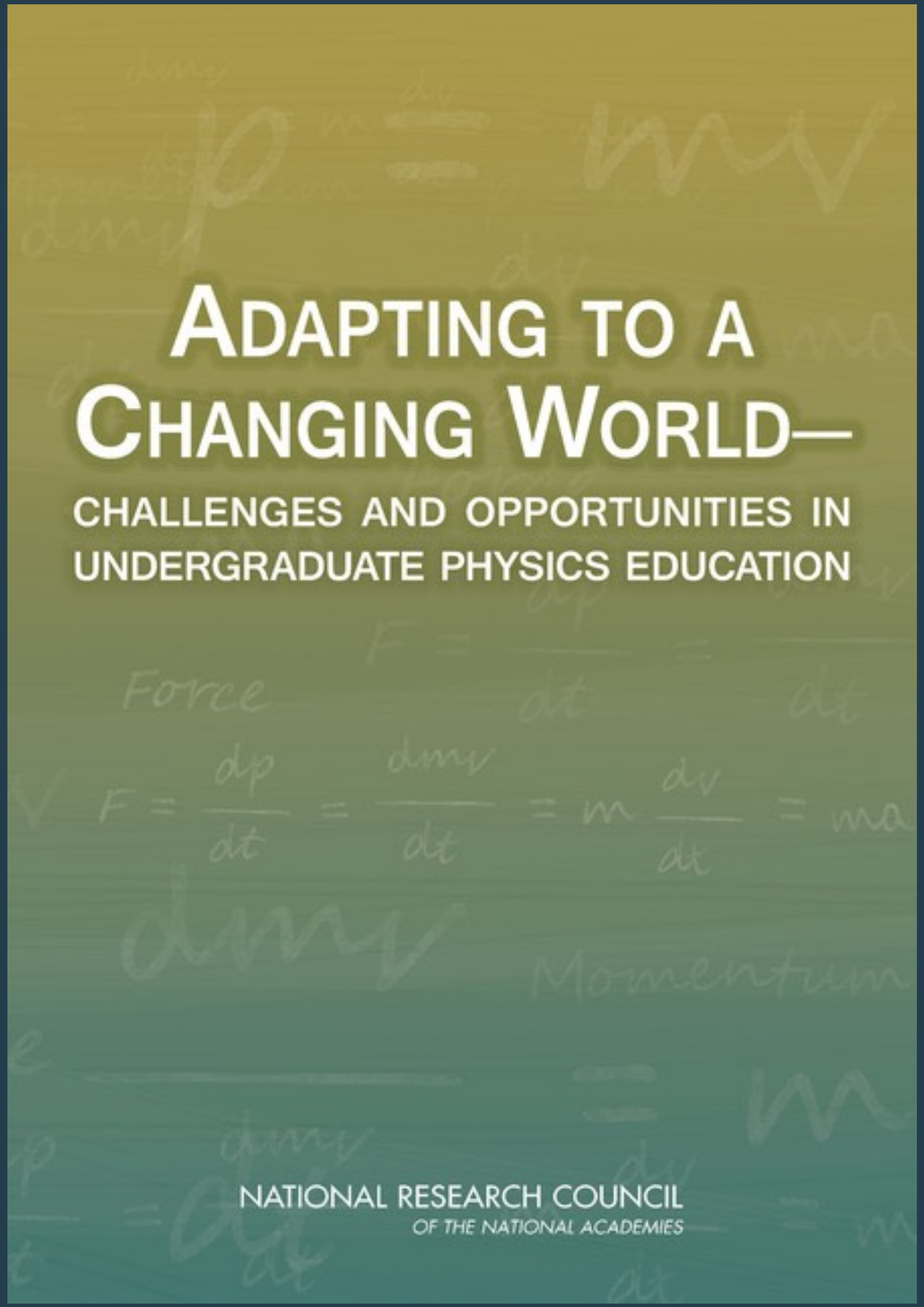
Educating the Next Generation

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 it[1] — 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)

[1]This 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)

```
from __future__ import division
from visual import *

craft = sphere(pos = vector(10e7,0,0), color = color.white, radius = 1e6)
Earth = sphere(pos = vector(0,0,0), color = color.blue, radius = 6.3e6)
trail = curve(color = craft.color)

G = 6.67e-11
mcraft = 1500
mEarth = 5.97e24

vcraft = vector(0,2400,0)
pcraft = mcraft*vcraft

t = 0
deltat = 60
tf = 365*24*60*60

while t < tf:

    r = craft.pos-Earth.pos
    rhat = r/mag(r)
    Fgrav = -G*mEarth*mcraft/mag(r)**2*rhat

    pcraft = pcraft+Fgrav*deltat
    craft.pos = craft.pos + pcraft/mcraft*deltat

    trail.append(pos = craft.pos)
    t = t + deltat

print 'Craft final position: ', craft.pos, 'meters.'
```

Initial Conditions

Force Calculation

Newton's Second Law

Position Update

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.

Caballero, Marcos D., Matthew A. Kohlmyer, and Michael F. Schatz. Physical Review Special Topics—Physics Education Research 8.2 (2012): 020106.

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PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH 15, 020152 (2019)

Editors' Suggestion

Physics computational literacy: An exploratory case study using computational essays

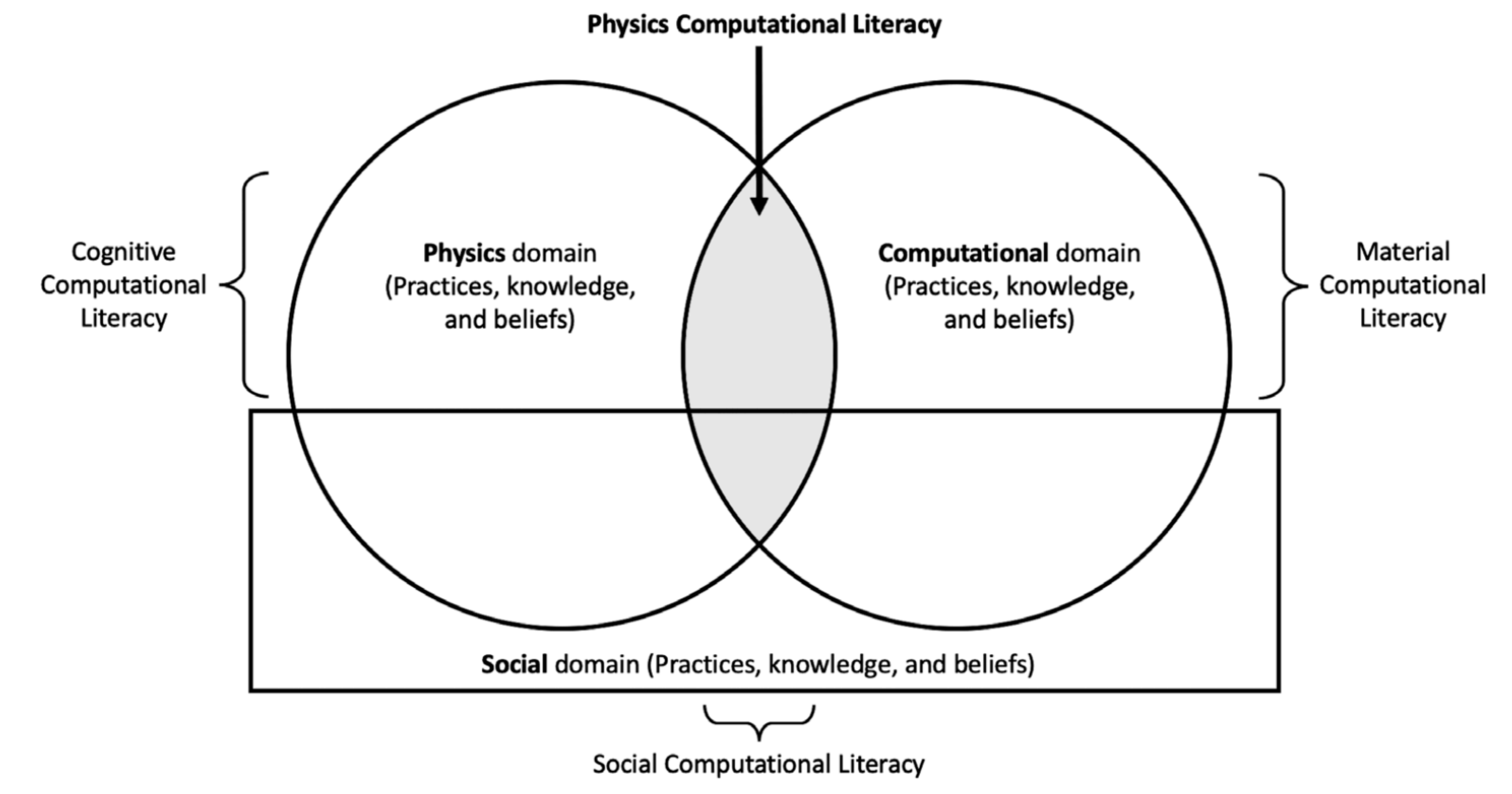
Tor Ole B. Odden,[1] Elise Lockwood,[2] and Marcos D. Caballero[1,3]

[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*

The Research Council of Norway

NSF

Computational Literacy involves cognitive, material, and social literacies



Overlapping practices, knowledge, and beliefs

Requires further R&D

Odden, Tor Ole B., Elise Lockwood, and Marcos D. Caballero. Physical Review Physics Education Research 15.2 (2019): 020152.

PCL is a model that informs activity development & pedagogy

JOURNAL OF THE LEARNING SCIENCES
https://doi.org/10.1080/10508406.2025.2494791

Routledge Taylor & Francis Group

OPEN ACCESS Check for updates

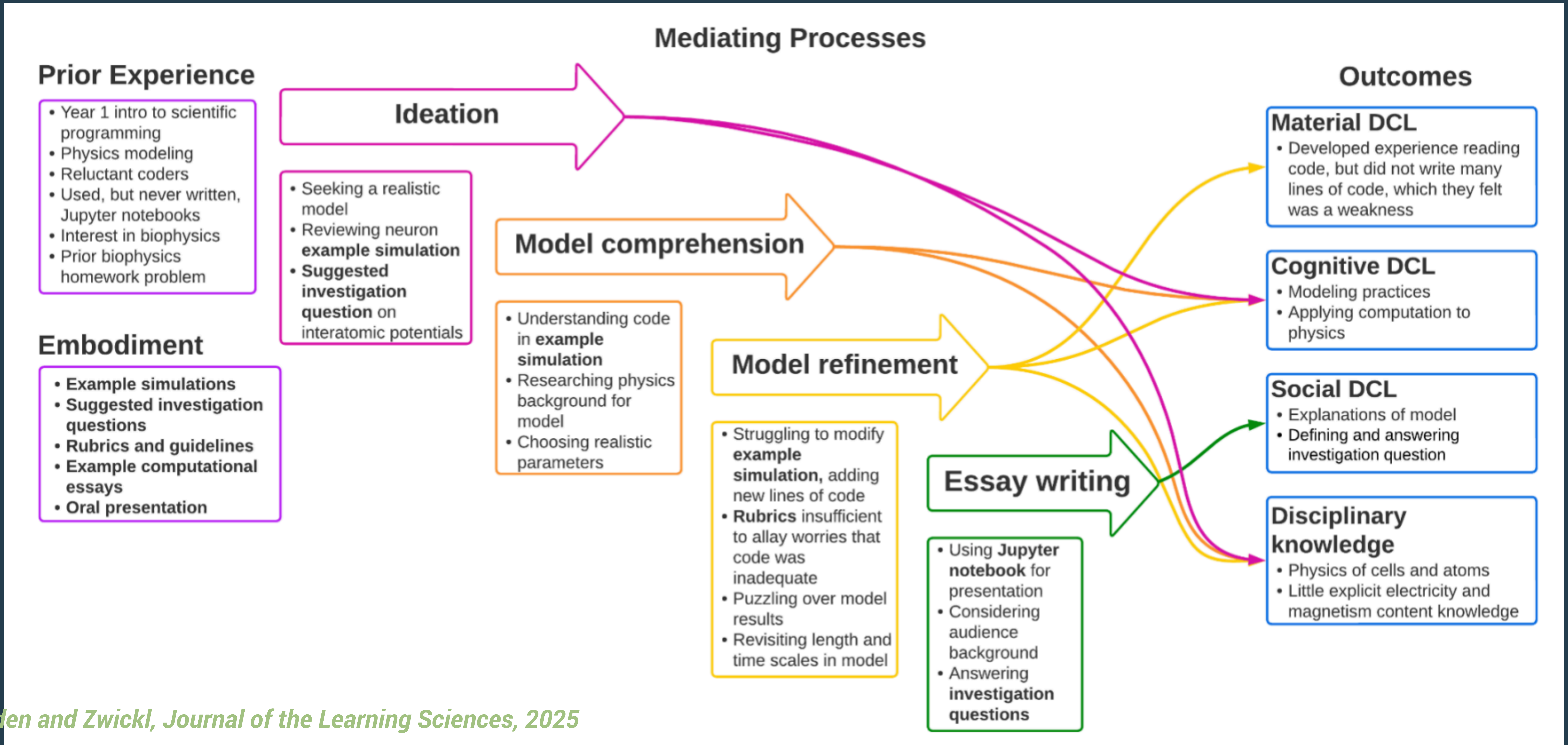
How physics students build computational literacy by creating computational literature

Tor Ole B. Odden[a] and Benjamin Zwickl[a,b]

[a]Center for Computing in Science Education, Department of Physics, University of Oslo; [b]School of Physics and Astronomy, Rochester Institute of Technology

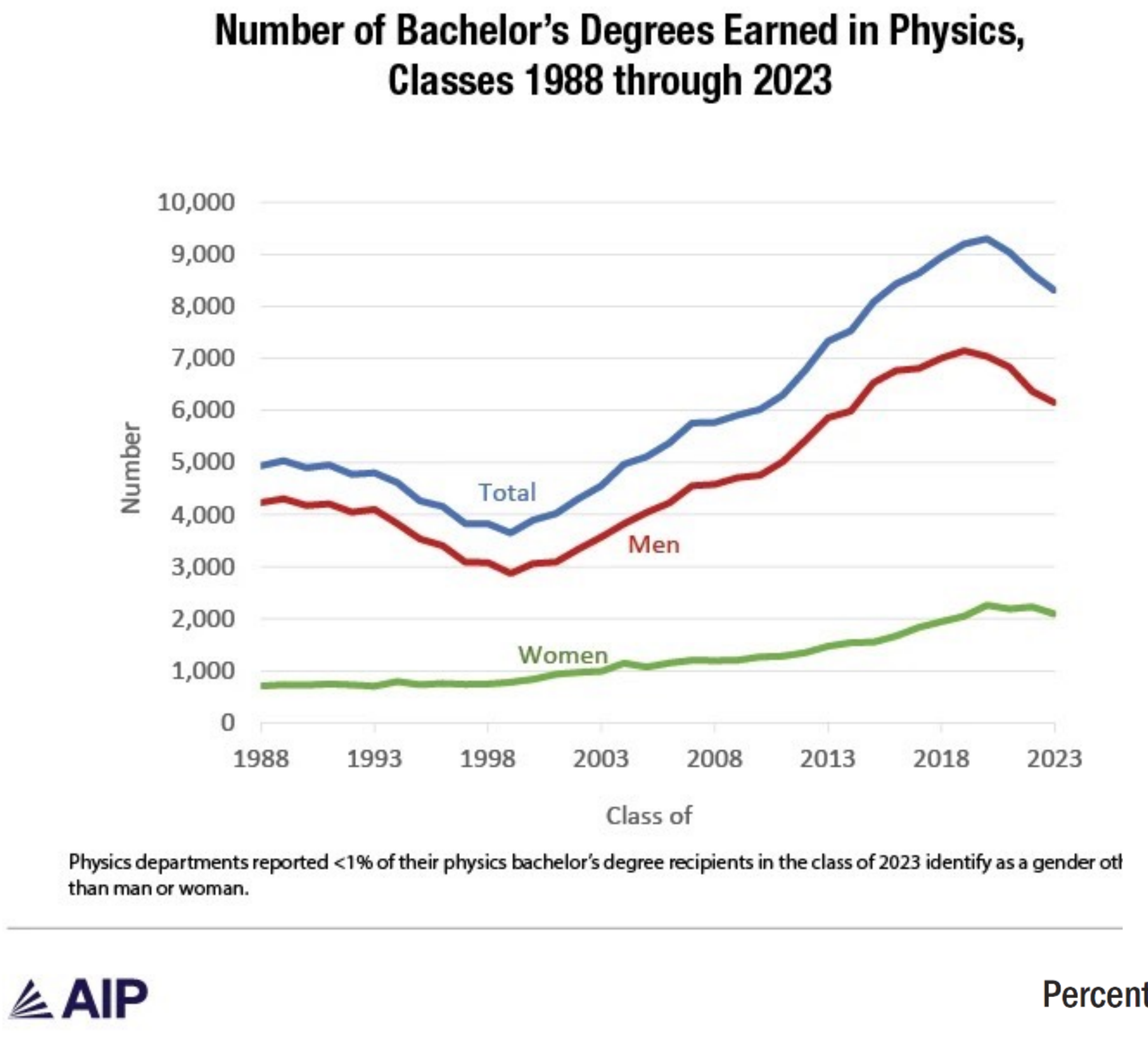
The Research Council of Norway

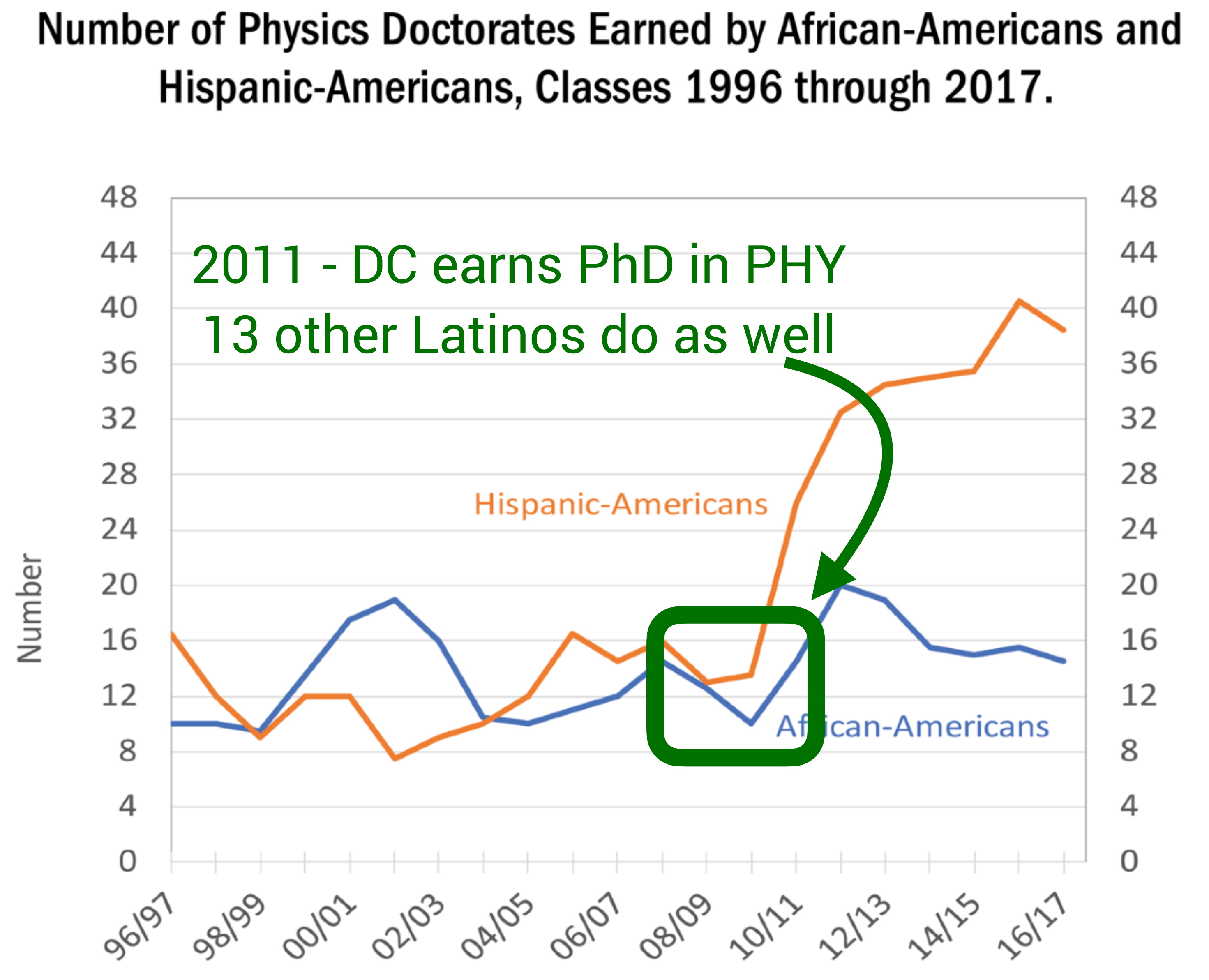
FULBRIGHT NORWAY

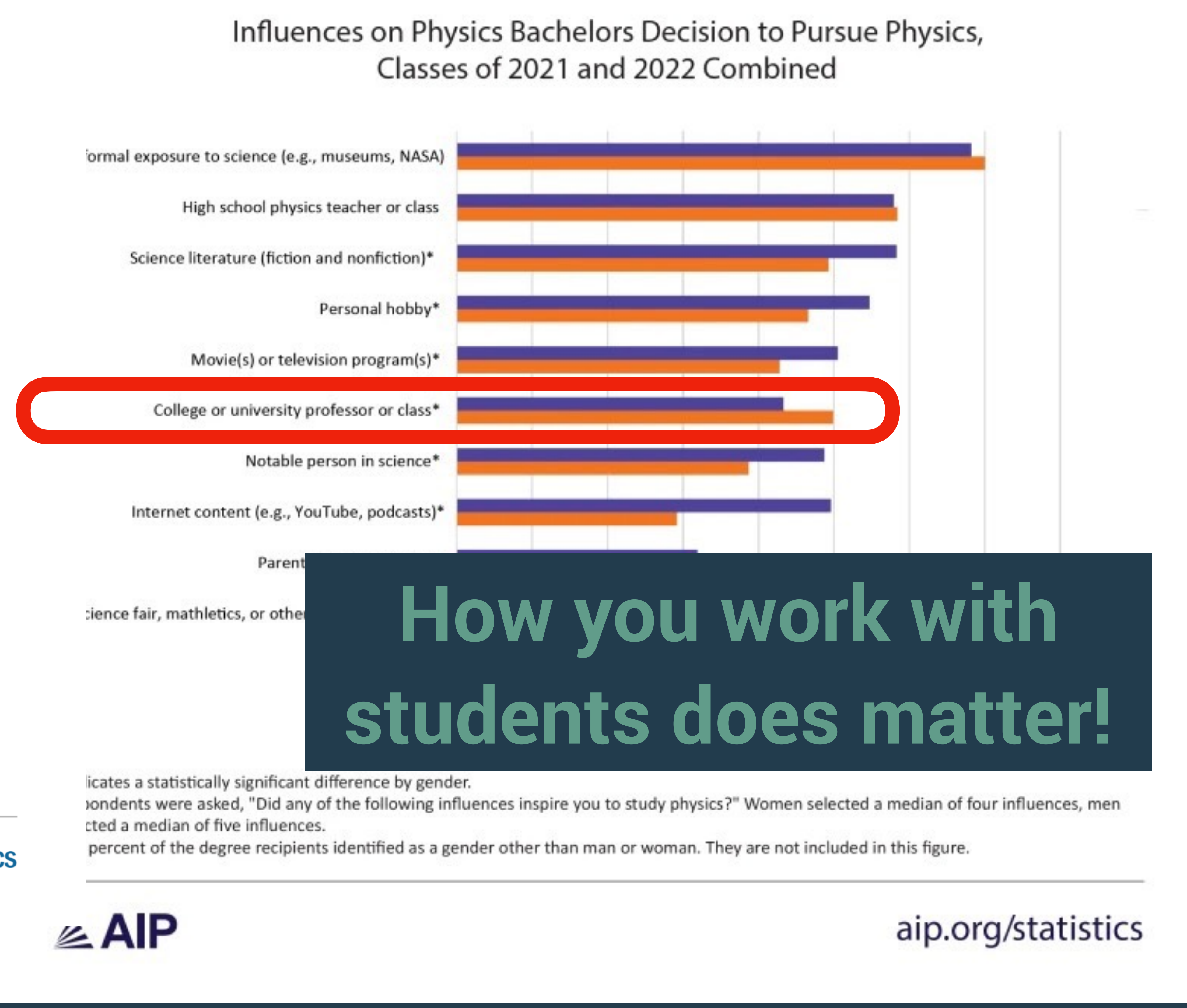


Odden and Zwickl, Journal of the Learning Sciences, 2025

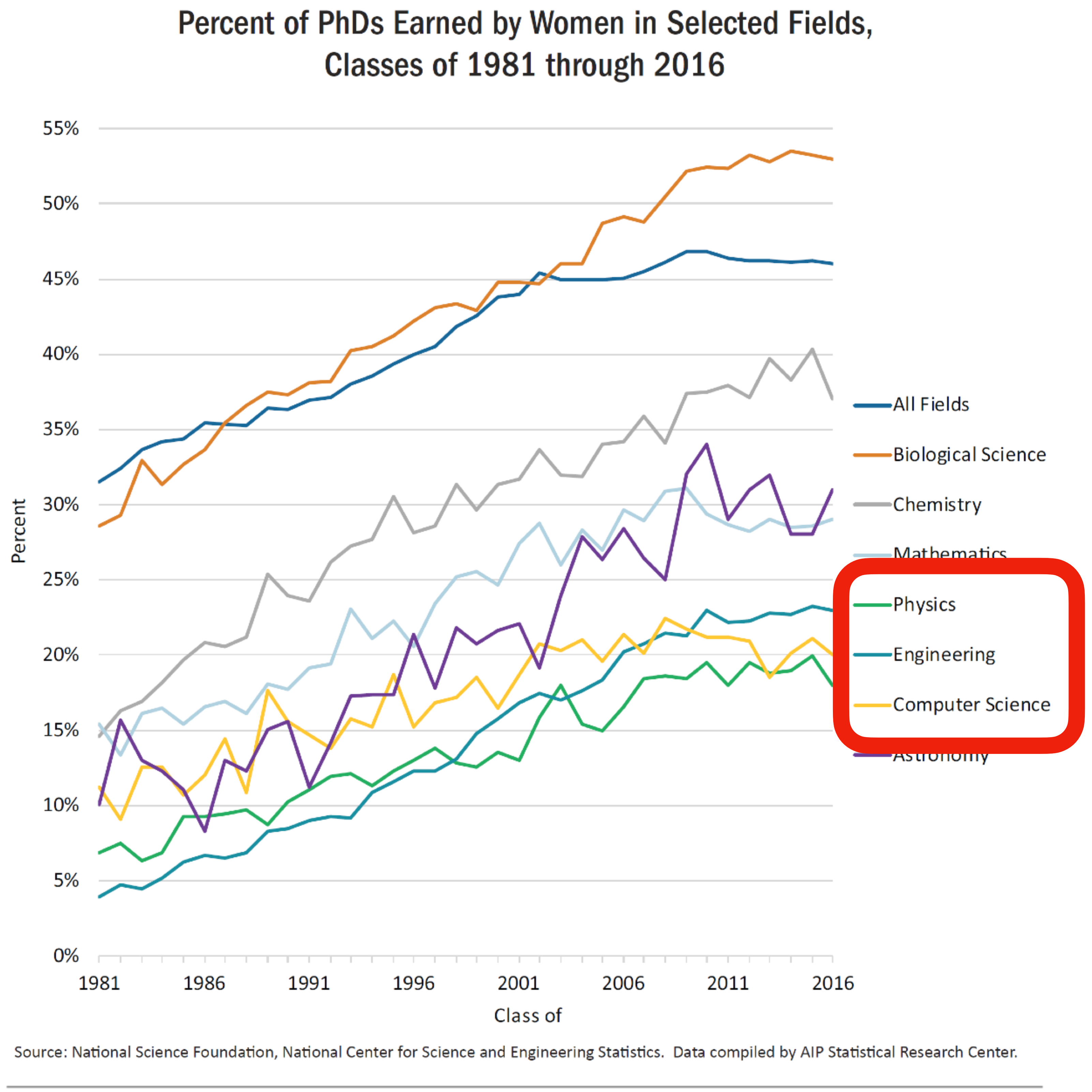
Twelve years have past between this paper and the first.







How you work with students does matter!



aip.org/statistics

Our work does not exist in a vacuum

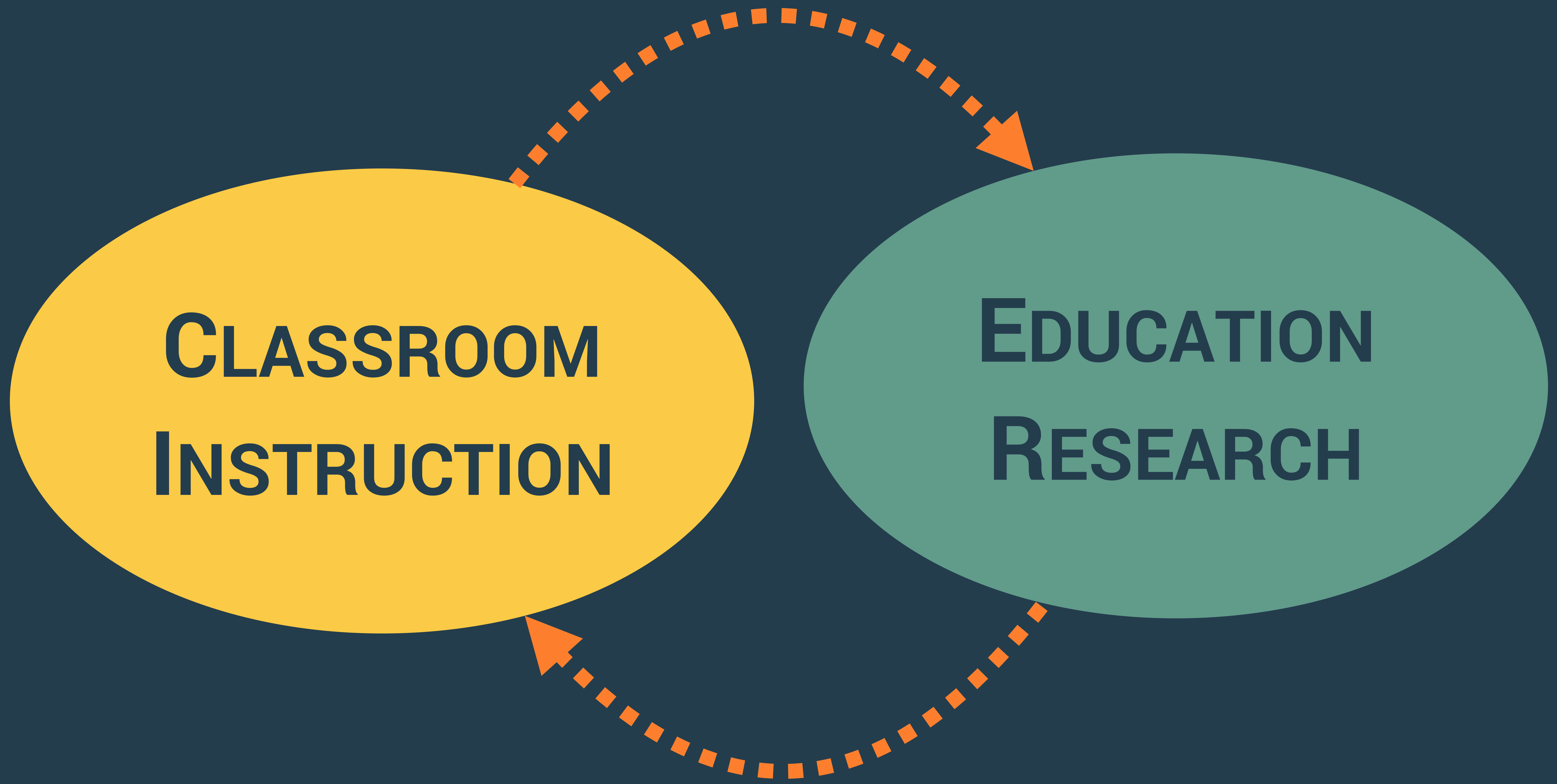
Women, LGBTQIA+, folks of color, the disabled, veterans, first generation students, and folks with these and other intersecting identities have been systematically excluded from physics historically and contemporaneously.

Investigating Physics Computational Literacy

Student Dimension

Investigating Physics Computational Literacy

What can computational instruction look like?


Classroom Instruction
Education Research

Projects and Practices in Physics

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: Geosynchronous Orbit: Part A

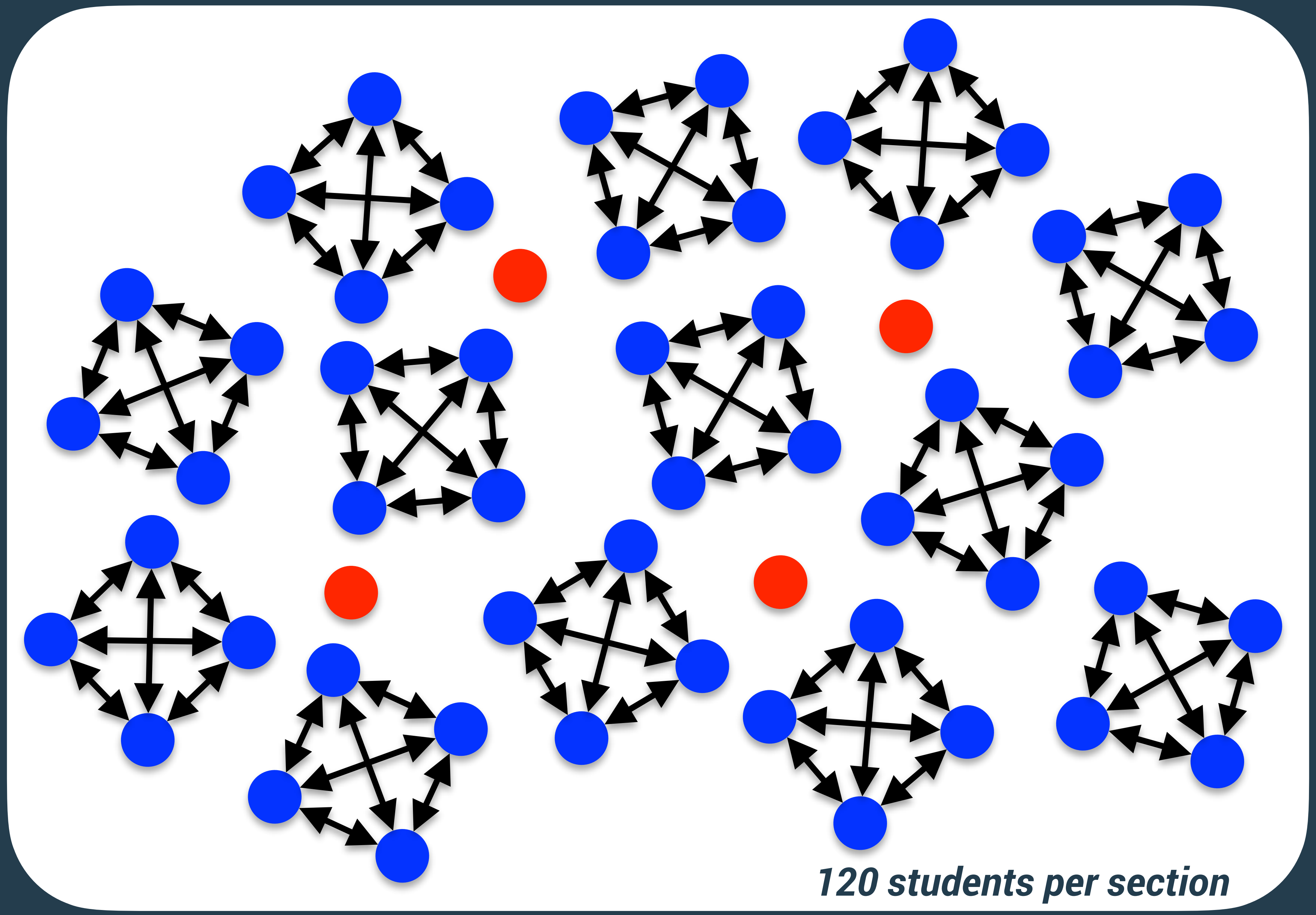
The Carver Media Group is planning the launch of a new communications satellite. Elliot Carver (head of Carver Media Group) is concerned about the launch. This is a $200,000,000 endeavor. In particular, he is worried about the orbital speed necessary to maintain the satellite's geosynchronous orbit (and 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 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 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

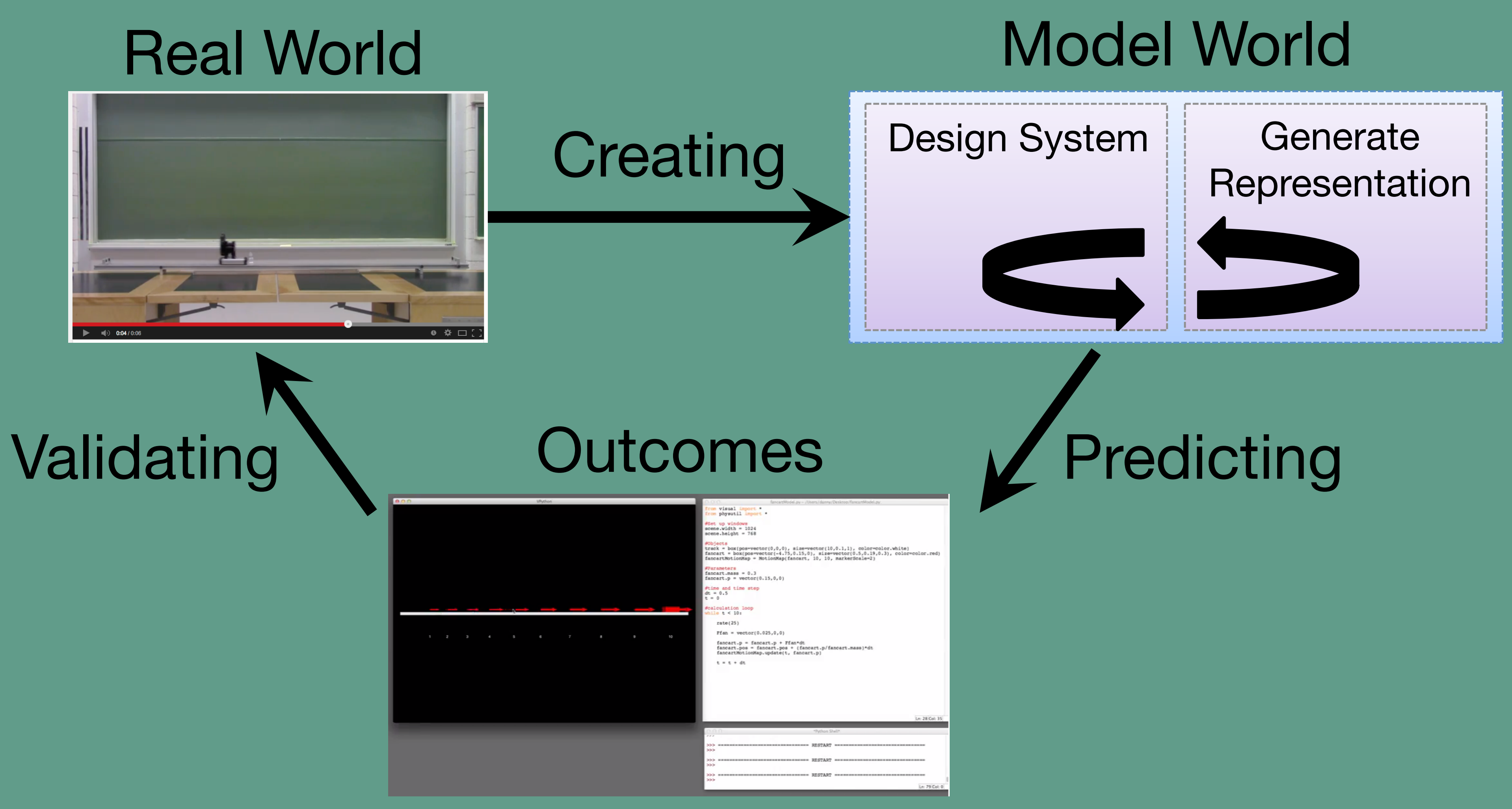


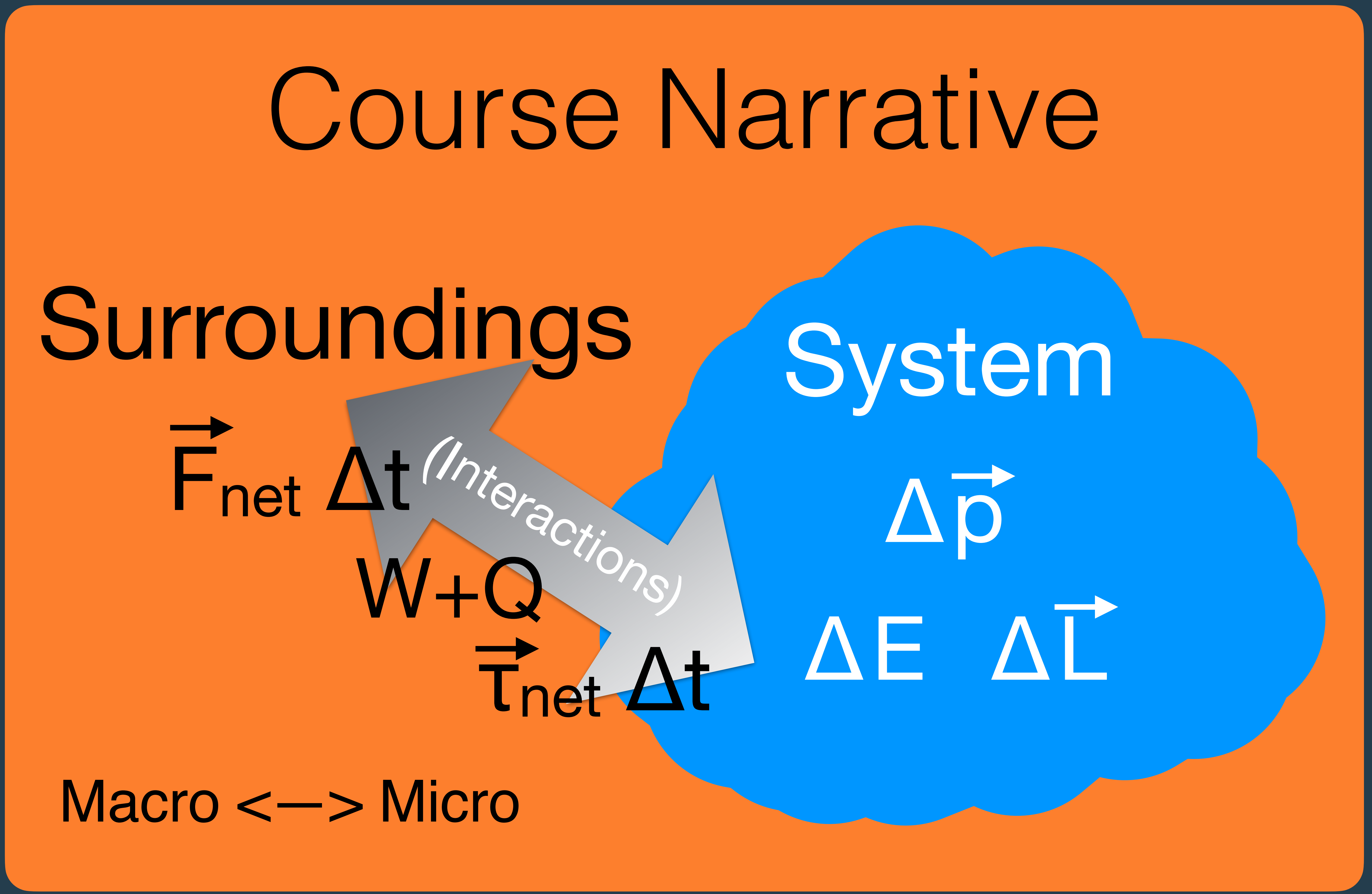
msuperl.org/wikis/pcubed/

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

Projects and Practices in Physics

Modeling cycles





Sample Learning Goals

- Students should be able to **develop computational models** of mechanical systems **using the Euler-Cromer method to predict and explain their motion**.
- Students should be able to **track the energies of mechanical systems over time** and **explain the 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

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

Learning Scaffolds

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

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

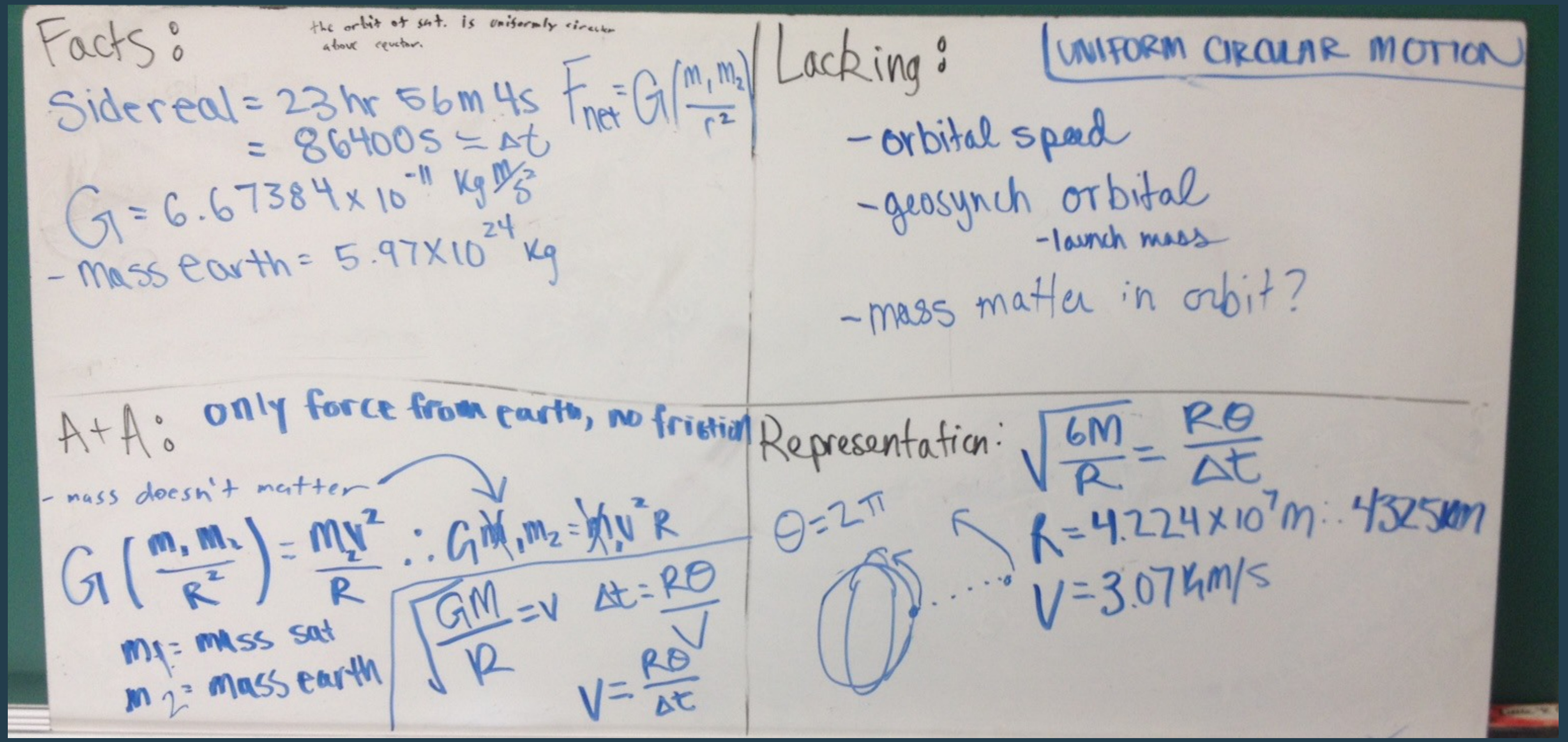
A hydrogen atom contains one electron of mass 9.00×10^{-31}kg and one proton of mass 1.90×10^{-27}kg which are separated by an average distance of 6.20×10^{-11}m. Calculate the magnitude of the gravitational force between the electron and the proton.

$|\vec{F}| = 2.967\times10^{-47}$ **N**

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

Previous Tries

Pre-class HW



4 Quadrants Whiteboard

(facts, lacking, assumptions & approximations, representations)

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

```
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

Weatherford, PhD Thesis, 2011
Weatherford and Lunk, *forthcoming book chapter*, 2025

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…

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

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

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```

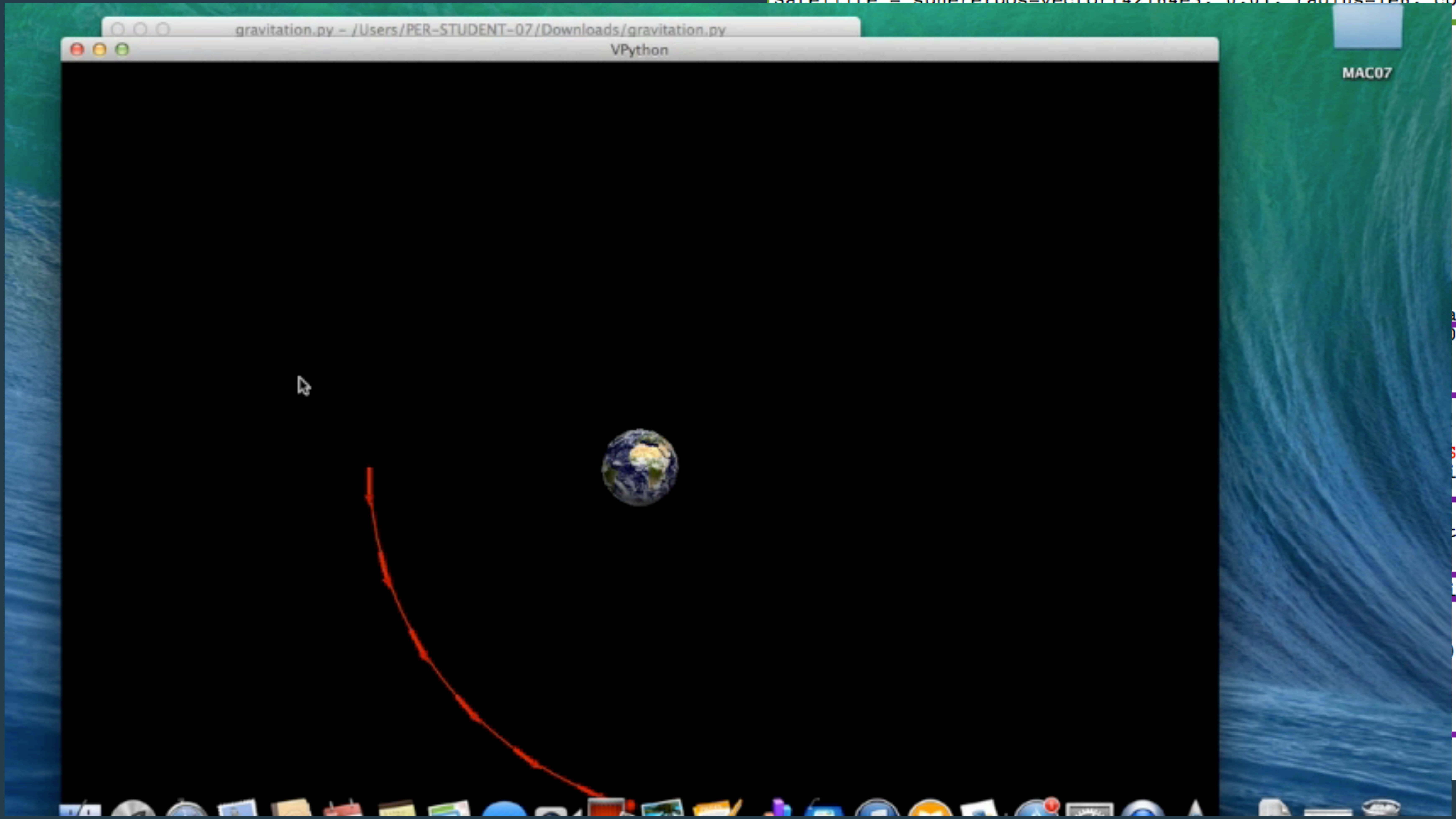


```
ale=2000, labelMarkerOrder=False)
000, labelMarkerOrder=False)

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

ellite.pos)**3)

ite*deltat
```

Note: video is sped up a bit.

Investigating Learning Assistants' Instructional Approaches

```
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Earth = sphere(pos=vector(0,0,0), radius=6.4e6, material=materials.BlueMarble)
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        rate(10000)

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

        SatelliteMotionMap.update(t, pSatellite/mSatellite)

        t = t + deltat
```
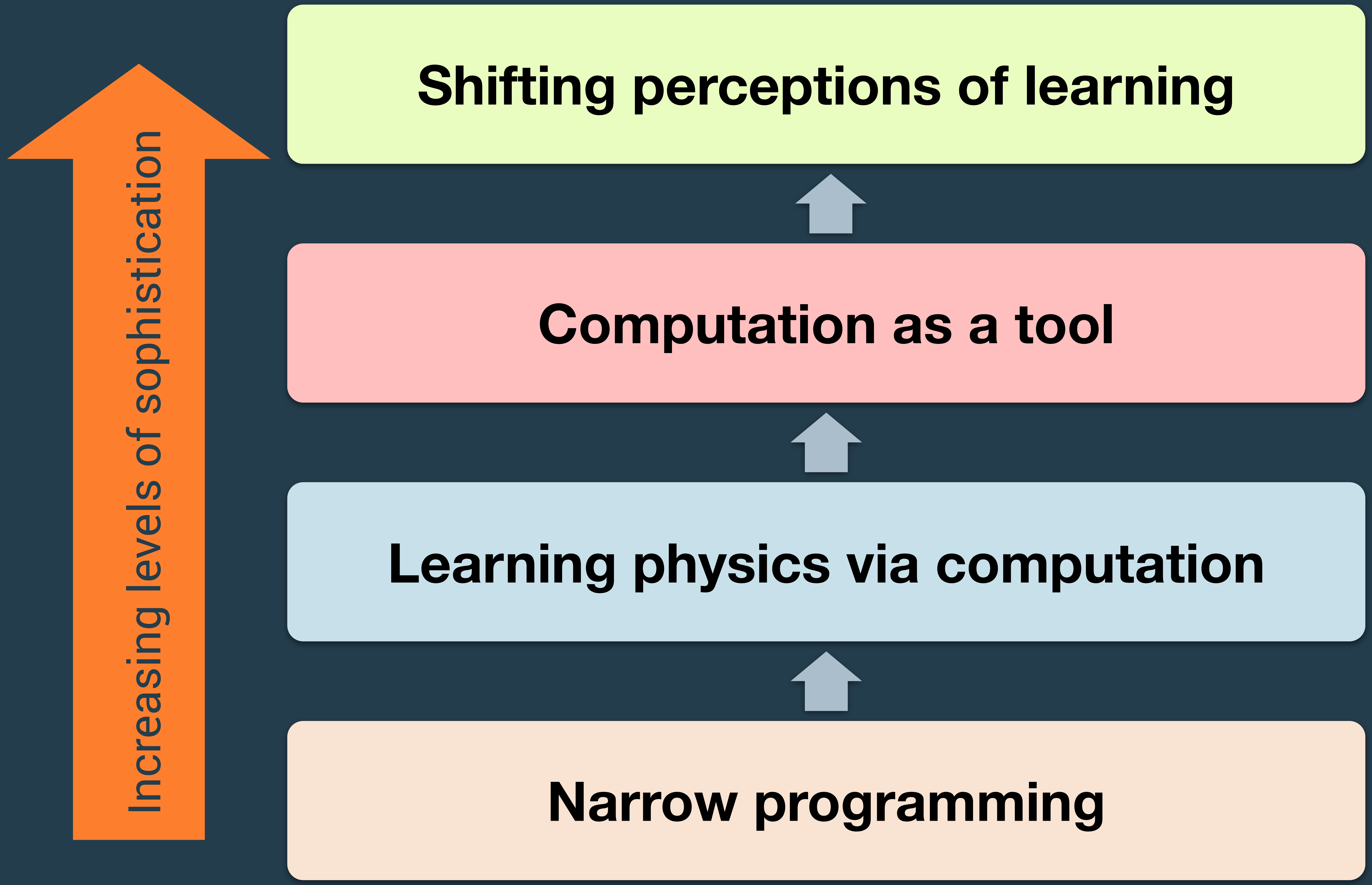

How do learning assistants approach teaching computational problems?

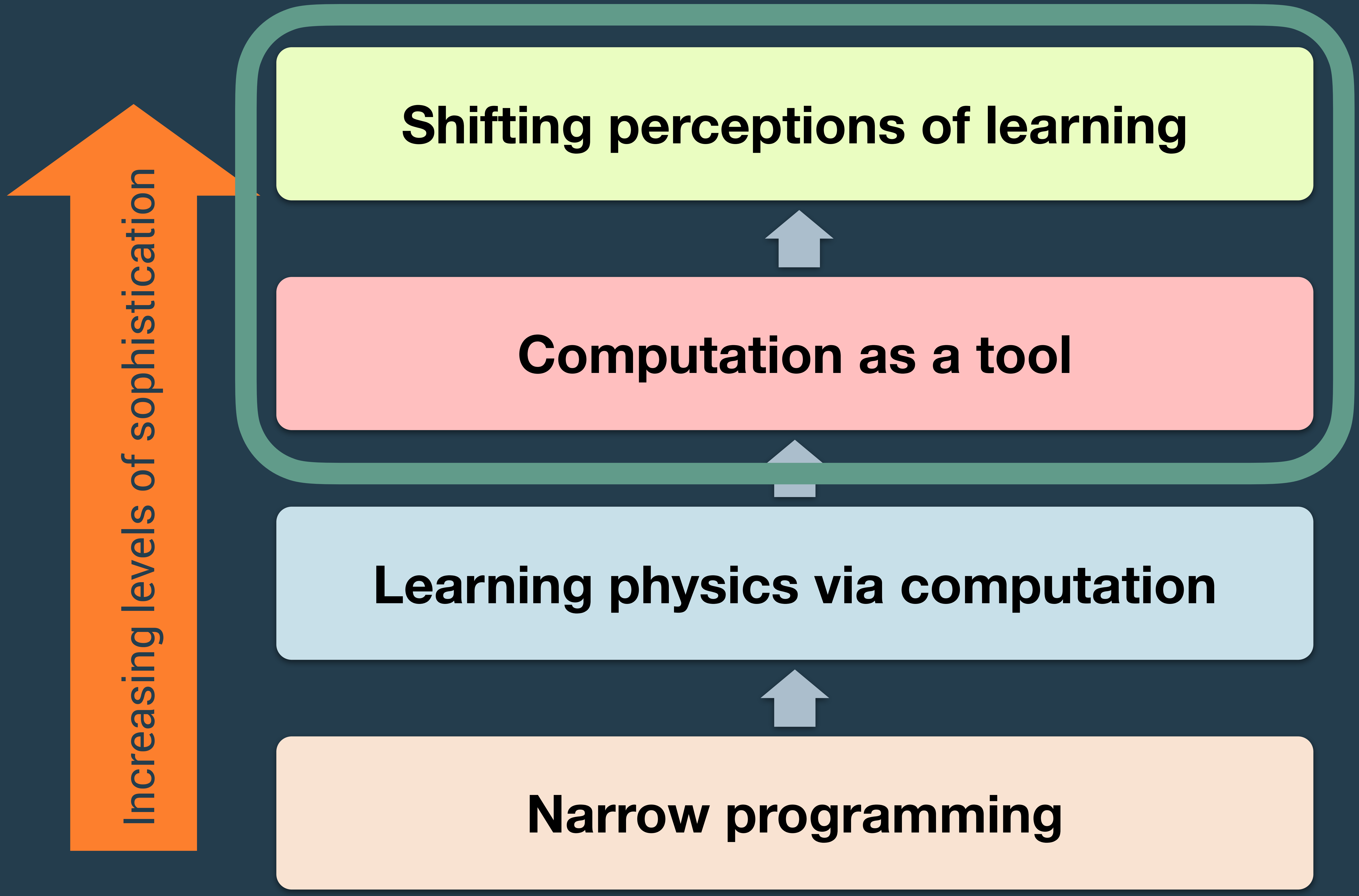
Irving, Obsniuk, & Caballero, EJP (2017)
Pawlak, Irving, & Caballero, Phys. Rev. PER (2020)
Irving, McPadden, & Caballero Phys. Rev. PER (2020)

Outcome space



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

Outcome space



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

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

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

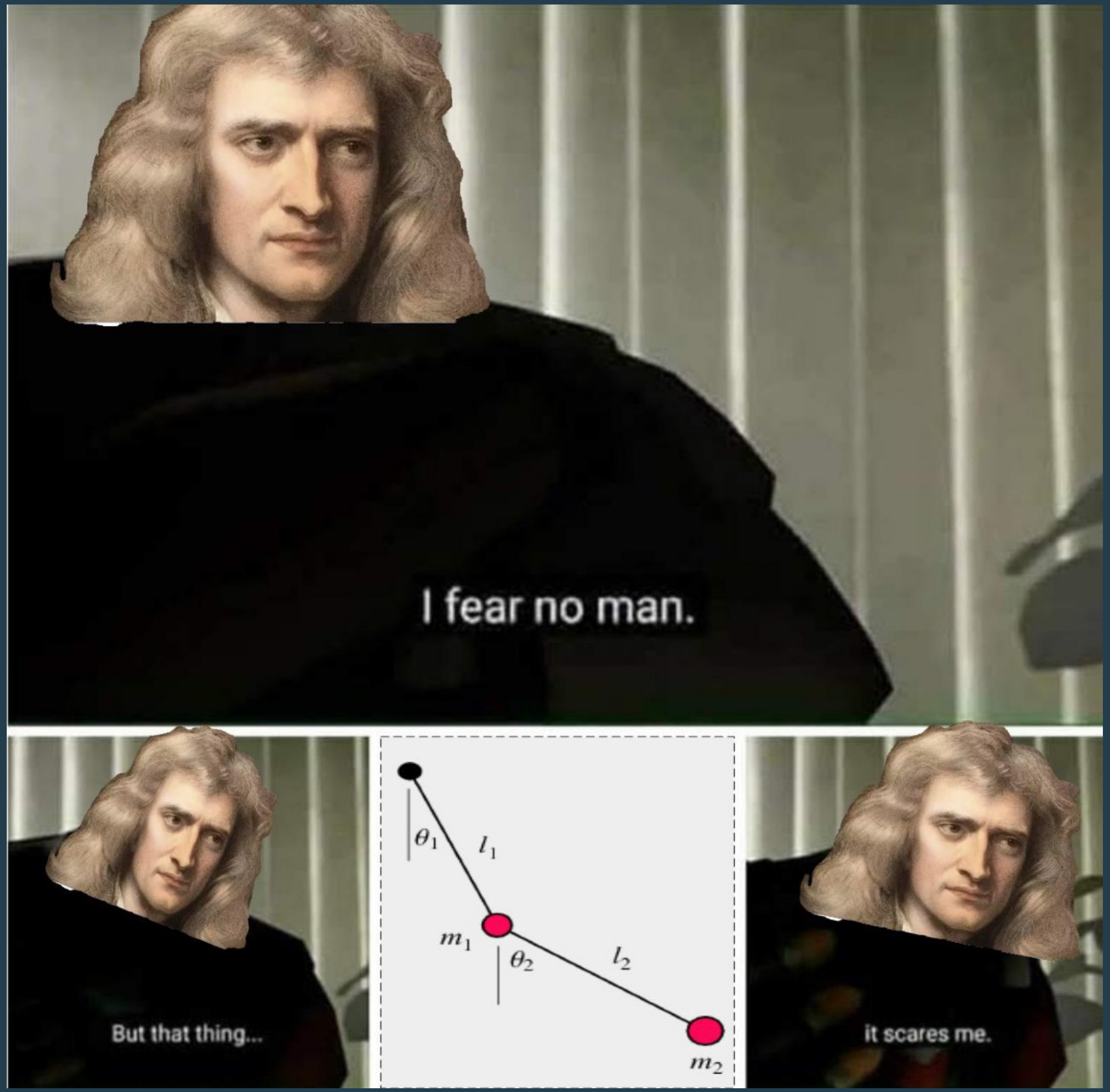
jupyter {book}

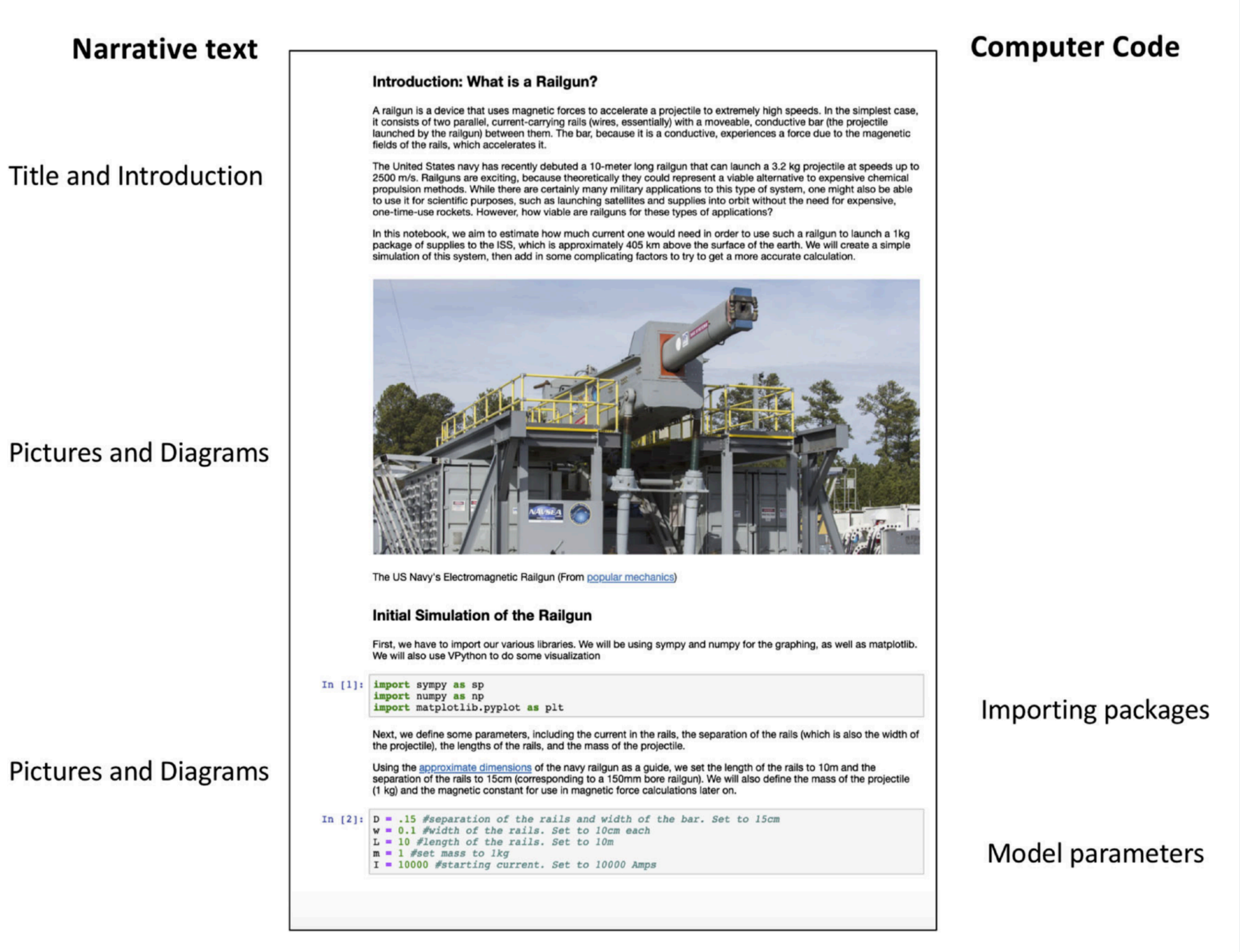
Computational Essays as a form of assessment

First majors course with BFY calculus

Makes use of evidence-based techniques

Emphasizes creativity, exploration, and agency





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 conductive, experiences a force due to the magenetic 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
```


Odden, Lockwood, Caballero. Physical Review Physics Education Research 15.2 (2019): 020152.

Odden, Silvia, Malthe-Sørenssen. Journal of Research in Science Teaching 60.5 (2023): 937-977.

Odden and Caballero. The International Handbook of Physics Education Research: Learning Physics 19 (2023).

With R. Henderson (MSU), M. Hjorth-Jensen (MSU, UiO)

“Textbook”: Interactive JupyterBook

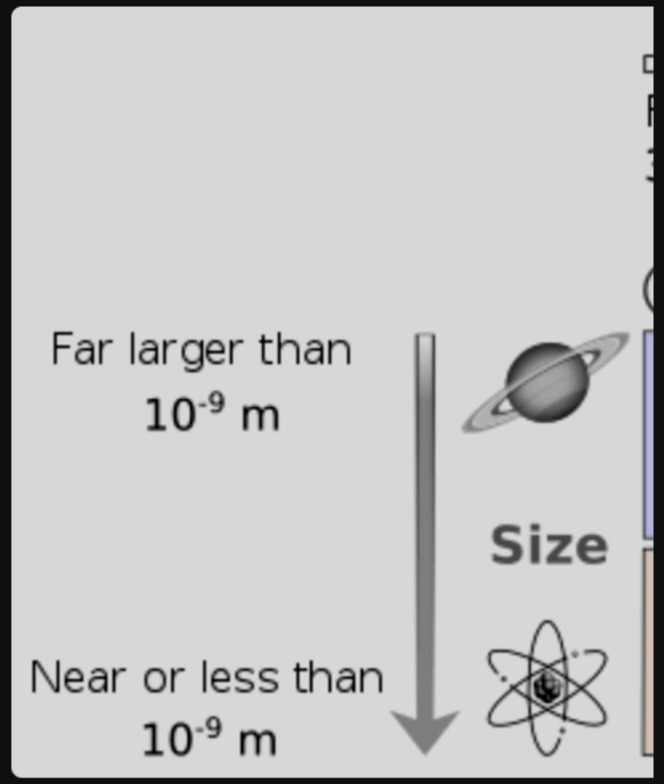
- Derivations & Examples
- Code & Resources
- Videos & Links

Week 1 - Overture: What is Classical Physics?

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

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

These are not hard and fast rules,
complex problems. For examples,
particle physics use physical mod
ourselves depends on how we de
field by size and speed is a useful
thus far. The figure below shows



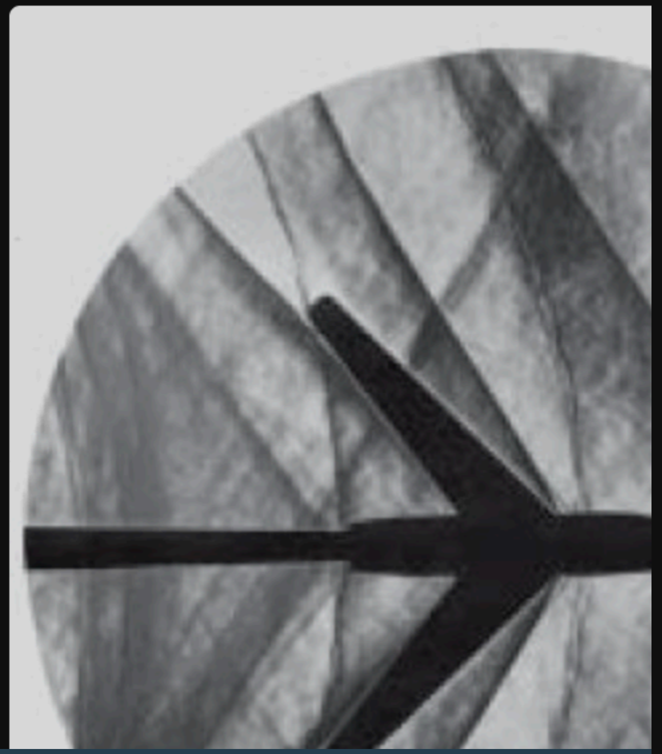
Source: *Wikipedia*

Week 4 - Why does fluid drag complicate things?

As an object moves through the f
This collision changes the momer
but the average effect of all those
of the object's velocity, $F(v)$. In s
times they might approach the ob
behaviors are both fluid drag, but

The first form ($F \sim v^2$) describes
baseball thrown through the air. E
moving through the ocean. Throu
forces, which can result in damag
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

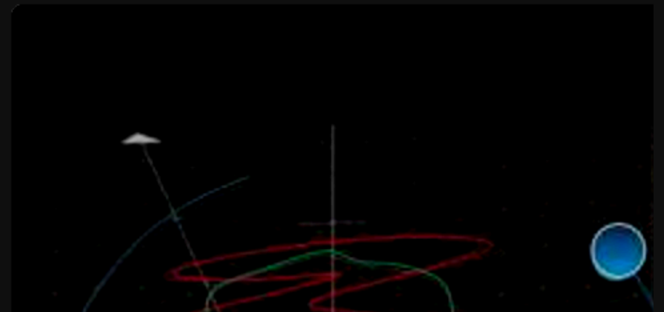
We have now built enough tools to tackle some challenging physical systems that have nonlinear equations
of motion. The broader field of st
dynamics or nonlinear science is
systems are often chaotic, meani
systems are treated using dynam

Nonlinear dynamics is the science
crystals and other optical system
in fluid dynamics, plasma physics
with nonlinear dynamics and is a
where the Hamiltonian is nonlinea
chaotic systems.

Nonlinear Differe

Differential equations are the lang
investigate evolve over time. They
For us, this is often the position c
gives a good overview of what dif
provides an introduction to the cc
variables of the system.

Differential equatio



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
measurements can lead to vastly
feedback loops, making them ver
mathematical tools we bring to be
simulate and understand the beh

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

Characteristics

Chaotic systems exhibit several k
systems

Sensitive Depende

One of the hallmark features of ch
differences in the starting state o
cases this means that we cannot
make accurate short-term predic
flapping its wings in Brazil can ca

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. However, the problem with Newton is that it requires a few things:

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 $\sum_i \vec{F}_i = \vec{F}_{net}$.

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.

https://dannycaballero.info/phy321msu/

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.

Math-Physics connection - explain derivation

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.

Math-Physics connection - explain motion

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.

Math-Physics connection - explain principle

7 / 10

60-100 students take PHY 321 each semester

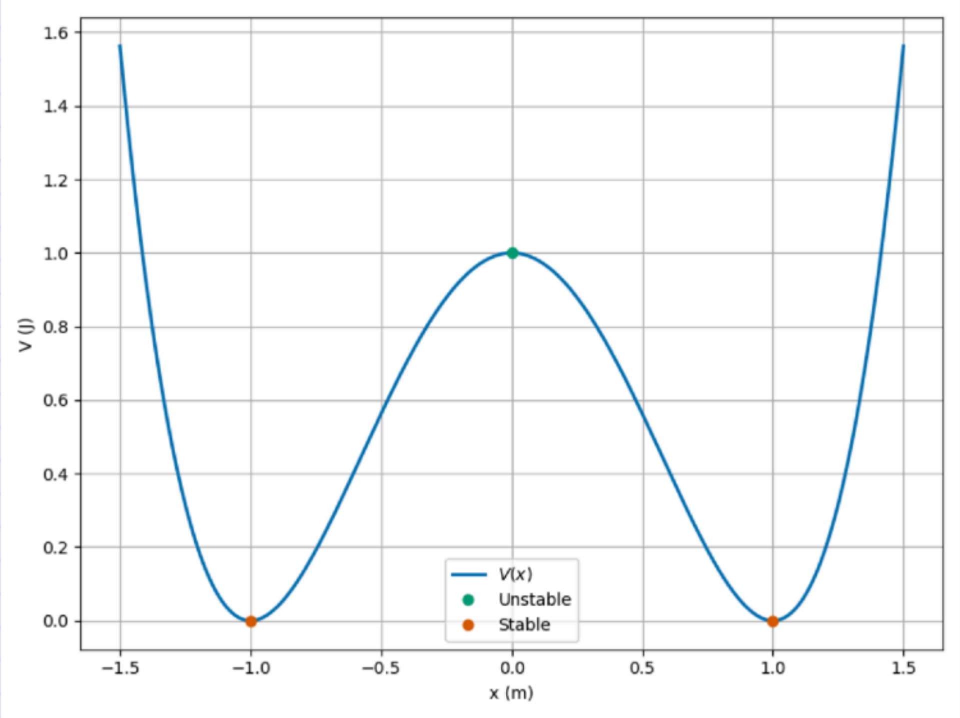
Group Activities

Clicker Question 15-5

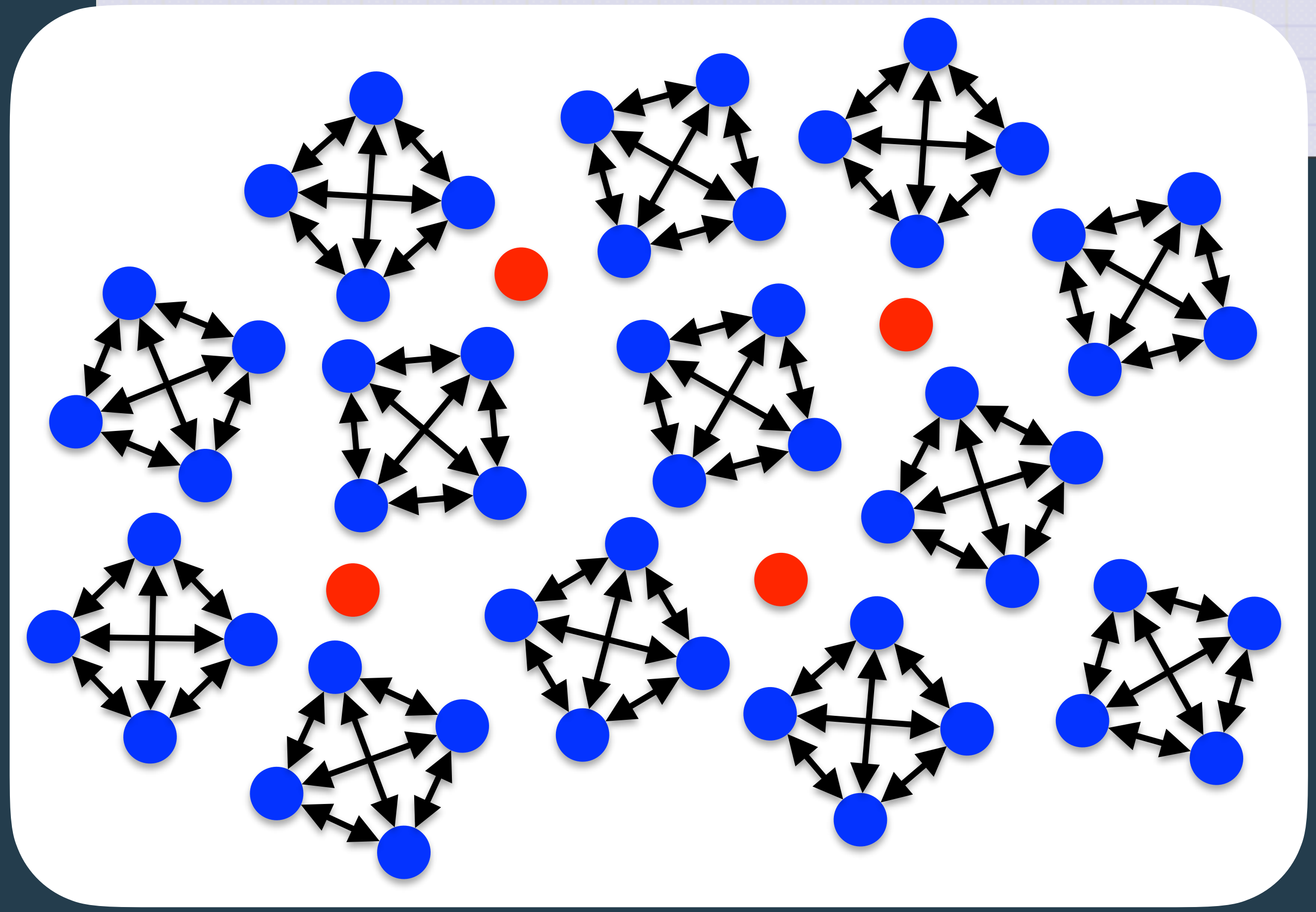
Here's a graph of the potential energy function $U(x)$ for a double-well potential.

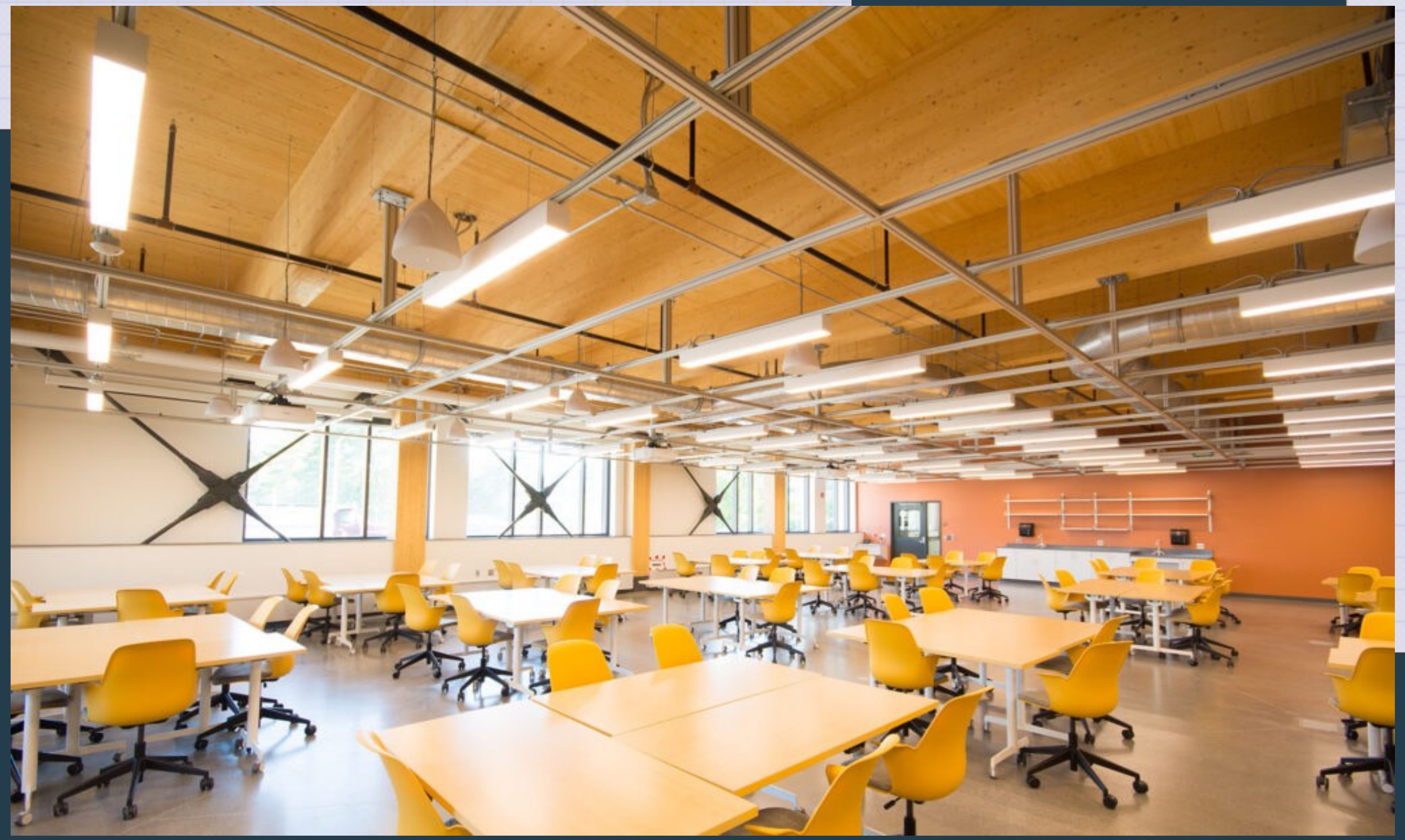
Describe the motion of a particle with the total energy, $E =$

1. $0.4\,\mathrm{J}$, $<$ barrier height
2. $1.2\,\mathrm{J}$, $>$ barrier height
3. $1.0\,\mathrm{J}$, $=$ 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:

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

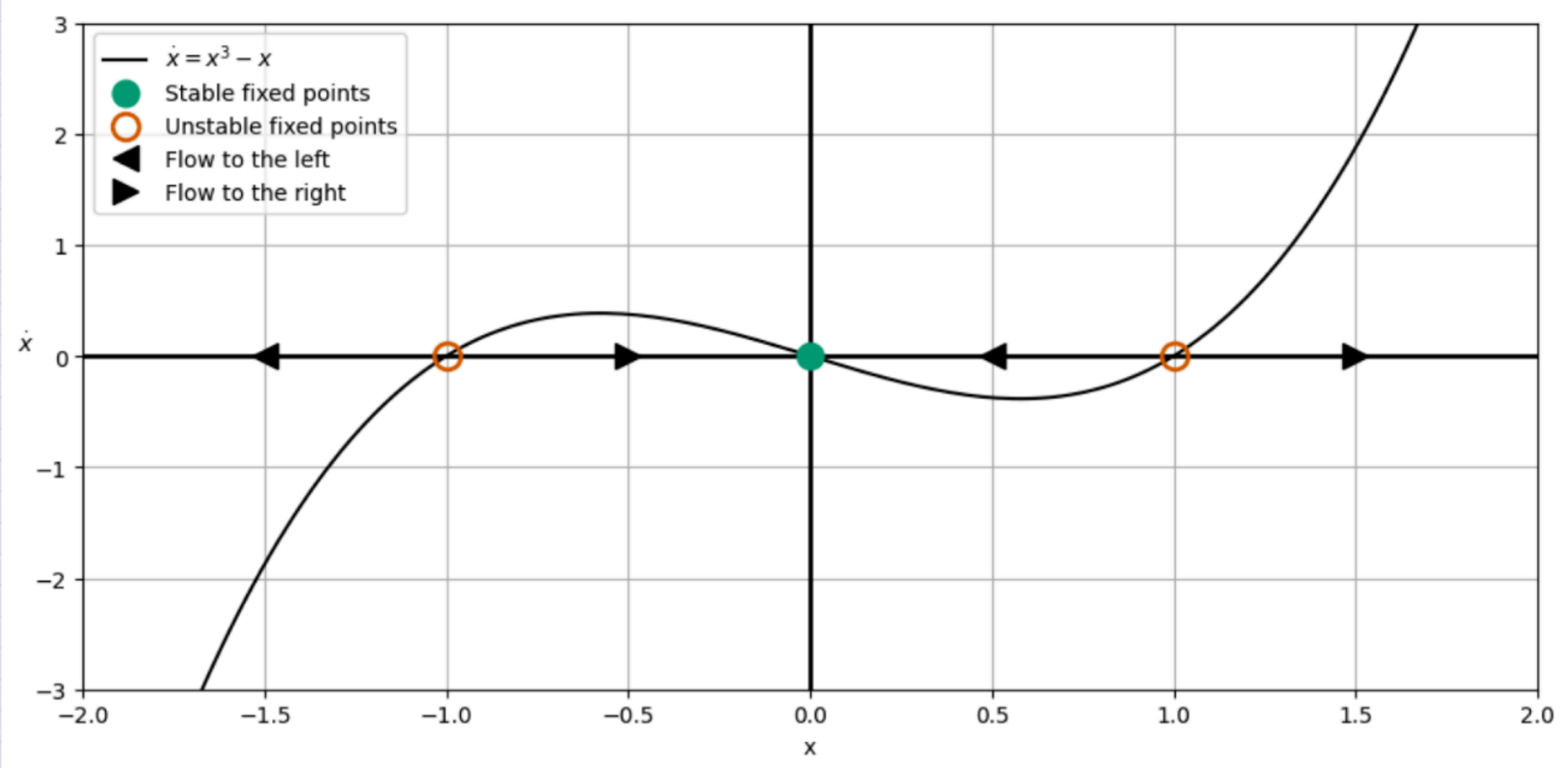
That yields the following solution (🤢🤢🤢):

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

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.

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



Representations of math and physics

Midterms help develop agency

Same Tasks
Student selected system

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.

1. (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-Sørenssen chapter 11.3) and mark the equilibrium points on the diagram and characterize their stability. The position of the particle is x.
2. (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.
3. (5pt) If the particle starts at rest at $x = 2d$, what is the velocity of the particle at the point $x = d$?
4. (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 $x = -d$?

Part 2, model your own system (50 points)

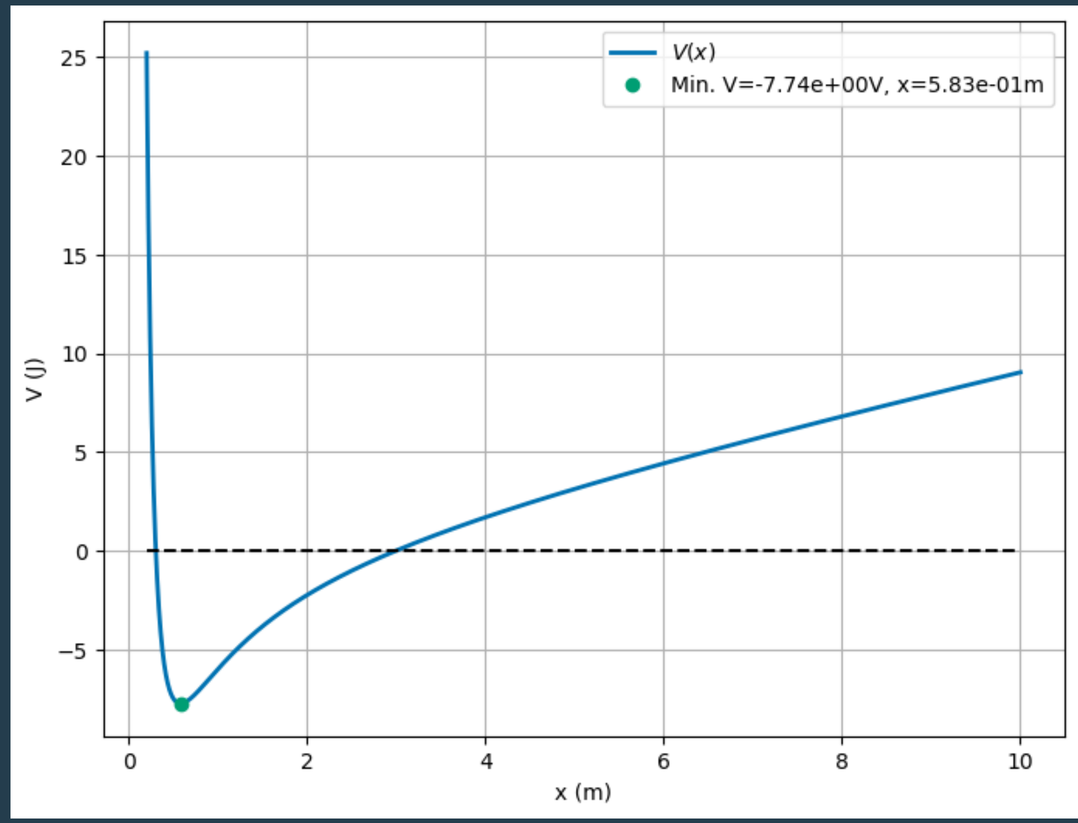
In this problem, you will choose a one dimensional system of your own. You may choose a known potential, or you may invent your own. Your potential must:

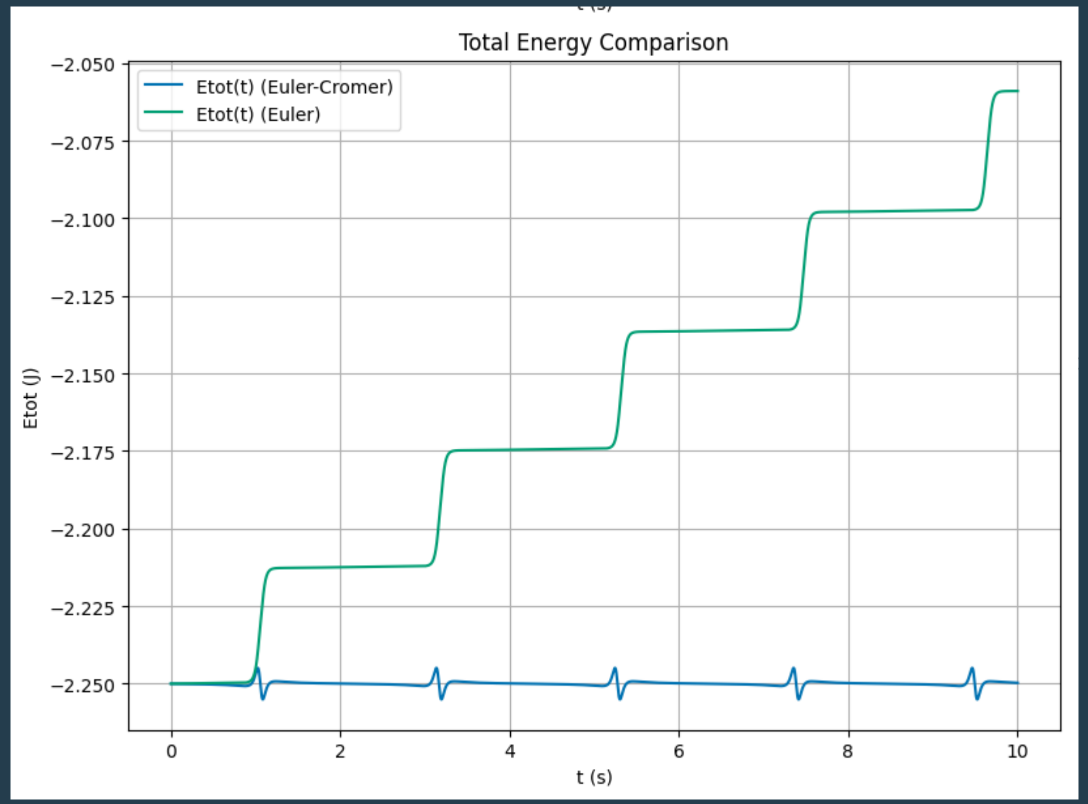
1. Have at least one stable equilibrium point.
2. Have at least one unstable equilibrium point, or some other interesting feature (e.g., asymptotic behavior).
3. For some choice of total energy, it should have oscillatory motion (i.e., classical turning points).
4. Produce a non-linear and conservative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

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

1. (5pts) Write down the potential and start to demonstrate that it meets the above criteria. **Make sure it is con… vative and that the force is nonlinear before proceeding.**
2. …h or plot the potential and find the equilibrium points. You need to show you can compute the …ium points and characterize their stability. For some choices of potential, you may need to use … umerical method to find the equilibrium points and conceptual arguments to determine their stability.
3. (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?
4. (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.**
5. (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:

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

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

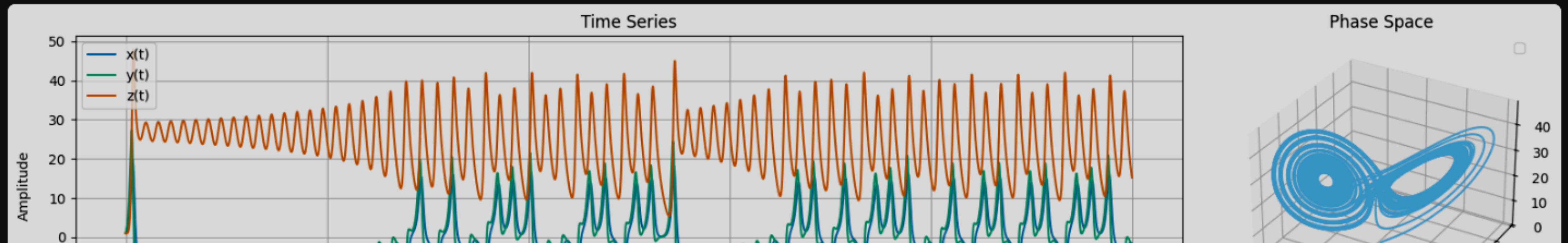
$$\frac{dz}{dt} = xy - \beta z$$

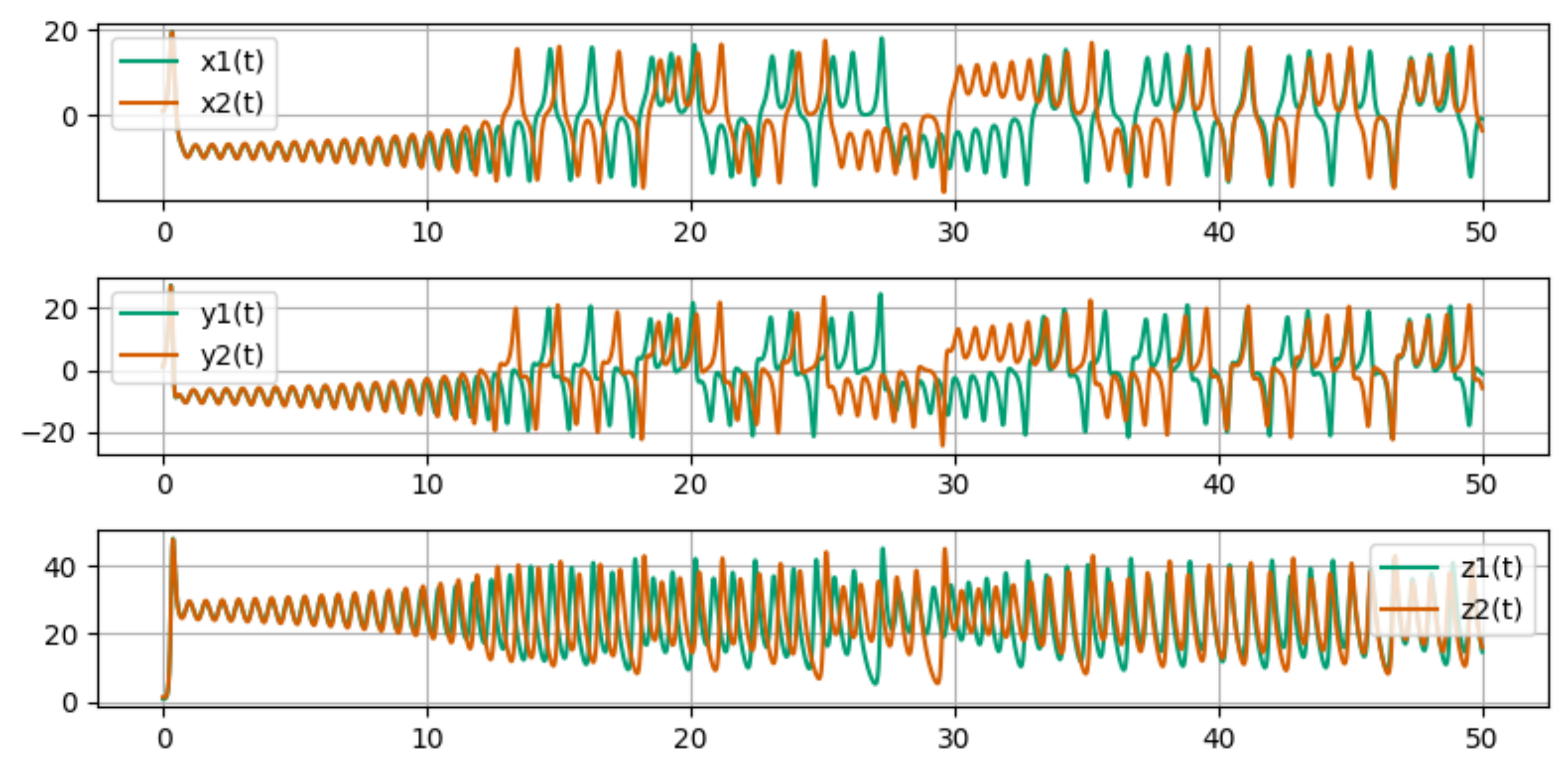
Where σ, ρ, and β are system parameters. The canonical values are $\sigma = 10$, $\rho = 28$

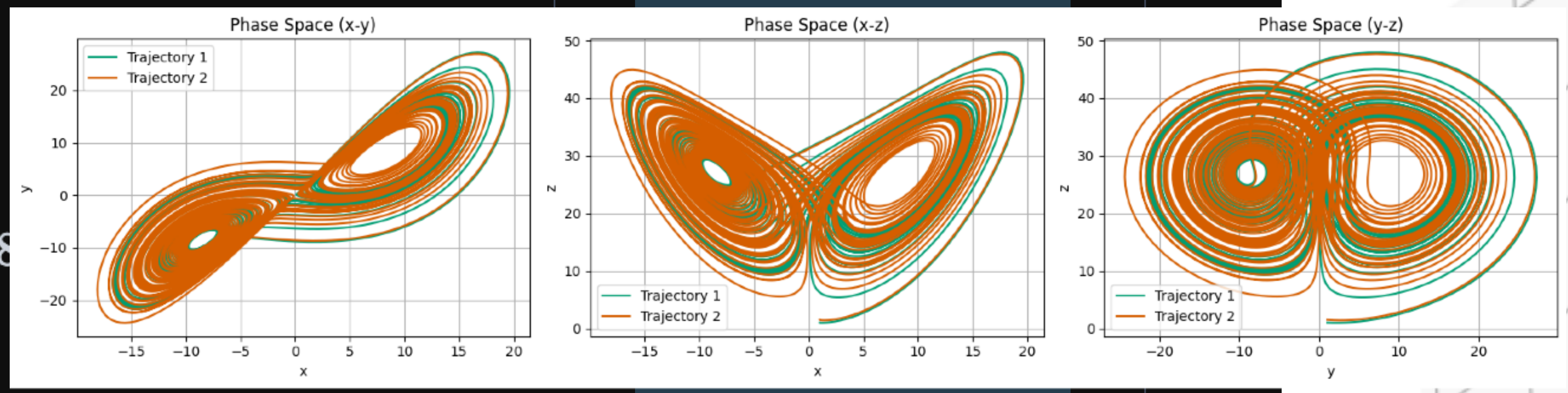
📝 Numerically Integrate the Lorenz Attractor

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.



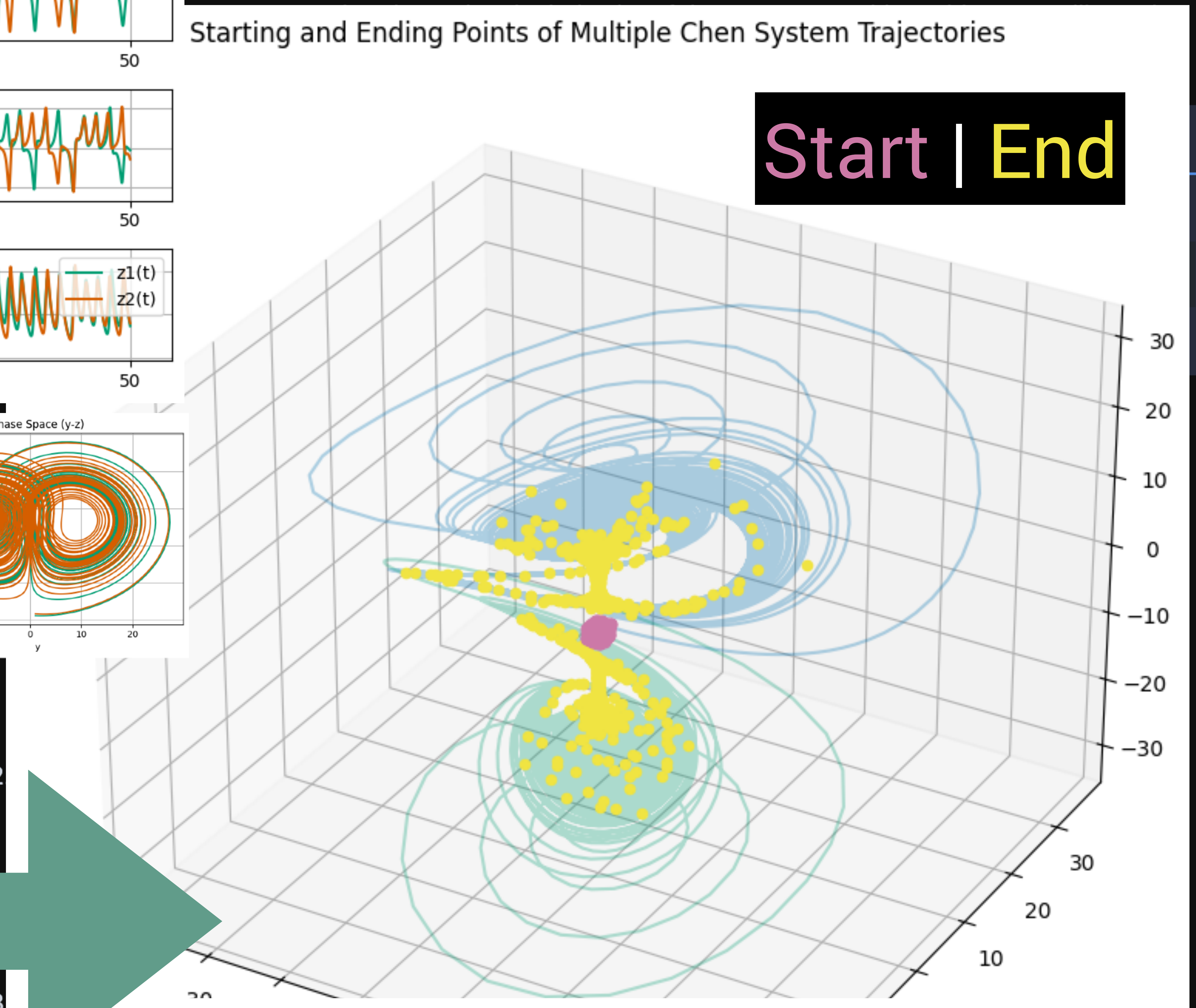




Part 2, Strange Attractor (40pt)

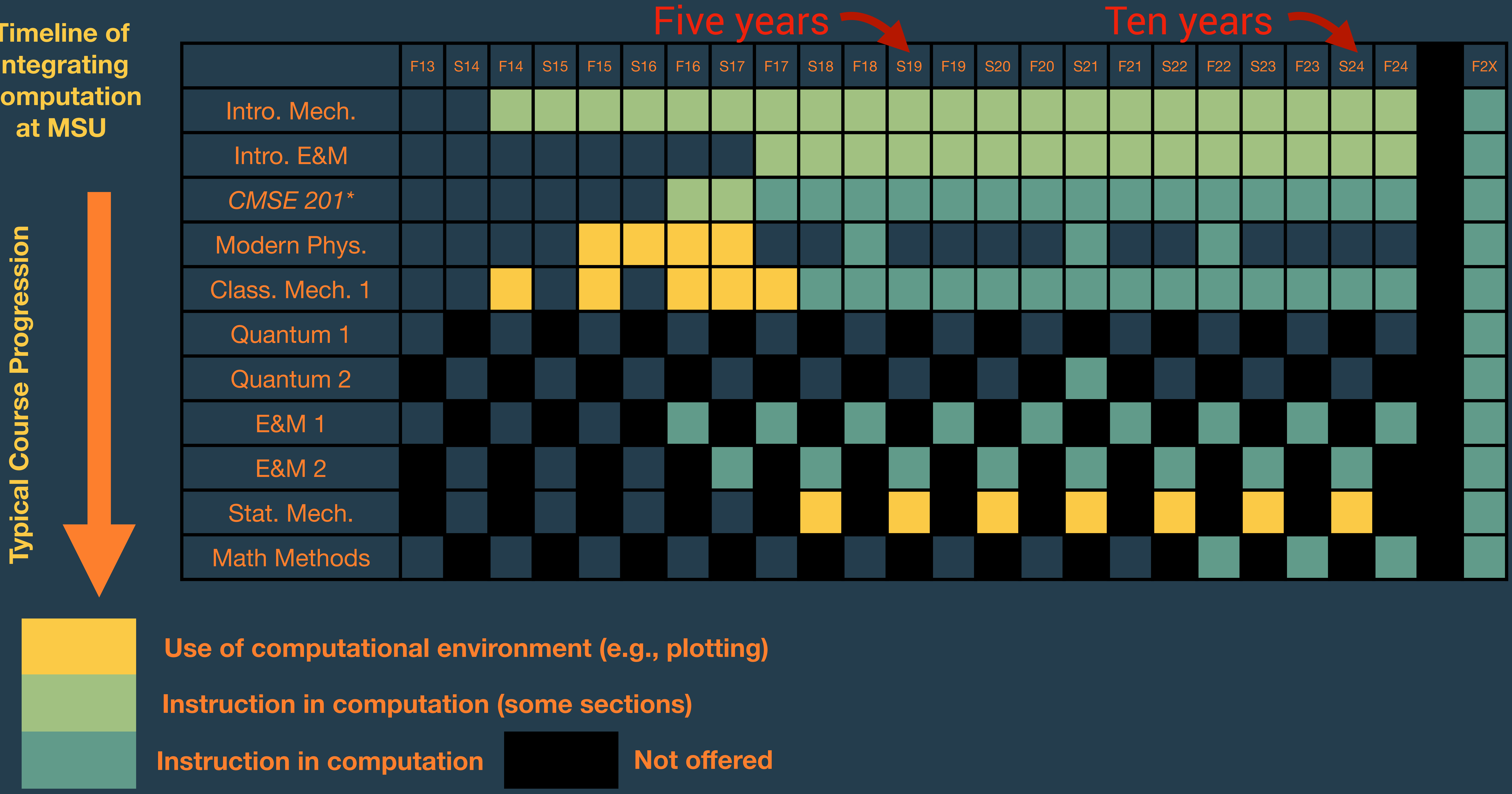
We learned about Strange Attractors when modeling the Lorenz system in class. In this part of the exam, we will explore the Chen system, which is another example of a system that exhibits chaotic behavior and has a strange attractor. The Chen system is given by the following set of ordinary differential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

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



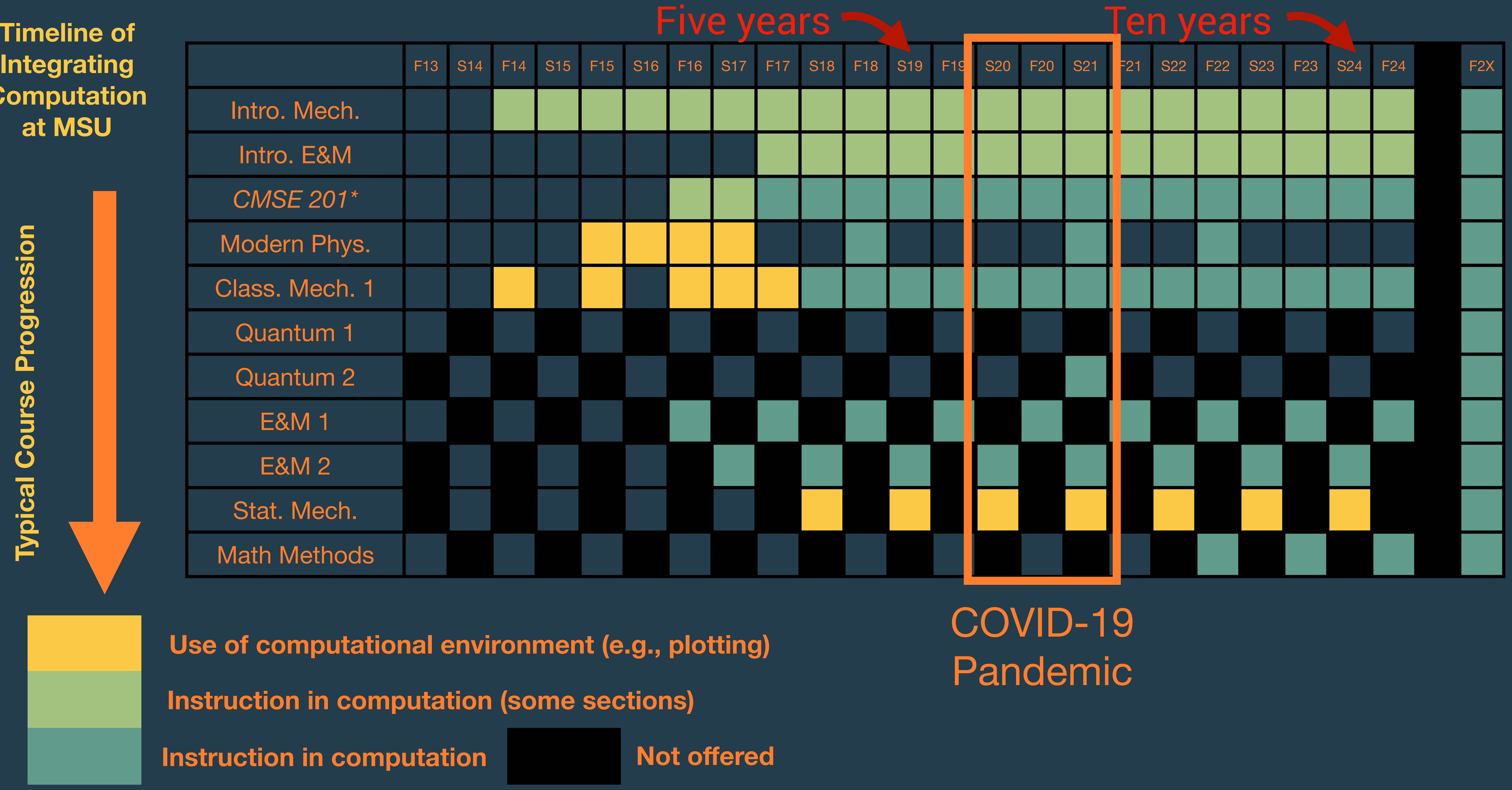
Student's illustration of initial condition sensitivity

Timeline of Integrating Computation at MSU



We are 11 years into a five year plan. 😅

Timeline of Integrating Computation at MSU



We are 11 years into a five year plan. 😅

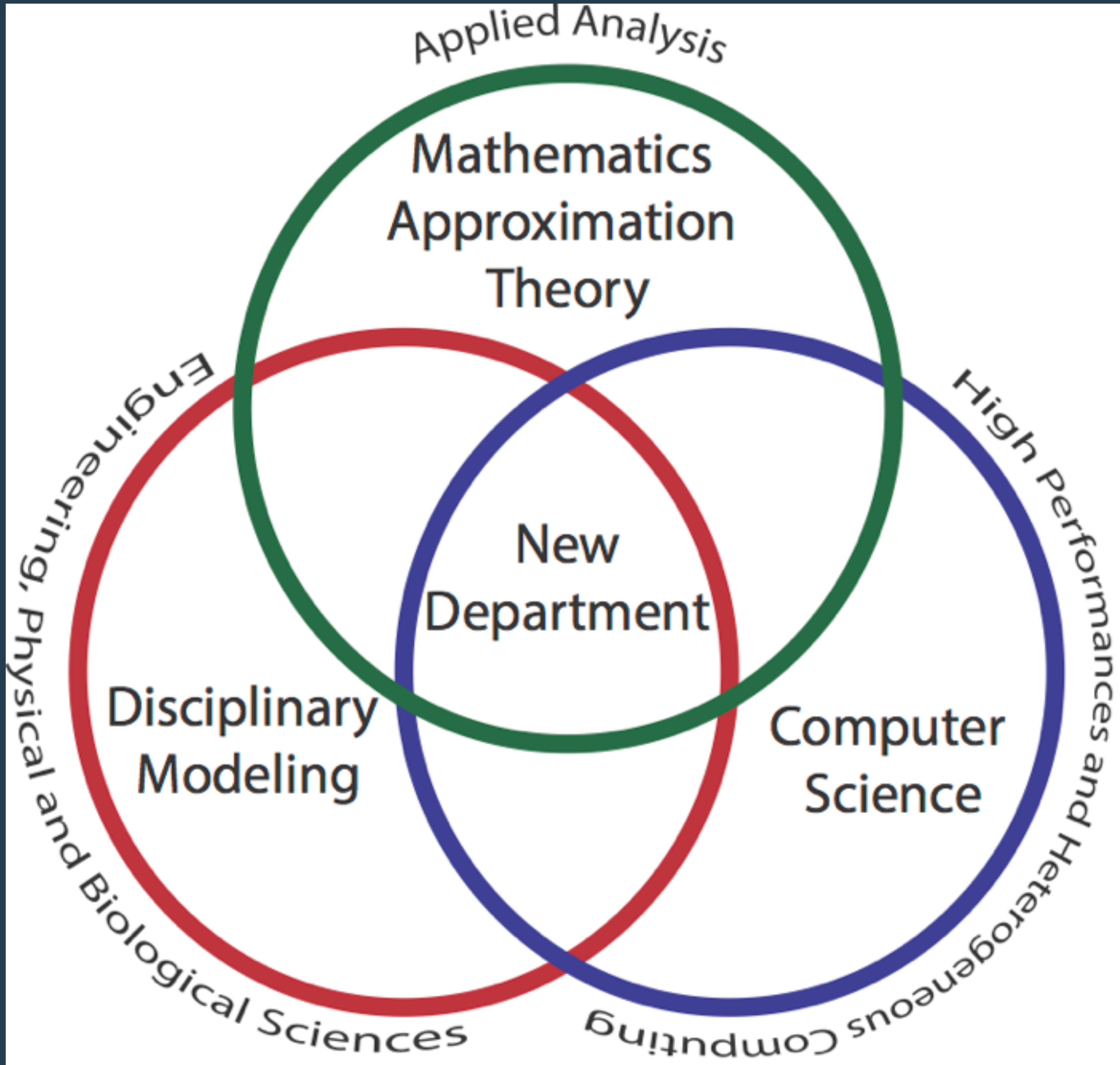
External support can help accelerate the process of integration.

Computational and data 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

cmse.msu.edu



We teach computational and data science

CMSE

From the articles:

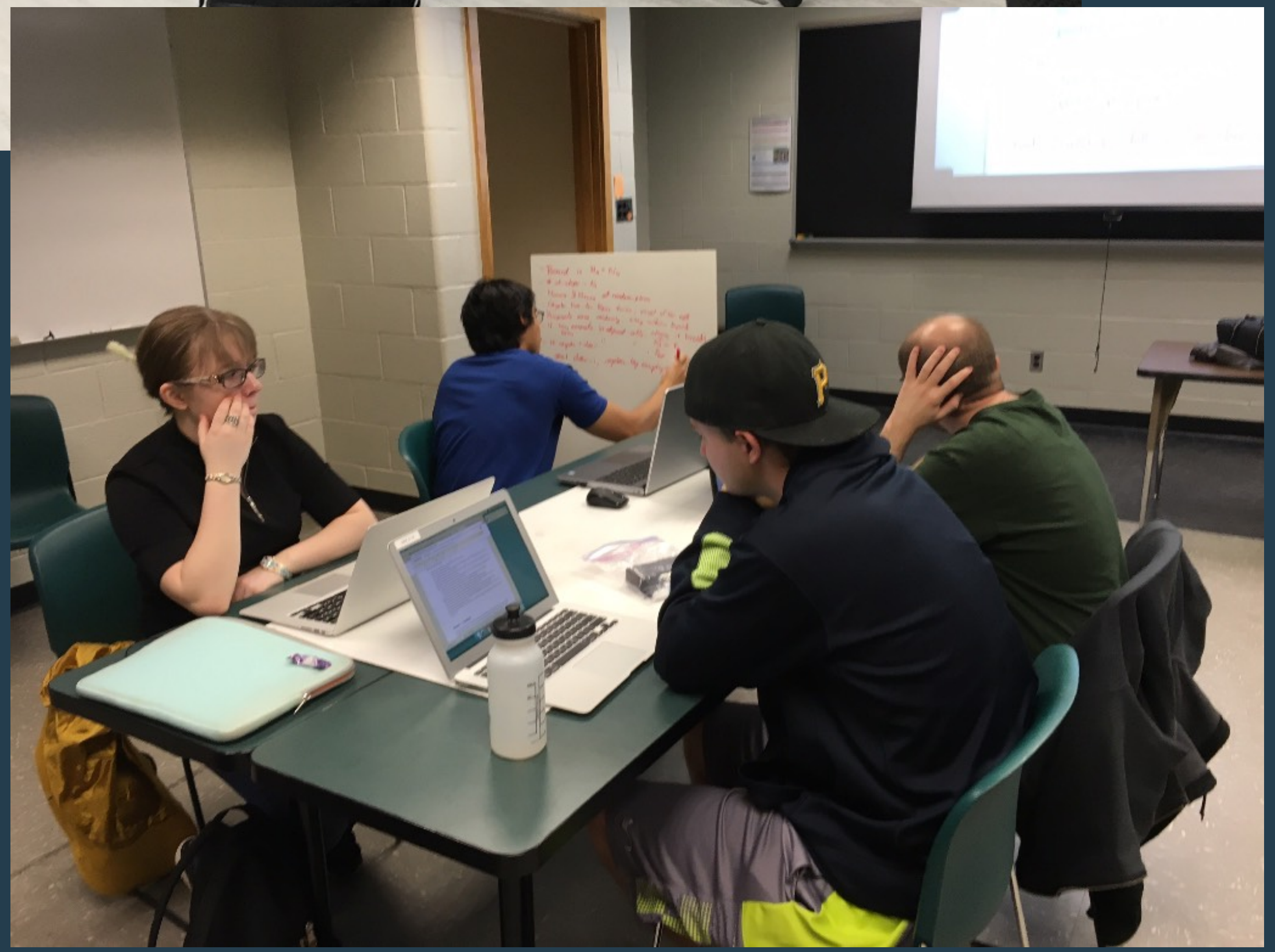
Summarize the main points of the article you read. You had your choice of three linked on D2L (around 250-500 words).

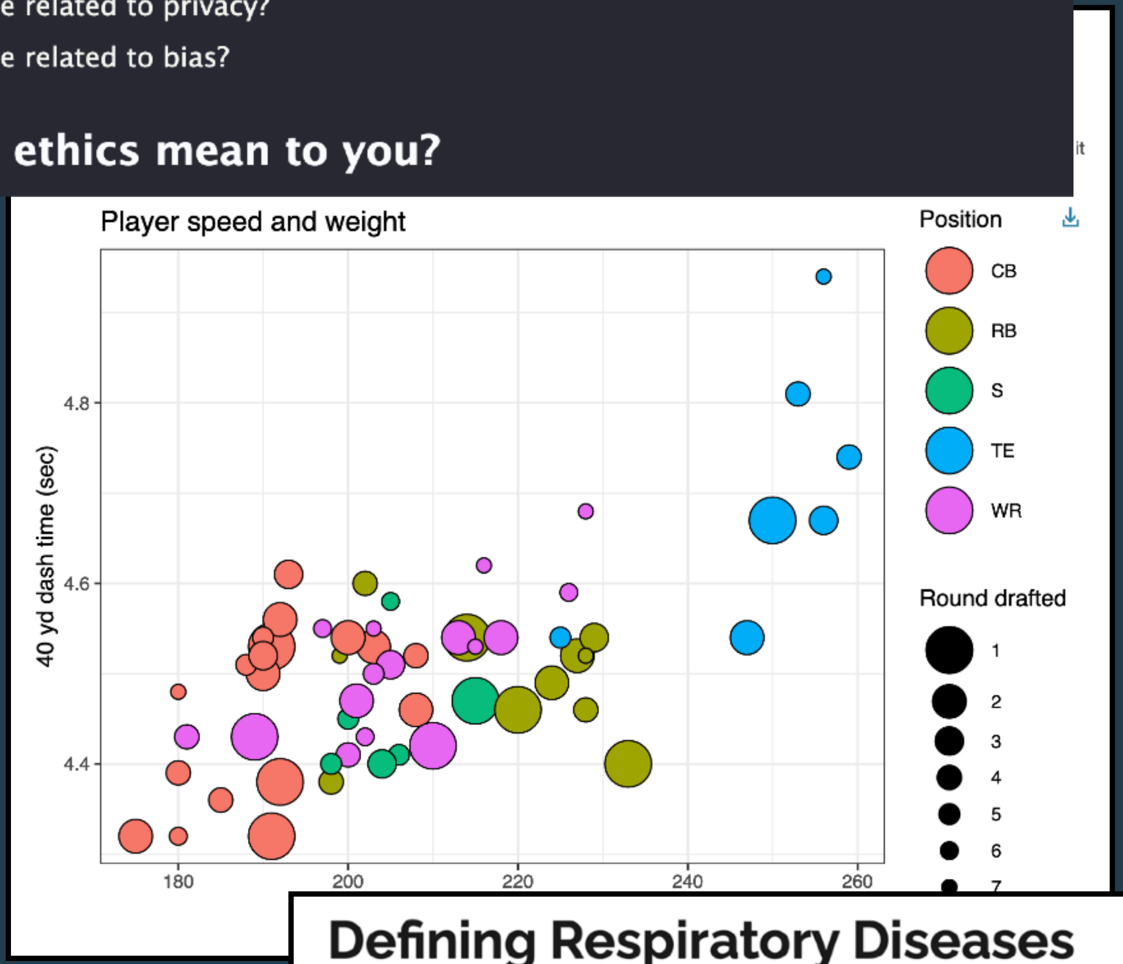
In your group, discuss how the articles and videos were related to data ethics and justice. Summarize your discussion below (around 250-500 words).

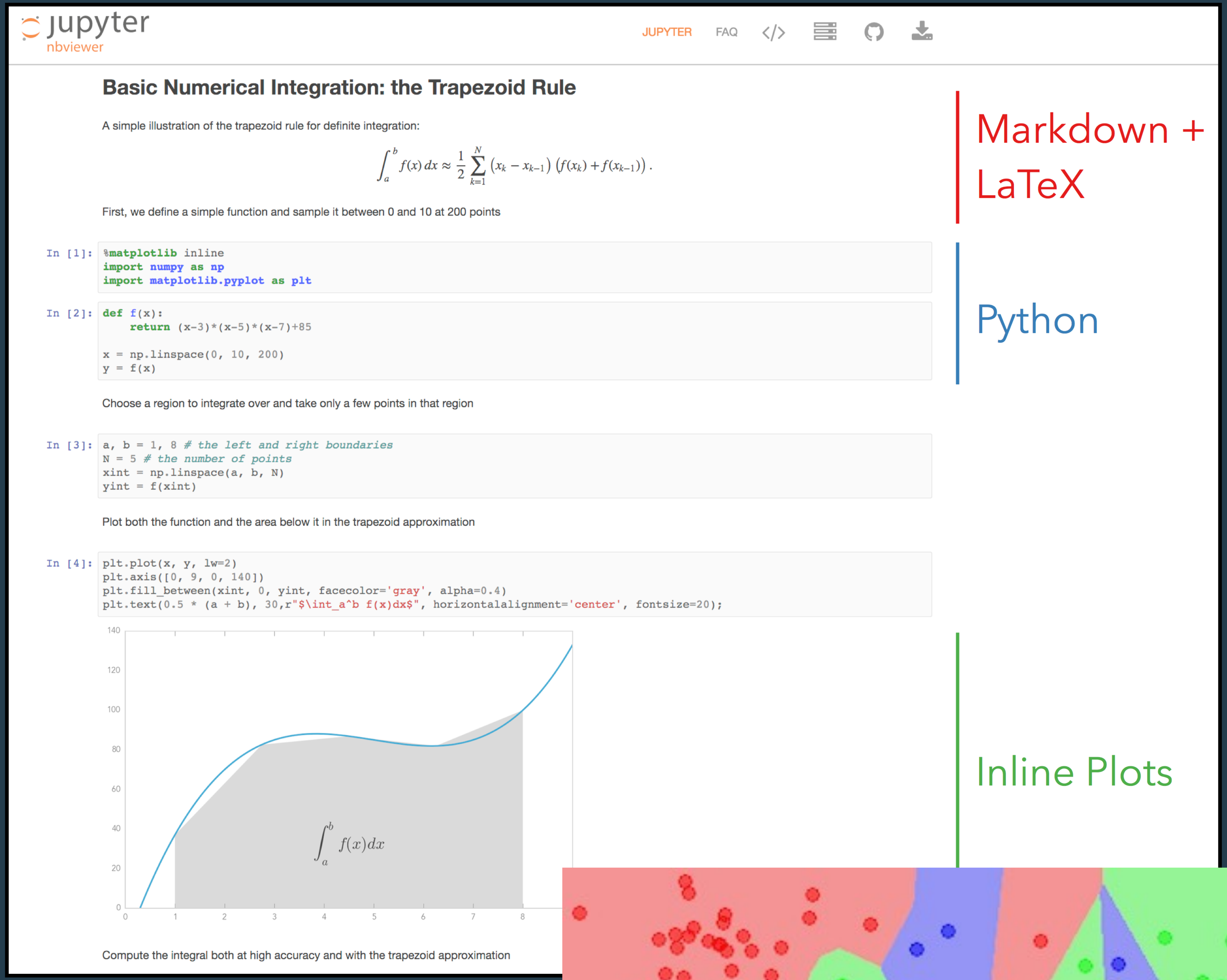
Some questions to consider:

- 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?



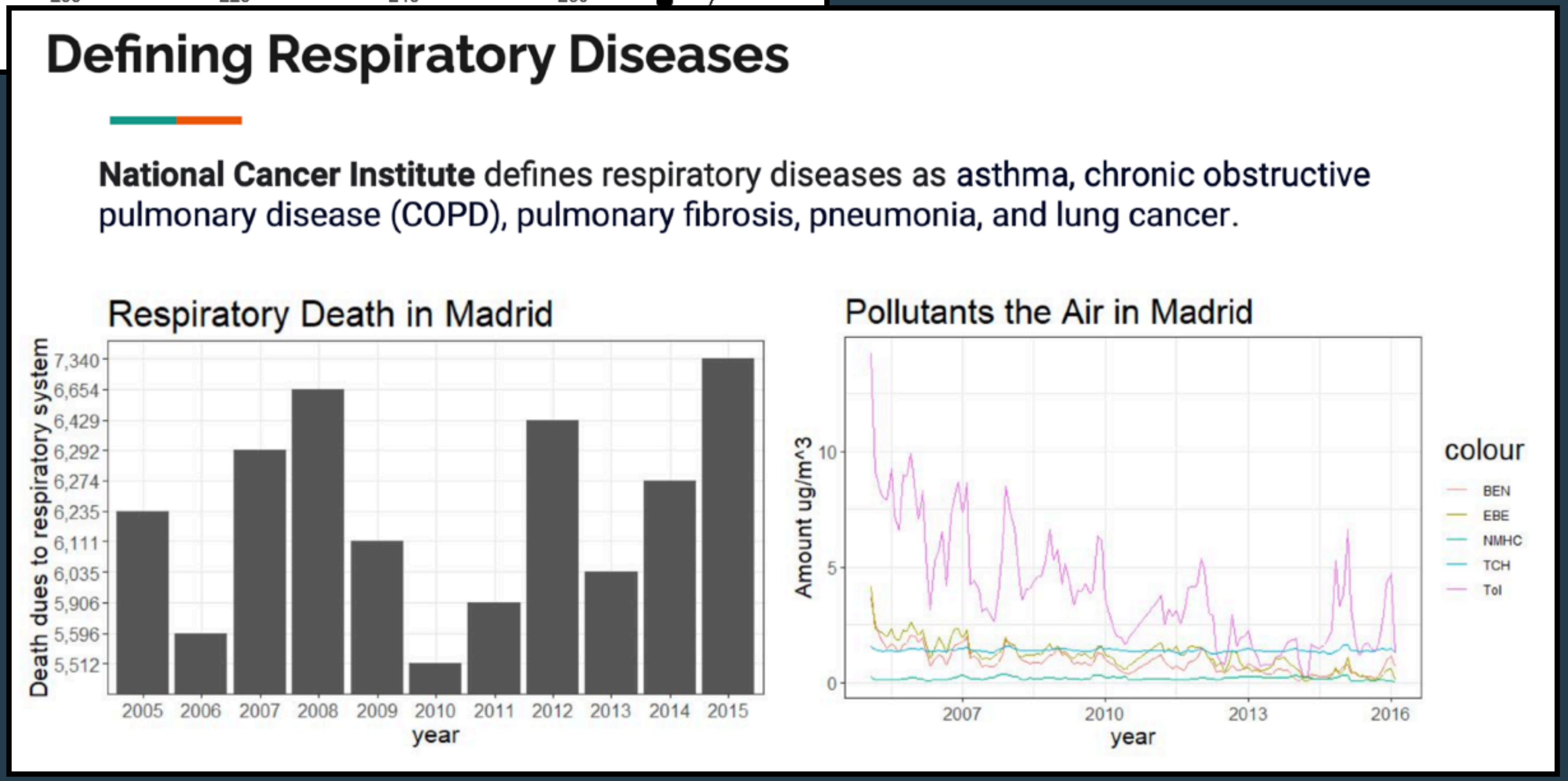


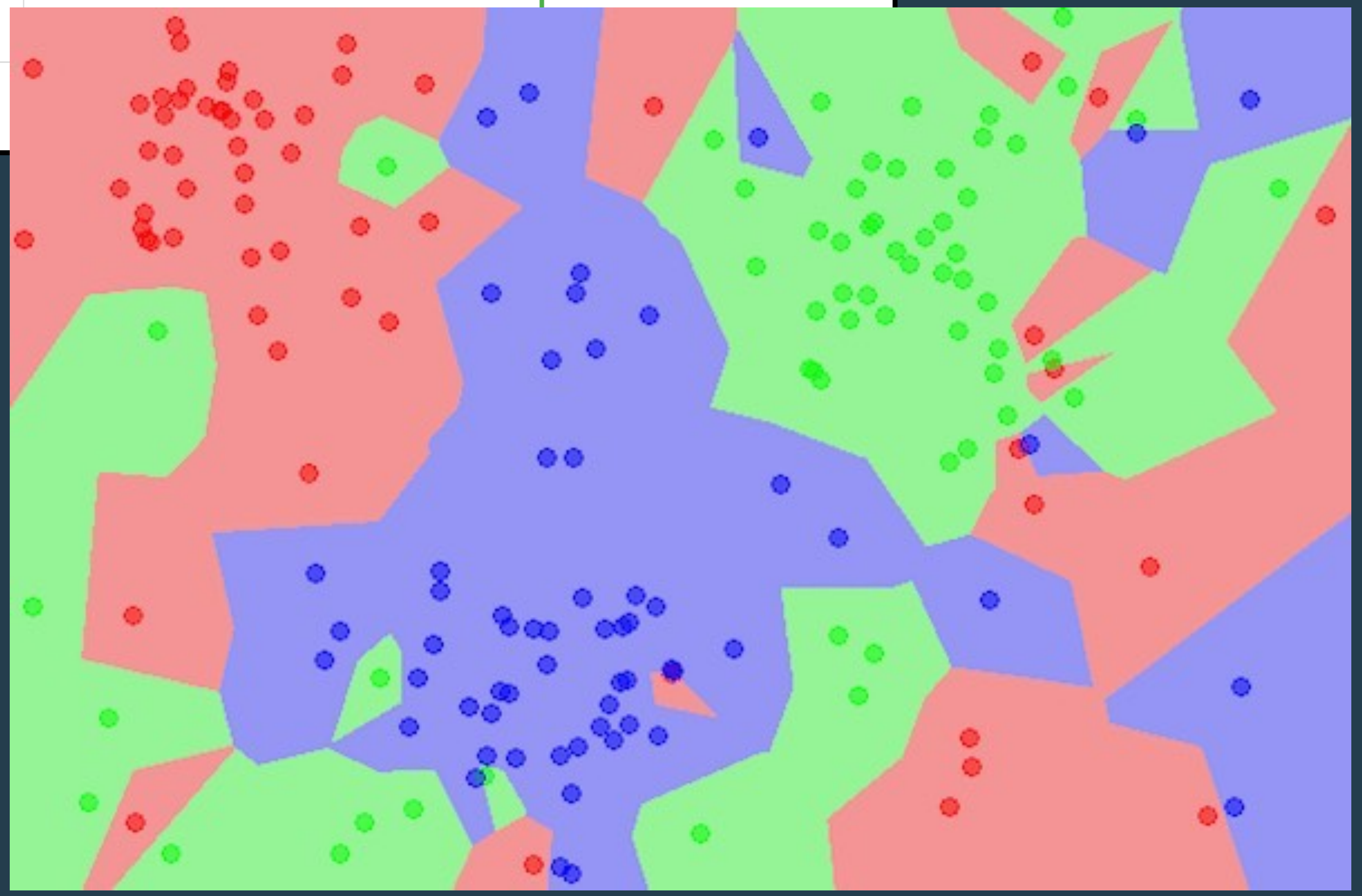


Markdown + LaTeX

Python

Inline Plots





Courtesy of Devin Silvia

Introductory Computational Science

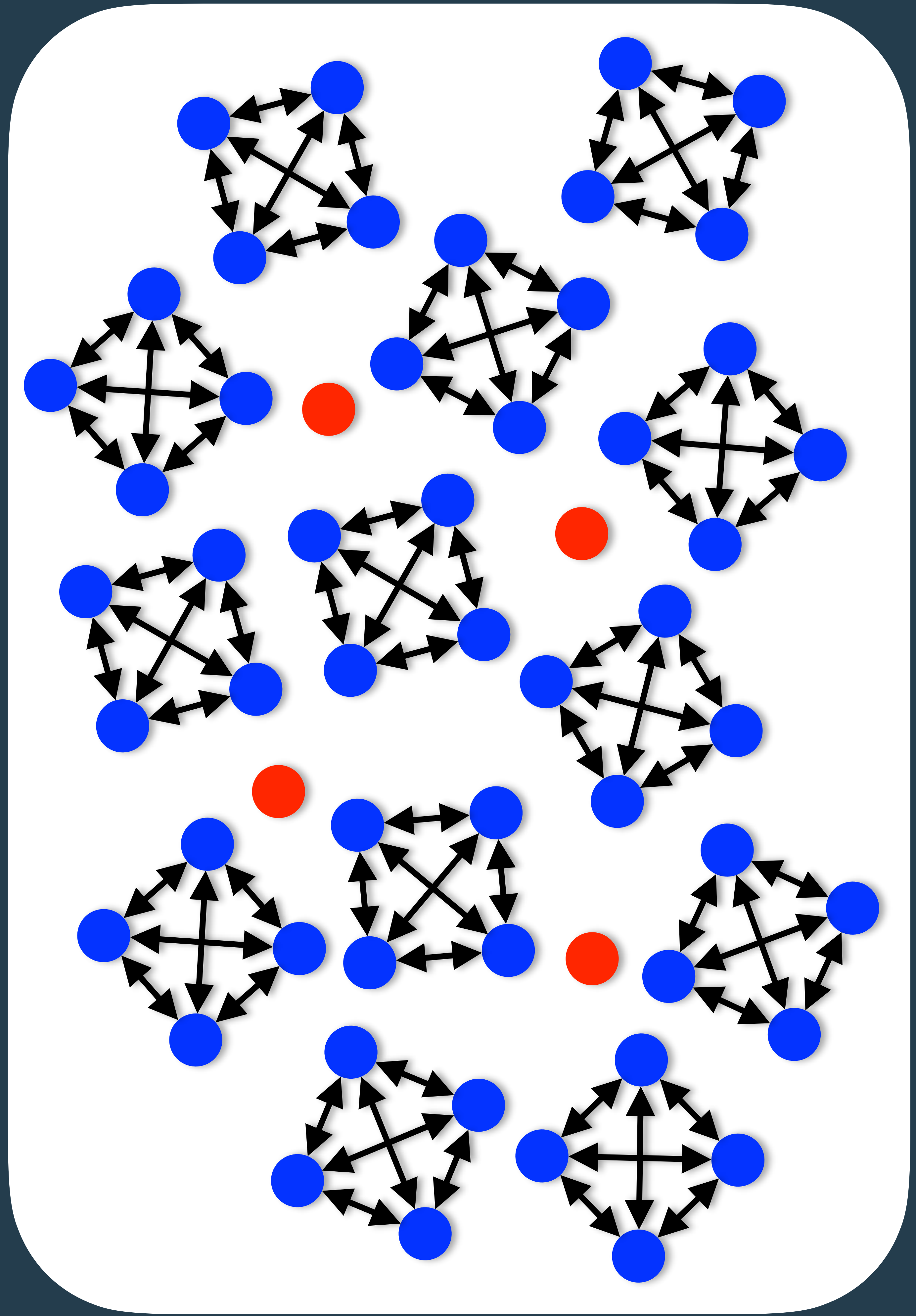
Learning Goals for CMSE 201

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)

50-70 students/section



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

Courtesy of Devin Silvia

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 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…

CMSE 201

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

jupyter

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 PHY/AST majors before Classical Mechanics

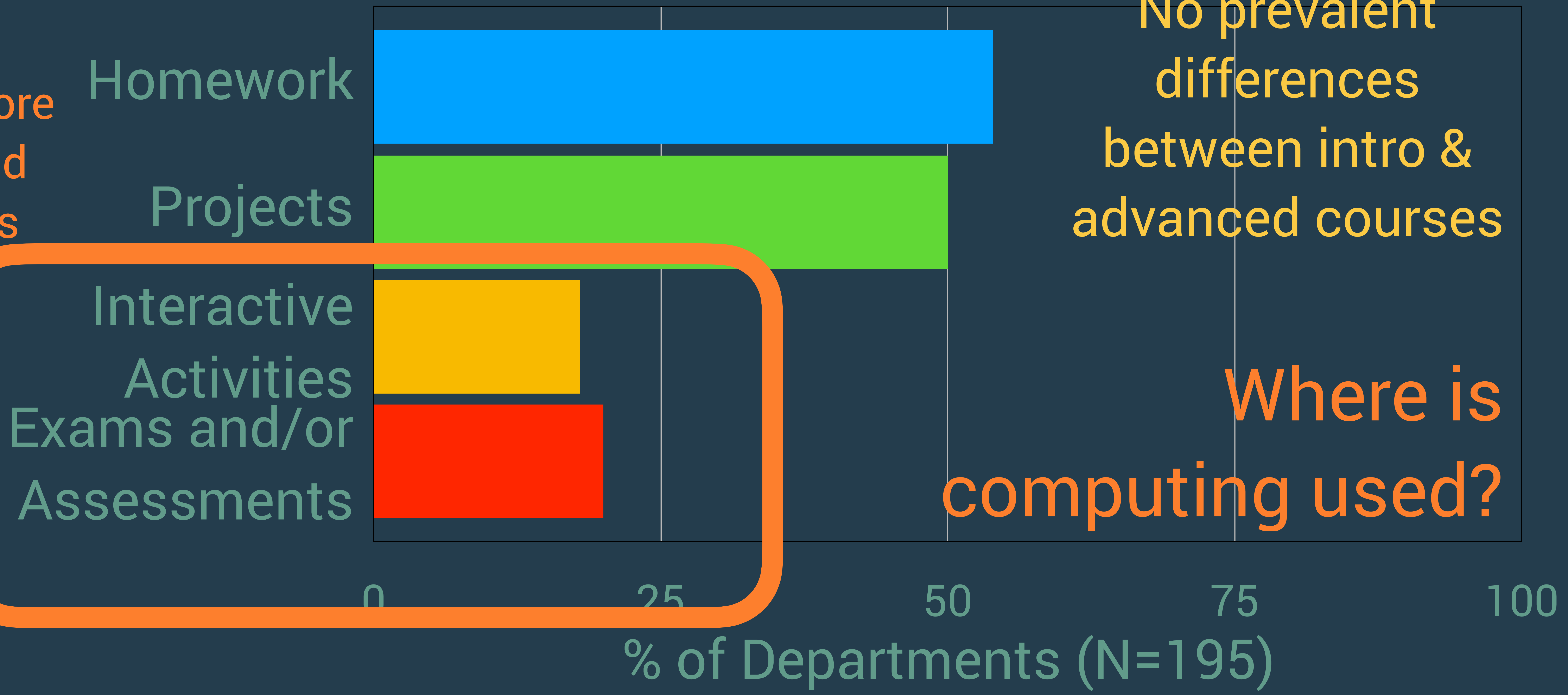

MICHIGAN STATE
UNIVERSITY

Who teaches computing in physics?

>50% departments report experience with teaching computing in physics*

Computational instruction is more prevalent than in the past[1]

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



No prevalent differences between intro & advanced courses

Where is computing used?

*Overestimated! Biased sample

PICUP

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

But “who” teaches computation?

Random Forest Classification

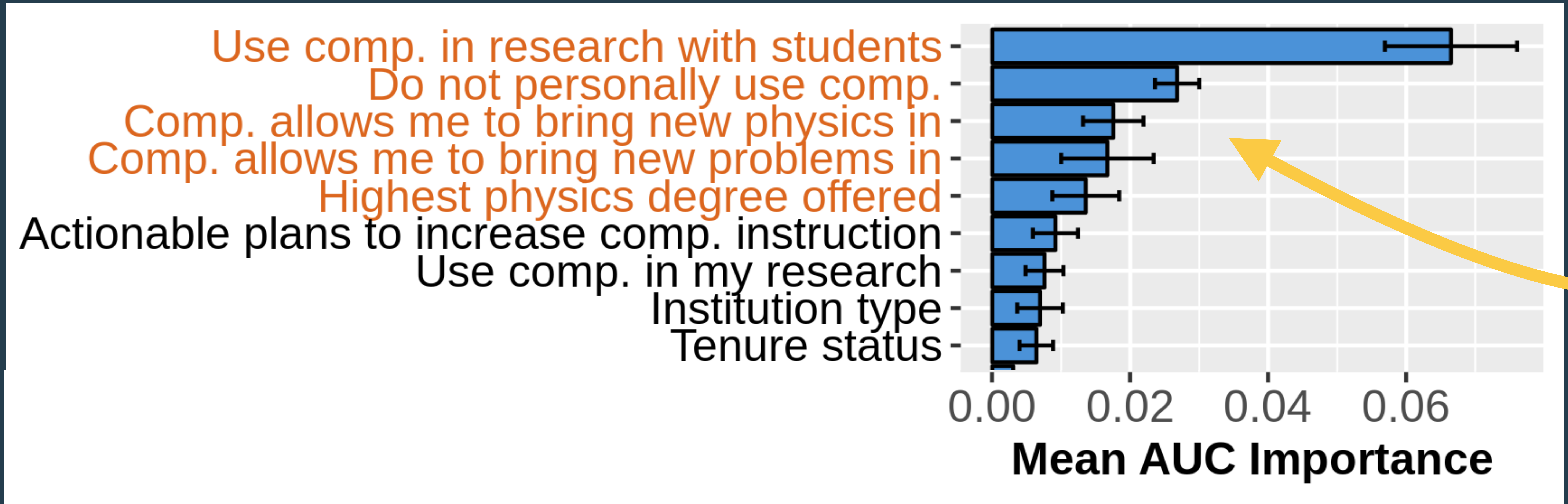
Rate on a scale of 1 (Strongly Agree) to 7 (Strongly Disagree)

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.

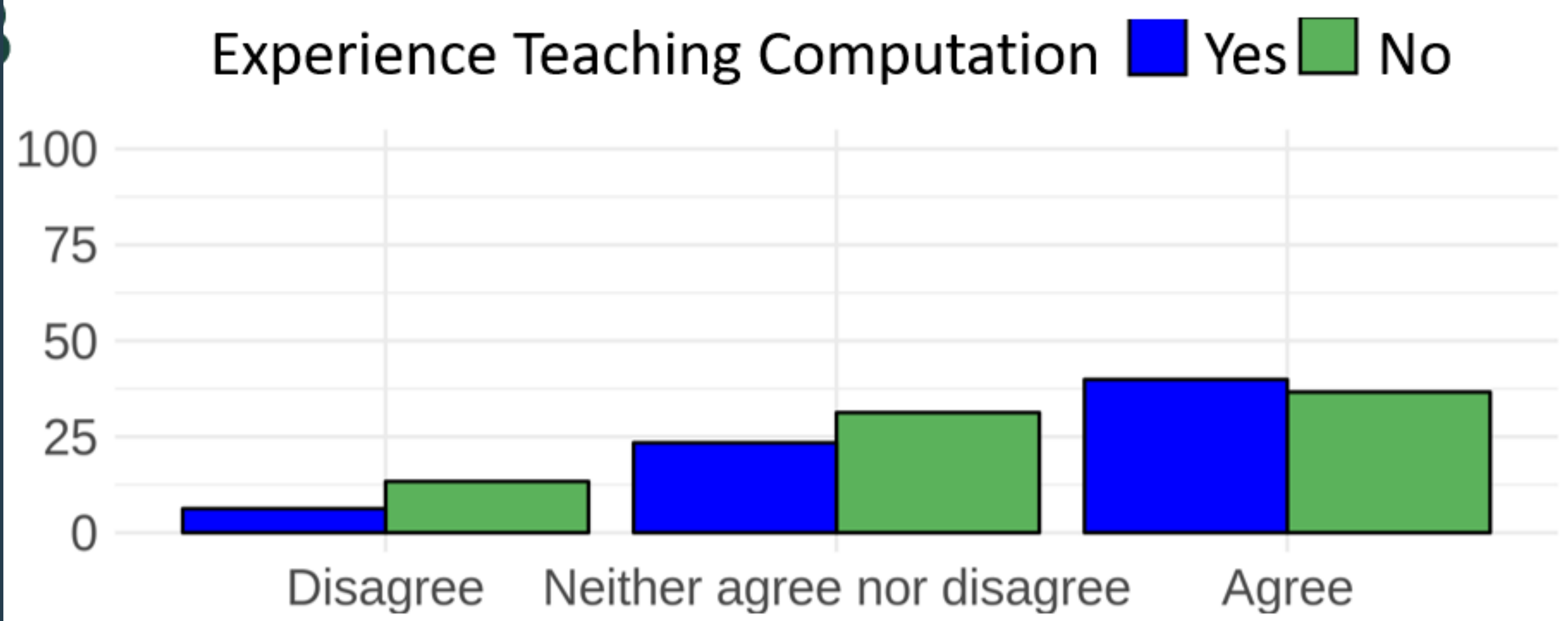
…



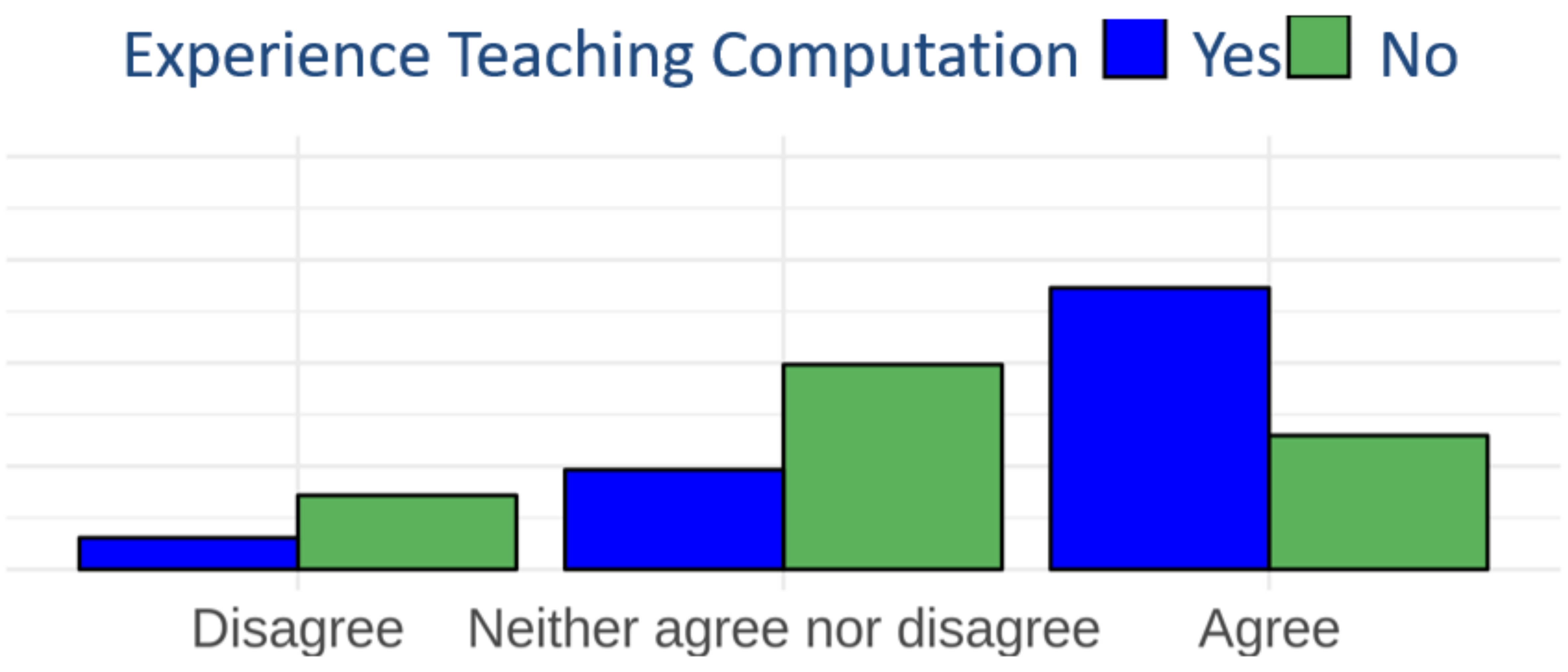
Most important factors in model

Young, et. al. Phys Rev. PER, 2019

Do these factors make sense? ✅



The undergraduate program in my department values instructing physics majors in computation



Computation allows me to bring new physics into the classroom that I otherwise could not

(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

Young, et. al. Phys Rev. PER, 2019

PICUP

PARTNERSHIP FOR INTEGRATION OF COMPUTATION INTO UNDERGRADUATE PHYSICS

2019 Faculty Development Workshop (FDW)   compadre.org/PICUP

Professional Development

compadre.org/PICUP

Teacher Centered Approach

Identify topics to "cover" in the course	Create the syllabus and lecture slides	Write exam questions
What topics do ***I*** *need to teach my students?*	When will ***I*** teach the topics? How will ***I*** give them the information?	How will ***I*** know that students learned the material ***I*** covered?

Learner Centered Approach

Identify learning goals/objectives	Decide on assessments	Create activities and syllabus
How will my ***students*** *be different?*	What evidence will ***students*** provide that they have changed?	What do ***students*** need to achieve those goals?

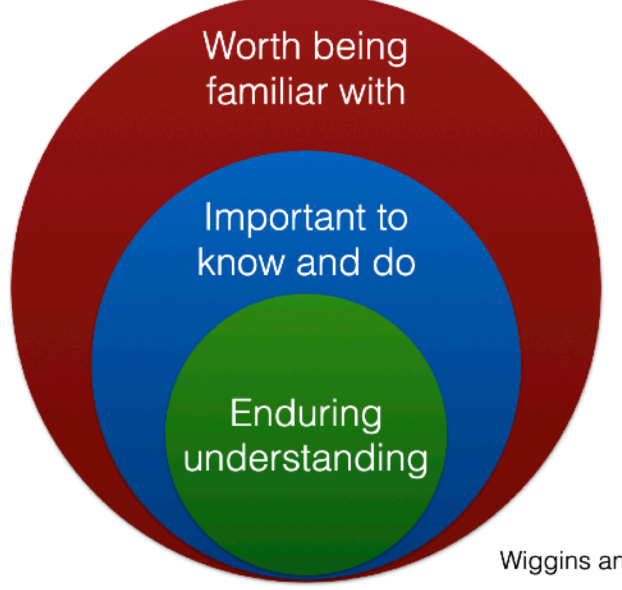
Backward Design

What should students know or be able to do by the end of the course/ session?

What evidence will convince you that they got there?

How will you help them get there?

Do your goals represent "enduring understandings"?



Wiggins and McTighe, 1998

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)

PICUP

❤️ 1 🙌 1 👍 2

In-person & virtual

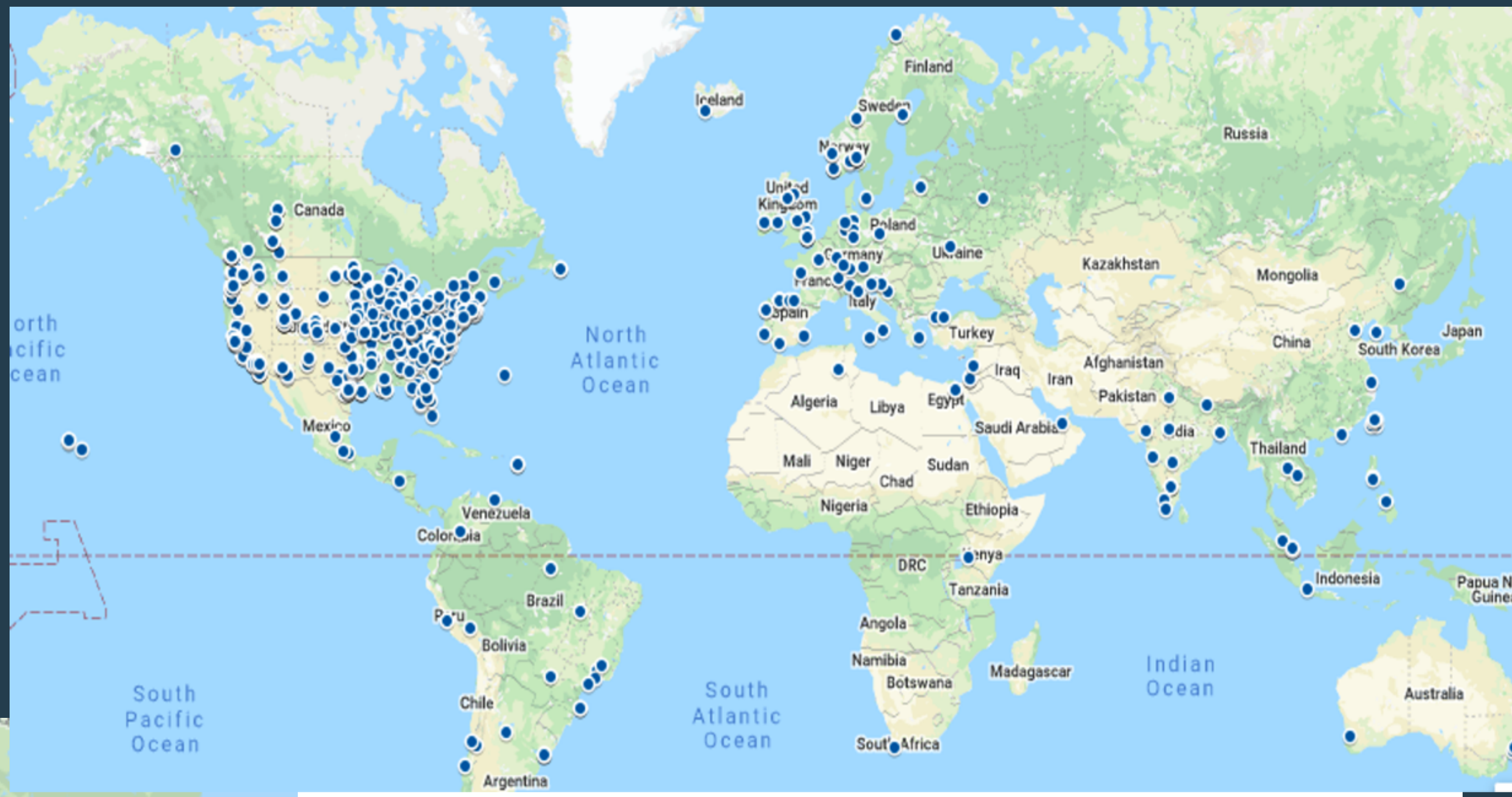
PICUP Community

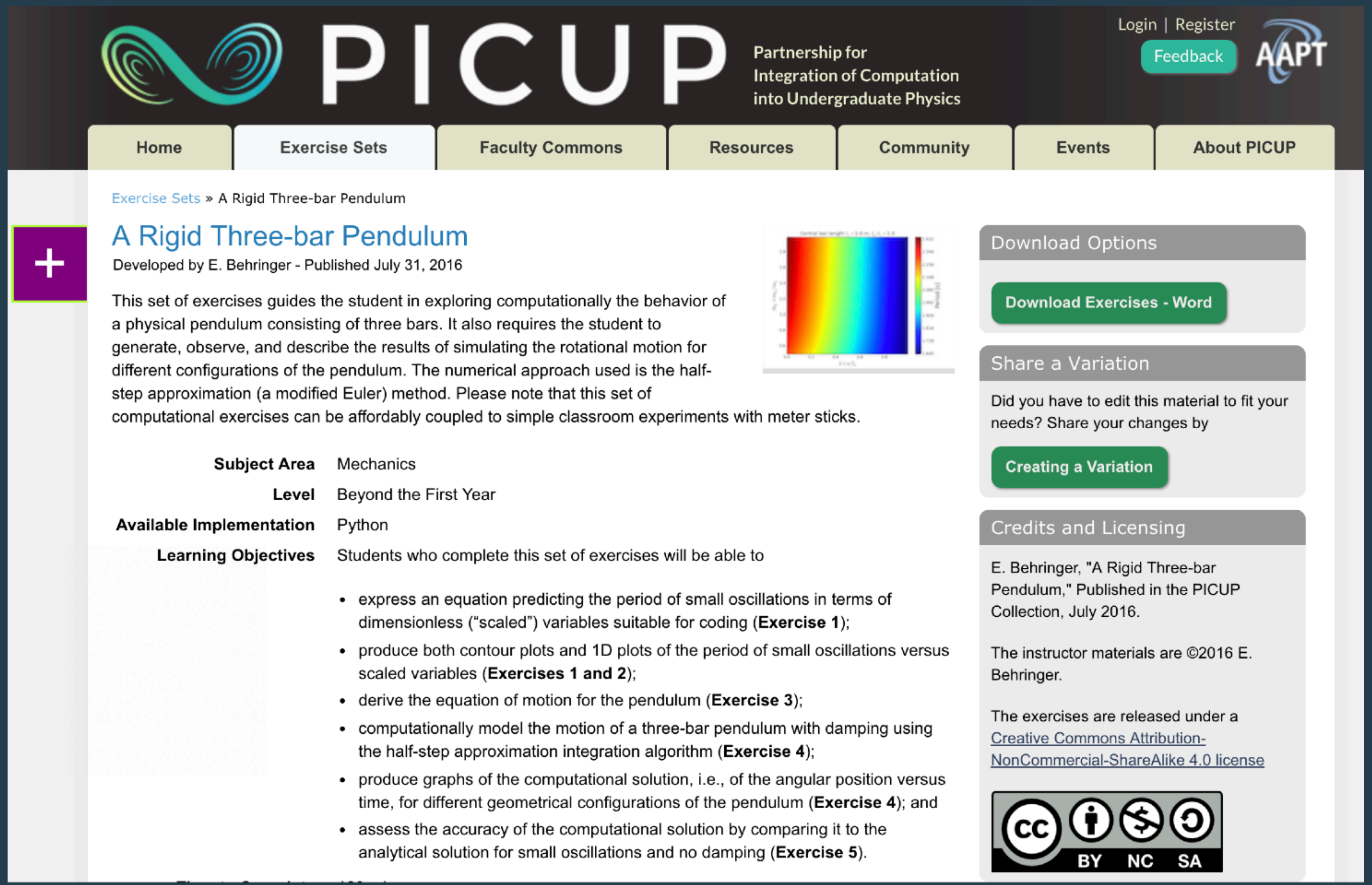
compadre.org/PICUP

FDW Participants

Verified educators submit academic documentation to gain access to:

Solutions & Source Codes
Implementation Guides
Additional Materials




PICUP
Partnership for Integration of Computation into Undergraduate Physics
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Feedback
AAPT
Home | Exercise Sets | Faculty Commons | Resources | Community | Events | About PICUP

Exercise Sets » A Rigid Three-bar Pendulum

A Rigid Three-bar Pendulum

Developed by E. Behringer - Published July 31, 2016

This set of exercises guides the student in exploring computationally the behavior of a physical pendulum consisting of three bars. It also requires the student to generate, observe, and describe the results of simulating the rotational motion for different configurations of the pendulum. The numerical approach used is the half-step approximation (a modified Euler) method. Please note that this set of computational exercises can be affordably coupled to simple classroom experiments with meter sticks.

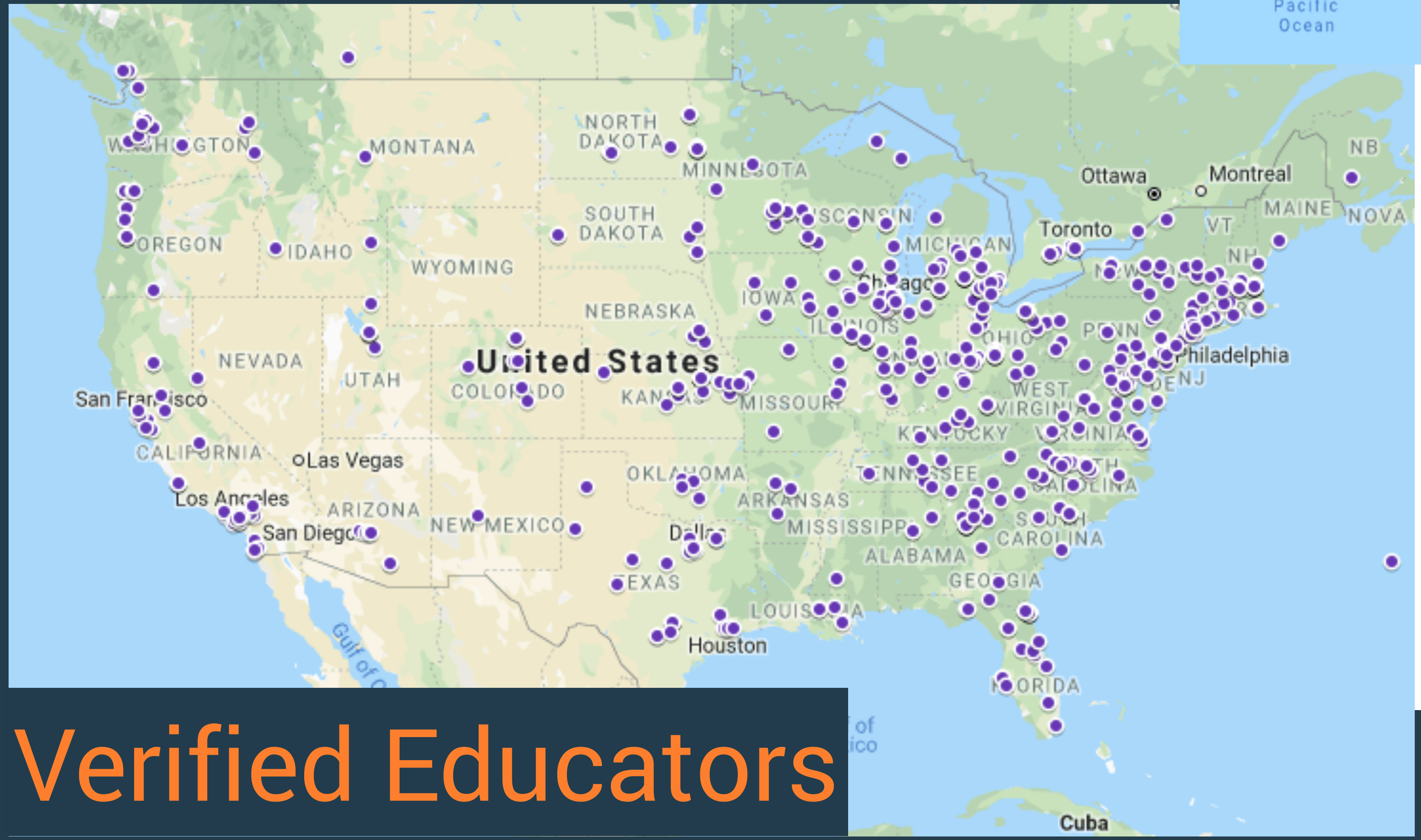
Subject Area	Mechanics
Level	Beyond the First Year
Available Implementation	Python
Learning Objectives	Students who complete this set of exercises will be able to

- express an equation predicting the period of small oscillations in terms of dimensionless ("scaled") variables suitable for coding (**Exercise 1**);
- produce both contour plots and 1D plots of the period of small oscillations versus scaled variables (**Exercises 1 and 2**);
- derive the equation of motion for the pendulum (**Exercise 3**);
- computationally model the motion of a three-bar pendulum with damping using the half-step approximation integration algorithm (**Exercise 4**);
- produce graphs of the computational solution, i.e., of the angular position versus time, for different geometrical configurations of the pendulum (**Exercise 4**); and
- assess the accuracy of the computational solution by comparing it to the analytical solution for small oscillations and no damping (**Exercise 5**).

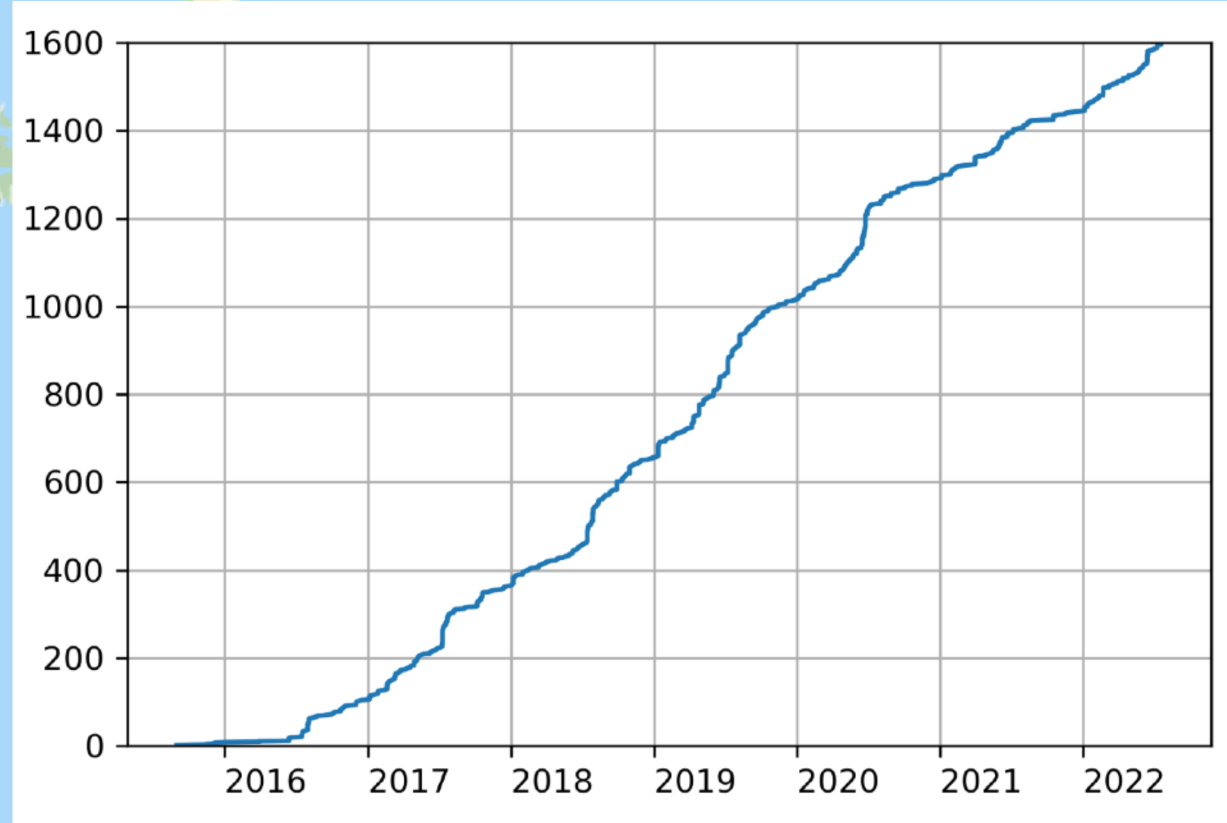
Download Options
Download Exercises - Word

Share a Variation
Did you have to edit this material to fit your needs? Share your changes by
Creating a Variation

Credits and Licensing
E. Behringer, "A Rigid Three-bar Pendulum," Published in the PICUP Collection, July 2016.
The instructor materials are ©2016 E. Behringer.
The exercises are released under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 license
BY NC SA



Verified Educators



Summer Leadership Institute

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

PICUP

PARTNERSHIP FOR INTEGRATION OF COMPUTATION INTO UNDERGRADUATE PHYSICS

Monday	Tuesday		Wednesday		Thursday		Friday
	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		
Arrival to MSP airport or drive to River Falls, WI	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	Group Discussion	Mini workshop	
	Break		Break		Break		
Working Dinner: Welcome	Working Dinner		Working Dinner		Working Dinner		

compadre.org/PICUP

Seemingly necessary but not sufficient conditions for change

How was this effort to integrate computing in physics done?

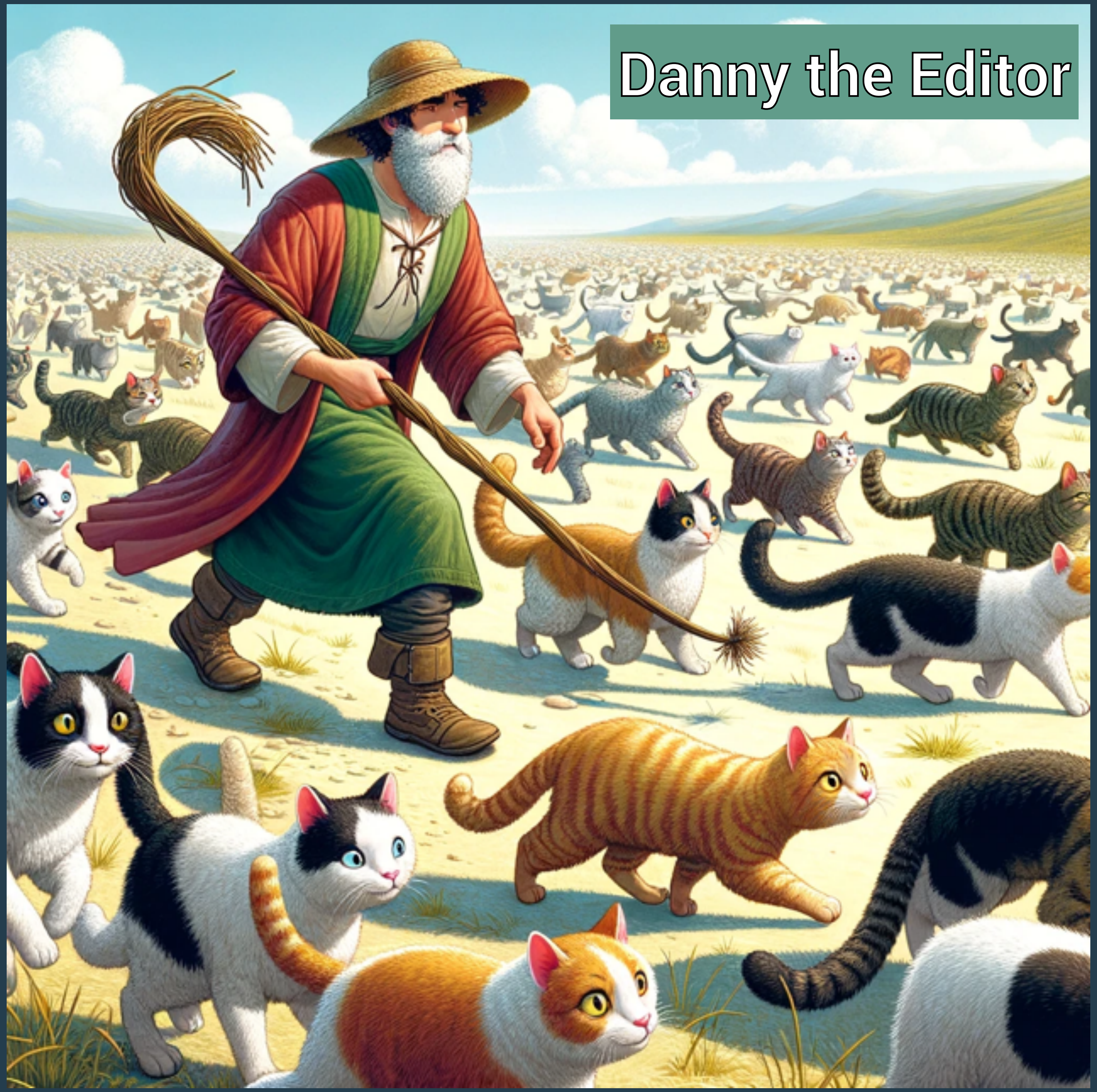
- Define goals and scope collectively
- Build professional development and community
- Respect institutional factors and diversity
- Acknowledge the complexity of the problem
- Collect data on experience and progress
- Share successful cases openly and transparently

Must happen in
disciplinary contexts

Needs scientists, educators,
& ed. researchers

Computing in Physics Education Book

Published by Institute of Physics (Summer 2025)



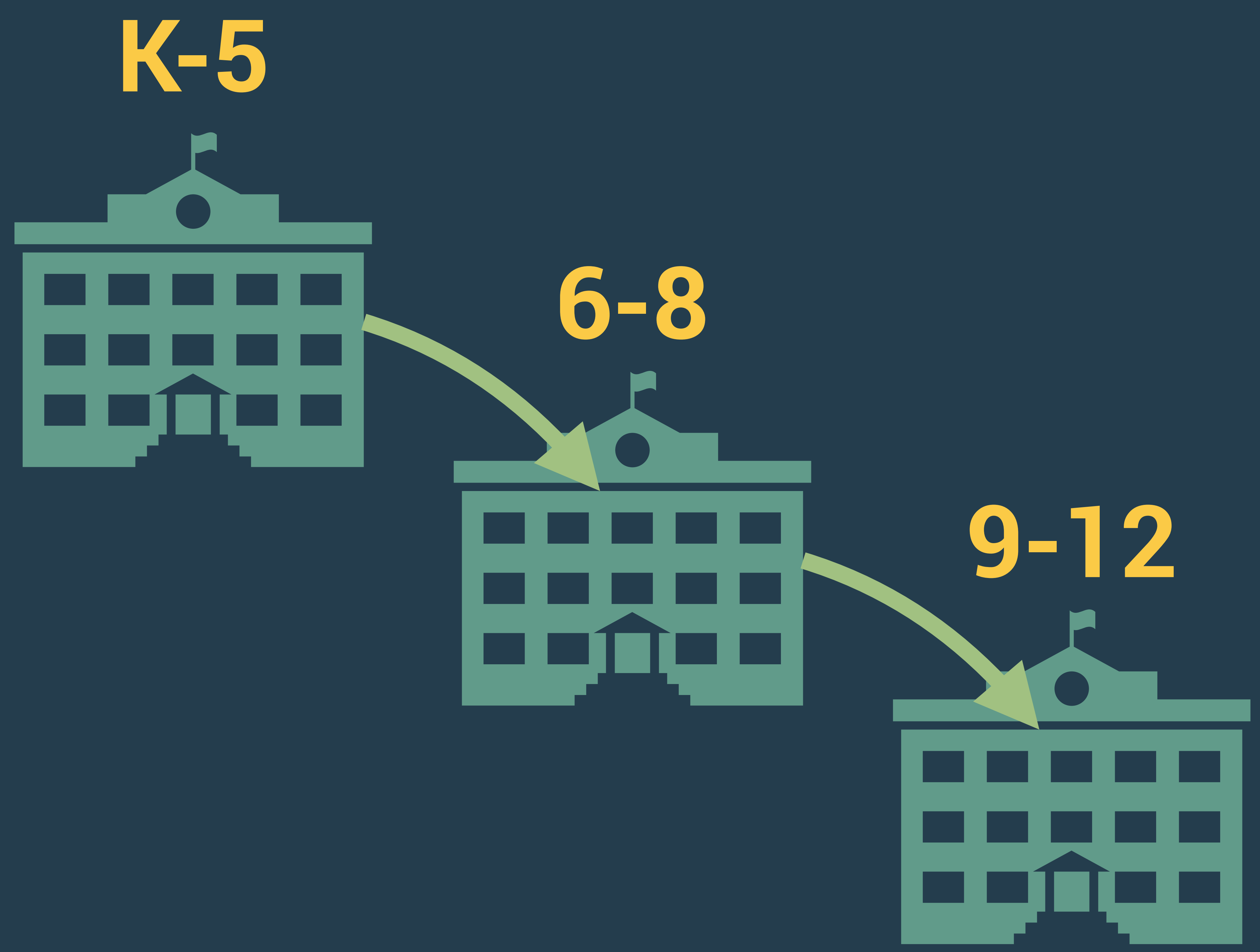
https://dannycaballero.info/iop-book/

AUTHORS	PRELIMINARY CHAPTER TITLE
K. Svennson and U. Erickson	Teachers' approach to computation in physics classrooms analyzed using social semiotics and variation theory of learning
B. Zwickl, C. Lusignan, and A. McGowan	Integrating computation into a physics bachelor's laboratory curriculum
T. Atherton, A. Phillips, B. Gravel, and E. Gouvea	Agency and Making in Computational Learning Environments
W. B. Lane and T. Galanti	Computing in General Education Physics
R. C. Mastroleo and B. Lunk	Departmental Emphasis on Computation for the Physics Major: Successes and Failures of a multi-tier curricular redesign
T. Odden	Teaching Scientific Writing using Computational Essays
M. Lopez del Puerto, L. Engelhardt, and K. Roos	Resources for Integrating Computation into Physics Courses: Exercise Sets, Workshops, and a Supportive Community
D. O'Neil	Integration of computation across the curriculum at Bridgewater College
B. Lunk and S. Weatherford	Student Engagement with Computational Models and the Development of the "Minimally Working Program" Instructional Tool
M. Hamilton	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
6-8


K-5
6-8
9-12


K-5
6-8
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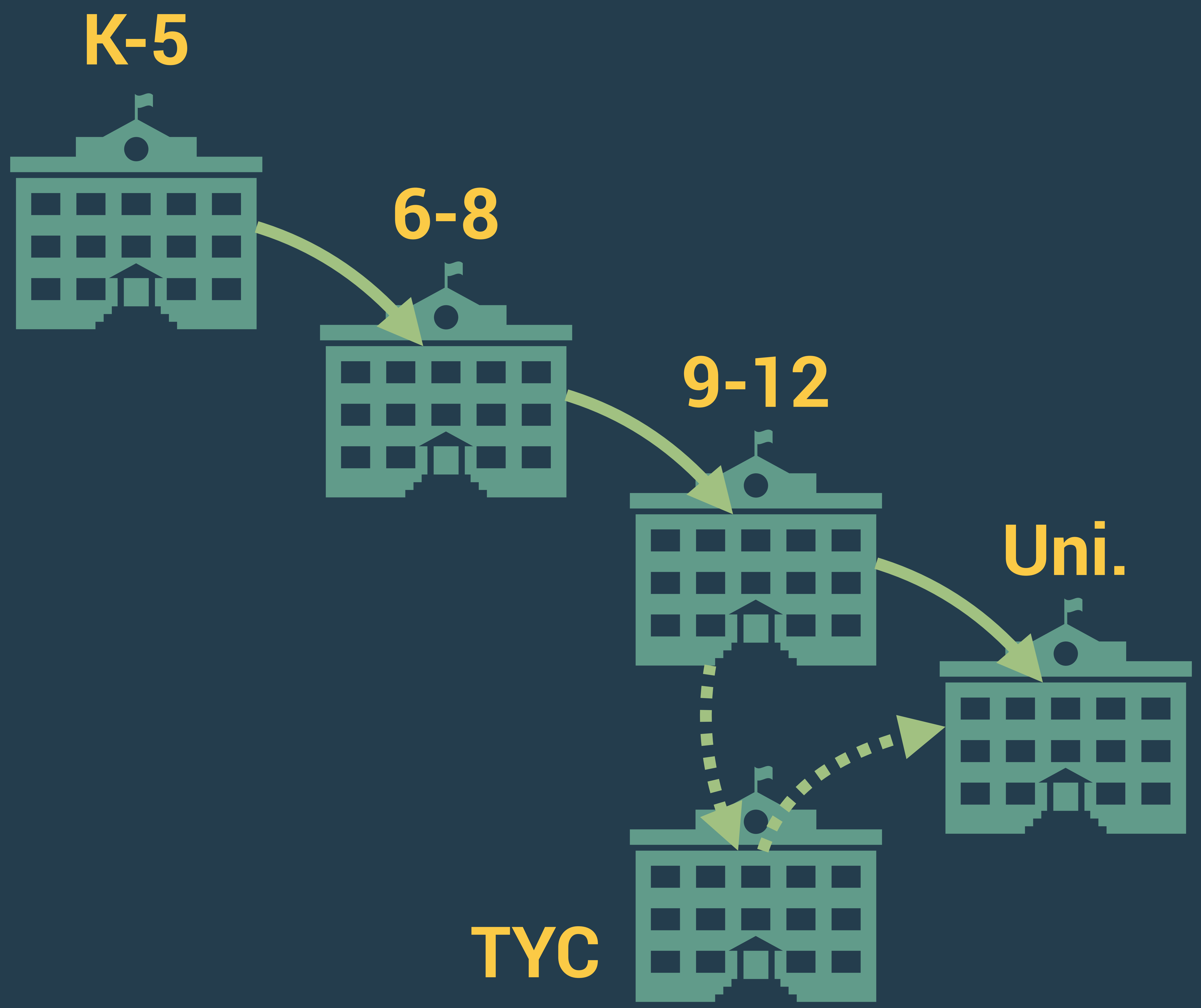
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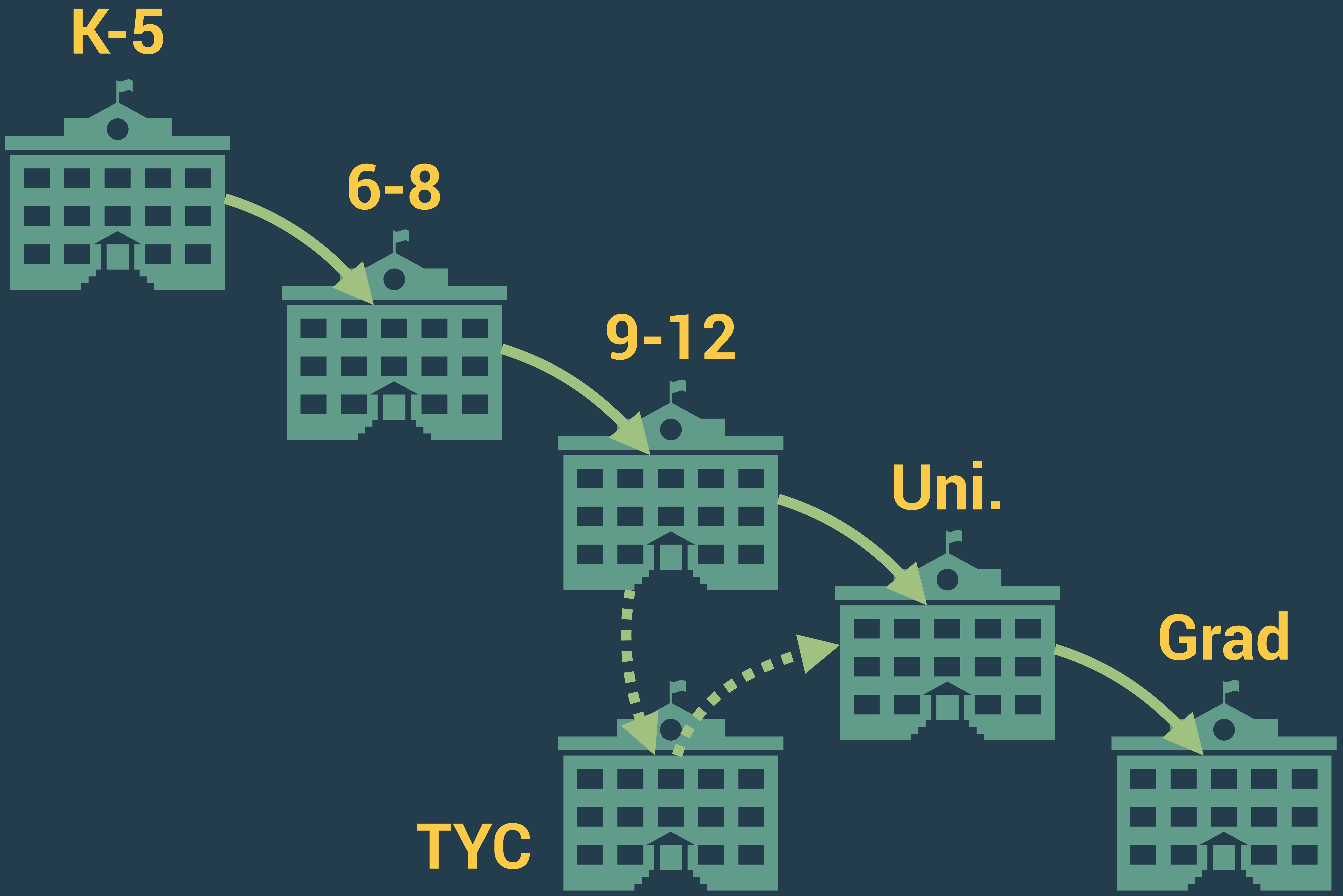
K-5
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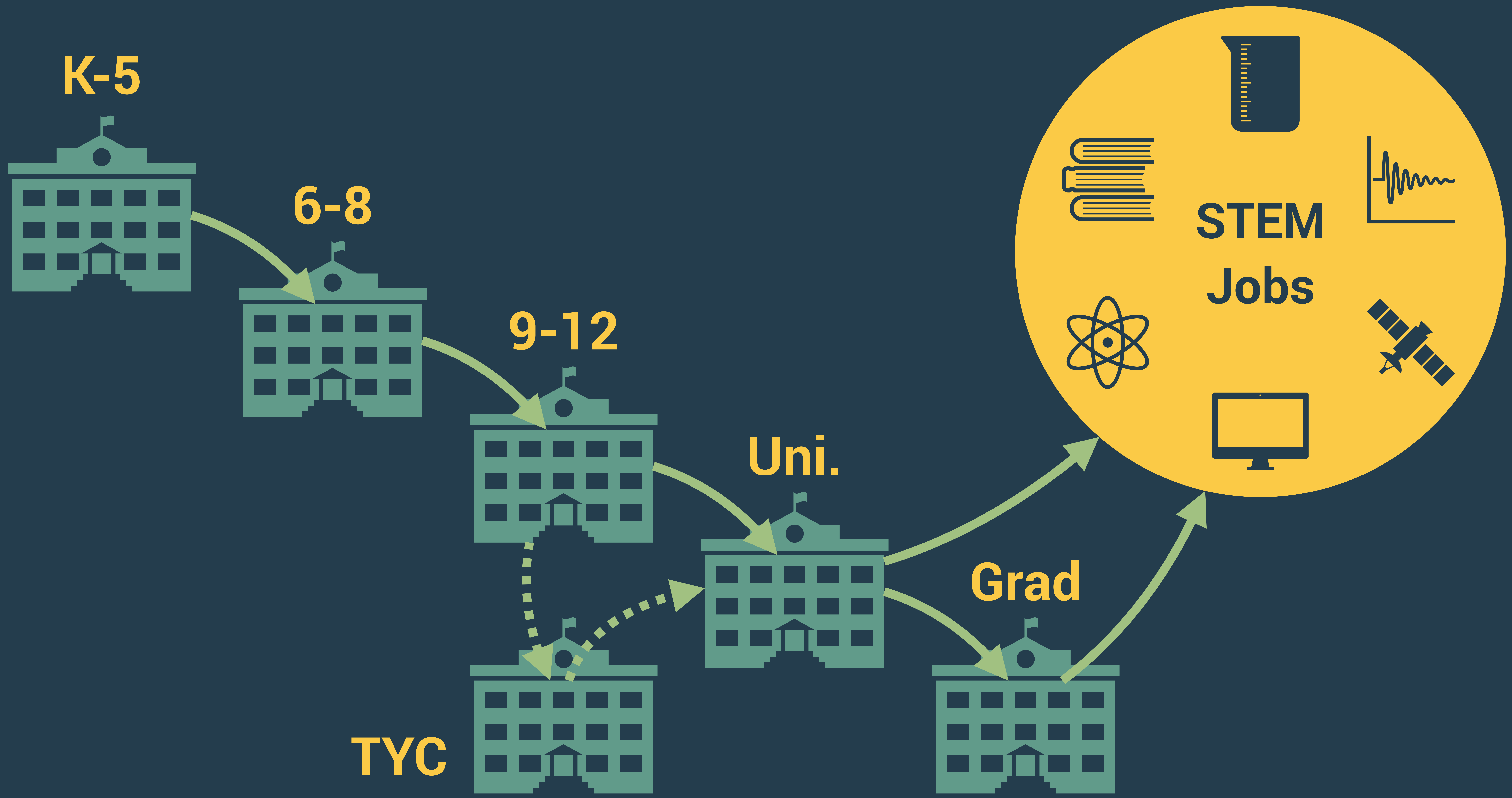
Grad
TYC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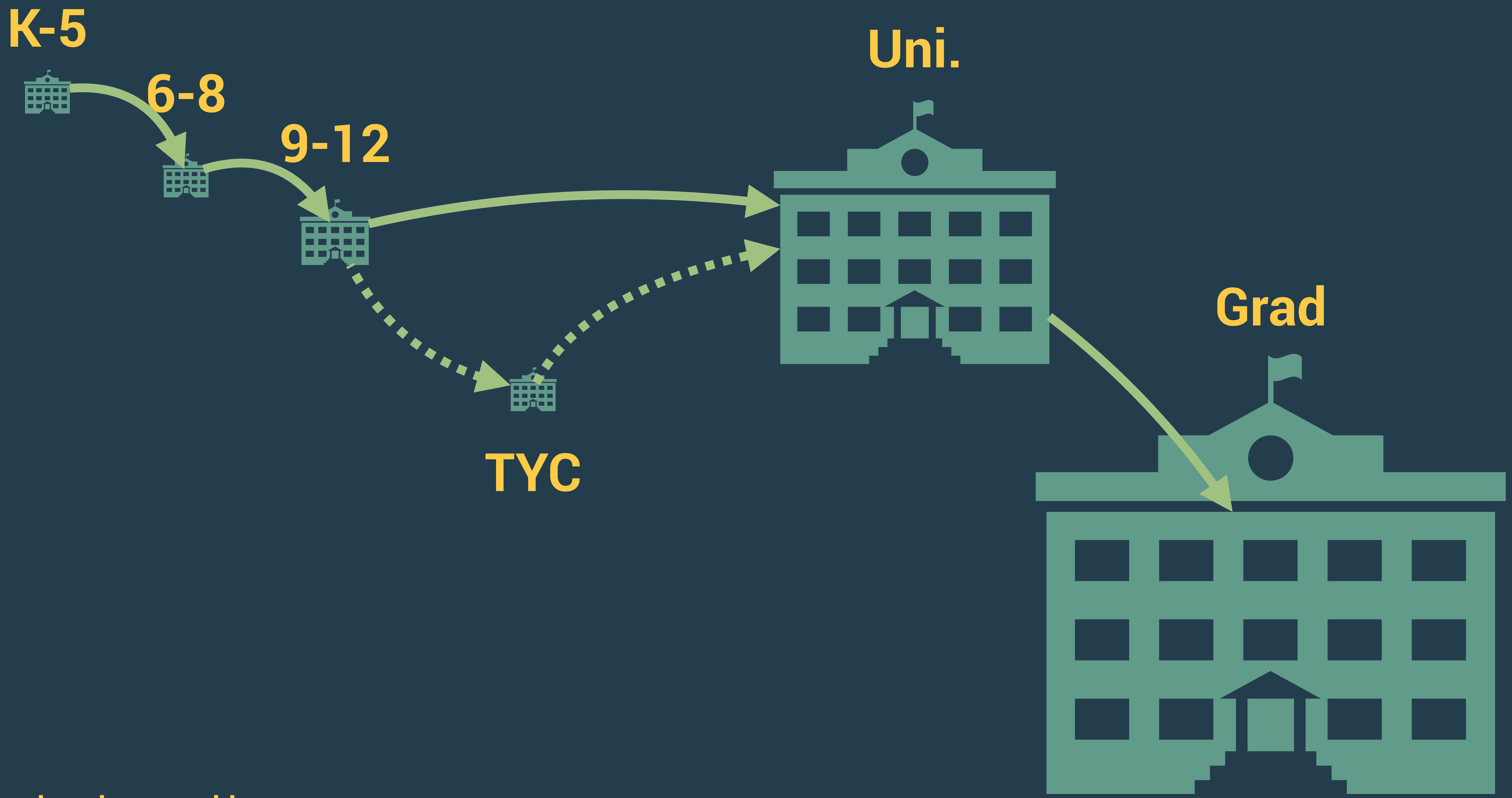
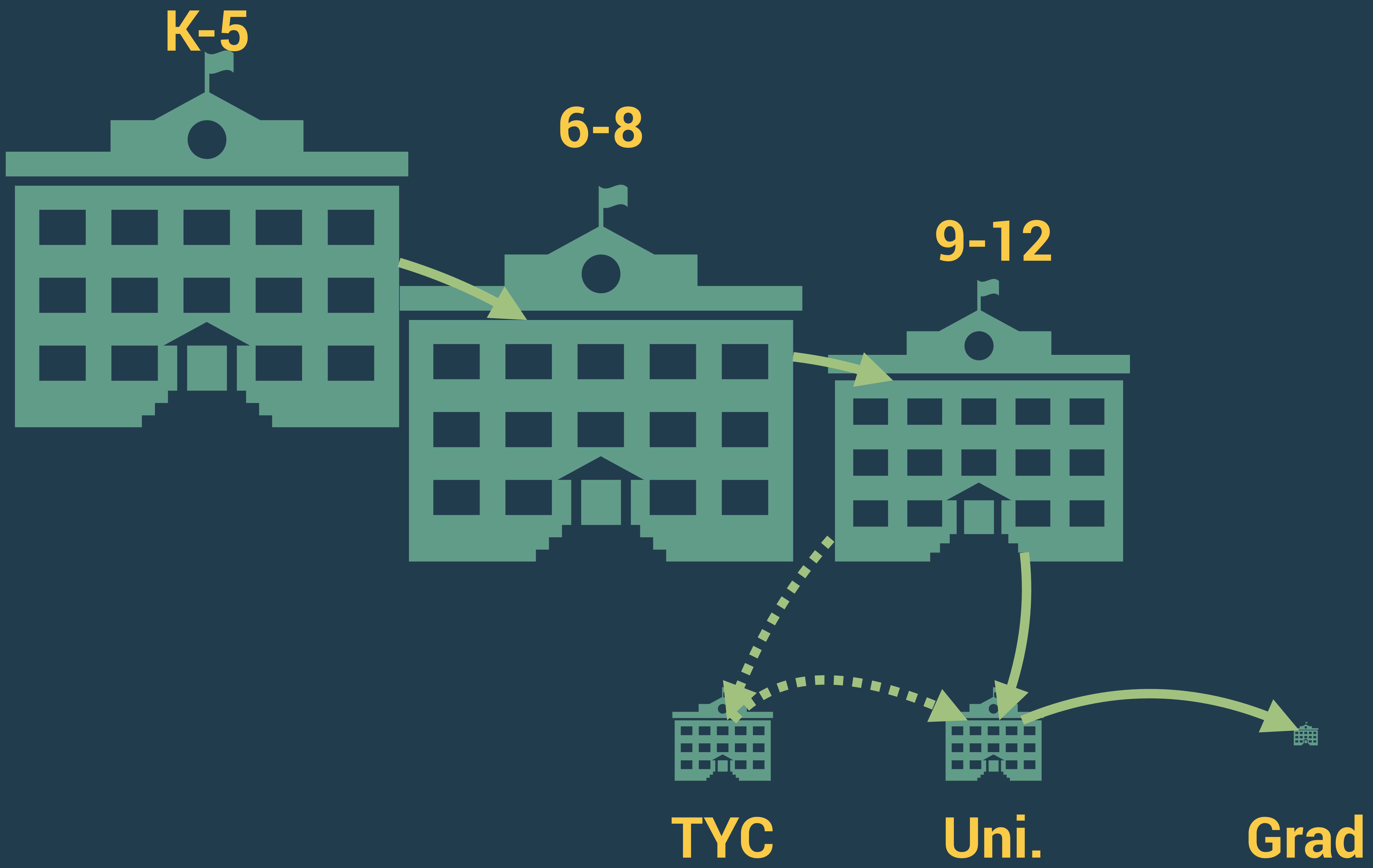
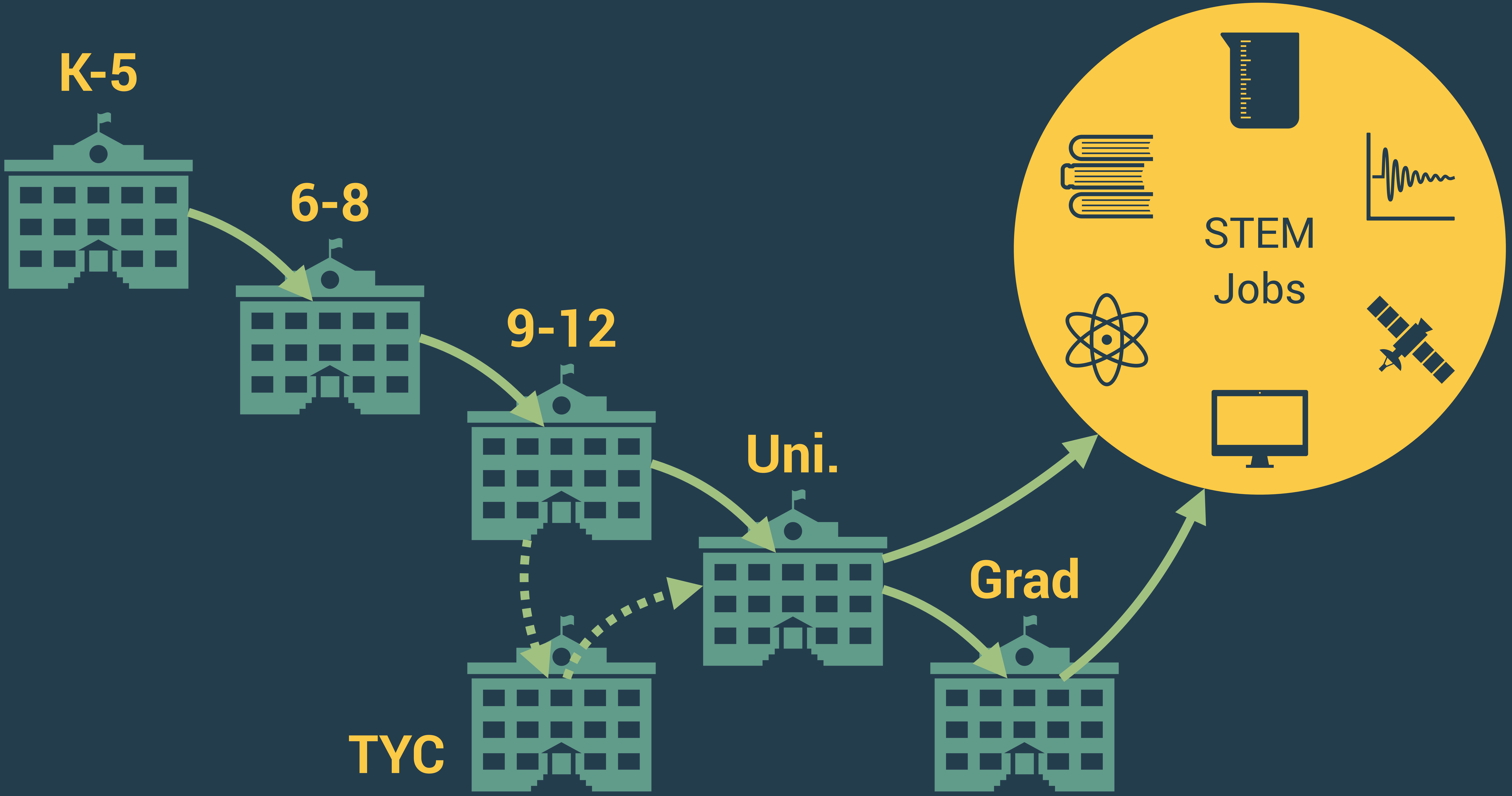
Grad
TYC
STEM
Jobs



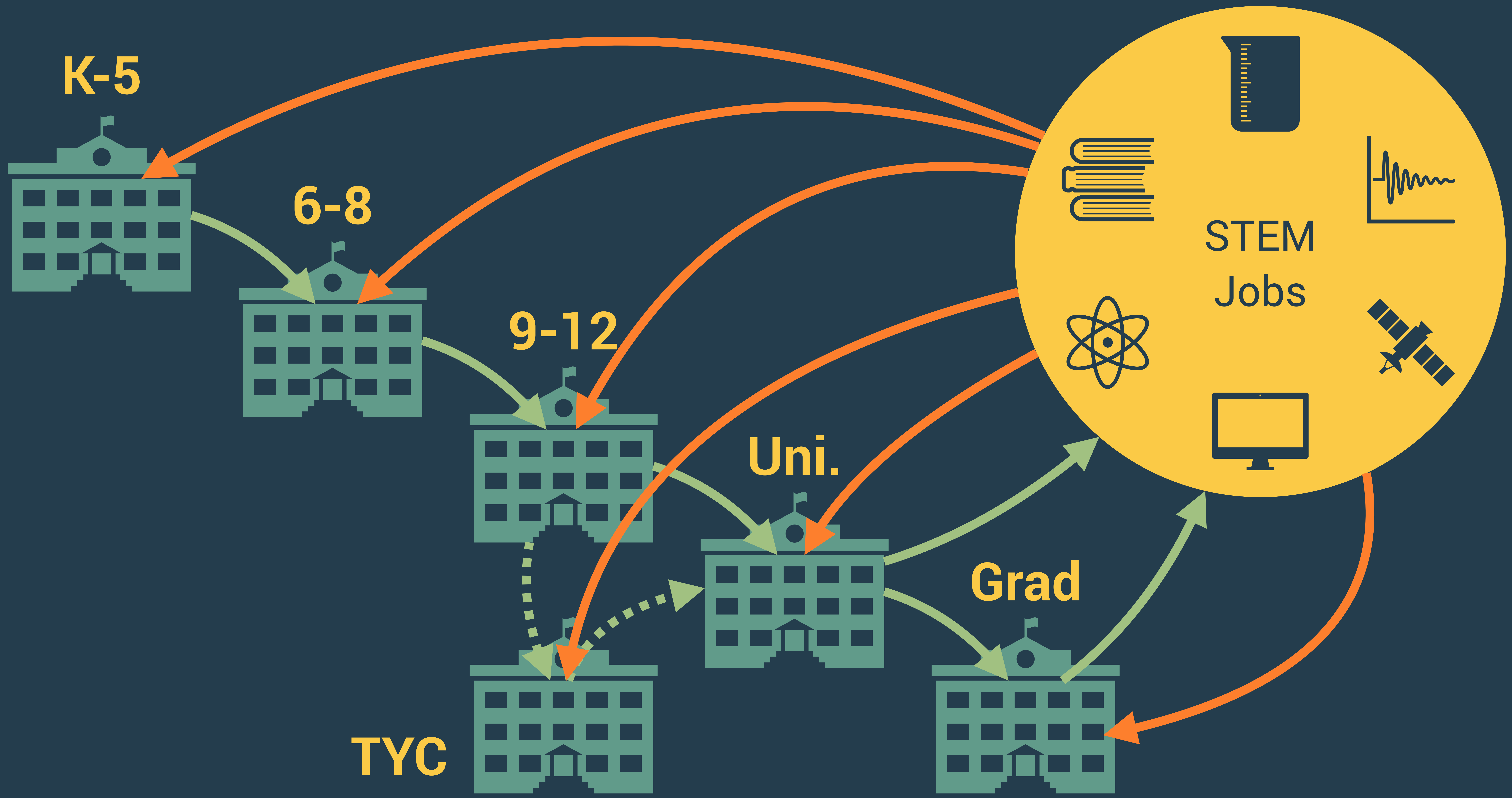
How my university sees things



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
MICHIGAN Department of Education

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…

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

ICSAM Workshop

Weeklong Summer Camp for High School Teachers

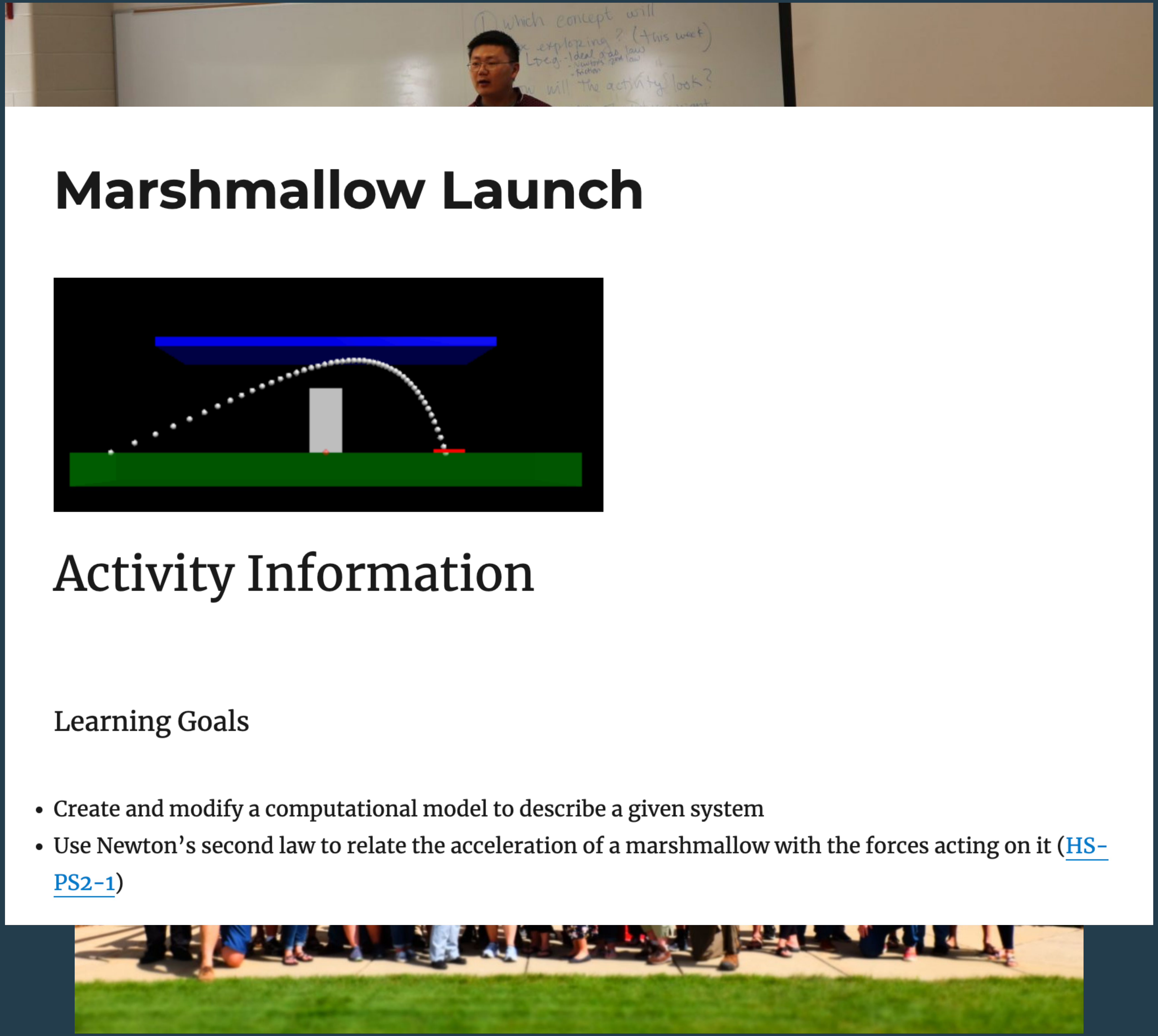
- Introduce computing
- Develop materials
- Grow community
- Focus on equity

Return to MSU (virtual during COVID)

- Addressing problems of practice
- Community building

https://www.msuperl.org/wp/icsam/

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

Many teacher-developed materials!

https://www.msuperl.org/wp/icsam/

ICSAM was 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,[1] Daryl McPadden,[1] Marcos D. Caballero,[1,2] and Paul W. Irving[1]

[1]*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA*
[2]*Department 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,[1,2] Theodore E. Bott,[1] Marcos D. Caballero,[1,3,4] and Paul W. Irving[1]

[1]*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA*
[2]*School of Mathematical and Physical Sciences, University of New England, Biddeford, Maine 04005, USA*
[3]*Department of Computational Mathematics, Science, and Engineering and CREATE for STEM Institute, Michigan State University, East Lansing, Michigan 48824, USA*
[4]*Department 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. Reinholz[d]

[a]College of Education, University of Washington, Seattle, USA; [b]College of Education, Michigan State University, East Lansing, MI, USA; [c]College of Education & Human Development, Georgia State University, Atlanta, GA, USA; [d]College 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. Reinholz, 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]

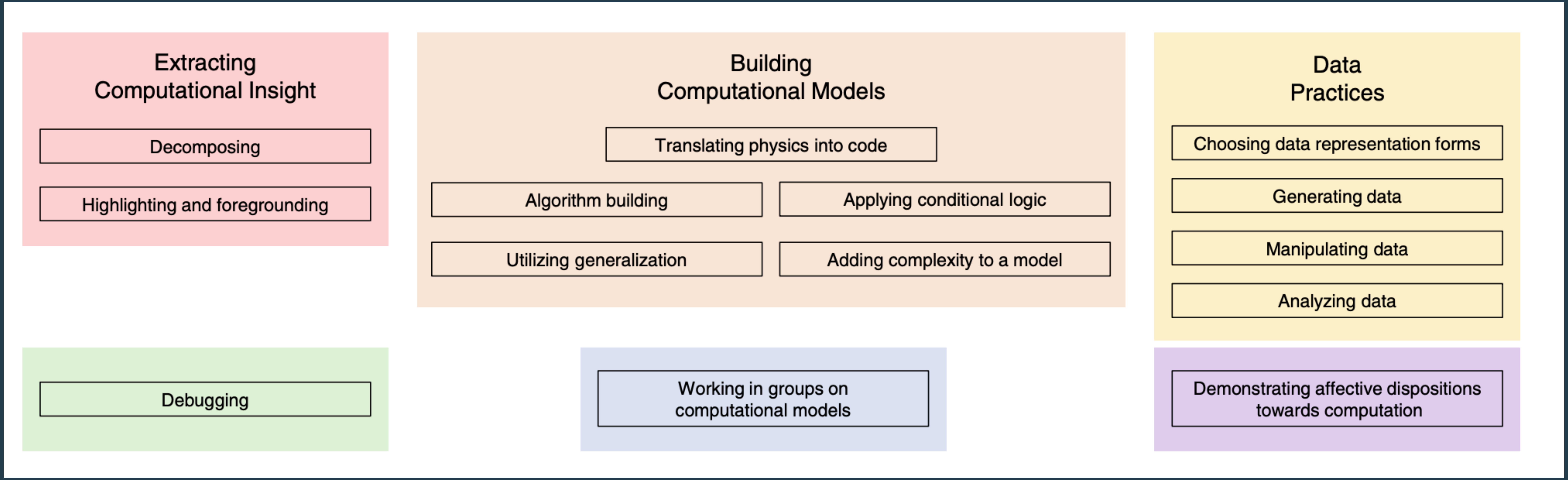
learners.[12,13] Therefore, we encourage teachers to consider past and contemporary forms of marginalization when determining standards of fairness. In other words, we recommend a "reparations-type" view when defining equity.

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 thi... about equity in terms of social marker patterns in ... teaching and learning situations. Then, we illu... our partner teachers used EQUIP in actio... sought to build equitable spaces for collabora... computation-based high school physics.

EQUIP: Equity QUantified In Par...

NSF

Analysis Framework for Computing Practices



Weller, Bott, et al, Phys Rev PER, 2022

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.

Weller, Bott, et al, Phys Rev PER, 2022

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.

Weller, Bott, et al, Phys Rev PER, 2022

Analysis Framework for Computing Practices

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

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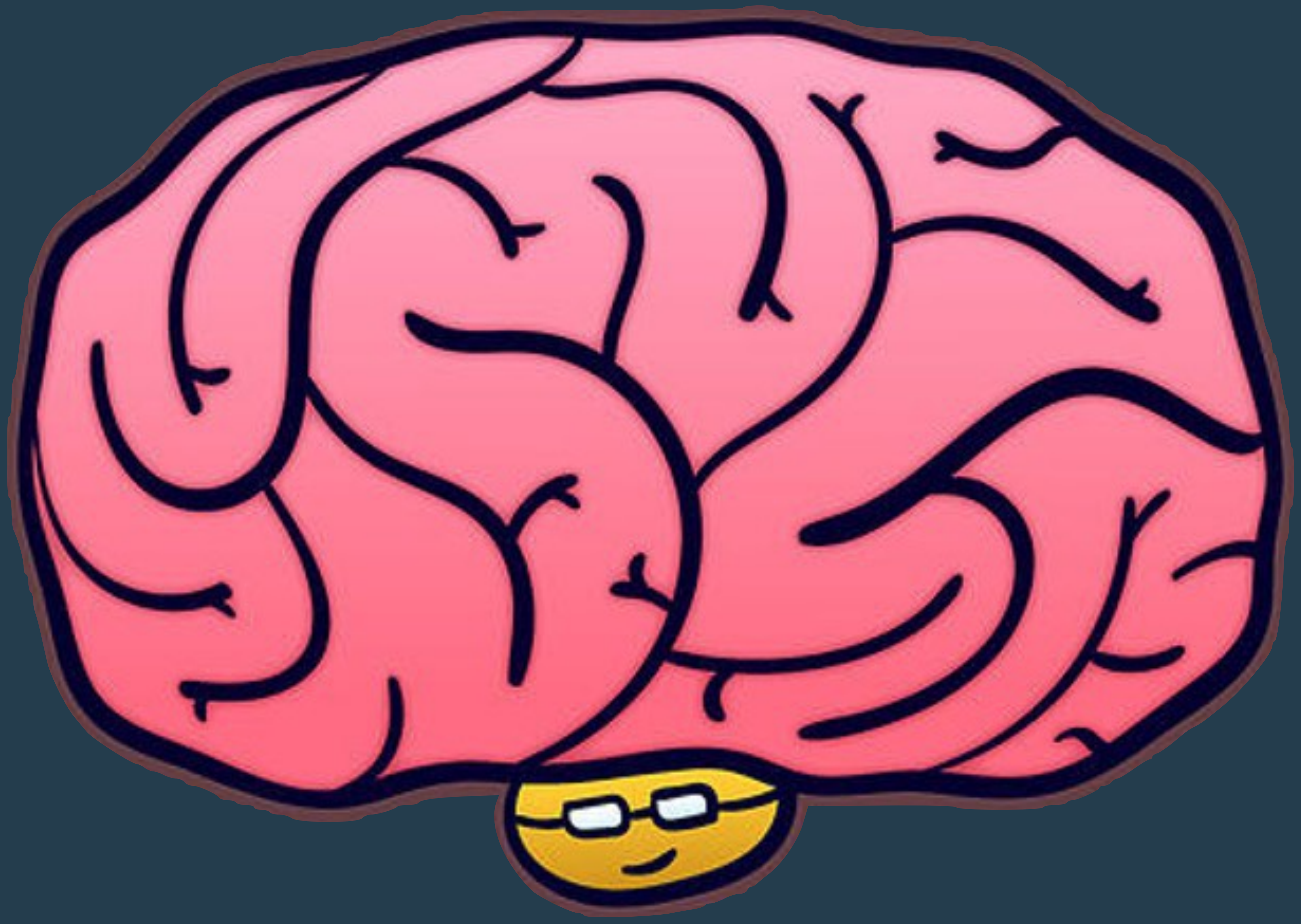
Weller, Bott, et al, Phys Rev PER, 2022


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?

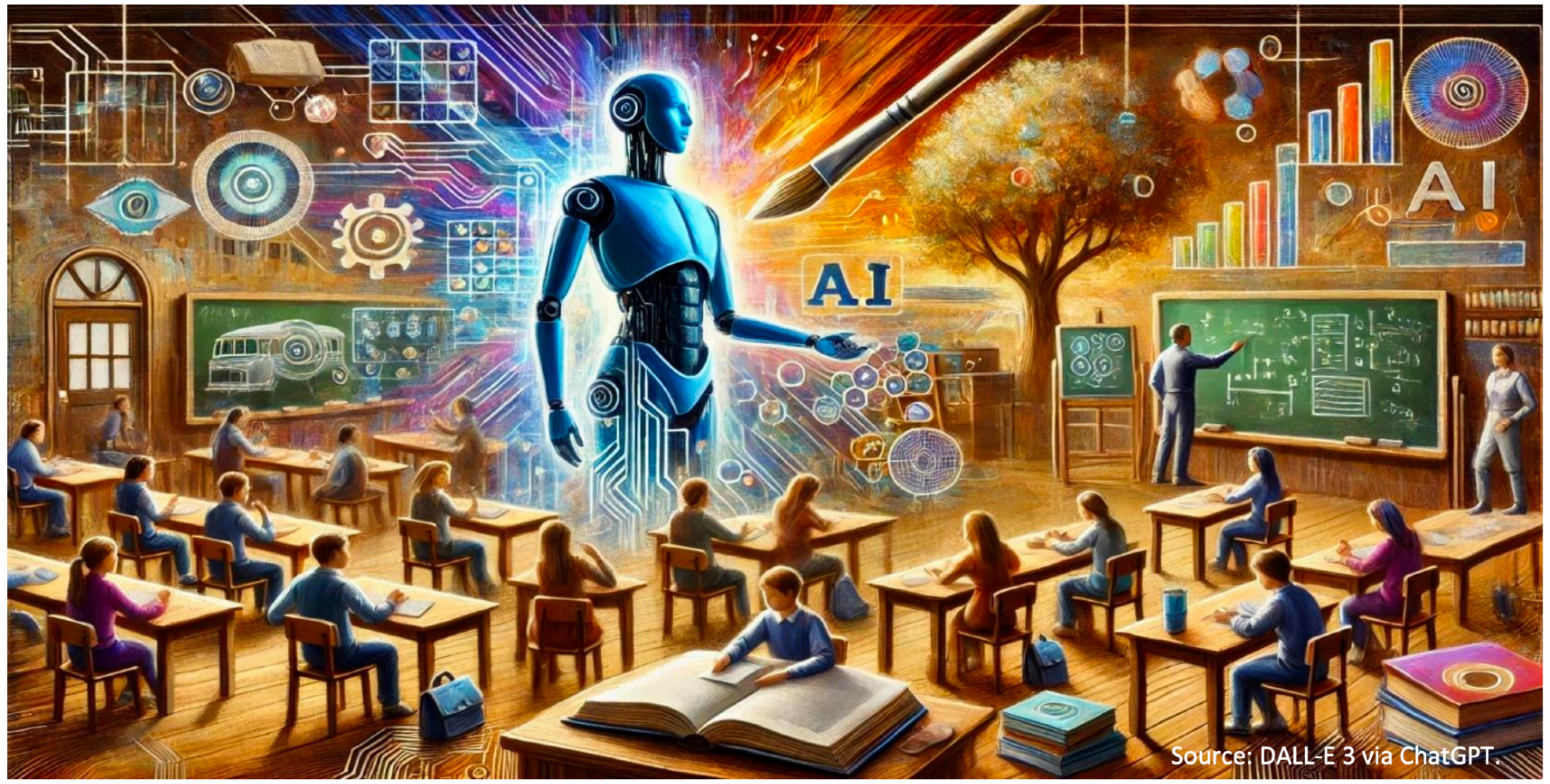
By Ray Schroeder

No. 10 | 2024 13 August 2024

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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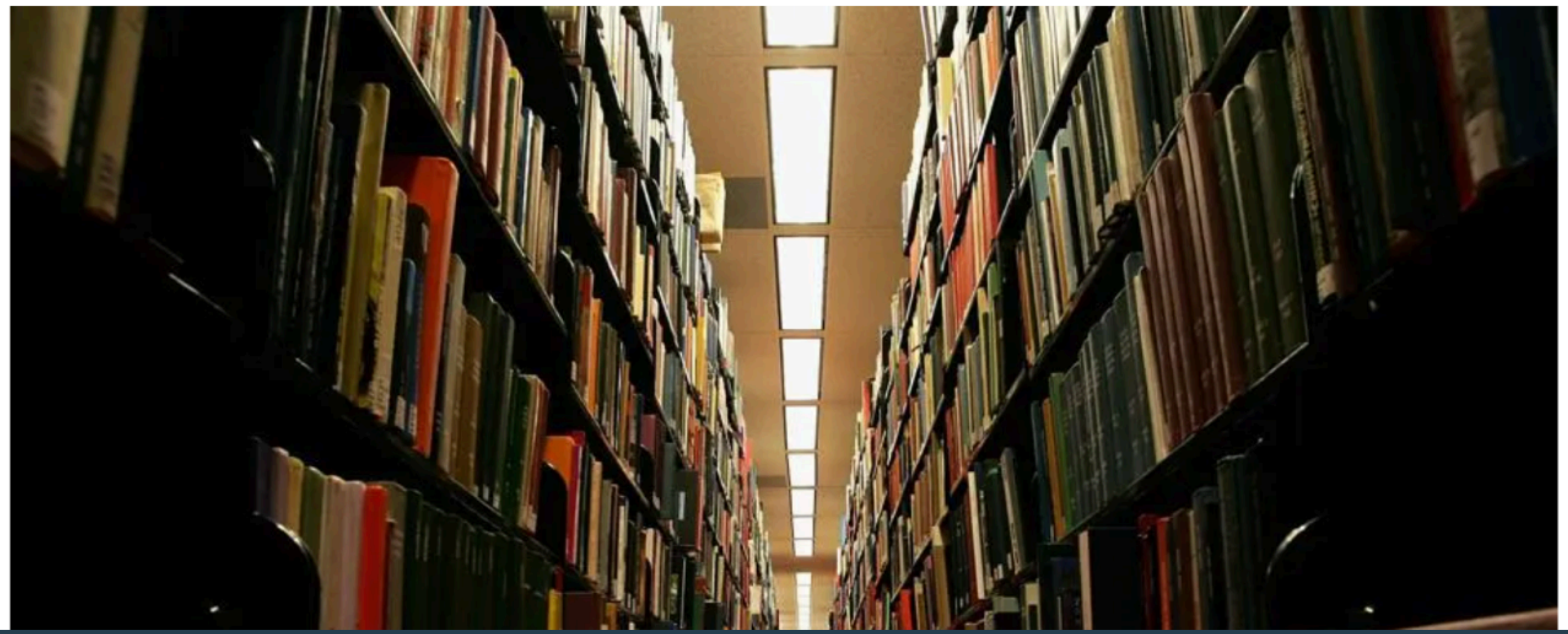
Jun 5, 2023, 09:25pm EDT

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

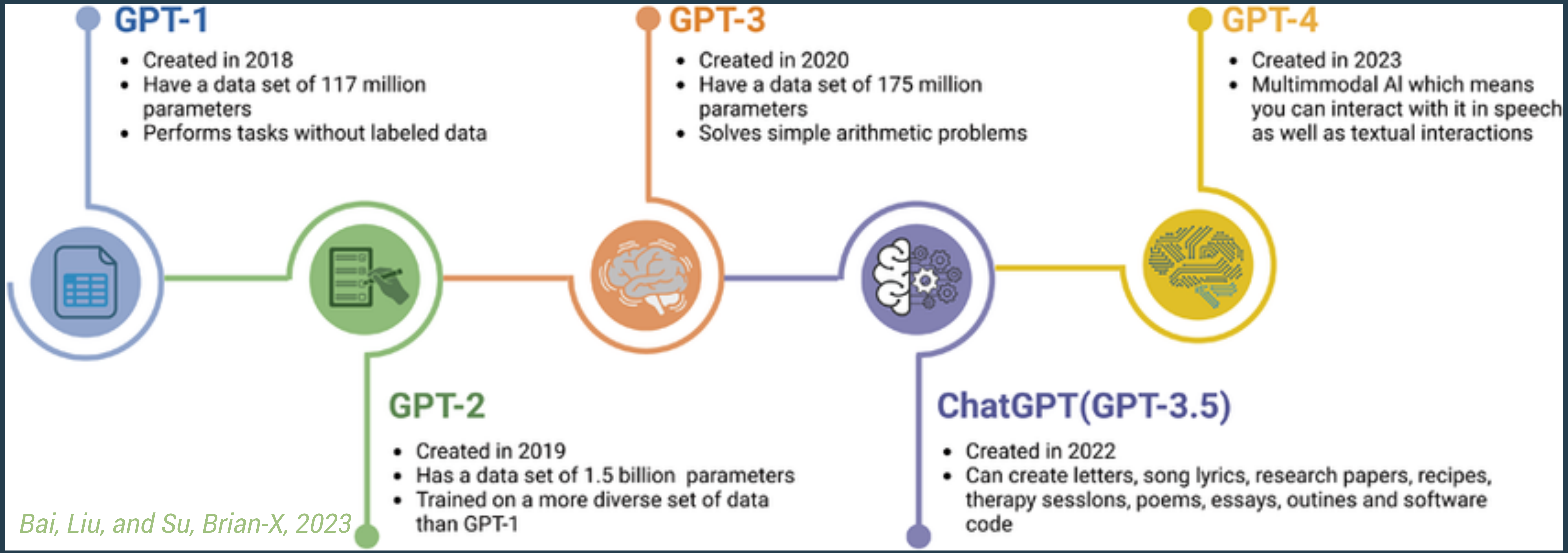
Education as a tool for Justice
education is a political act of liberation

- 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

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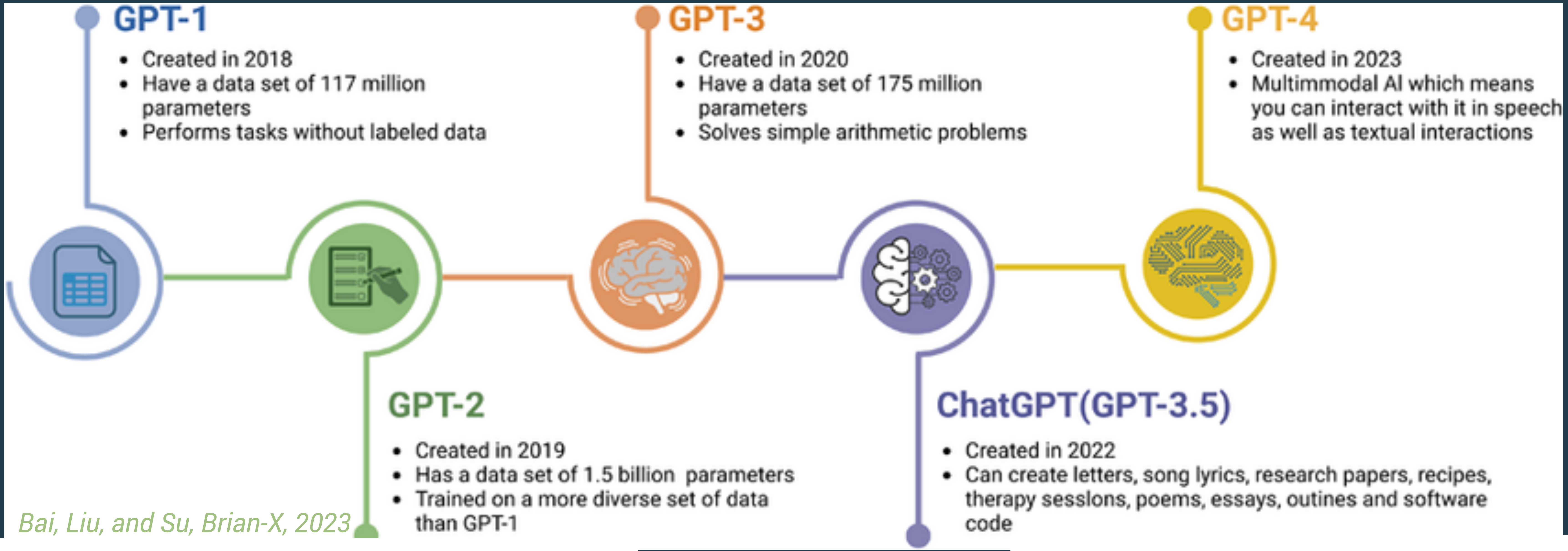
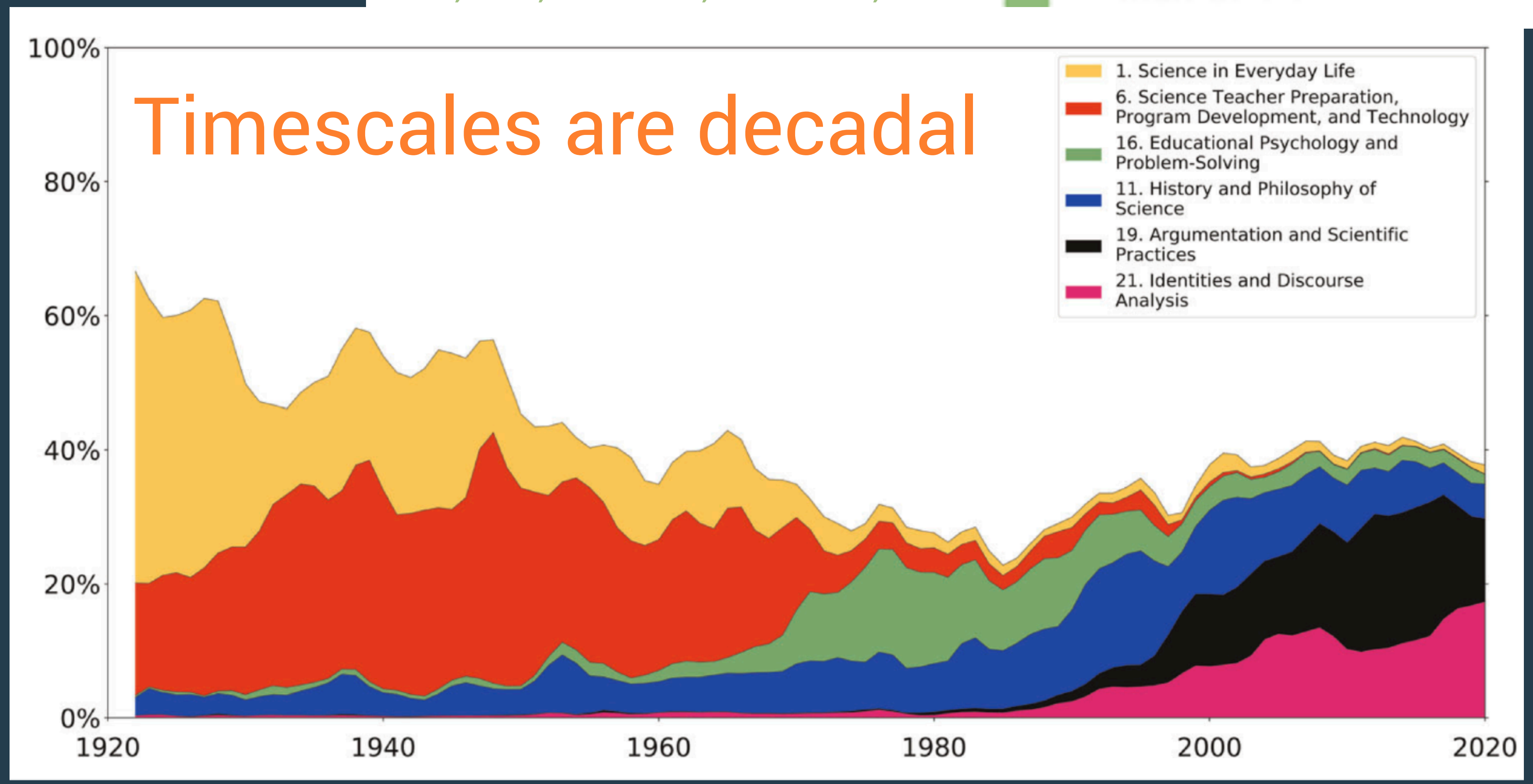
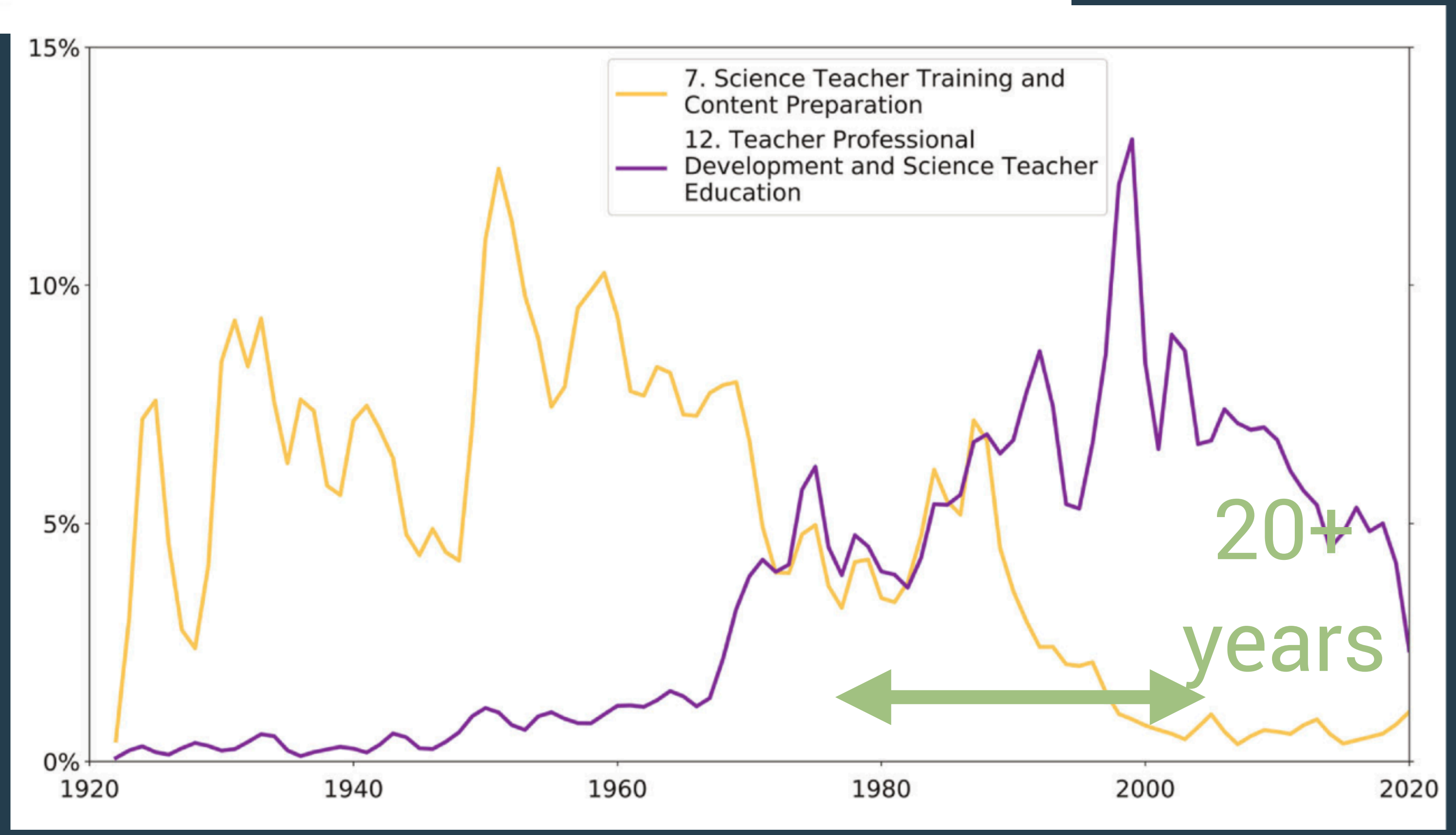


Bai, Liu, and Su, Brian-X, 2023





Odden, Marin, and Rudolph, Science Education, 2021

Computing Education Research Lab

CMSE Research Program

CERL@MSU
COMPUTING EDUCATION RESEARCH LAB

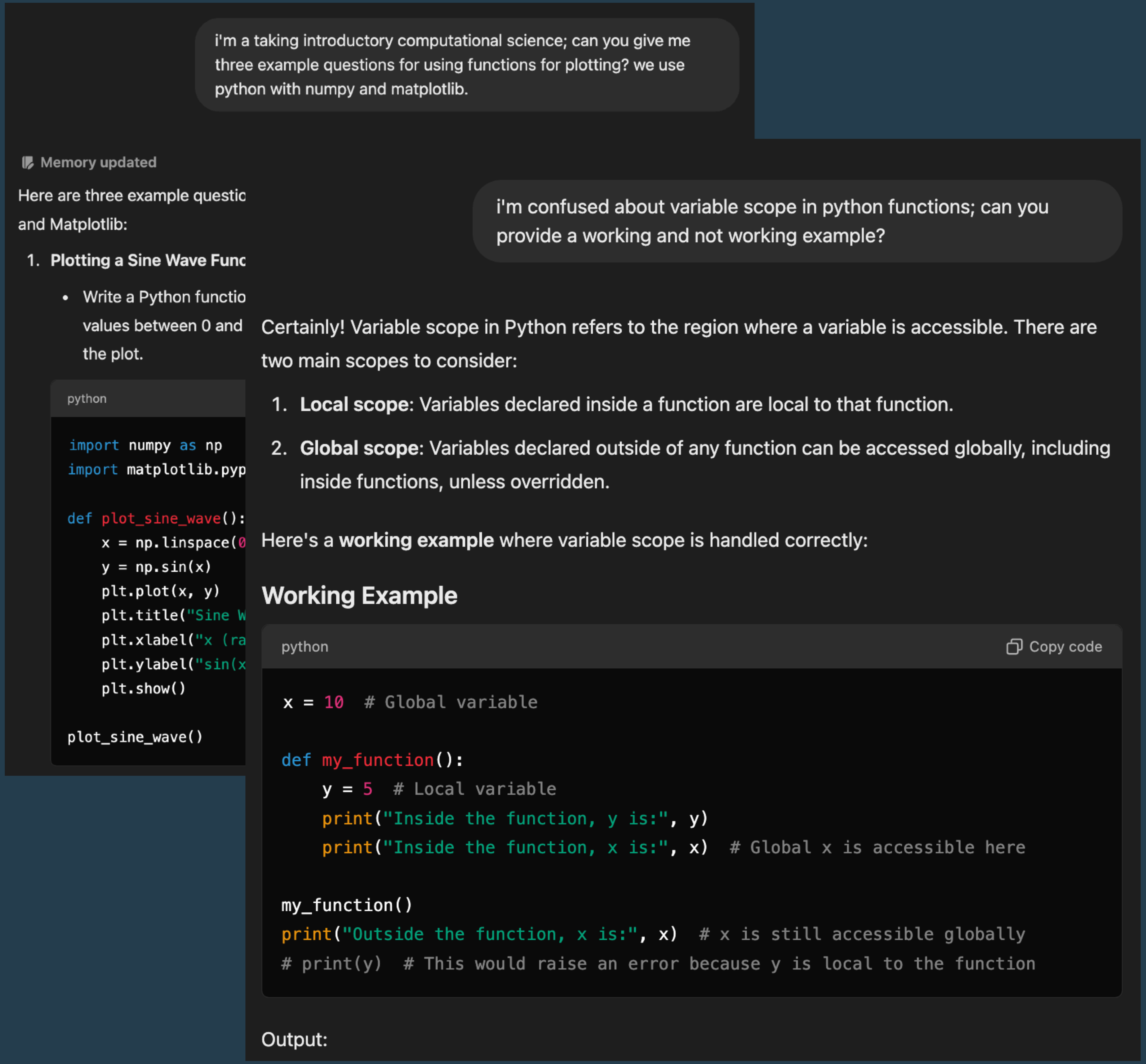
The CERL squirrels

Driving Questions

- 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?

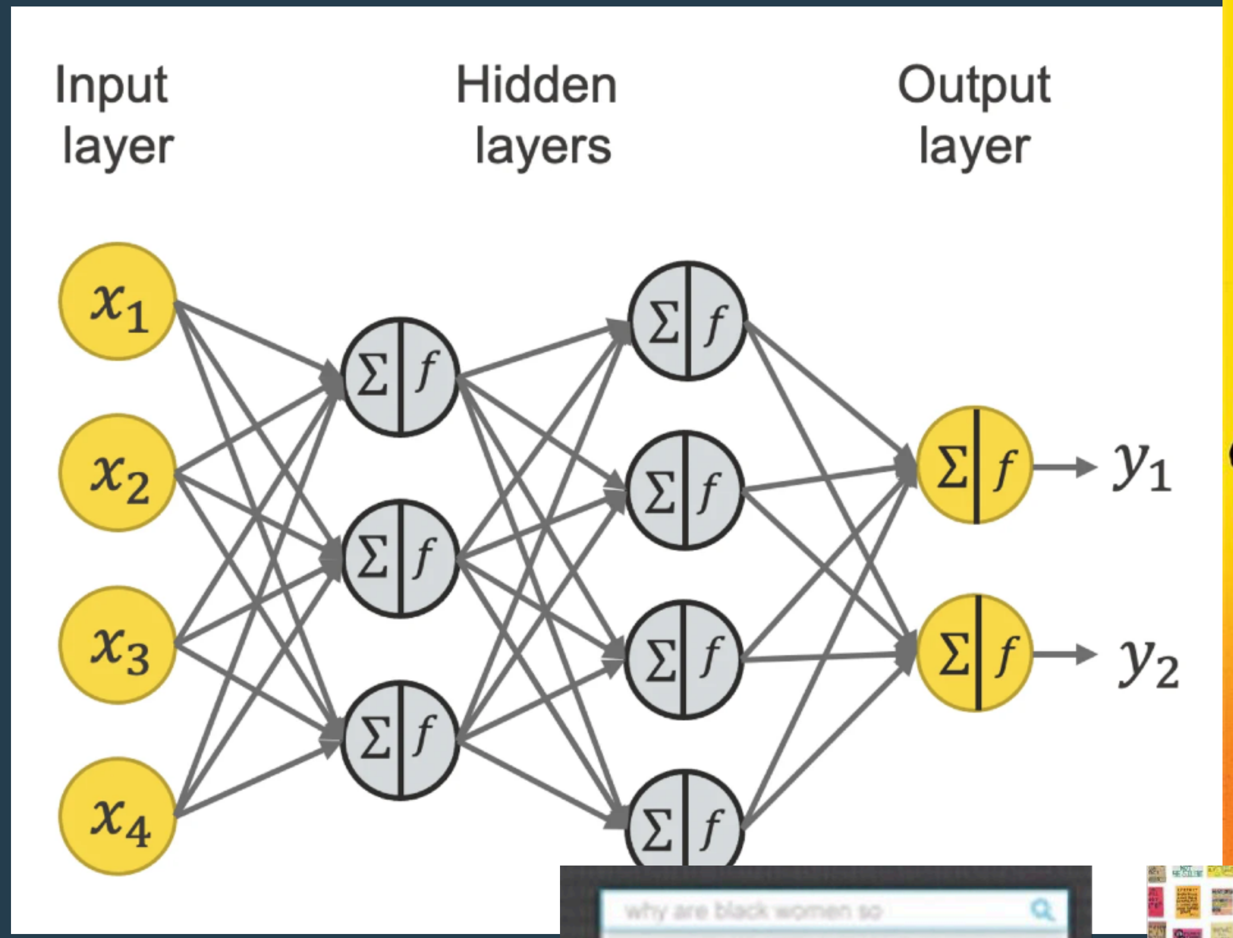
https://msu-cerl.github.io/

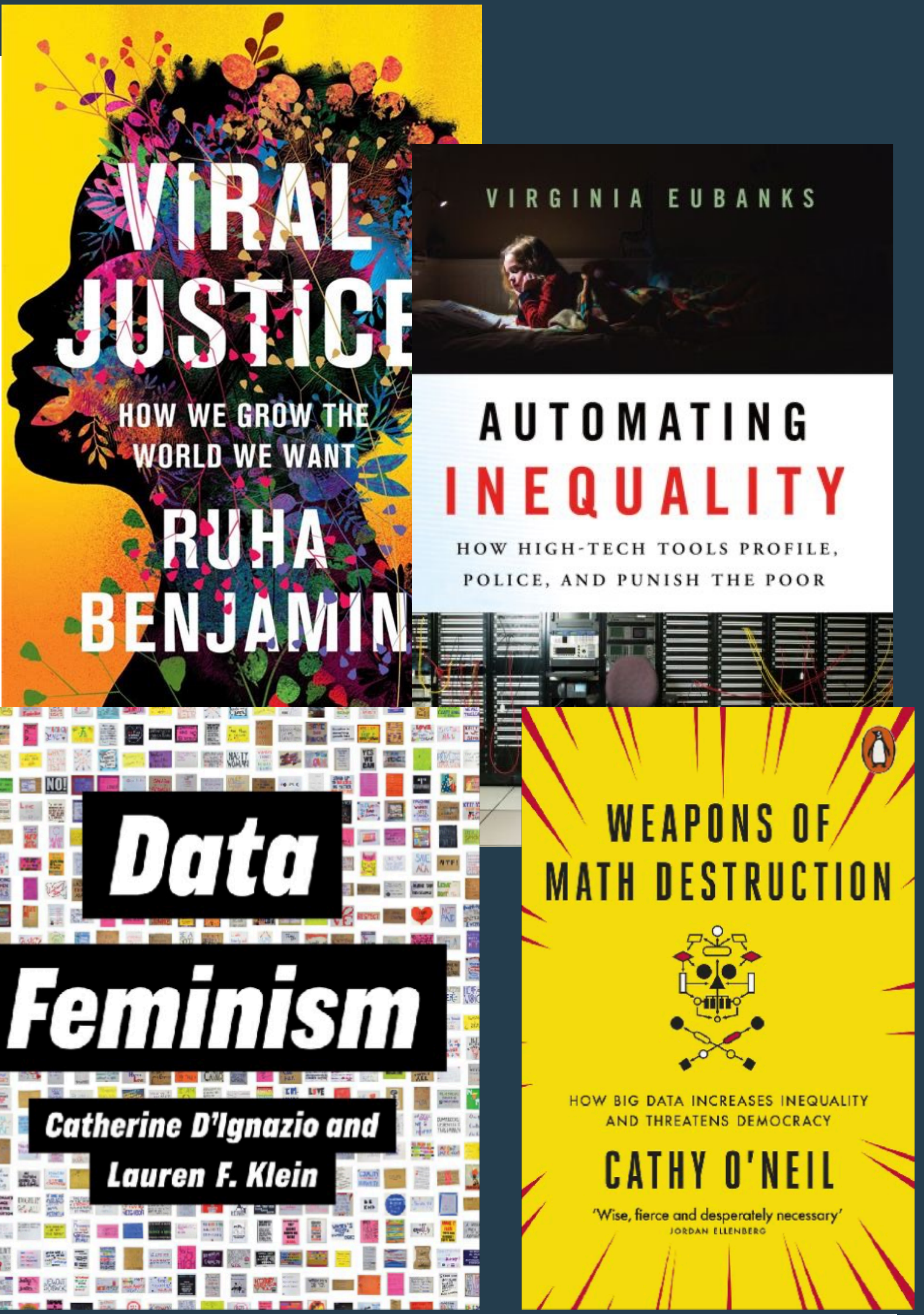
Two Concerns (for now)

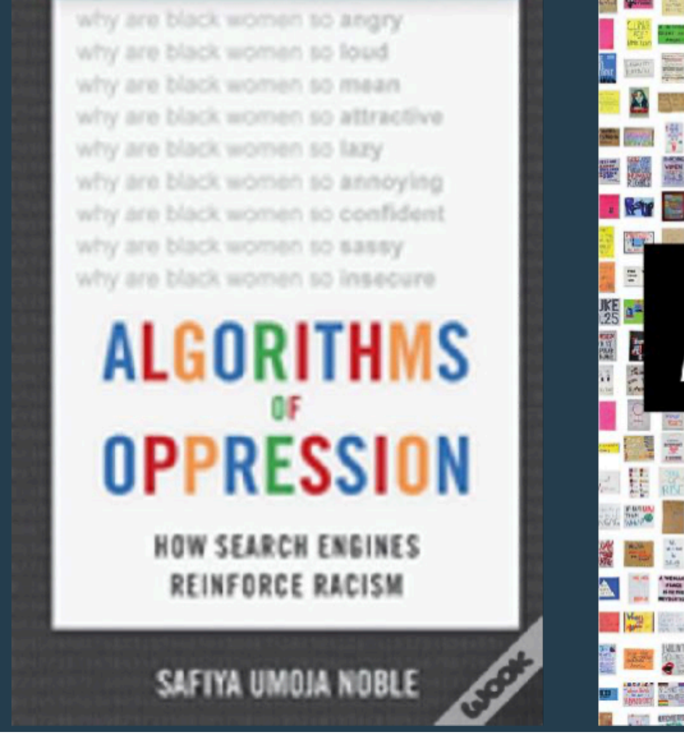


The Use of AI in CMSE classrooms

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 Shah[1] · Aman Yadav[2]

Educating students for a world with ML & AI

AI in my classes

Co-designed policy

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

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

jupyter {book}

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

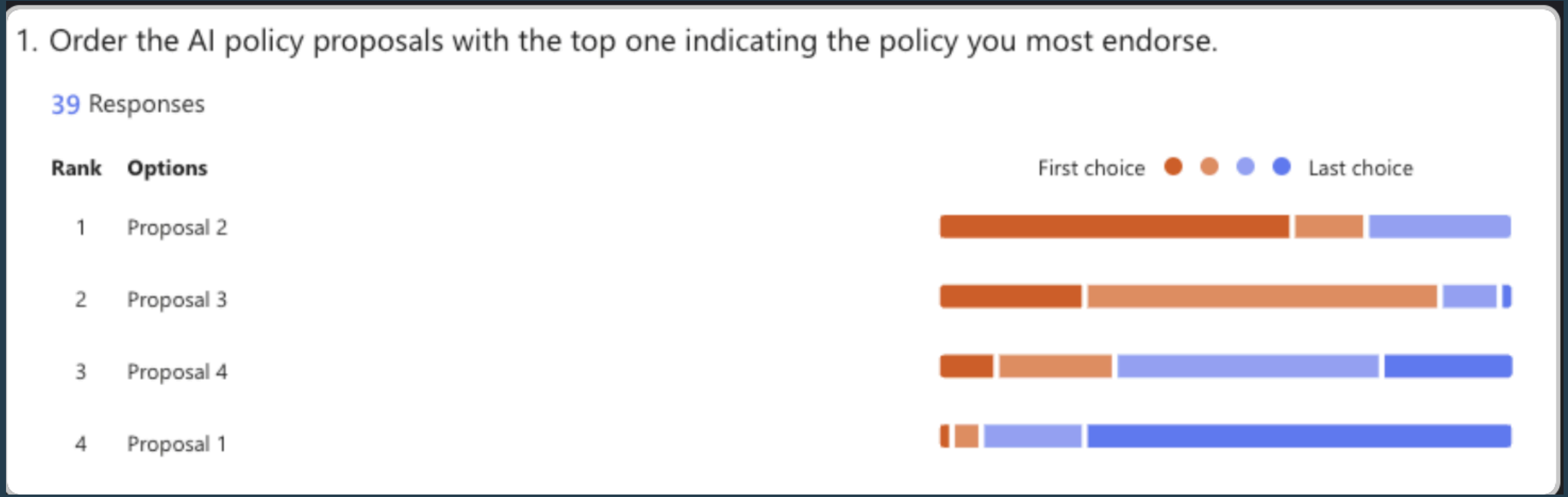
We define **productivity** as the ability to use Generative AI to deepen your understanding of Classical Mechanics.

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

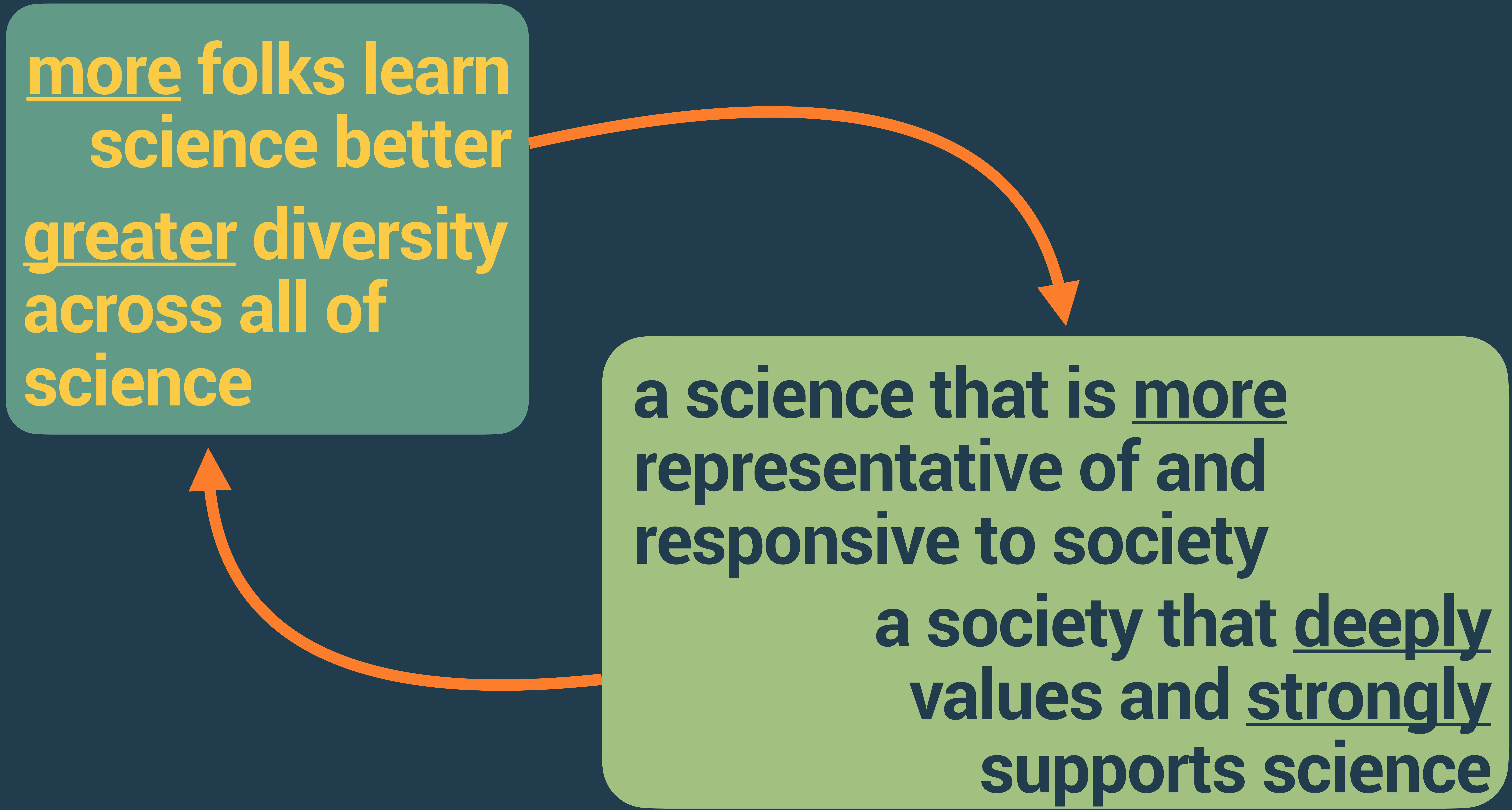


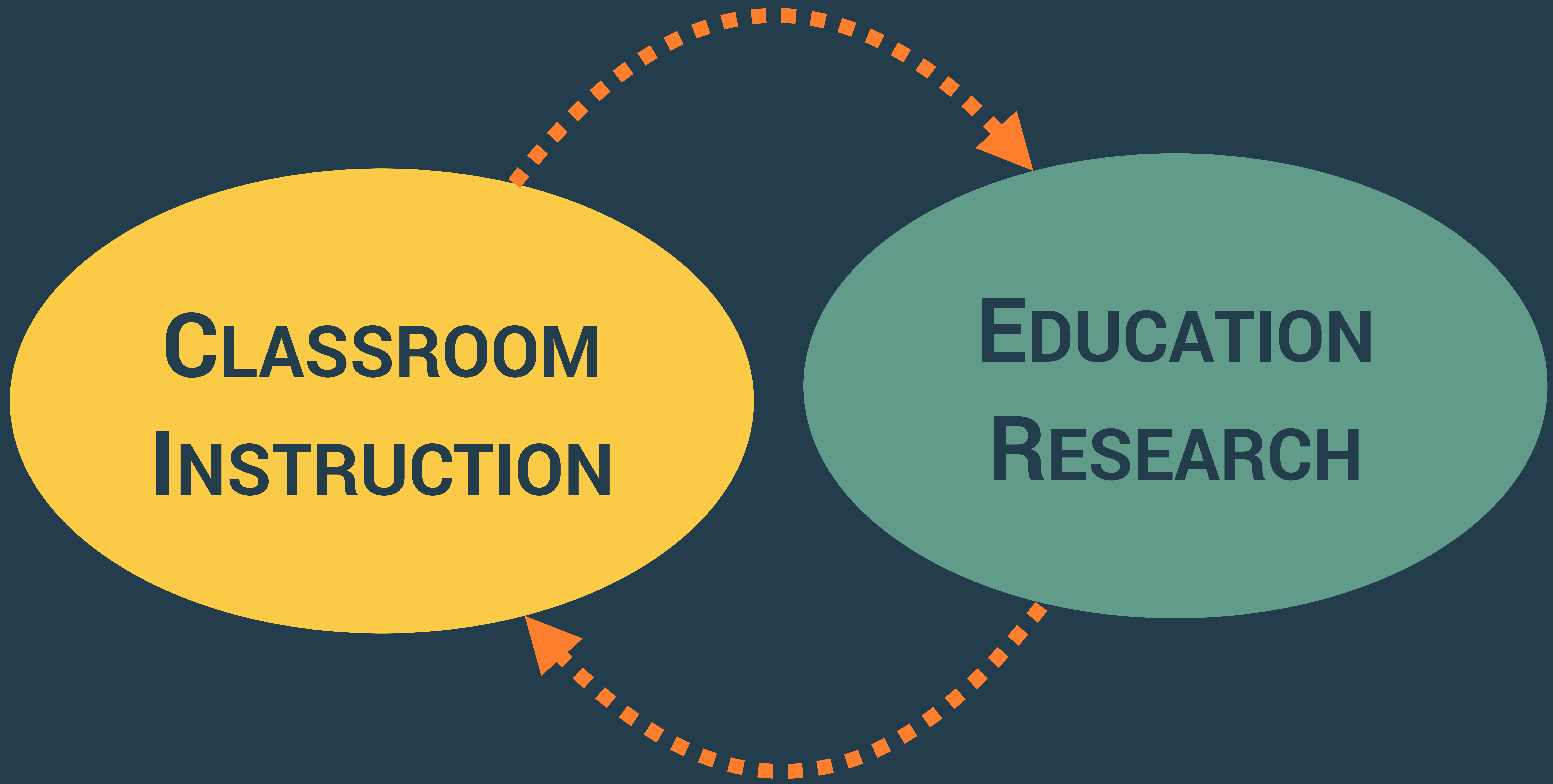
Proposal 2: We adopt a policy that allows AI use for brainstorming, help, and editing.

- 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

- 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 into STEM courses. The future of STEM demands it.
- It’s important that we engage with AI and STEM 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 science that is more representative of and responsive to society
a society that deeply values and strongly supports science


Classroom Instruction
Education Research

Thanks, y'all!

¿questions?

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msu-cerl.github.io

slides?

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Centre for Computing in Science Education

I stand with my queer and undocumented family, friends, and colleagues.

Extra Slides