MICHIGAN STATE UNIVERSITY

UiO : University of Oslo

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

Department of Physics and Astronomy

CMSE

CCSE
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

UTSF
MICHIGAN STATE UNIVERSITY
UNION OF TENURE SYSTEM FACULTY

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.

Twin goals of our program

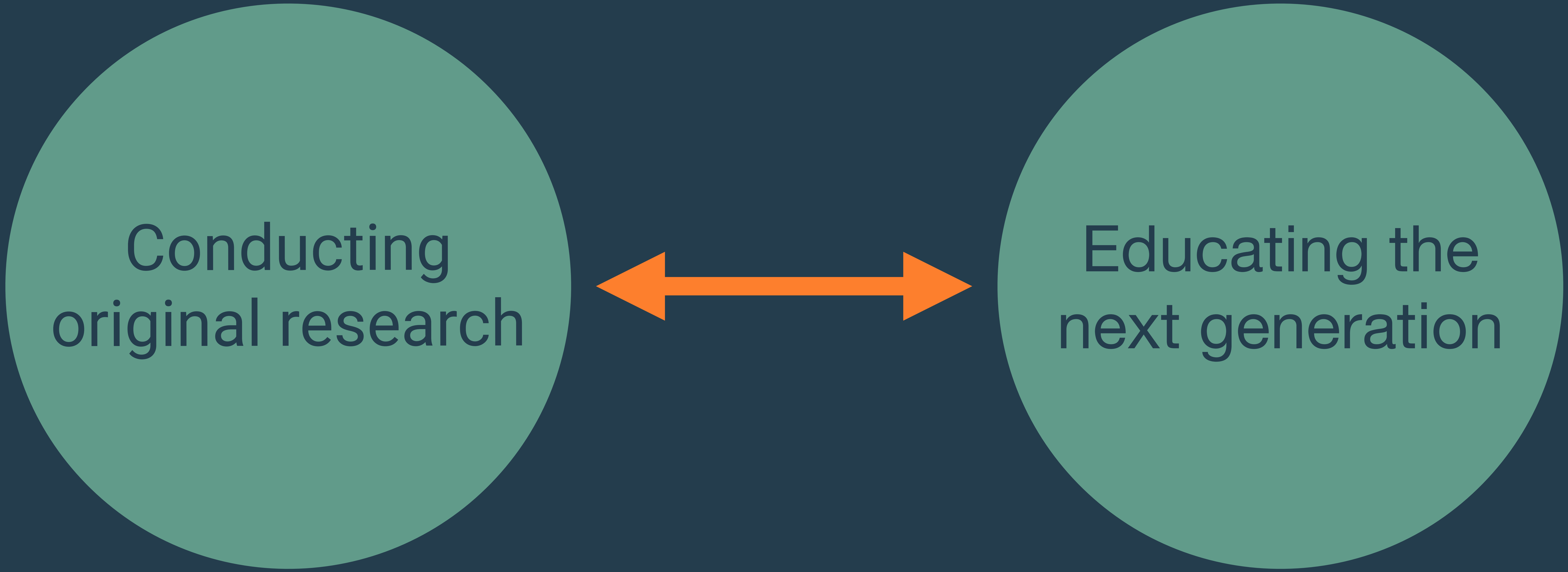
MICHIGAN STATE UNIVERSITY

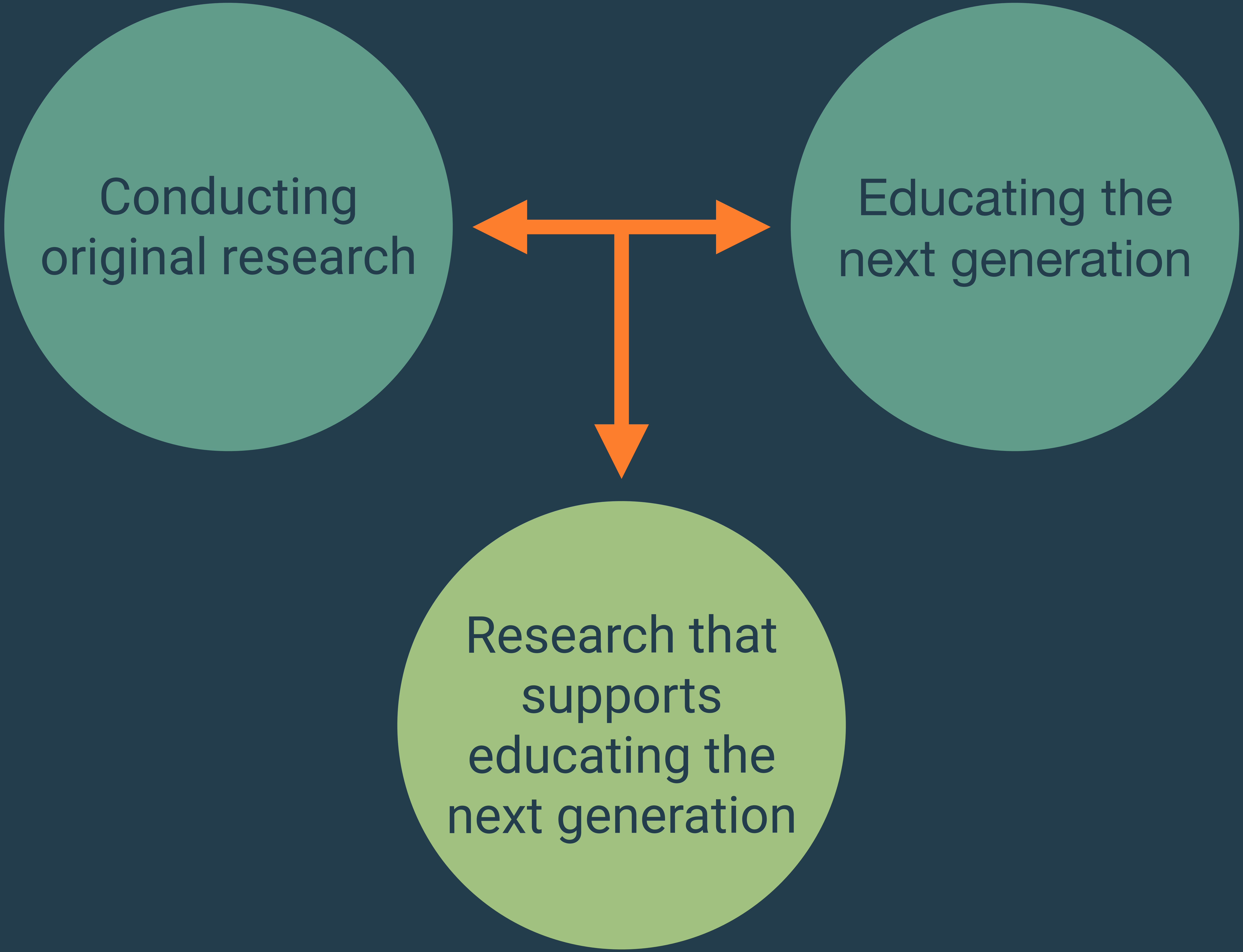
Conducting Original Research

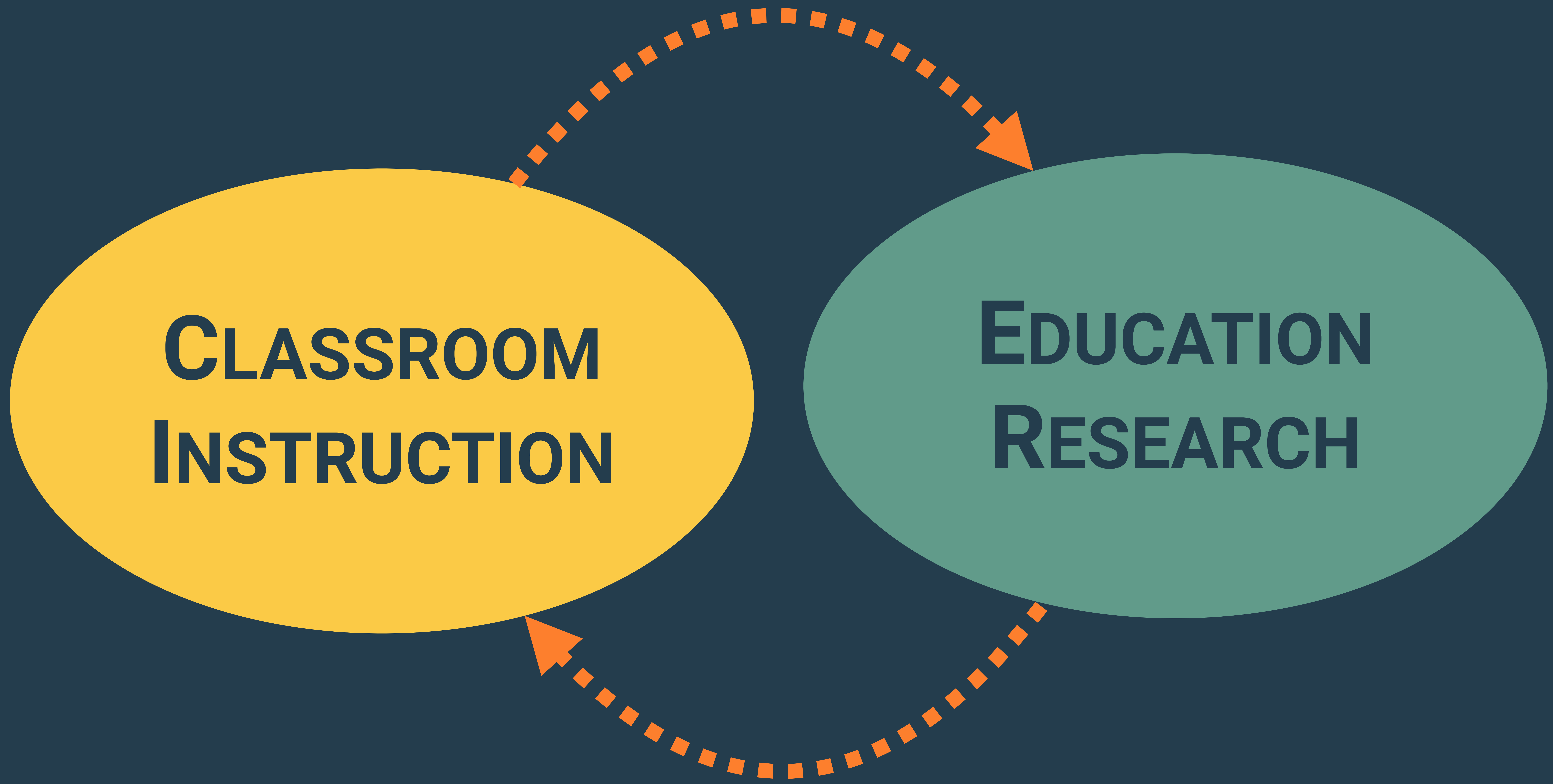
Two students working on
an FRIB experiment

Educating the Next Generation

Students working on introductory physics
lab in Lyman Briggs College

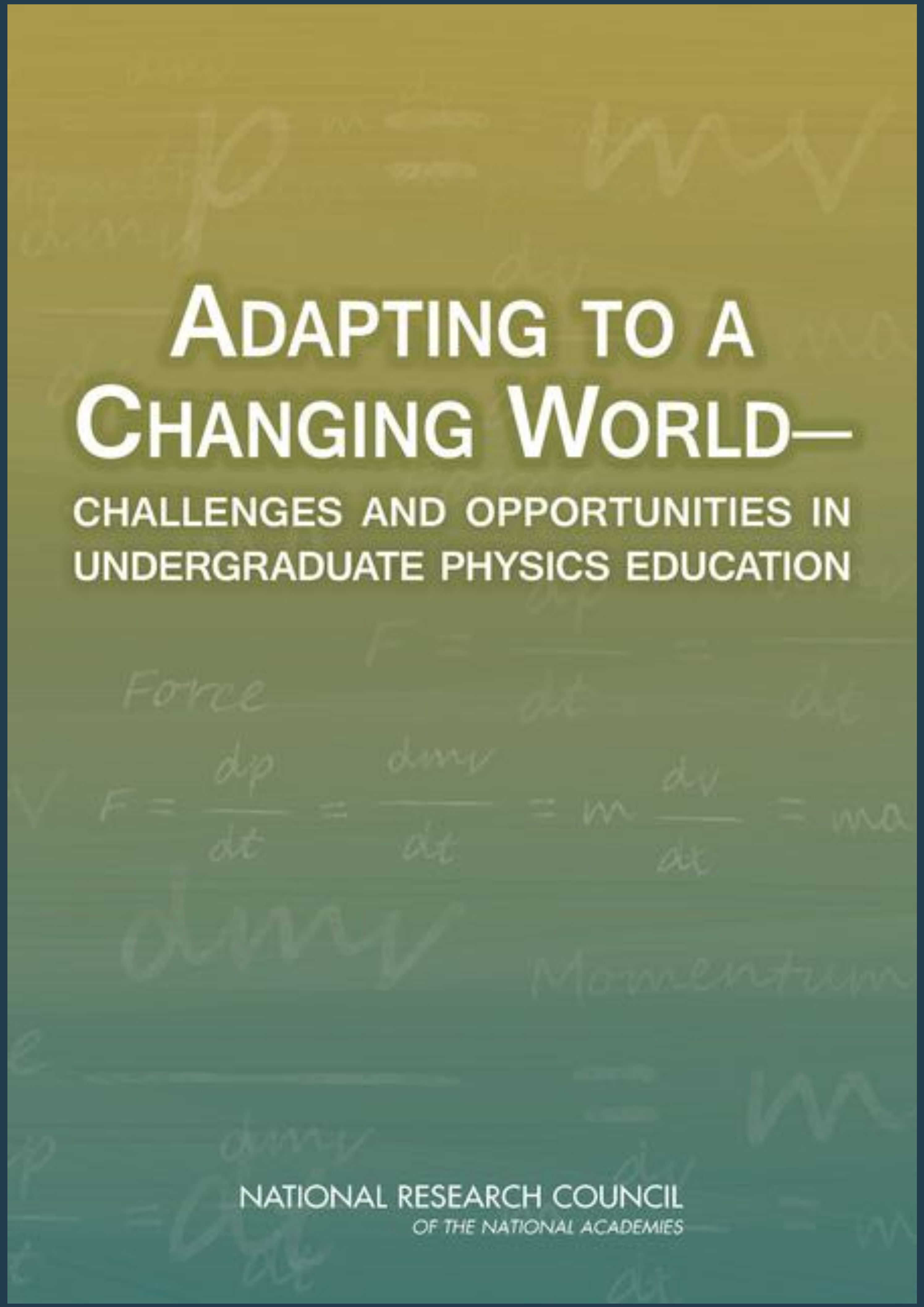

Conducting original research
Educating the next generation


Conducting original research
Educating the next generation
Research that supports educating the next generation


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.

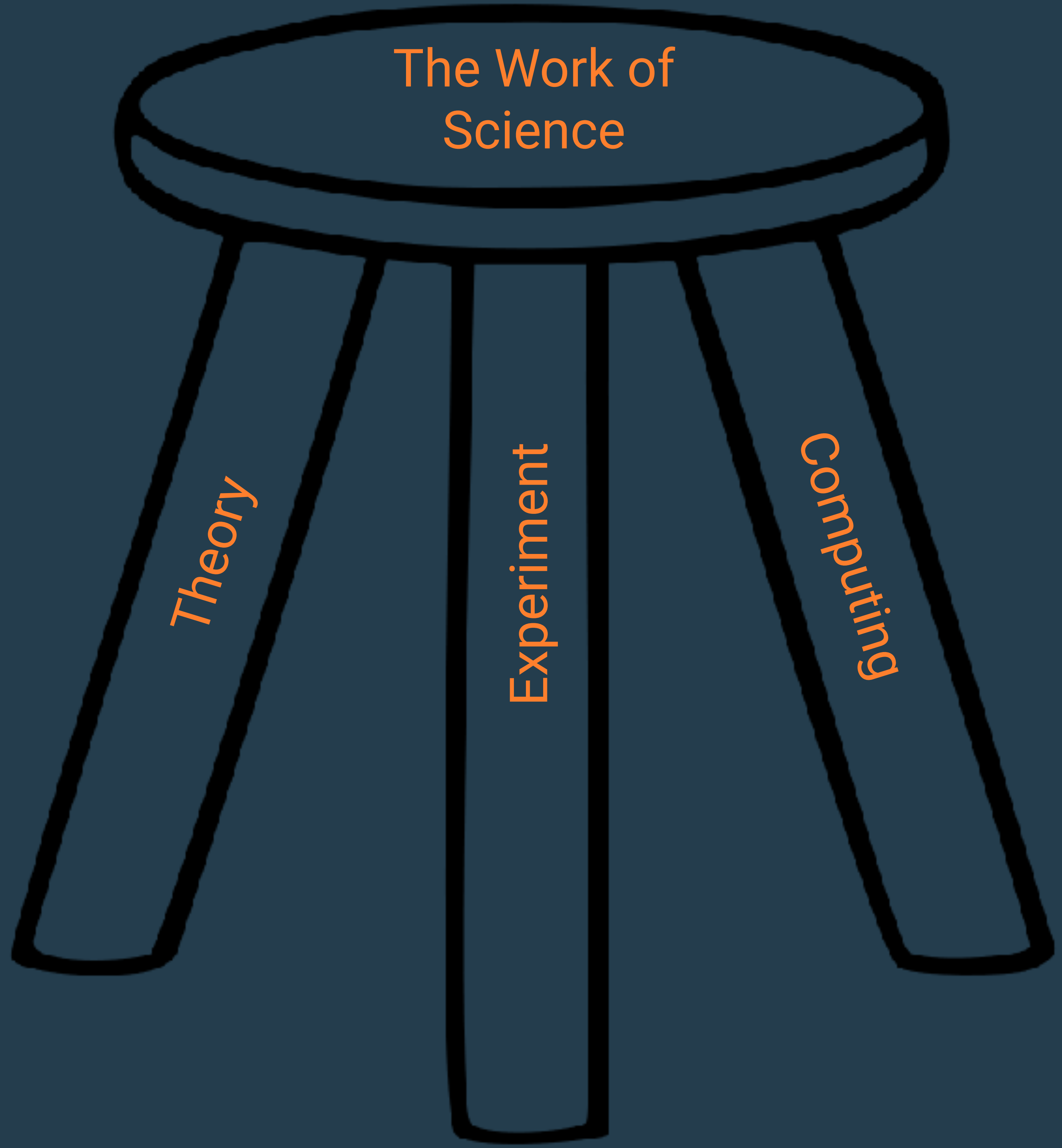
Nicholson and Mulvey (AIP, 2011); White and Chu (AIP, 2014); Porter, Church, and Ivie (AIP, 2024)

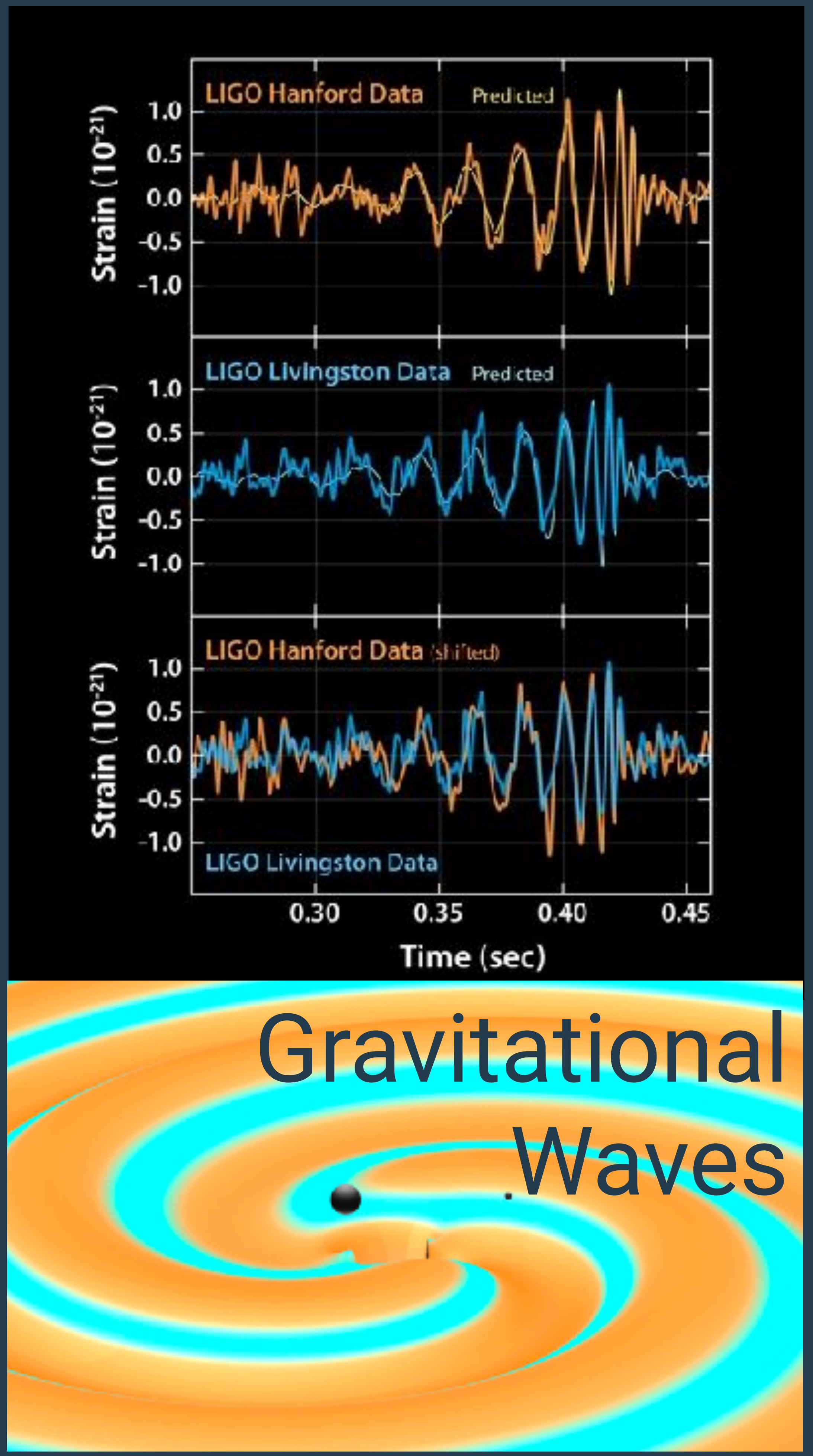
Physics is changing; we are using new tools and new techniques

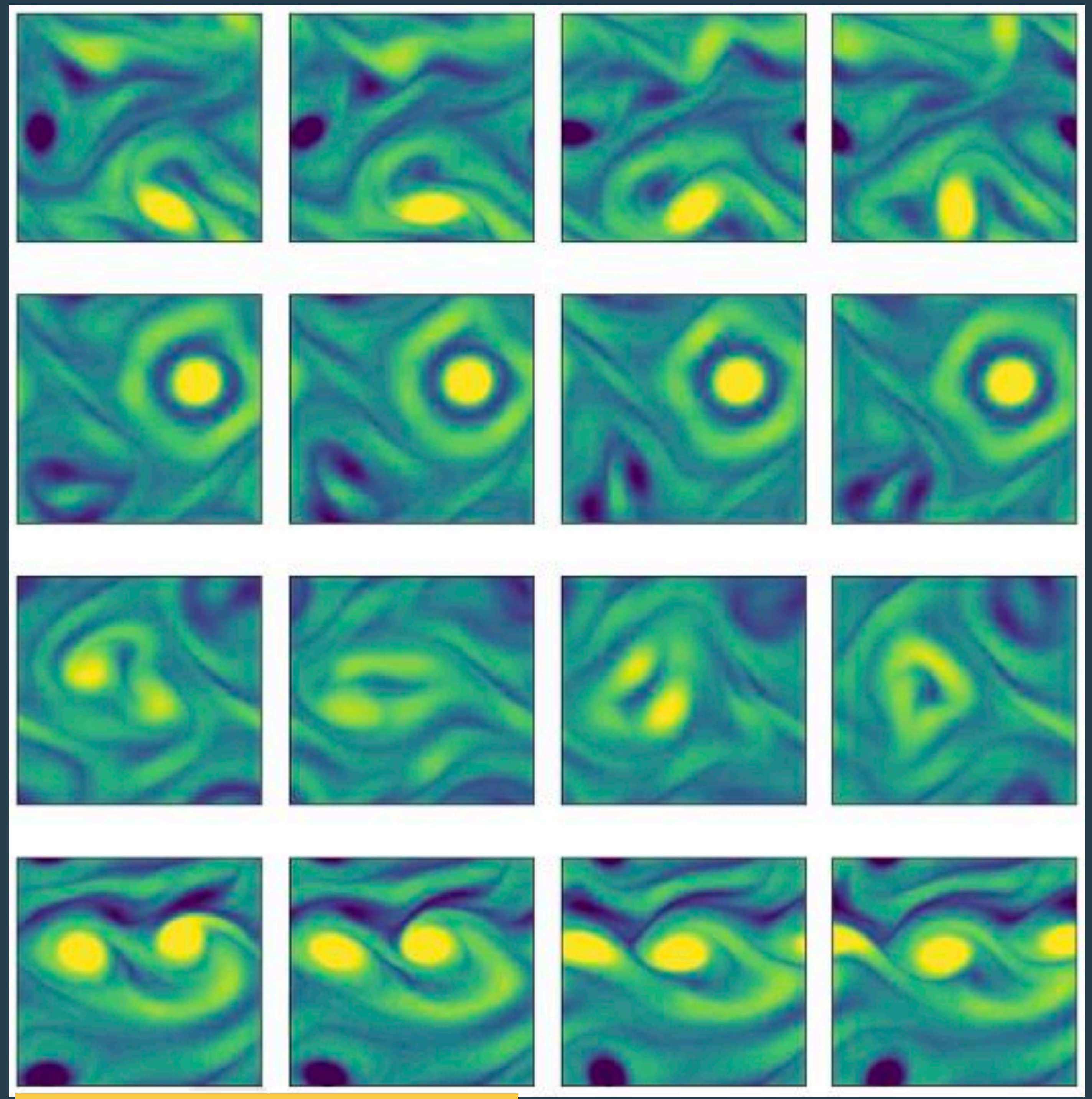
Kozminski et al (AAPT, 2014); Behringer et al (AAPT, 2016); Caballero et al (AAPT, 2020)

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

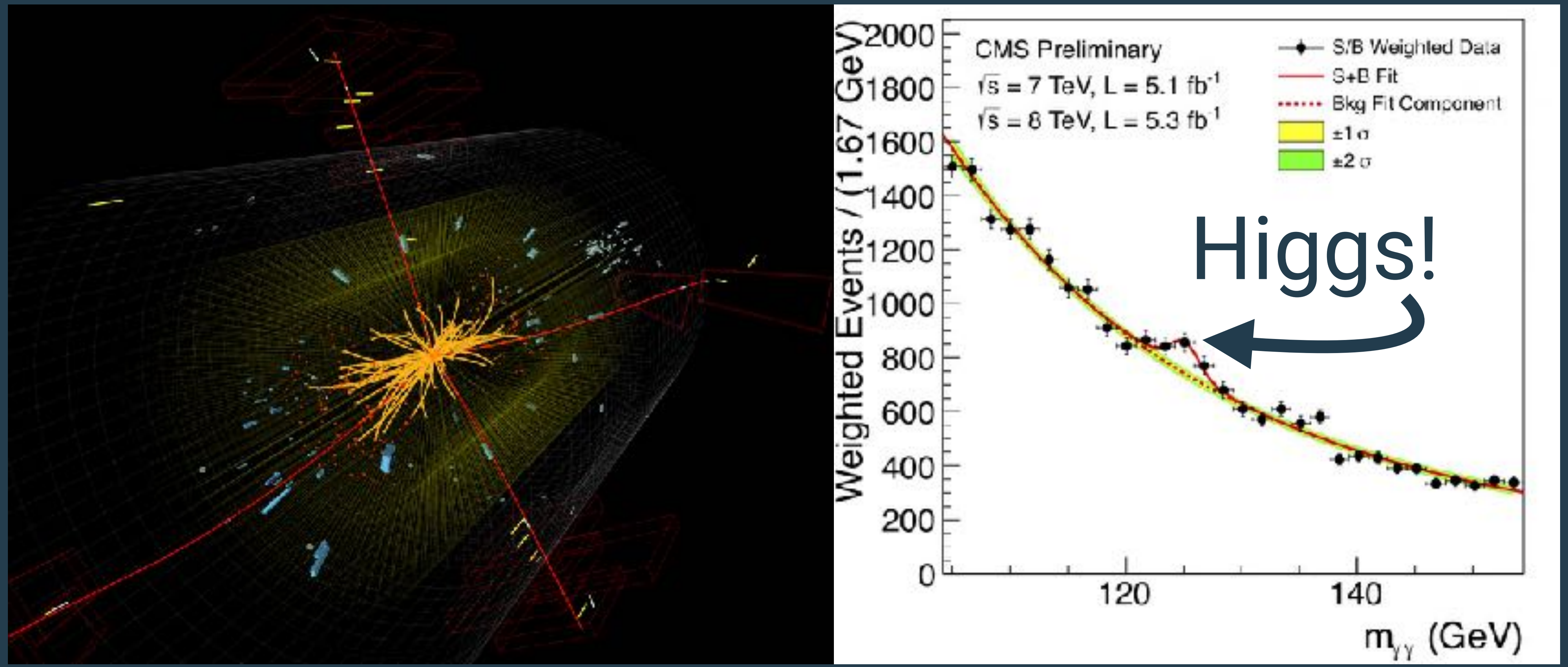
Computing is how science is done.





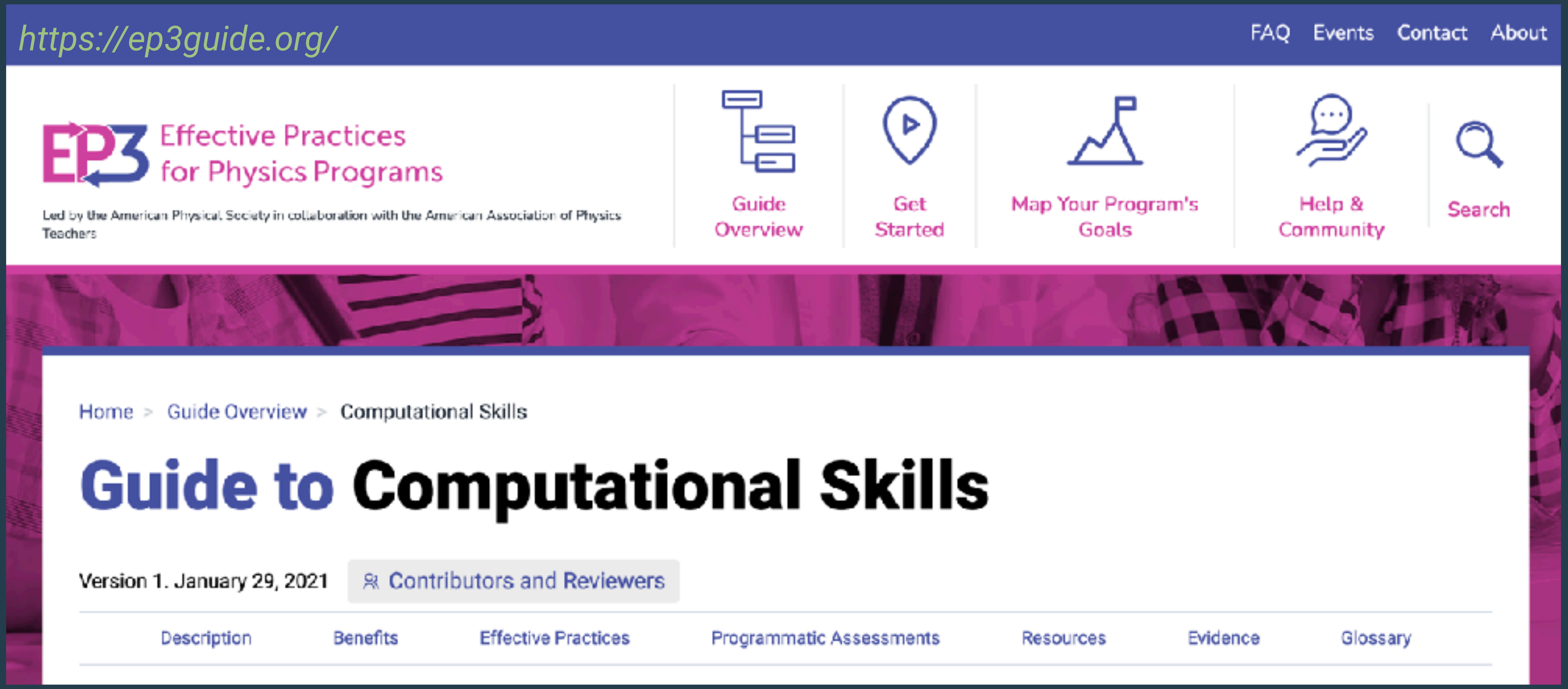


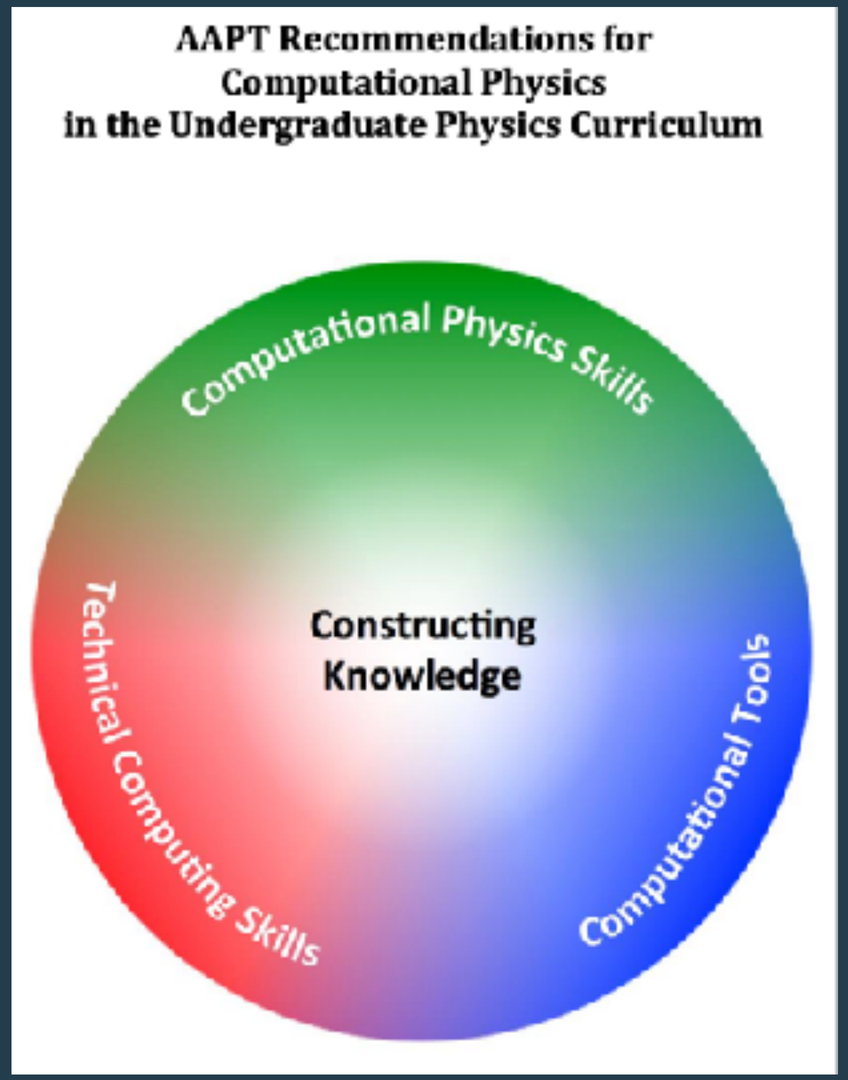
Turbulence



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



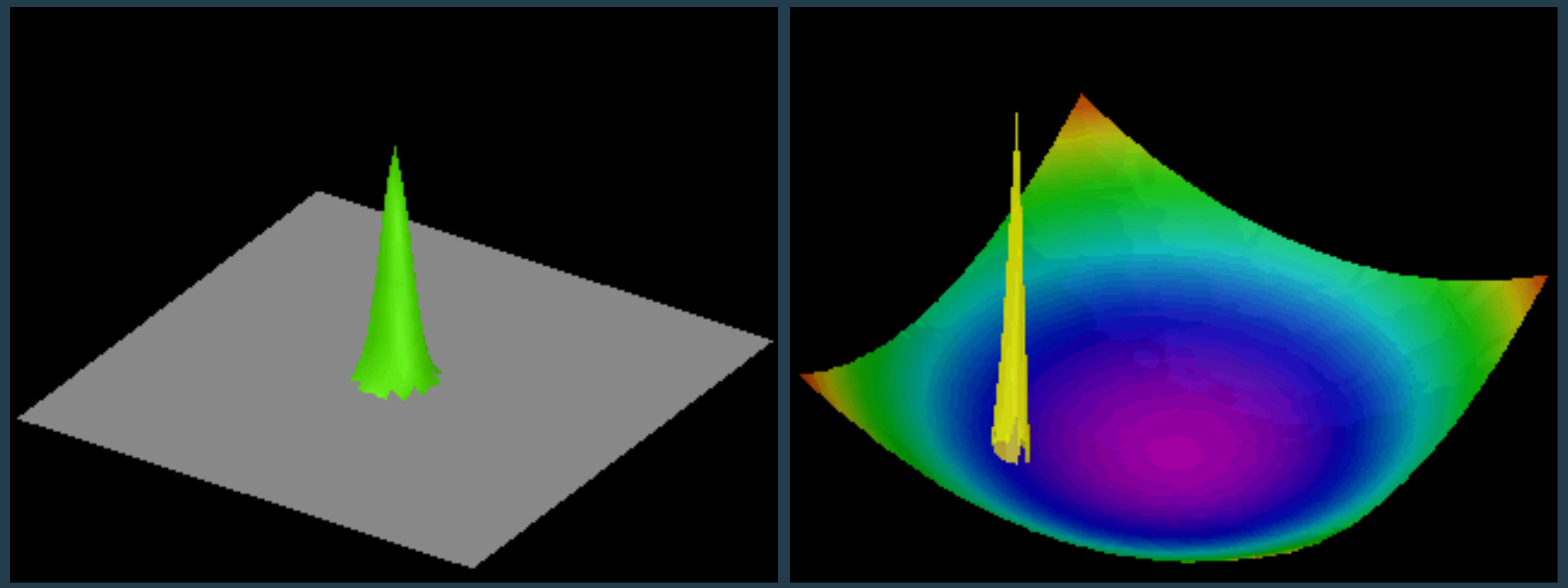


Departments should strive to:

- 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

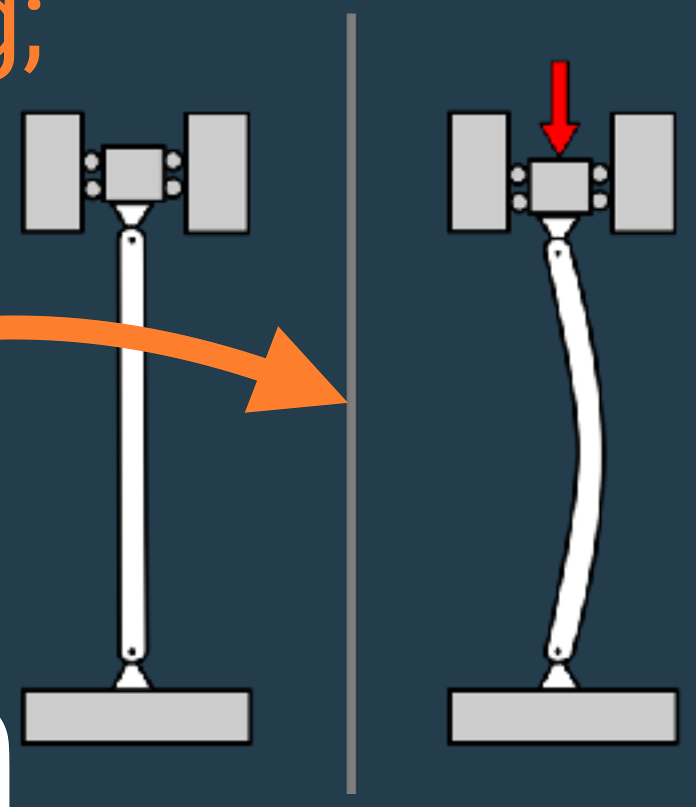
Physics education requires a computing education

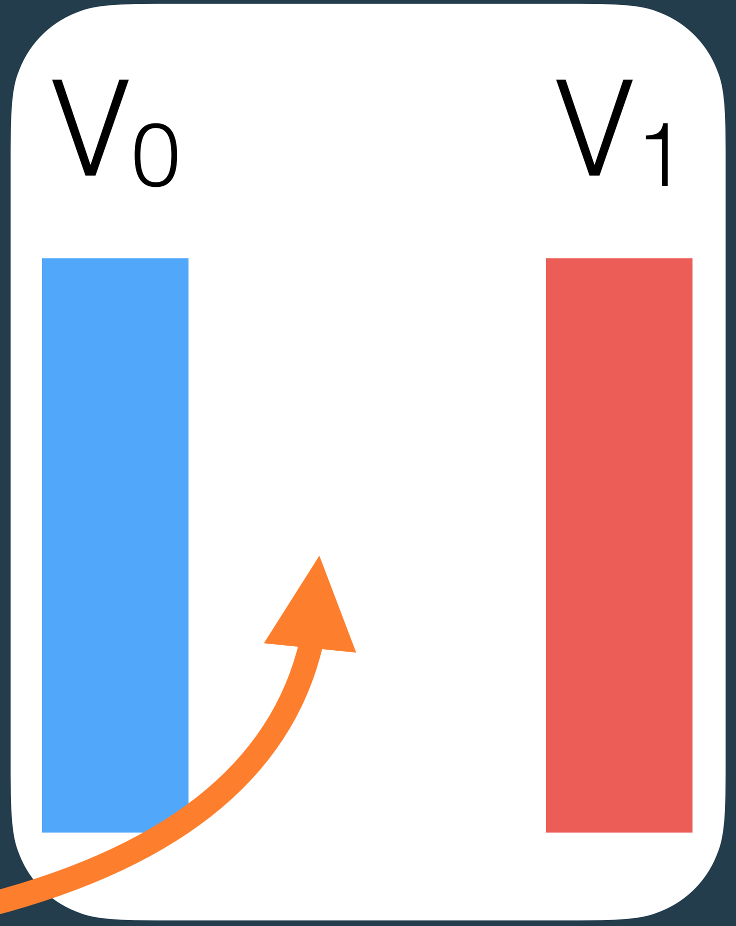


Michielson and De Raedt, 2012

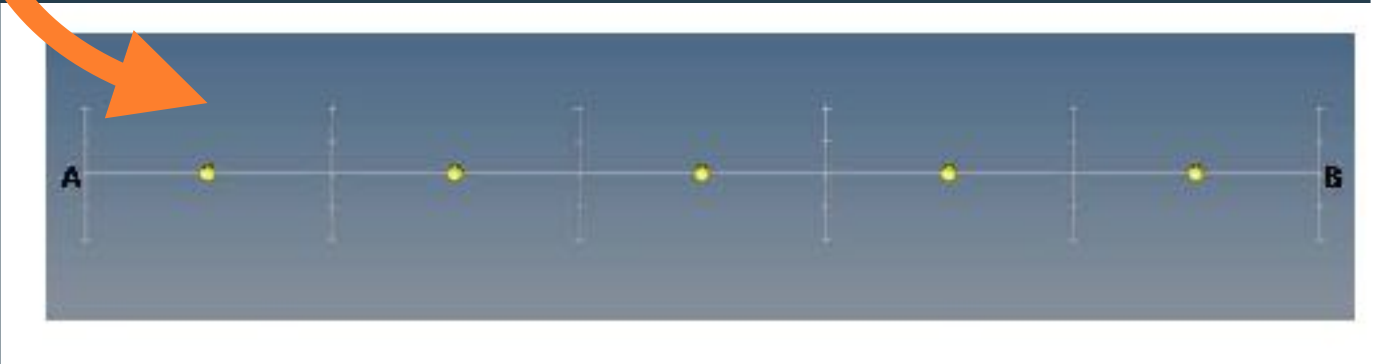
Construct visualizations; develop conceptual understanding

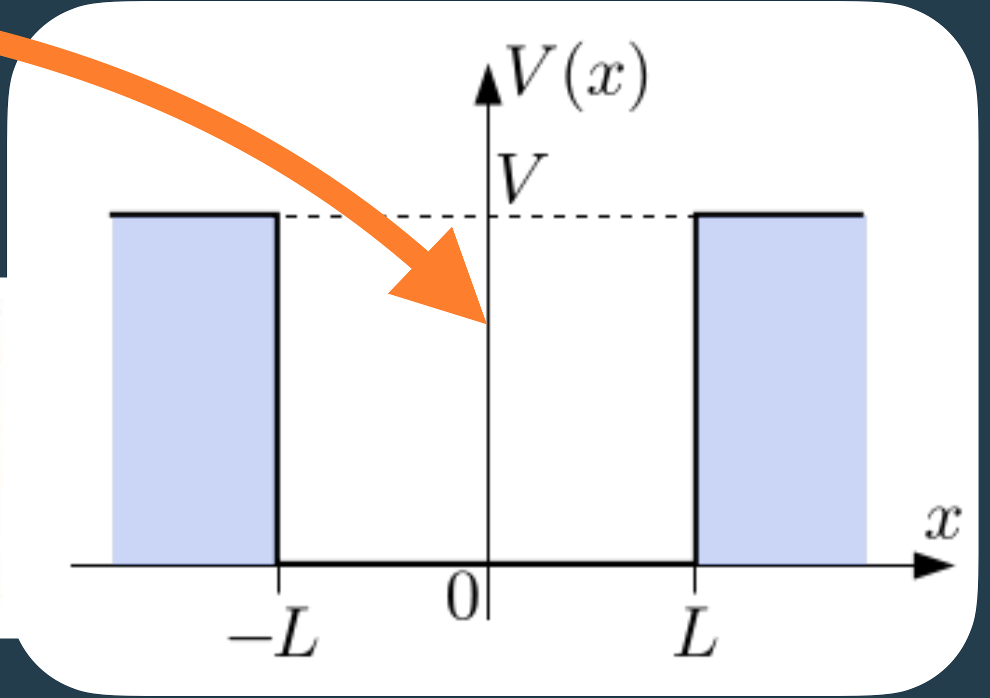
Apply algorithmic thinking; generalize problem solving





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





Teach necessary skills; prepare workforce

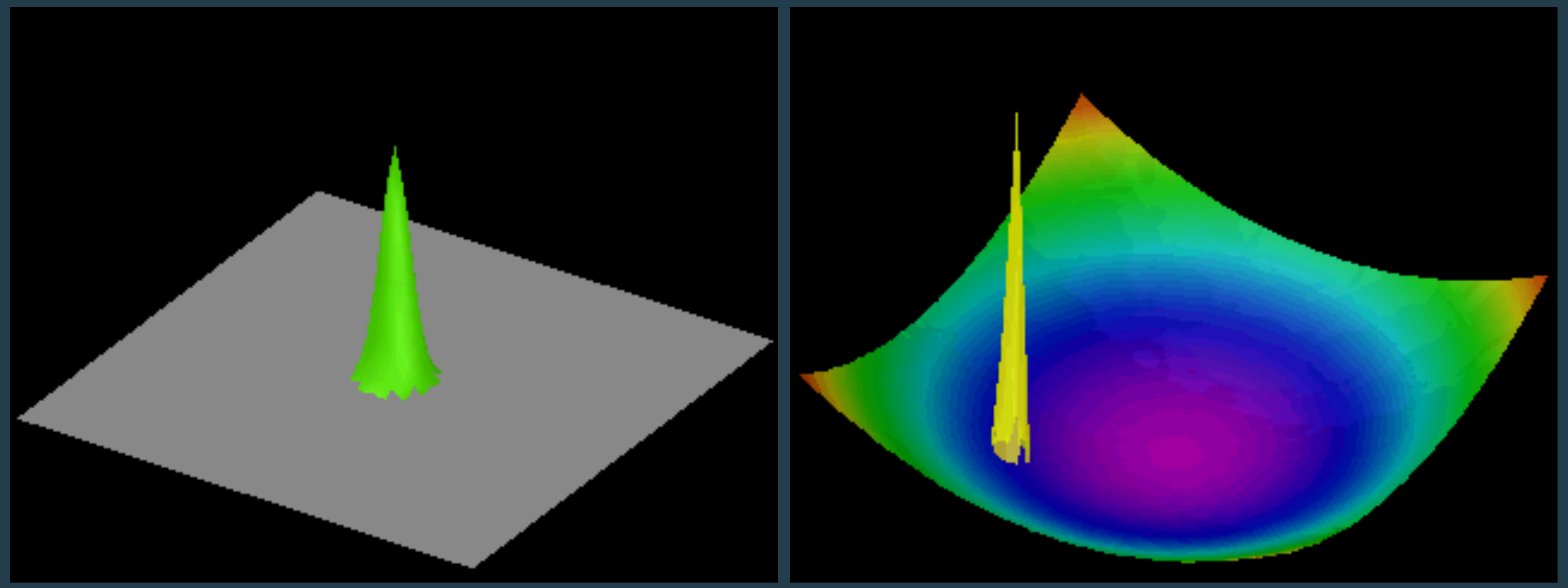
Graduate Study

Workforce

Not Employed

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

Developing students' computational competencies



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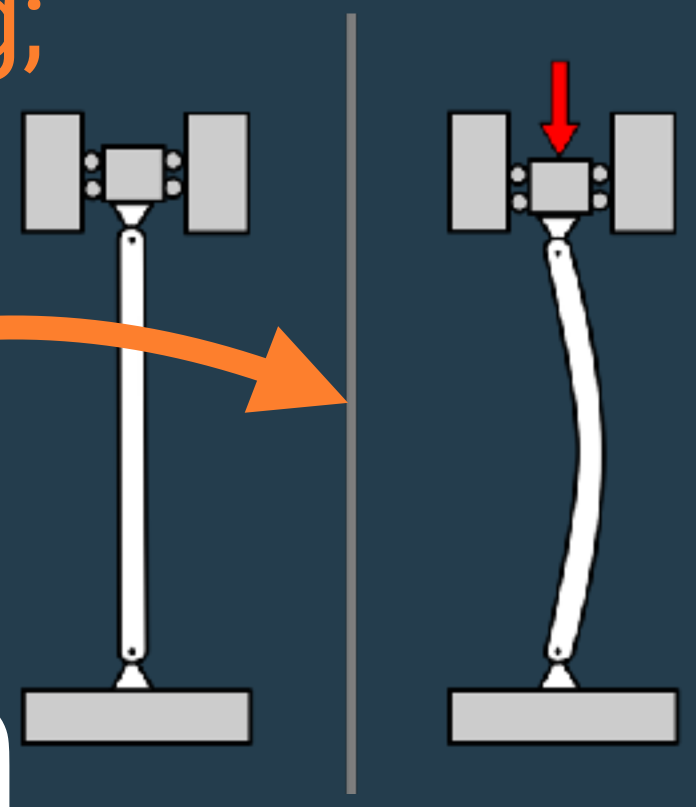

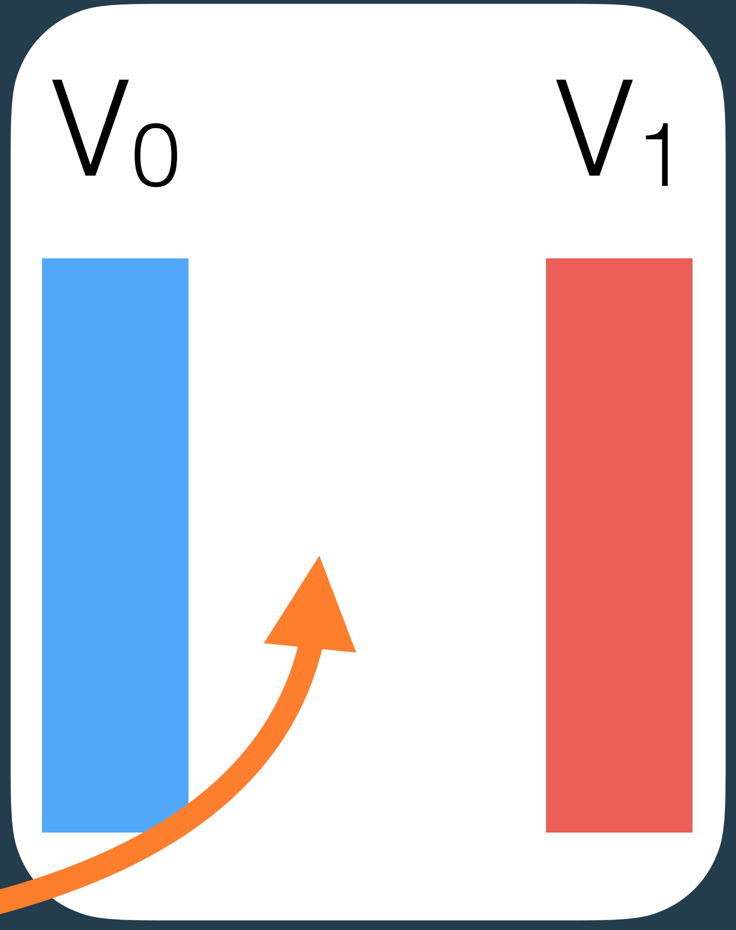

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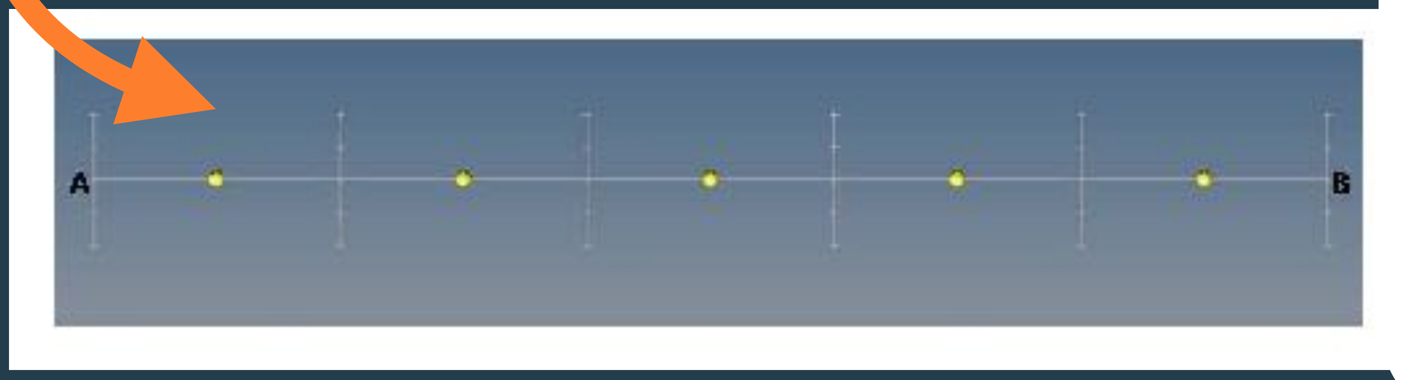

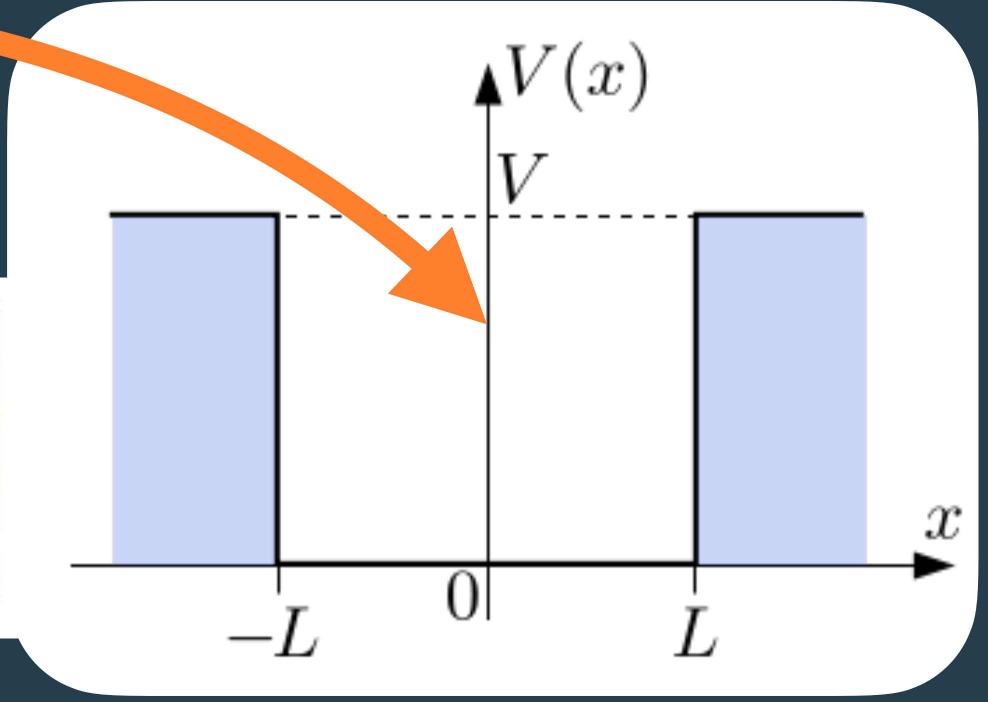

Teach necessary skills; prepare workforce

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

Developing students' computational competencies

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

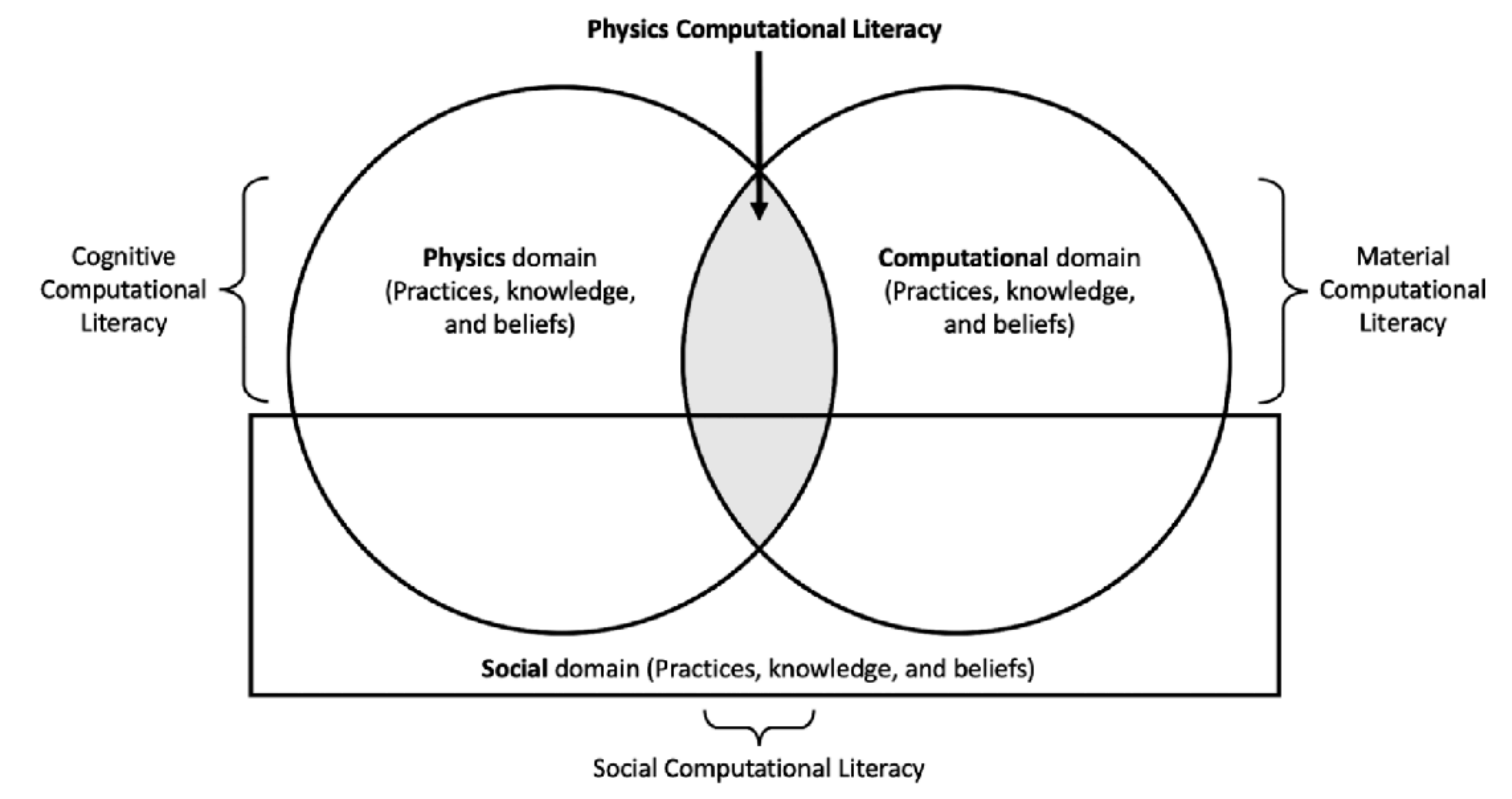
PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **15**, 020152 (2019)

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

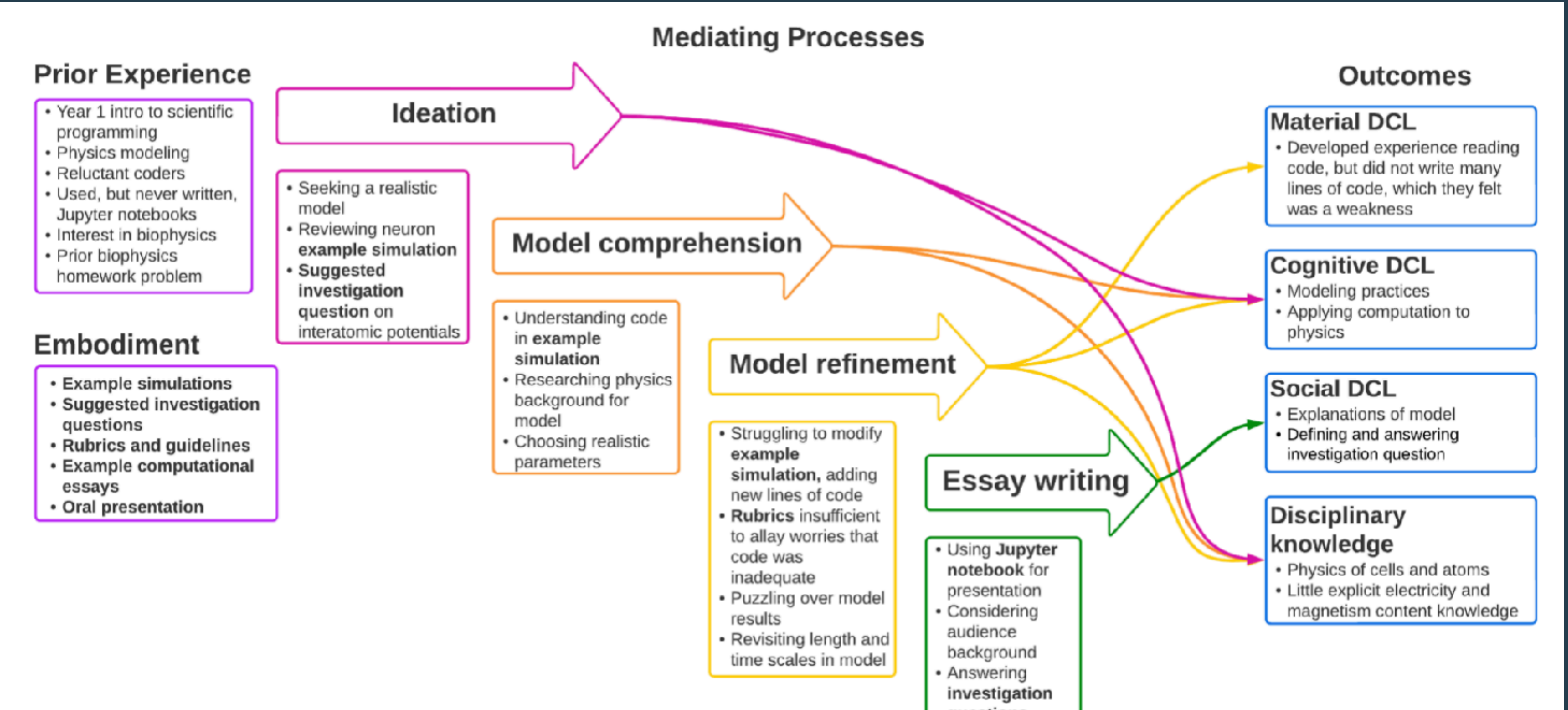
Odden, Tor Ole B., Elise Lockwood, and Marcos D. Caballero. Physical Review Physics Education Research 15.2 (2019): 020152.

PCL is a model that informs activity development & pedagogy

How Physics Students Develop Disciplinary Computational Literacy

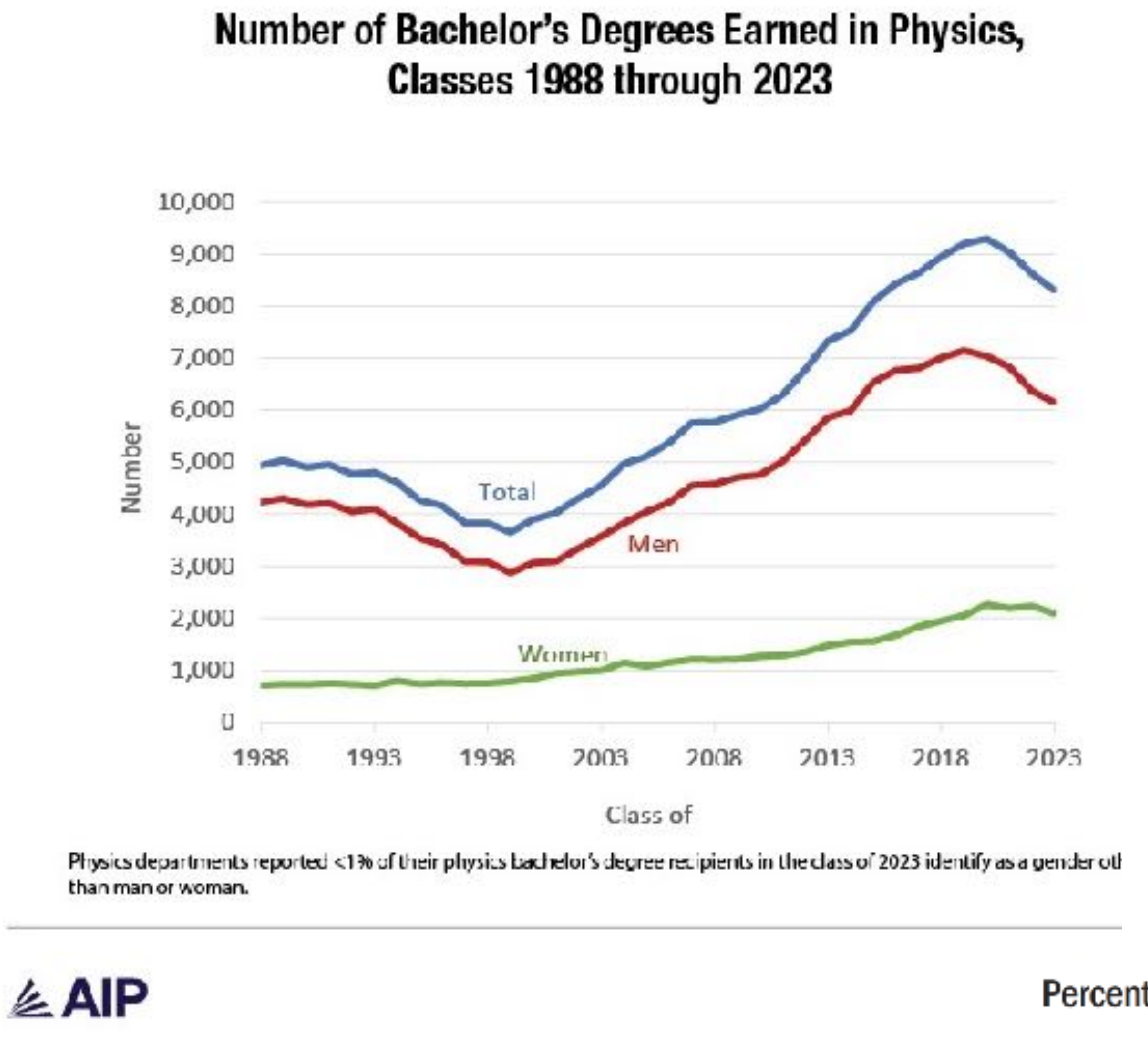
Tor Ole B. Odden[1*] and Benjamin Zwickl[1,2]

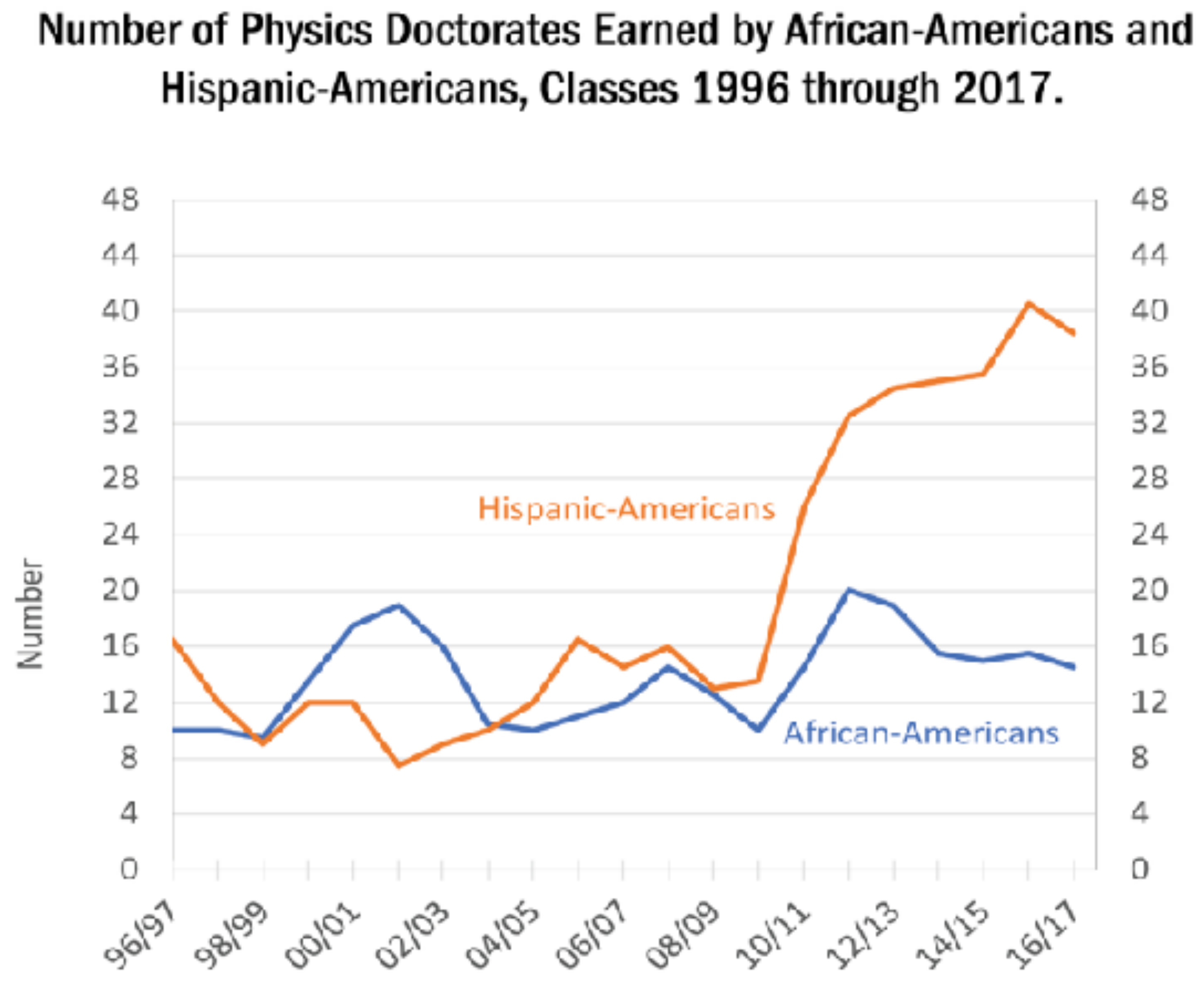
[1] Center for Computing in Science Education, Department of Physics, University of Oslo, 0316 Oslo, Norway
[2] School of Physics and Astronomy, Rochester Institute of Technology, 84 Lomb Memorial Drive, Rochester, NY, 14607
*t.o.b.odden@fys.uio.no (corresponding author)

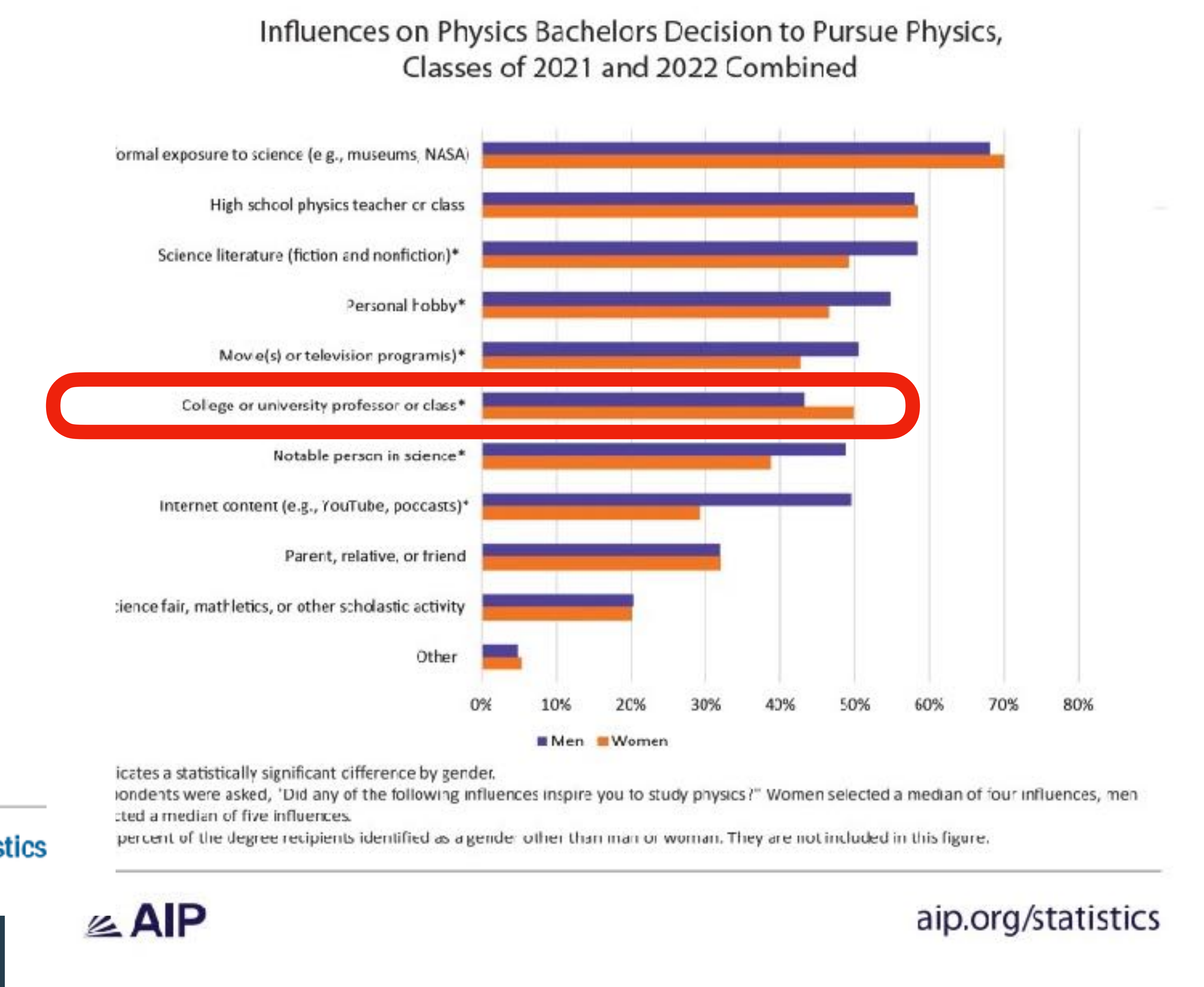


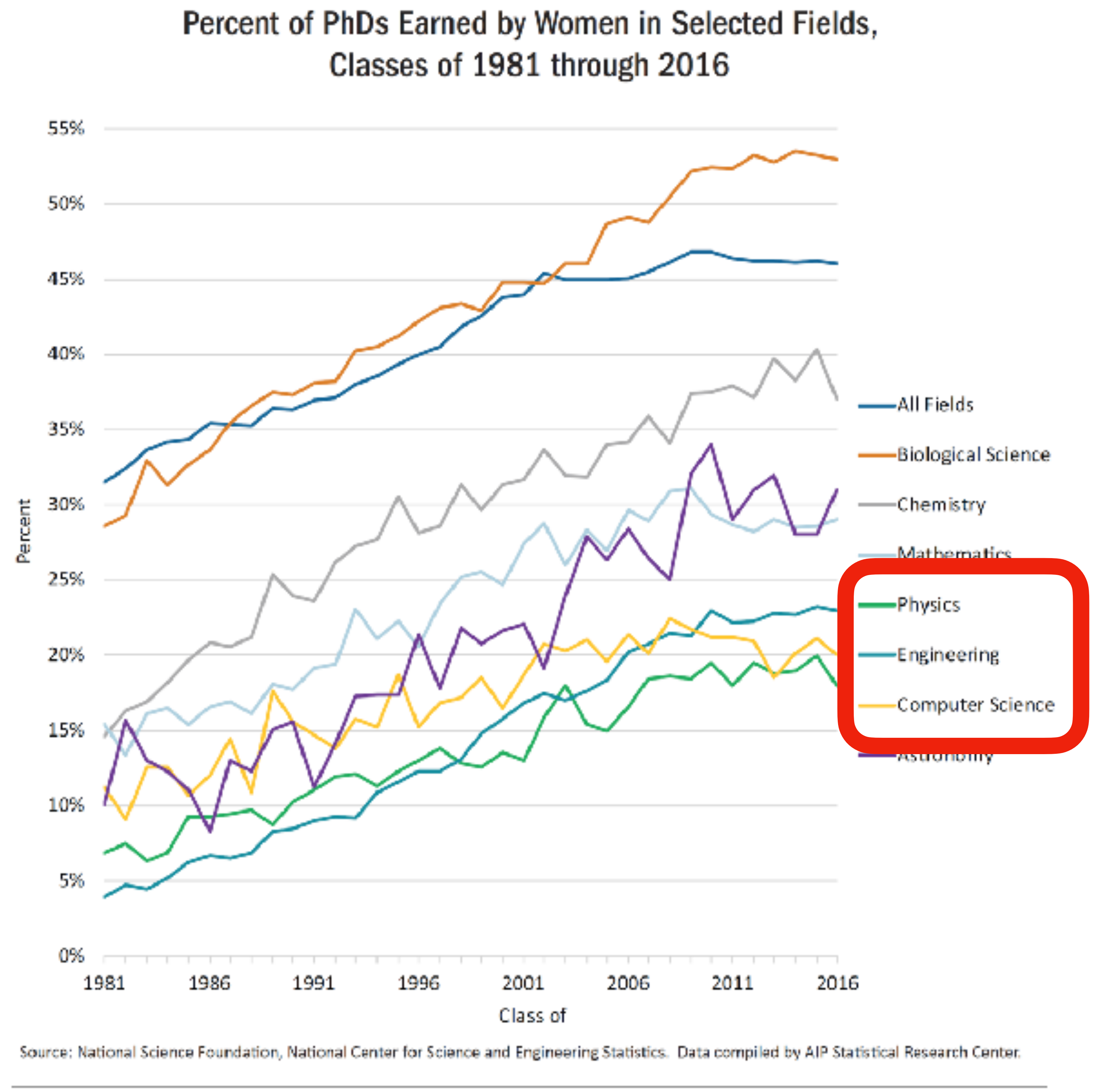
Odden and Zwickl, ArXiV, 2024

Twelve years have past between this paper and the first.









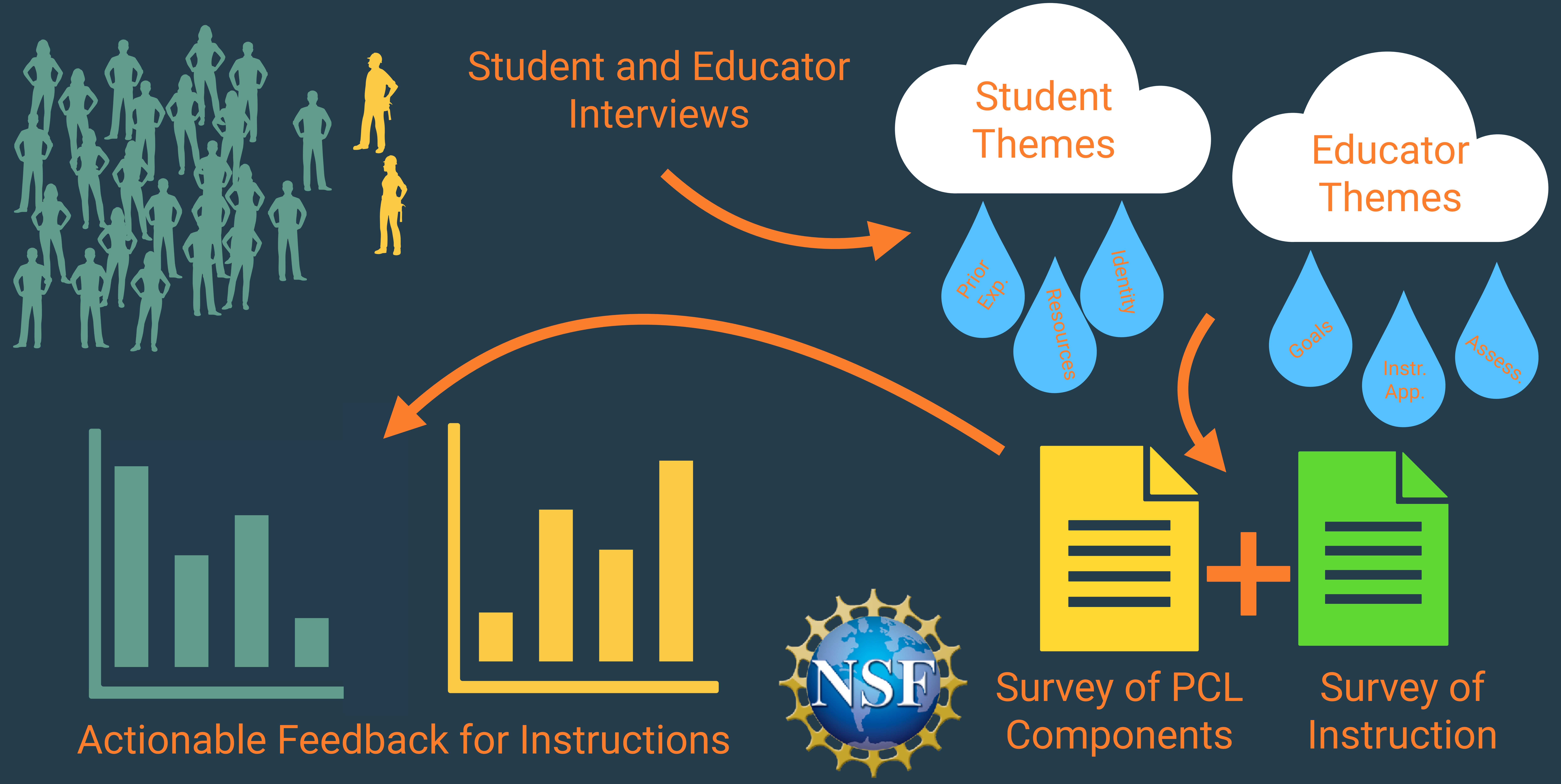
Our work does not exist in a vacuum

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

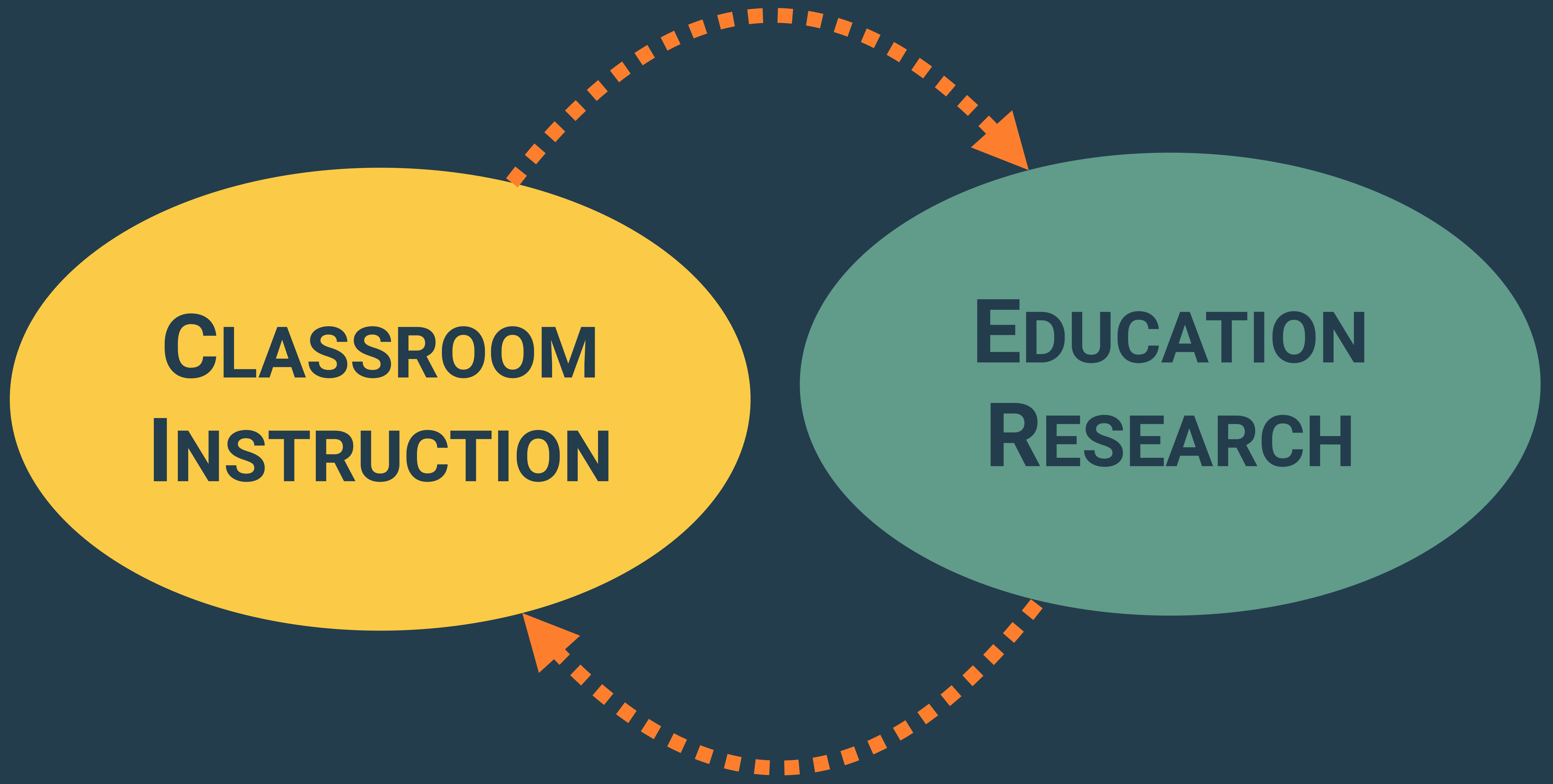
Investigating Physics Computational Literacy

Student Dimension

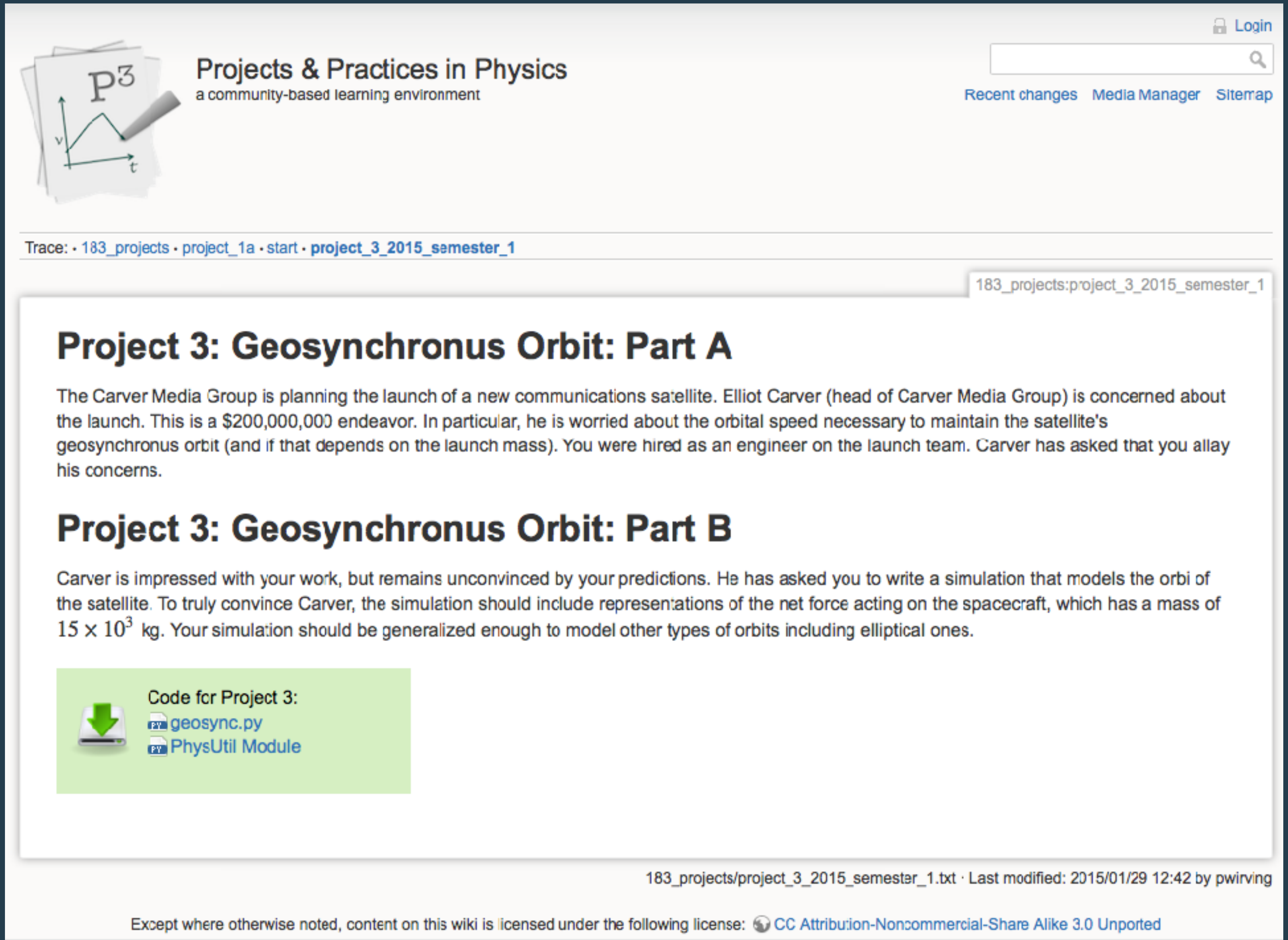
Investigating Physics Computational Literacy



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: Geosynchronus Orbit: Part A

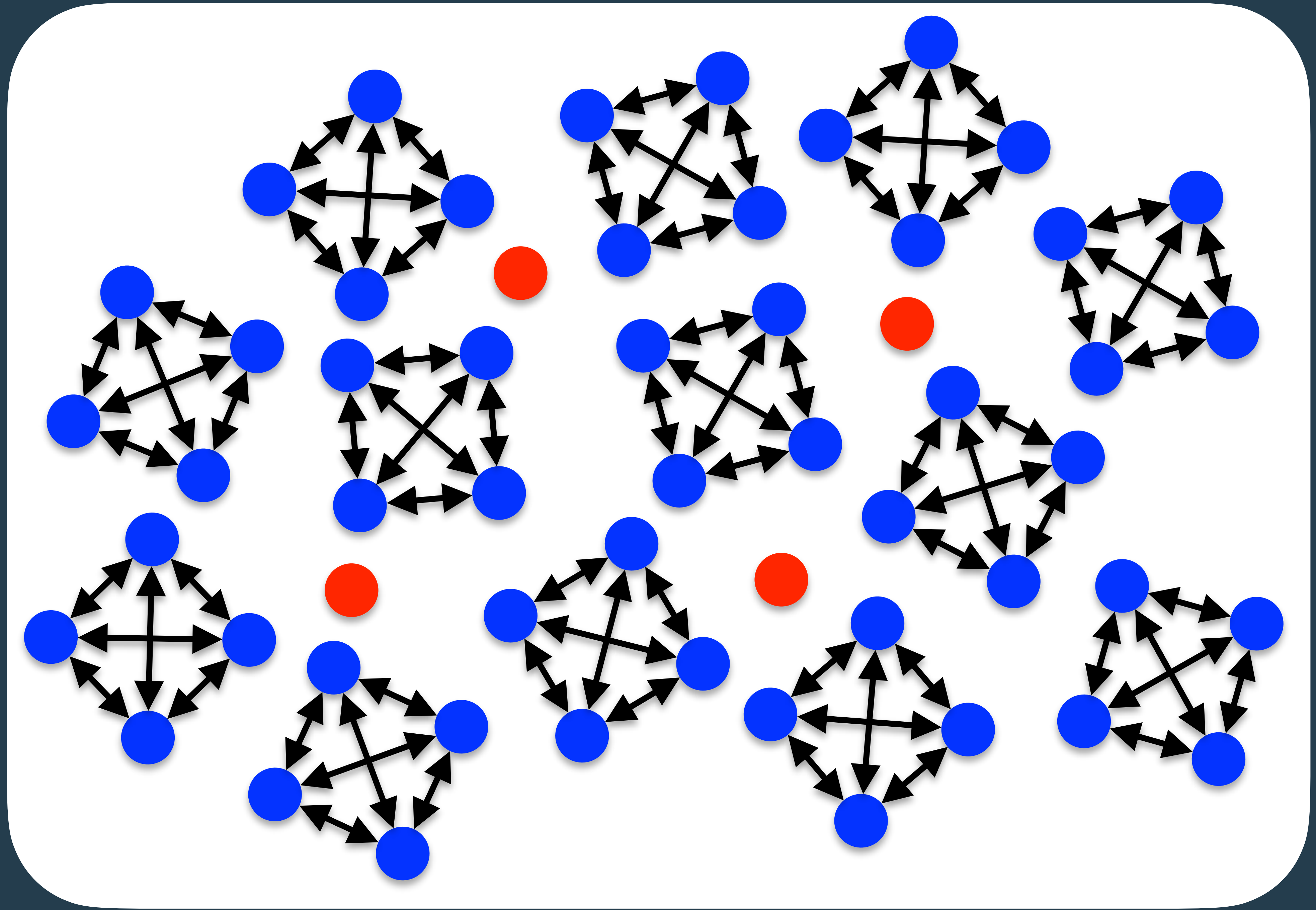
The Carver Media Group is planning the launch of a new communications satellite. Elliot Carver (head of Carver Media Group) is concerned about the launch. This is a $200,000,000 endeavor. In particular, he is worried about the orbital speed necessary to maintain the satellite's geosynchronus orbit (and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

Project 3: Geosynchronus Orbit: Part B

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

Investigating Learning Assistants' Instructional Approaches

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

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

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

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

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

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

Results

12 LAs Interviewed

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

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

Results

12 LAs Interviewed

Theme and Variation

Utility of coding	Teaching outcome	Characteristic to moderate	Teaching strategy
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Pawlak, Irving, & Caballero, Phys. Rev. PER (2020)

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Category of Description

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

Teaching strategy

Most of the time, I just teach them how to do it because it's usually when they've just like edited like one line of code, and then it's like, "Oh, we have the tabbing error." I'll just be like, "Here's how you solve that: Highlight, and then do the thing, and then, yay, it's good." Then they'll be like, "Okay. Cool. Now I know how to do this in the future."

Kendra

Teaching strategy
Focus on navigating programming errors
Leverage affordances of computational problems
Encourage reflection on coding
Leverage collaboration

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

Teaching strategy

I might say something like you know, ask somebody, ask a group what they are doing and if someone responds and it looks like the other two aren't paying any attention, I might ask, "Oh, are you guys good with that?" Or like "Are you guys on the same page?" Or "Do these guys understand that?" Or something like that to sort of let them know that they should be conversing.

Molly

Teaching strategy
Focus on navigating programming errors
Leverage affordances of computational problems
Encourage reflection on coding
Leverage collaboration

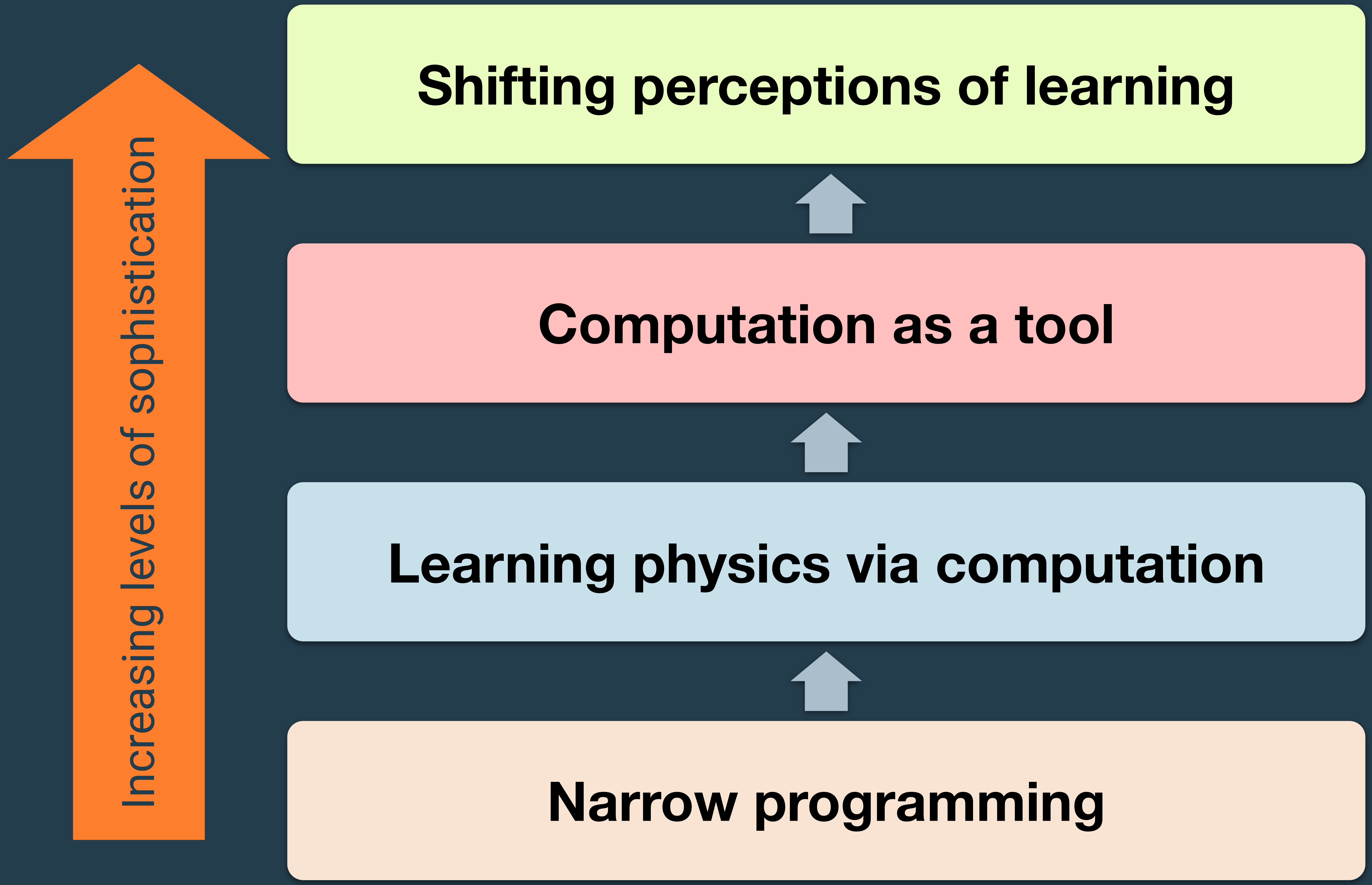
Pawlak, Irving, & Caballero, Phys. Rev. PER (2020)

Categories of description

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

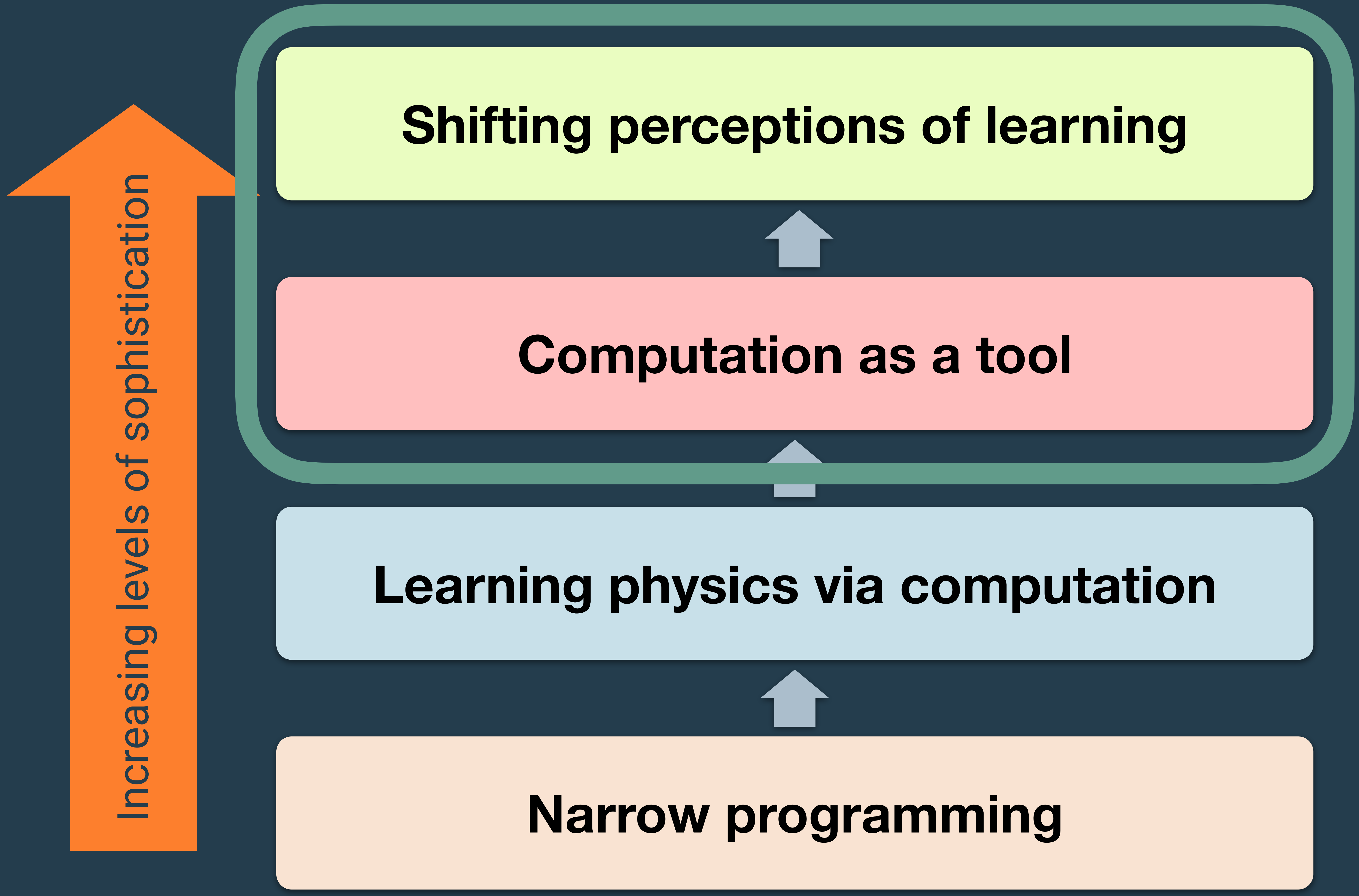
Pawlak, Irving, & Caballero, Phys. Rev. PER (2020)

Outcome space



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

Outcome space



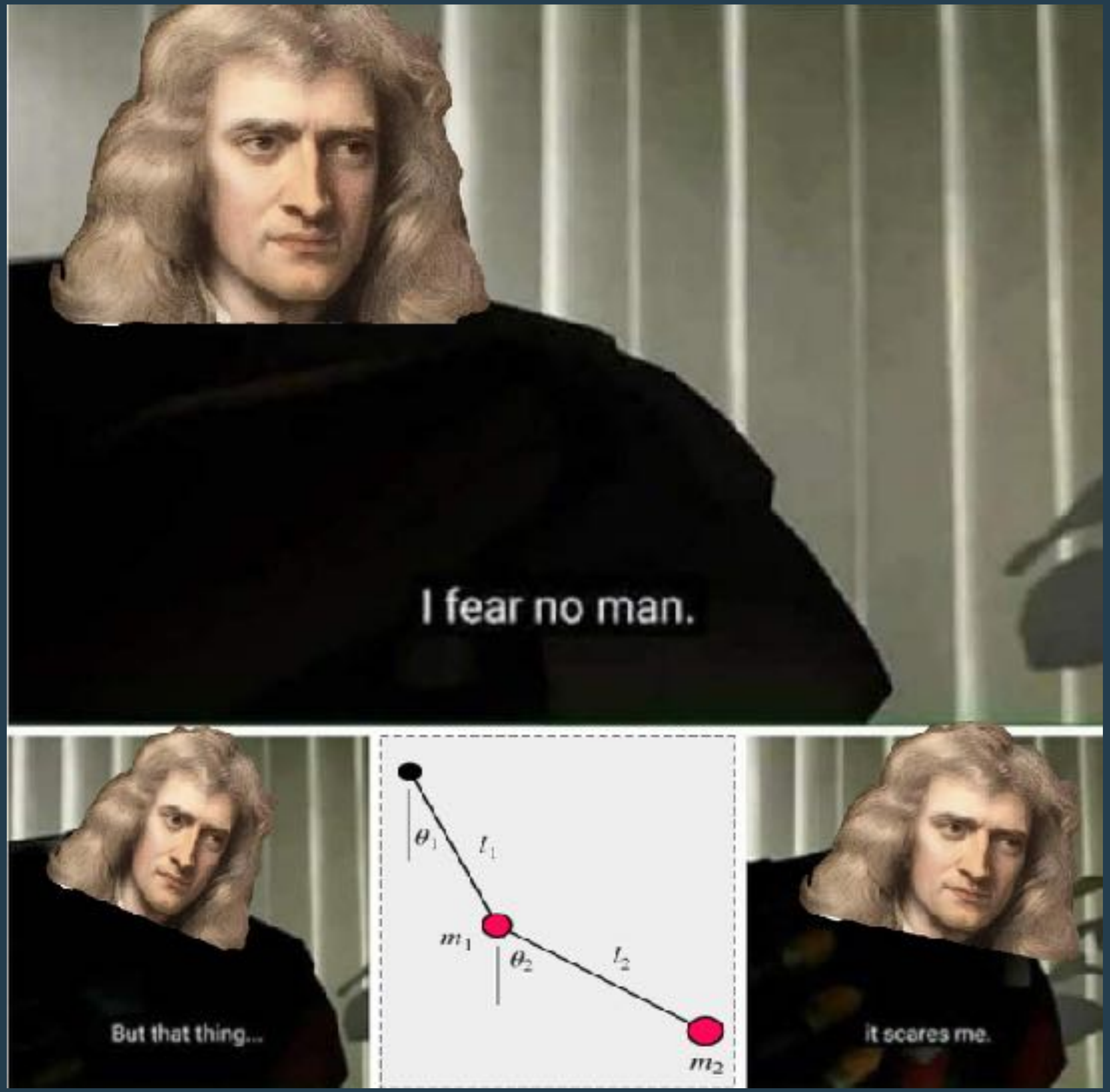
Pawlak, Irving, & Caballero, Phys. Rev. PER (2020)

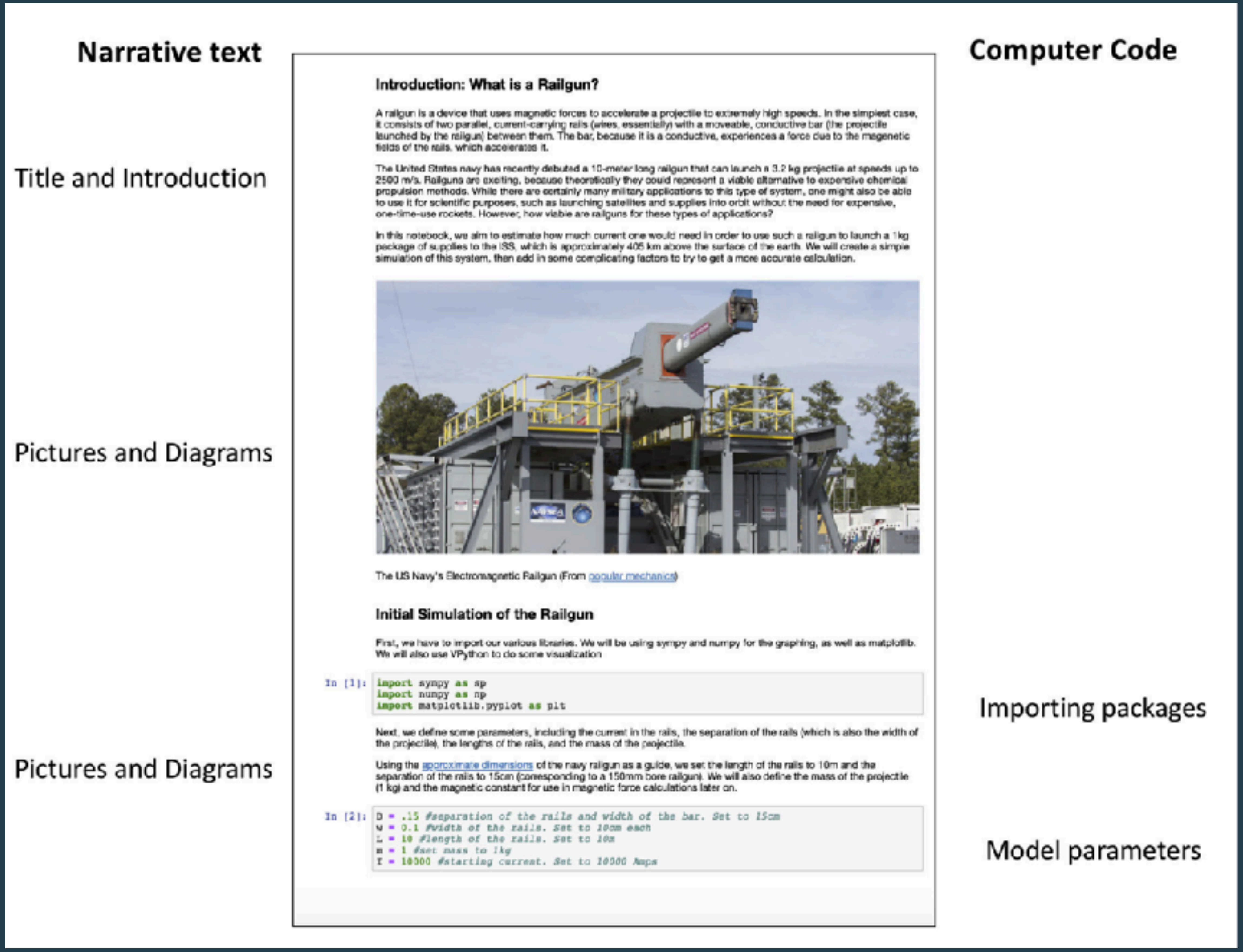
PHY 321: Classical Mechanics 1, Michigan State University, Spring 2025

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

Computational Essays as a form of assessment

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

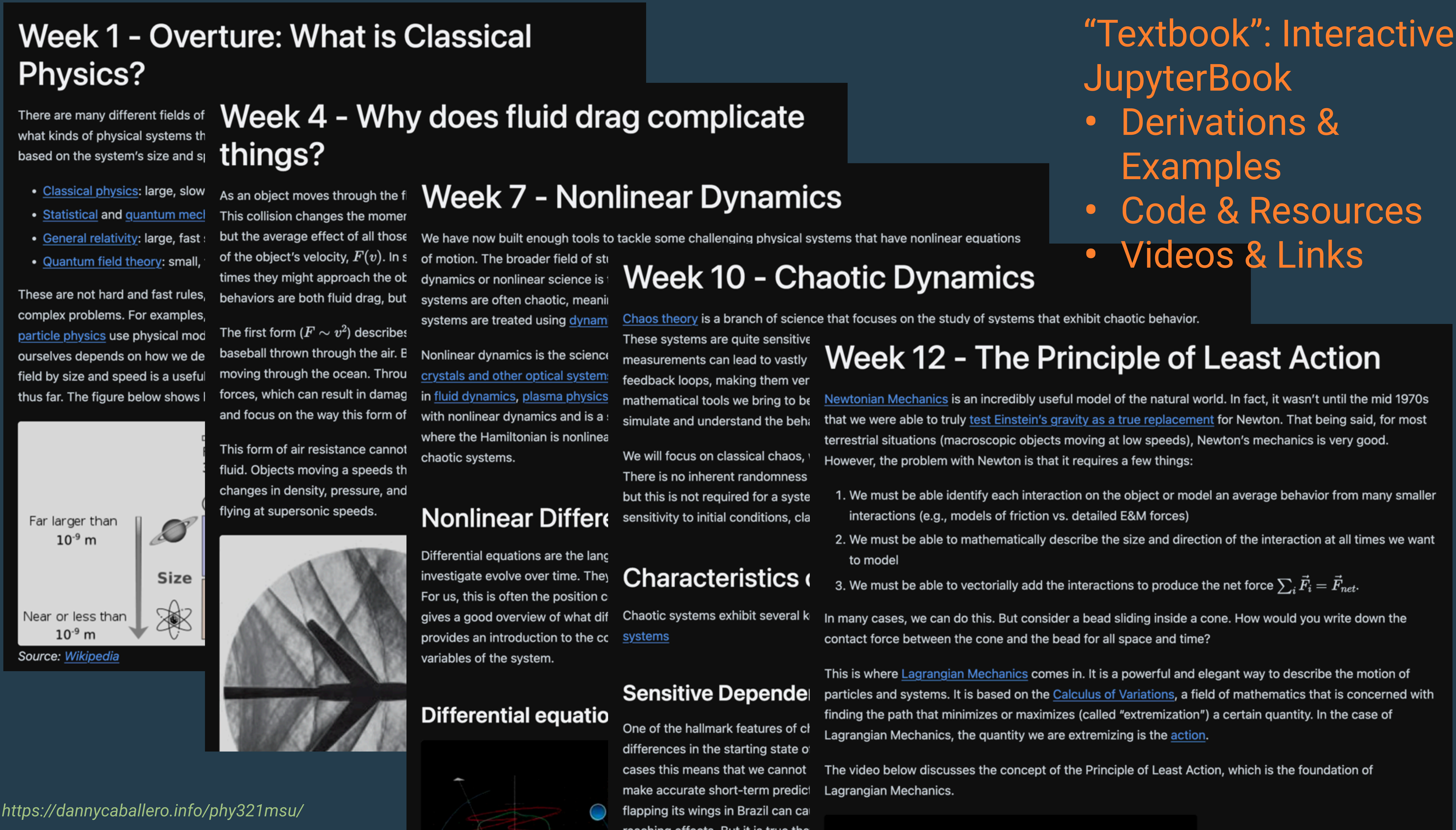




With R. Henderson (MSU), M. Hjorth-Jensen (MSU, UiO)

“Textbook”: Interactive JupyterBook

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



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.

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.

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?

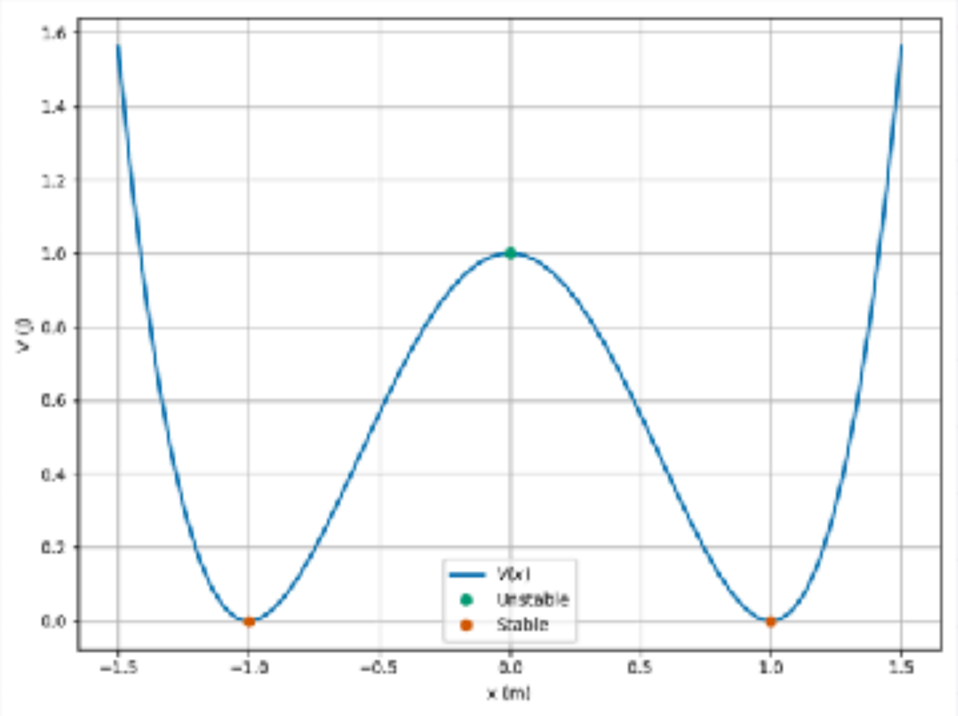
1. Conservation of energy. True.
2. Conservation of energy. False.
3. Conservation of linear momentum. True.
4. Conservation of linear momentum. False.

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. $0.4\,\mathrm{J}$, $<$ 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 (😖😖😖):

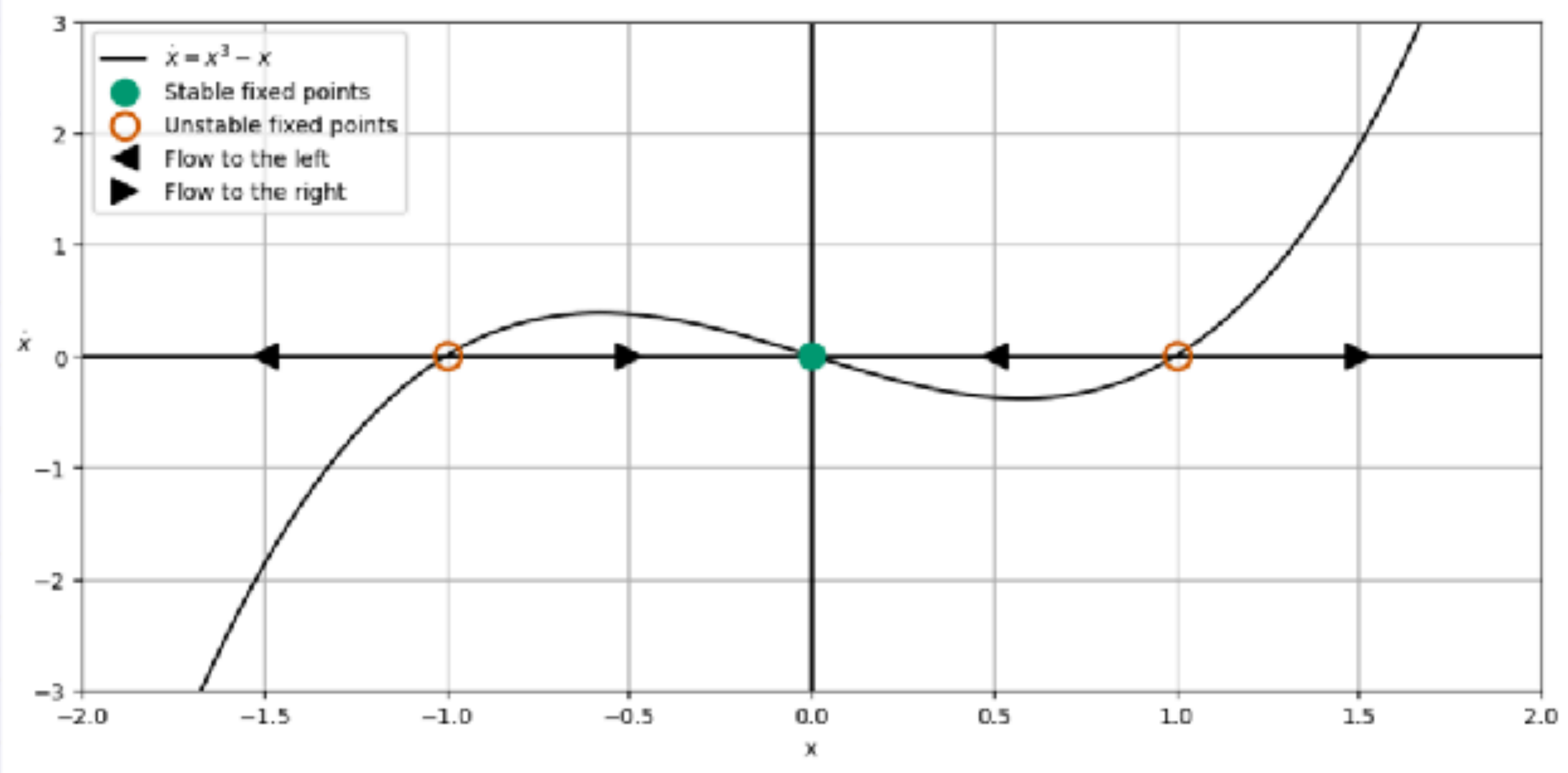
$$t(x) = \left(\frac{1}{2}\ln(1-x^2) - \ln(x)\right) - \left(\frac{1}{2}\ln(1-x_0^2) - \ln(x_0)\right)$$

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.

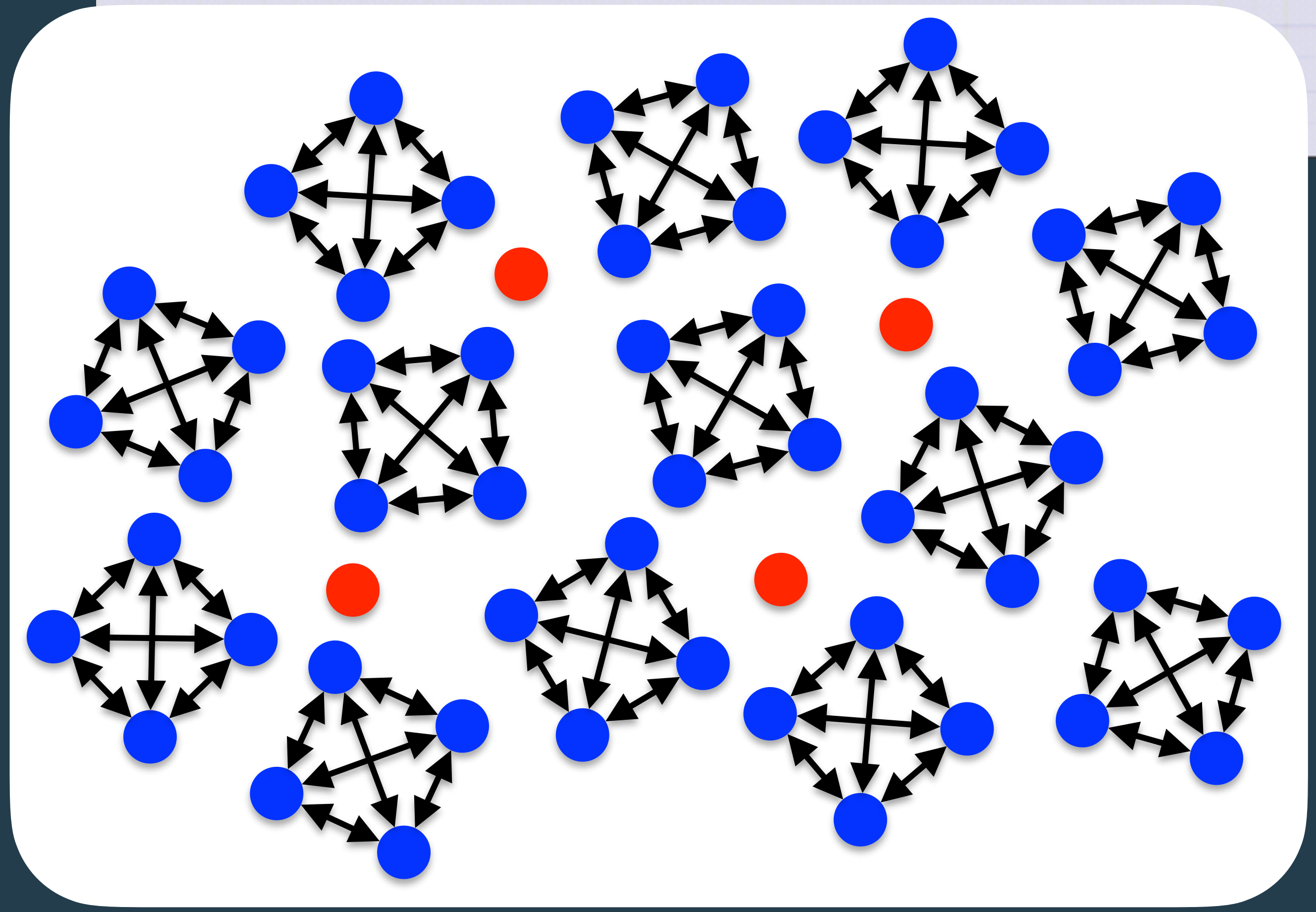
Click when you and your table are done.

14 / 17

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



15 / 17



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)

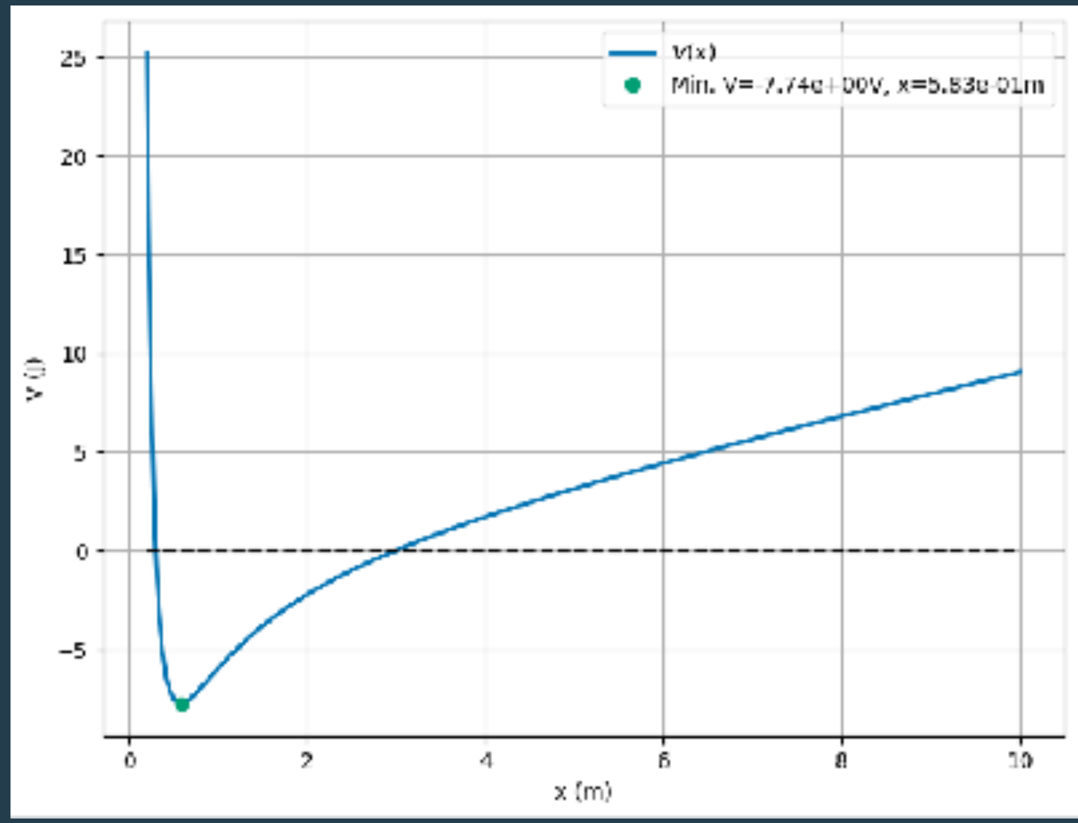
In this problem, you will choose a one dimensional system of your own. You may choose a known potential, or you may invent your own. Your potential must:

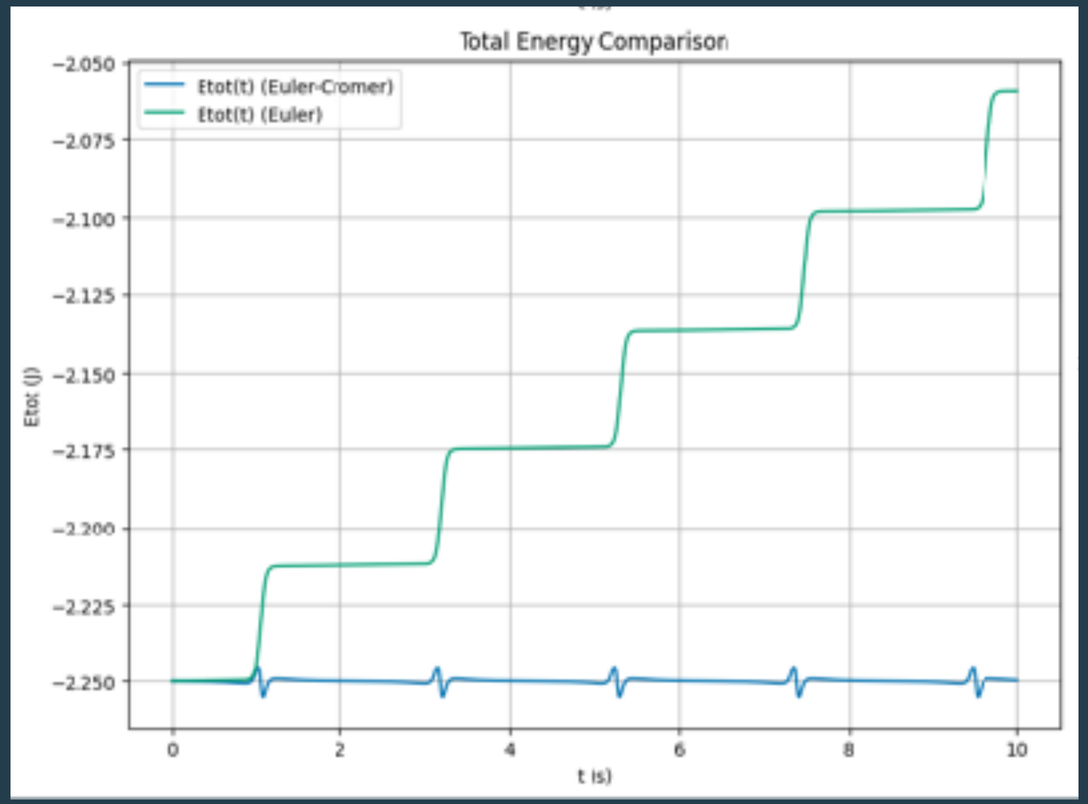
1. Have at least one stable equilibrium point.
2. Have at least one unstable equilibrium point, or some other interesting feature (e.g., asymptotic behavior).
3. For some choice of total energy, it should have oscillatory motion (i.e., classical turning points).
4. Produce a non-linear and conservative 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 [...]um 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:

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

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

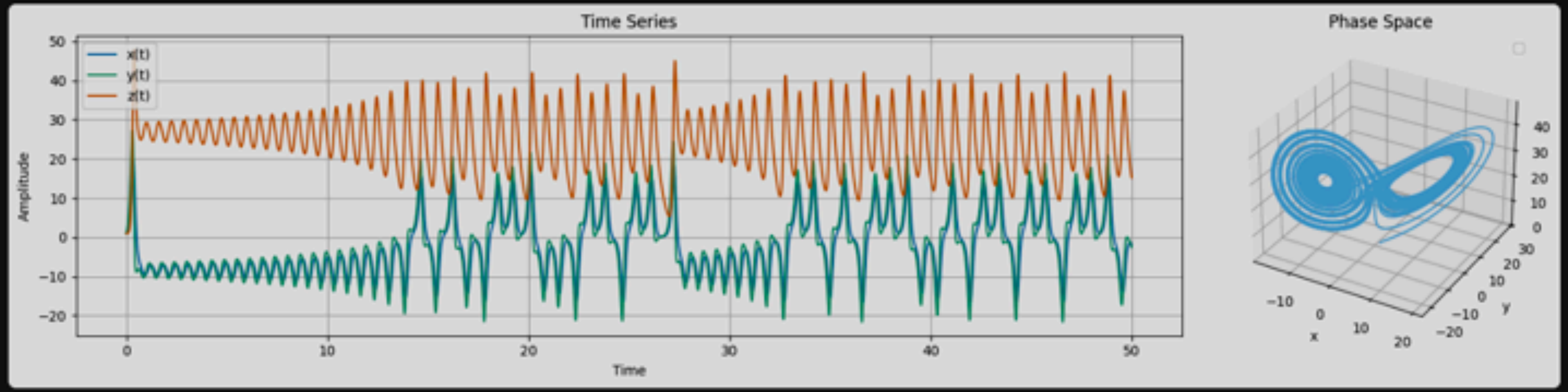
$$\frac{dz}{dt} = xy - \beta z$$

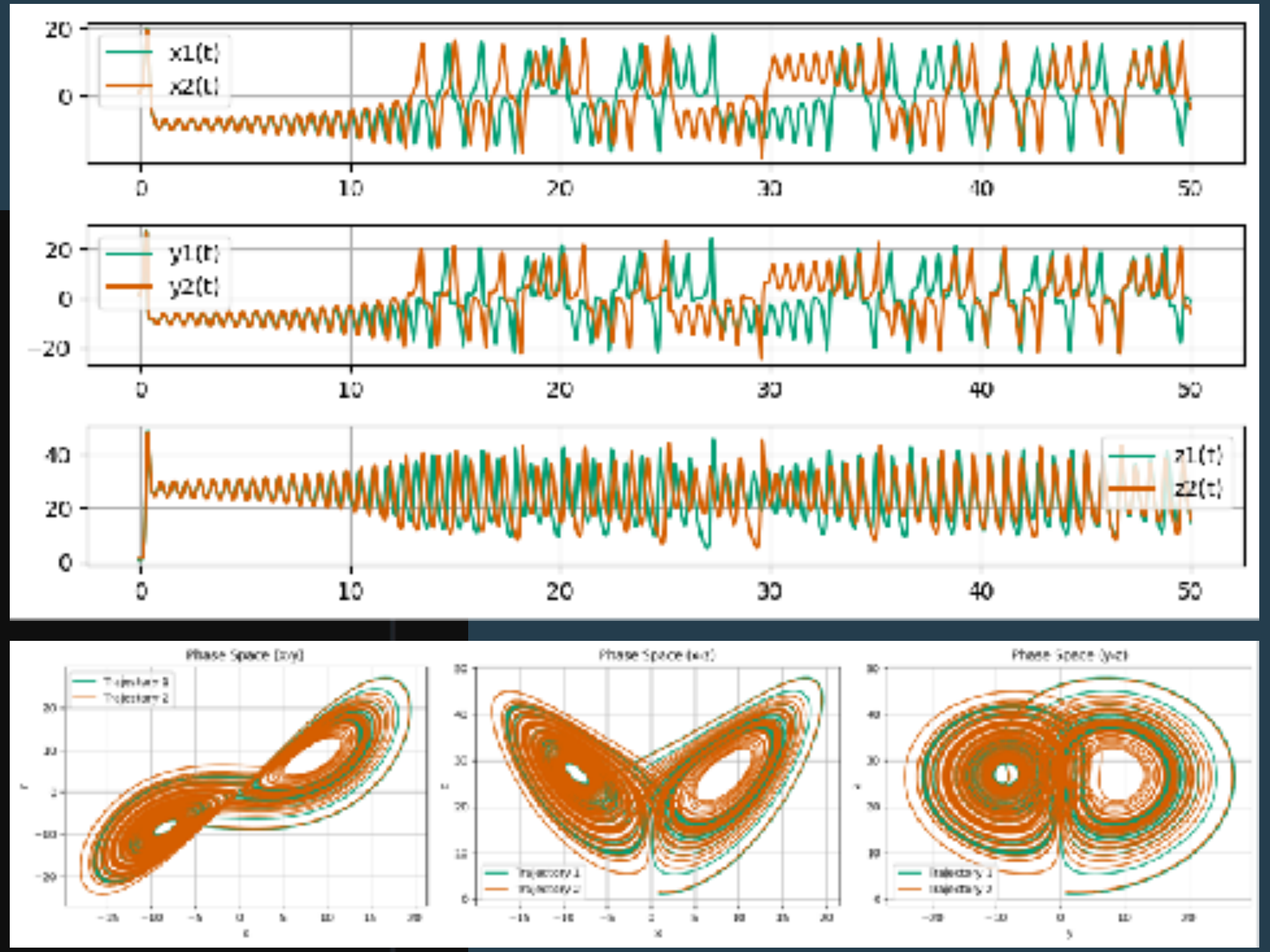
Where σ, ρ, and β are system parameters. The canonical values are $\sigma = 10$, $\rho = 28$, and $\beta = \frac{8}{3}$.

📝 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.





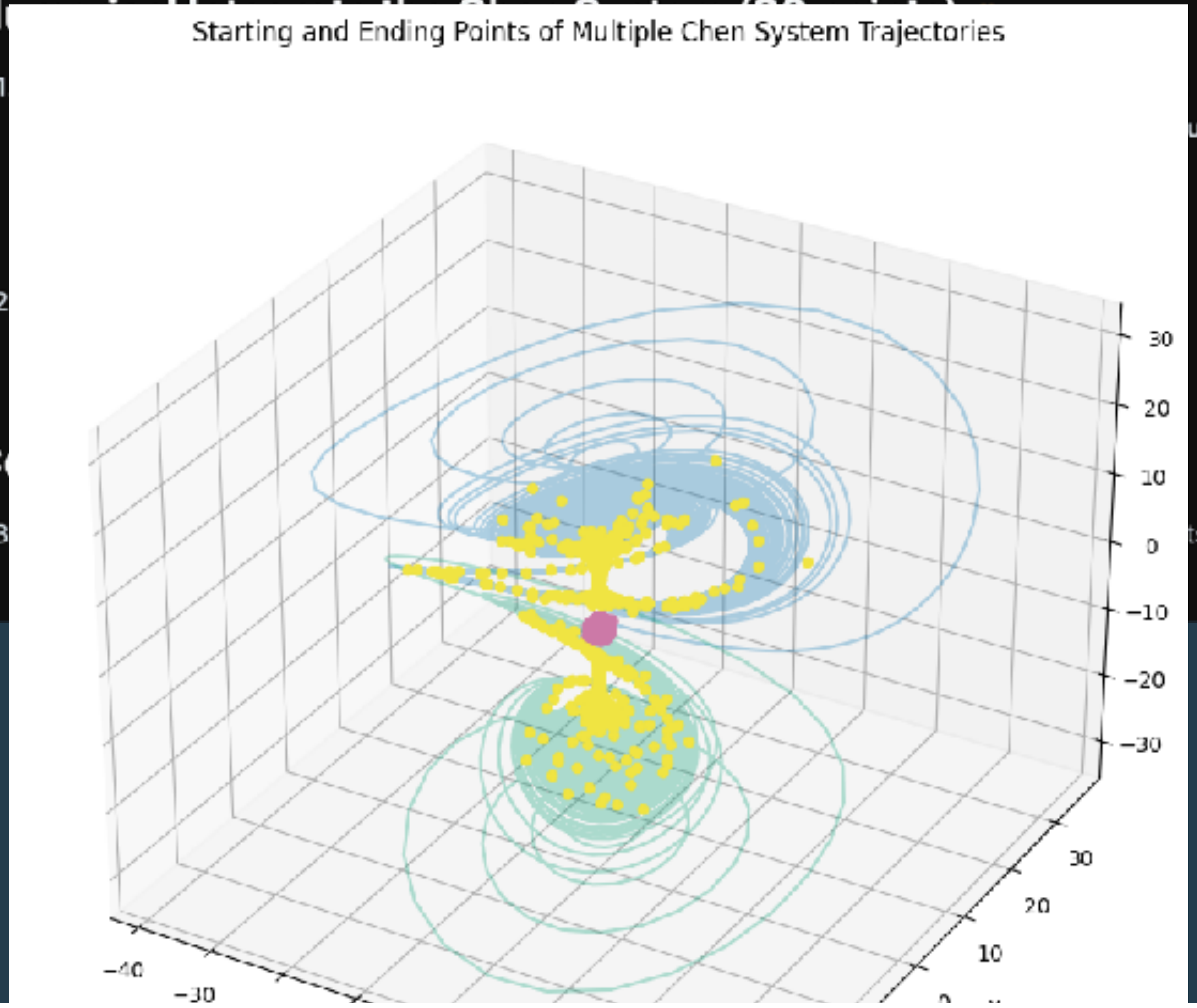
Part 2, Strange Attractor (40pt)

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:

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

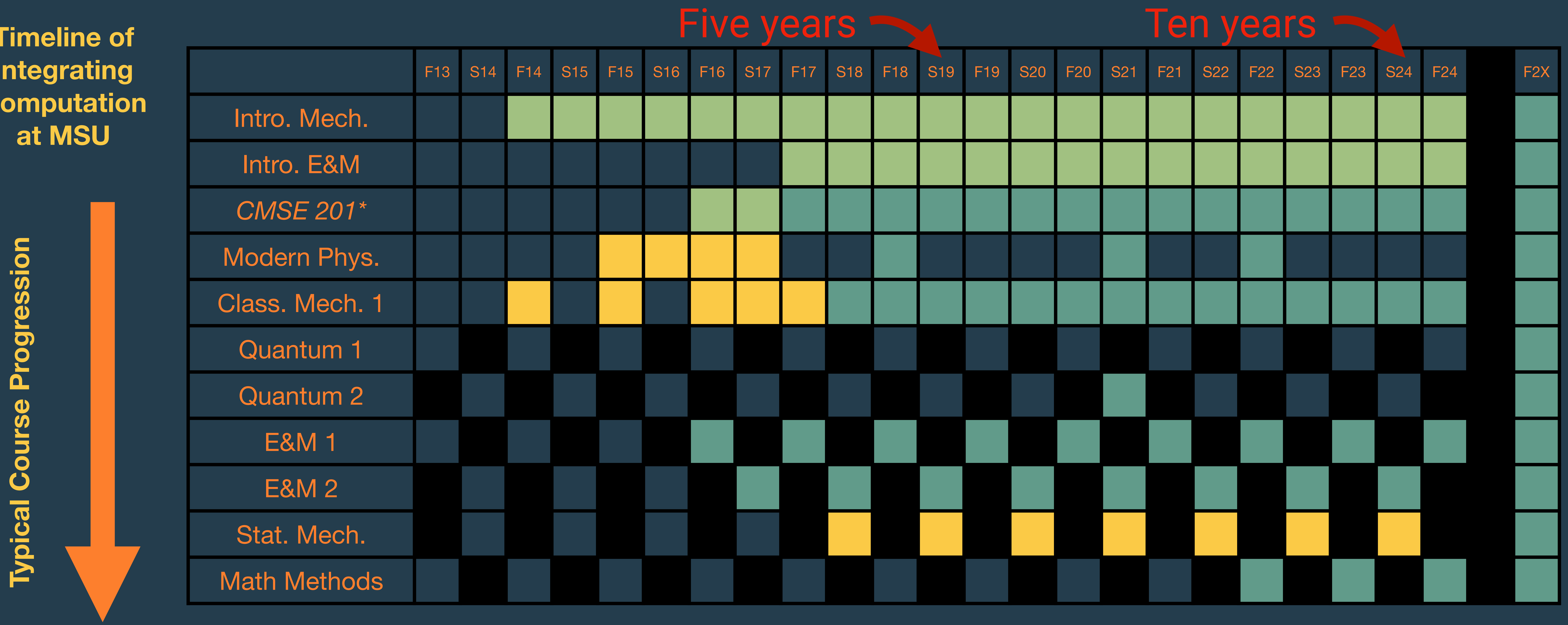
where α, β, and δ are constants that determine the behavior of the system. For this problem, we will use the following values:

Parameter	Value
α	5.0
β	-10.0
δ	-0.38



Student's illustration of initial condition sensitivity

Timeline of Integrating Computation at MSU



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

Instruction in computation (some sections)

Instruction in computation

Not offered

We are 11 years into a five year plan. 😅


Timeline of Integrating Computation at MSU
Typical Course Progression
Five years
Ten years
F13
S14
F14
S15
F15
S16
F16
S17
F17
S18
F18
S19
F19
S20
F20
S21
F21
S22
F22
S23
F23
S24
F24
F2X
Intro. Mech.
Intro. E&M
CMSE 201*
Modern Phys.
Class. Mech. 1
Quantum 1
Quantum 2
E&M 1
E&M 2
Stat. Mech.
Math Methods
COVID-19 Pandemic
Use of computational environment (e.g., plotting)
Instruction in computation (some sections)
Instruction in computation
Not offered
We are 11 years into a five year plan.

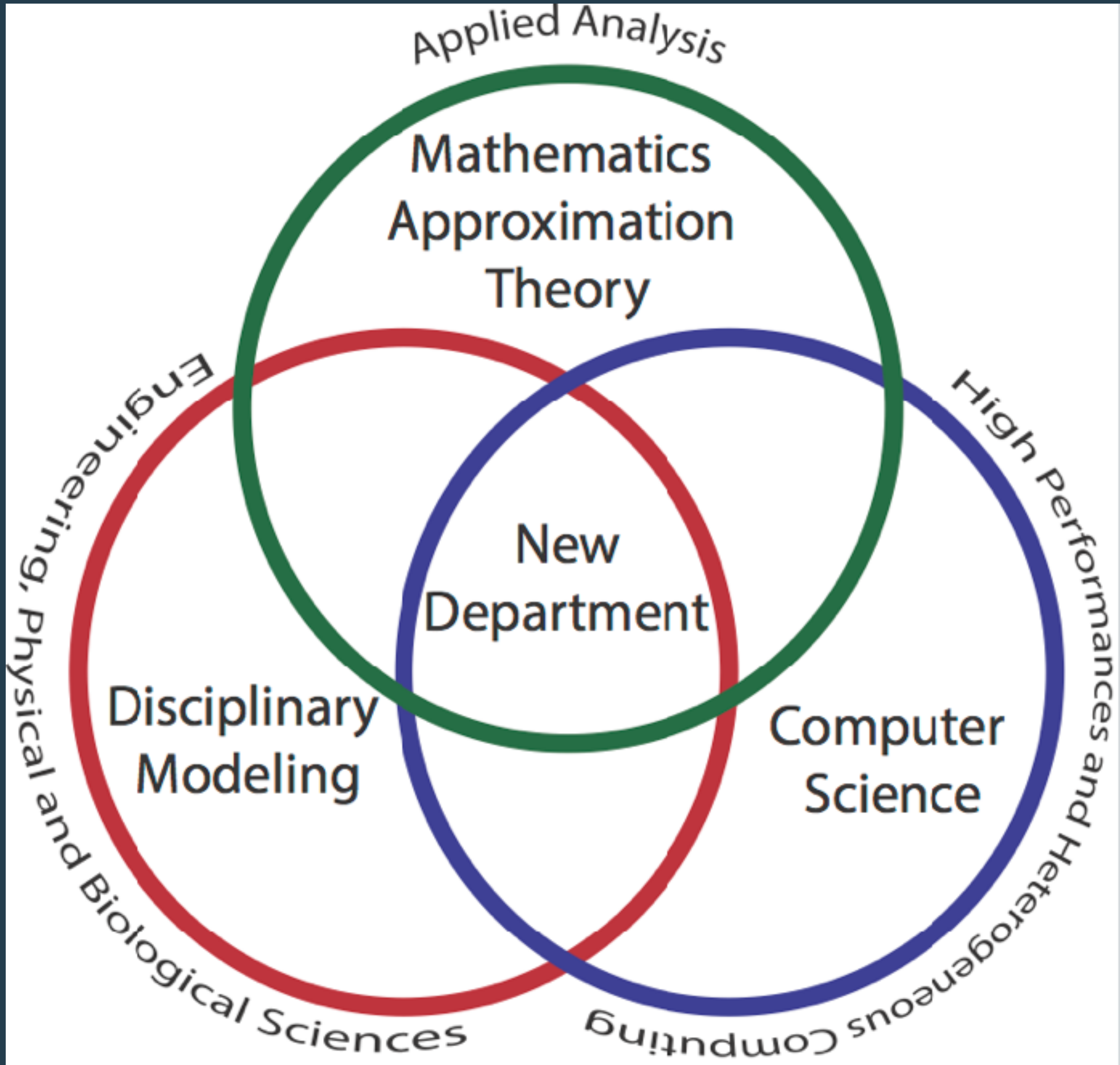
External support can help accelerate the process of integration.

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

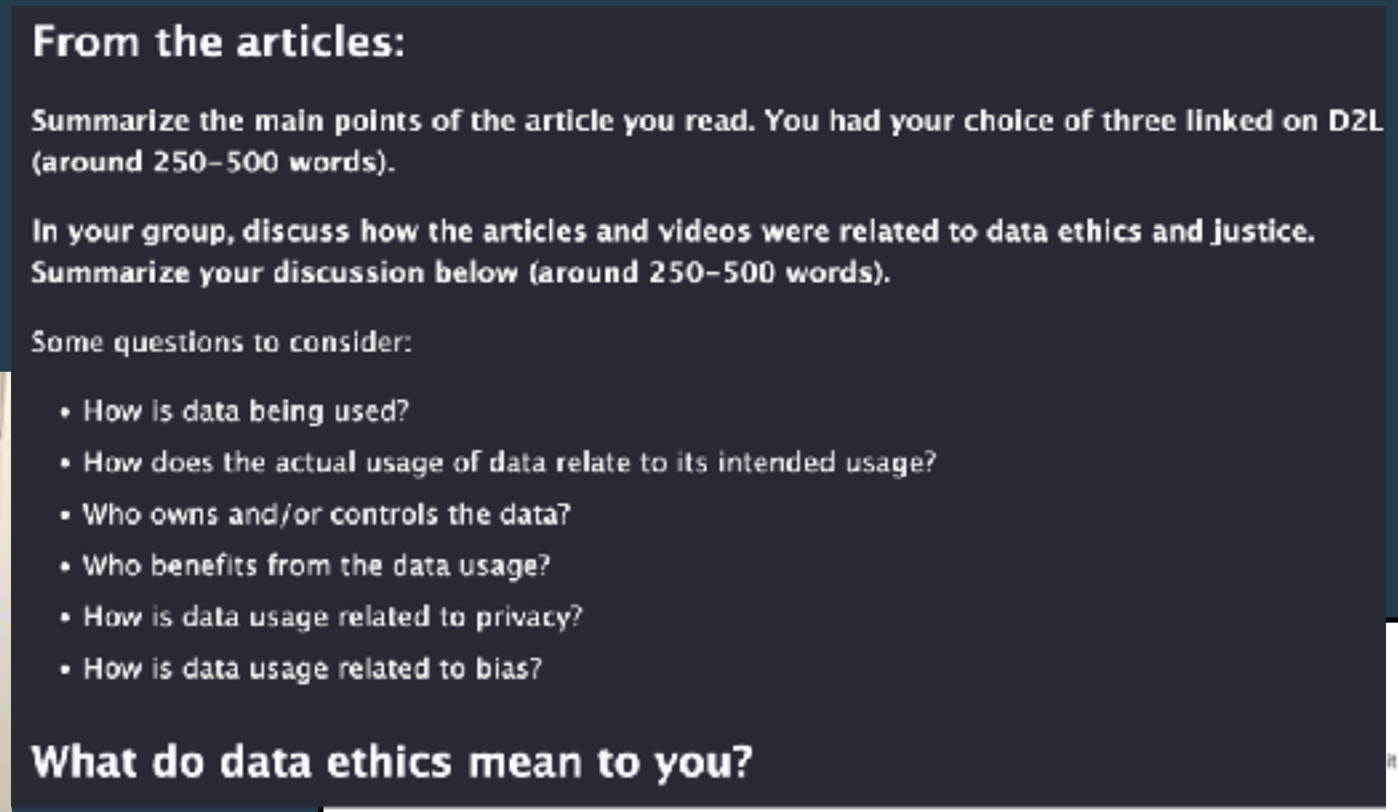
BS, MS, and PhD granting department

CMSE



We teach computational and data science

CMSE


From the articles:

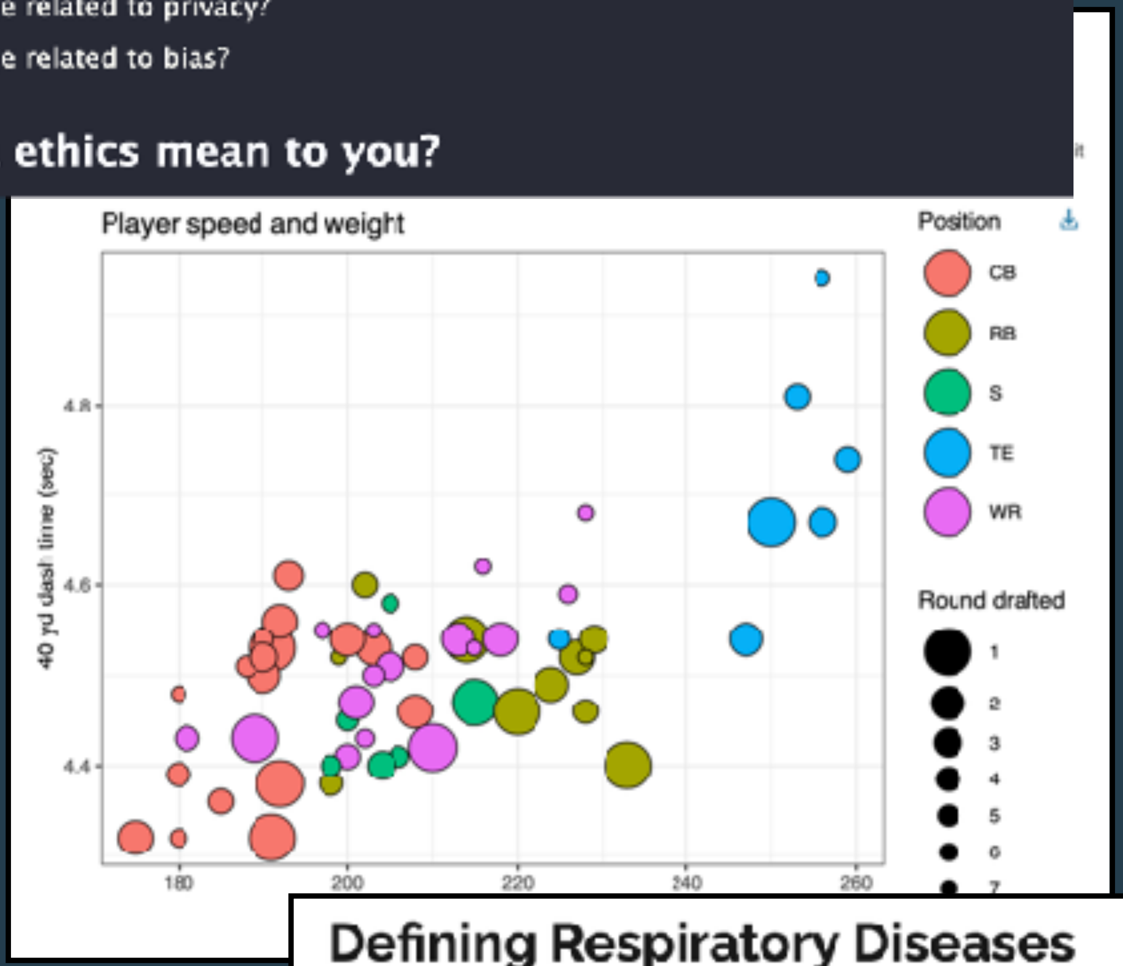
Summarize the main points of the article you read. You had your choice of three linked on D2L (around 250-500 words).

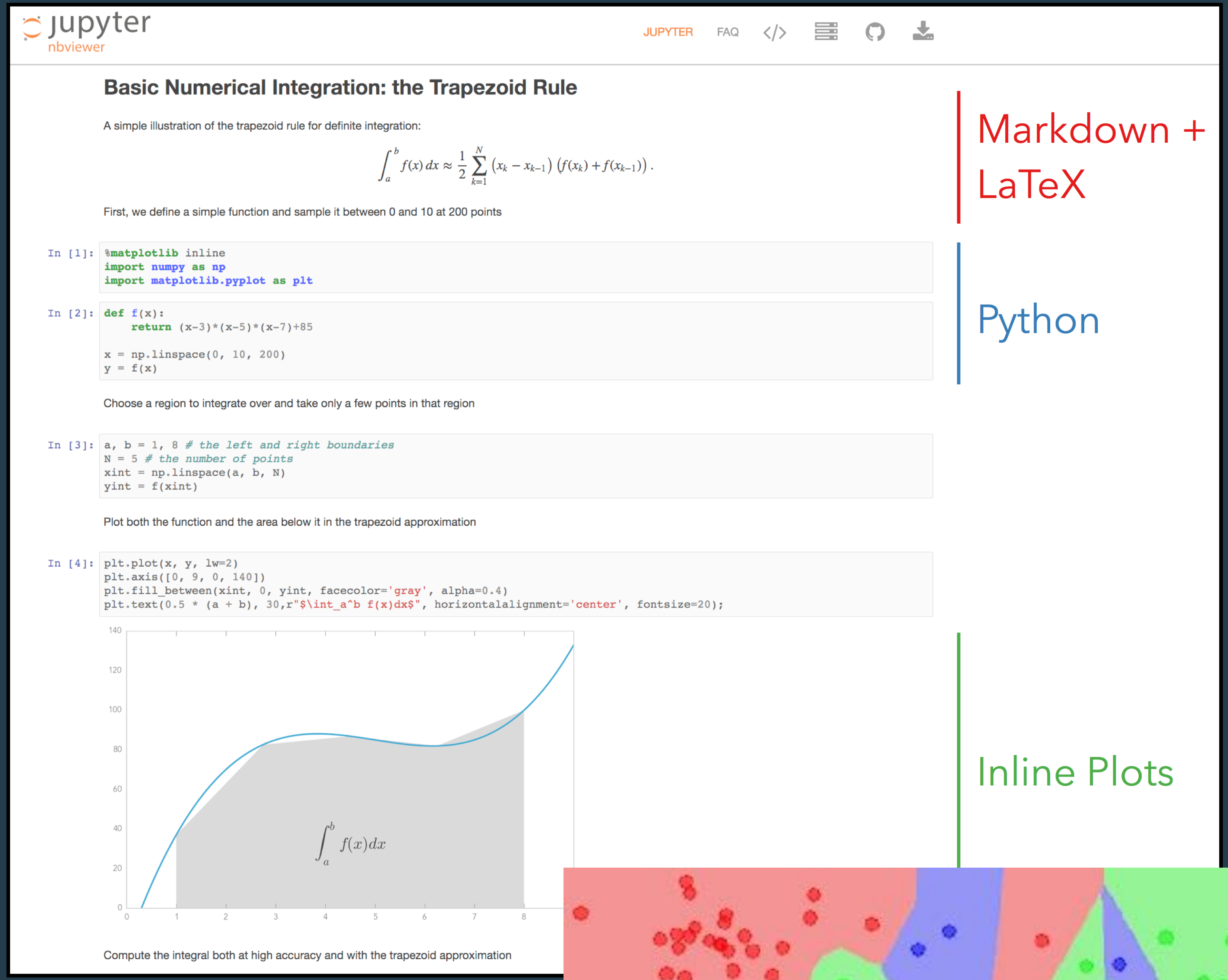
In your group, discuss how the articles and videos were related to data ethics and justice. Summarize your discussion below (around 250-500 words).

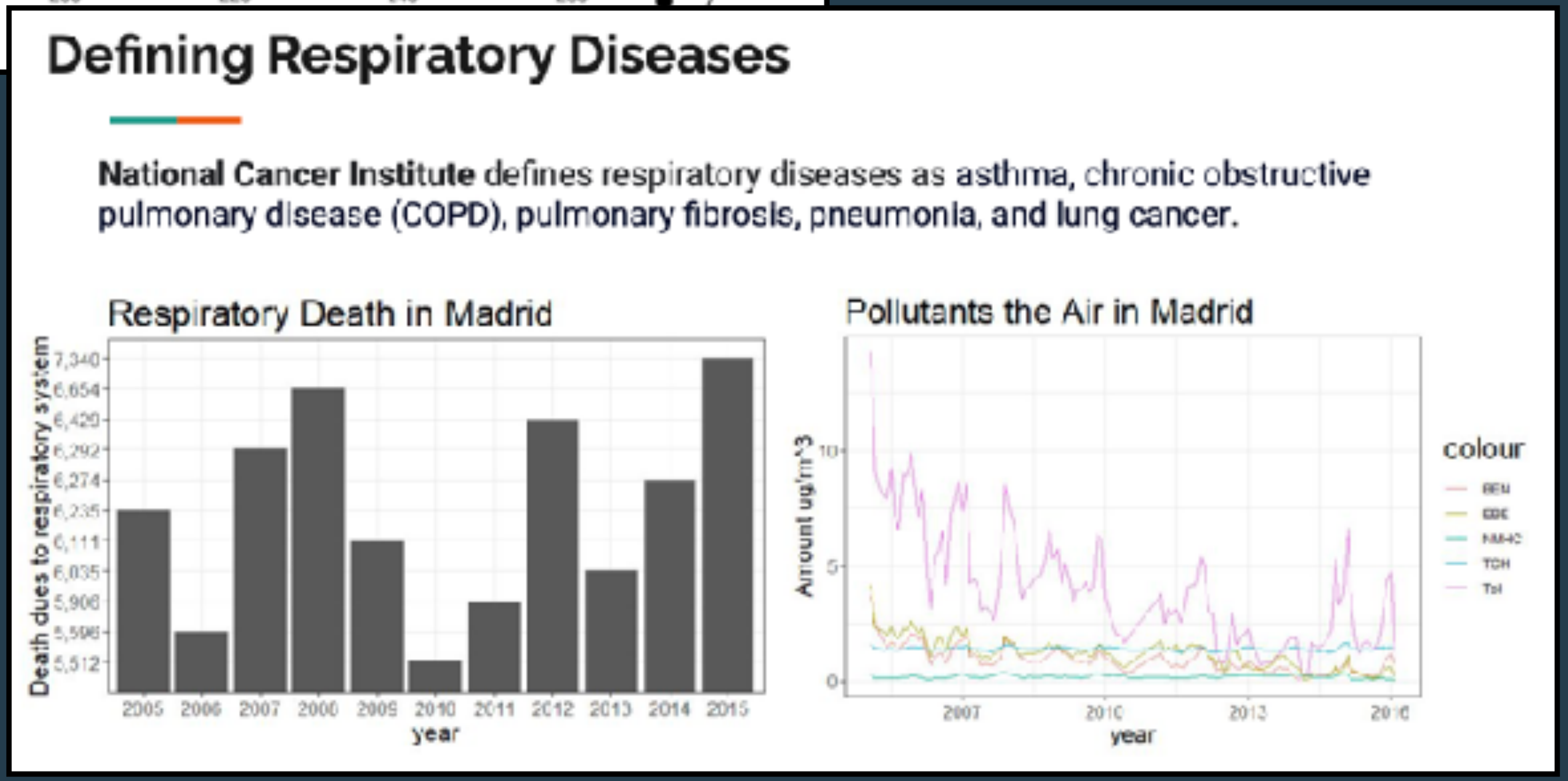
Some questions to consider:

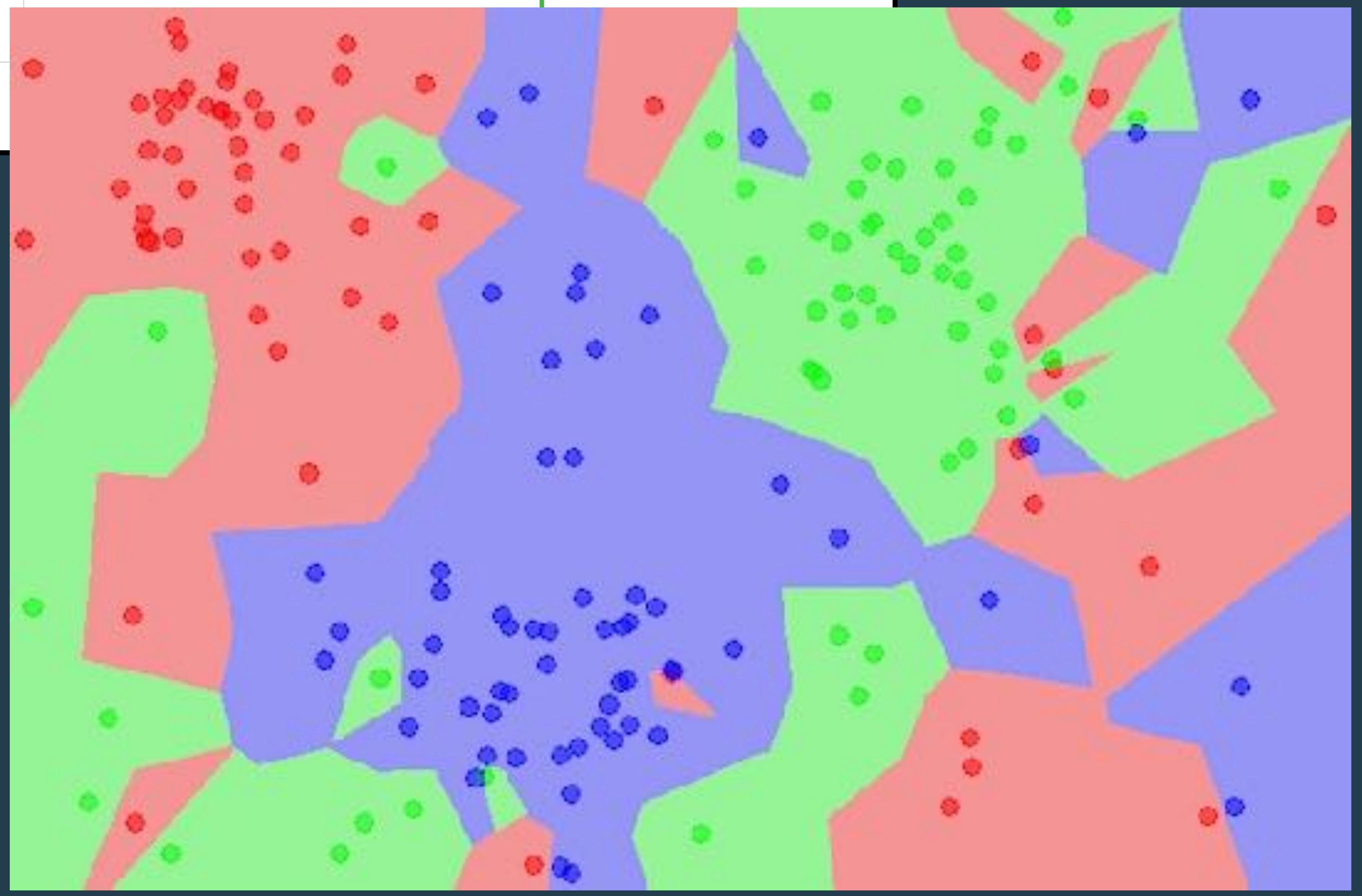
- How is data being used?
- How does the actual usage of data relate to its intended usage?
- Who owns and/or controls the data?
- Who benefits from the data usage?
- How is data usage related to privacy?
- How is data usage related to bias?

What do data ethics mean to you?









Courtesy of Devin Silvia

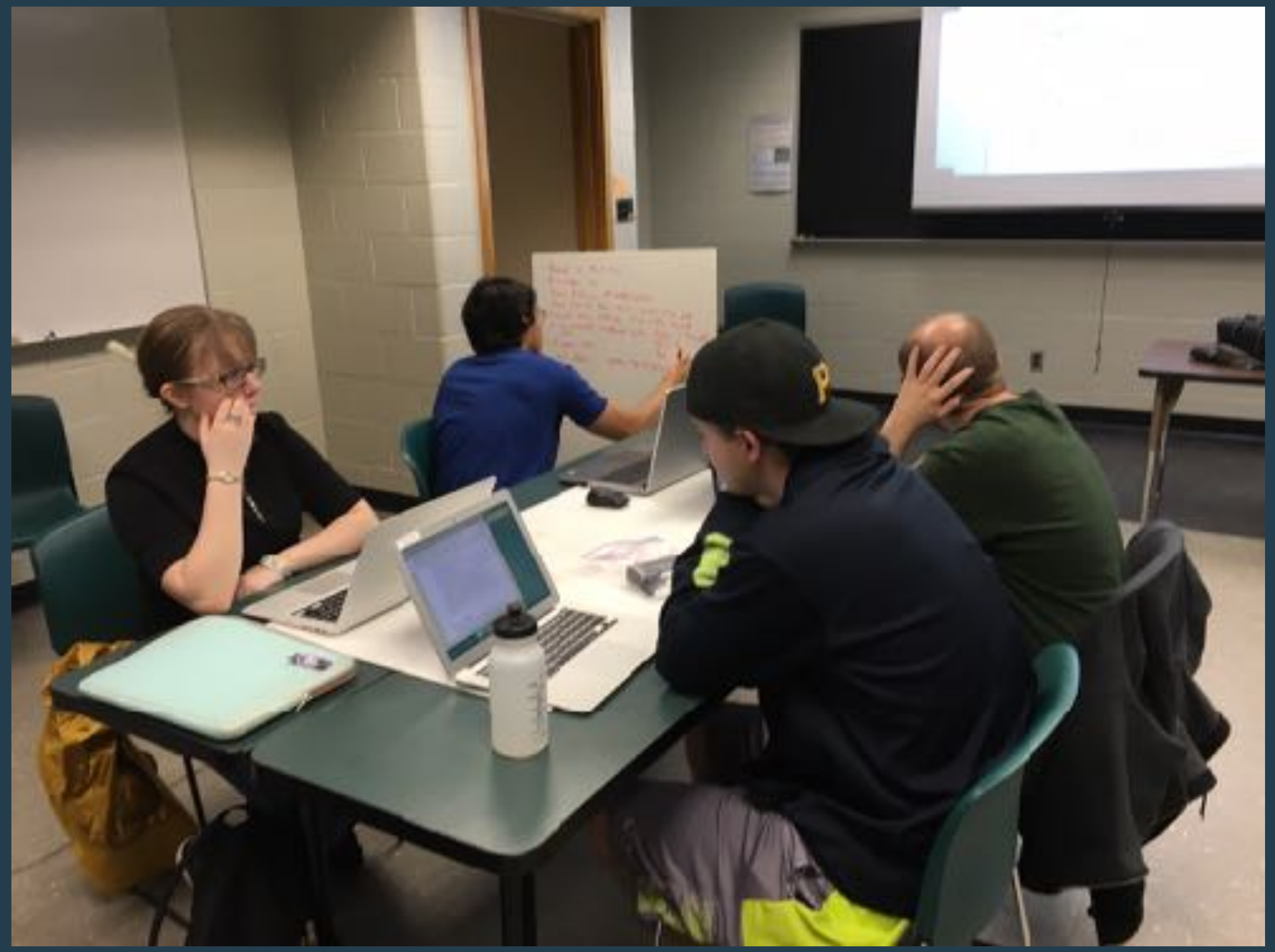
Introductory Computational Science

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.

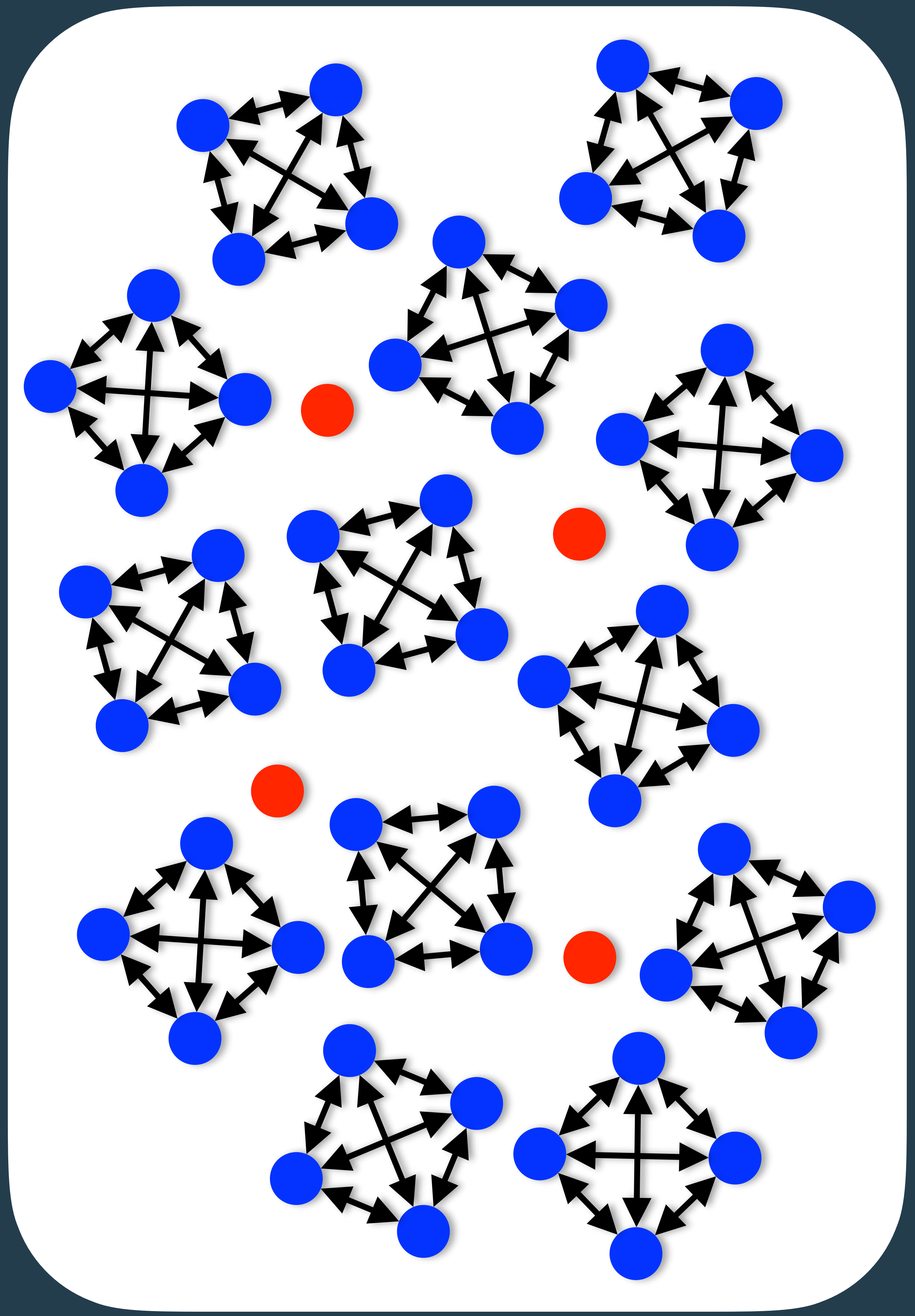
For any STEM major - pre-req: Calculus 1

Intro. Comp. Modeling (CMSE 201)



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

50-70 students/section



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

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

Courtesy of 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 PA majors before Classical Mechanics


MICHIGAN STATE

PICUP

PARTNERSHIP FOR INTEGRATION OF COMPUTATION INTO UNDERGRADUATE PHYSICS

NSF

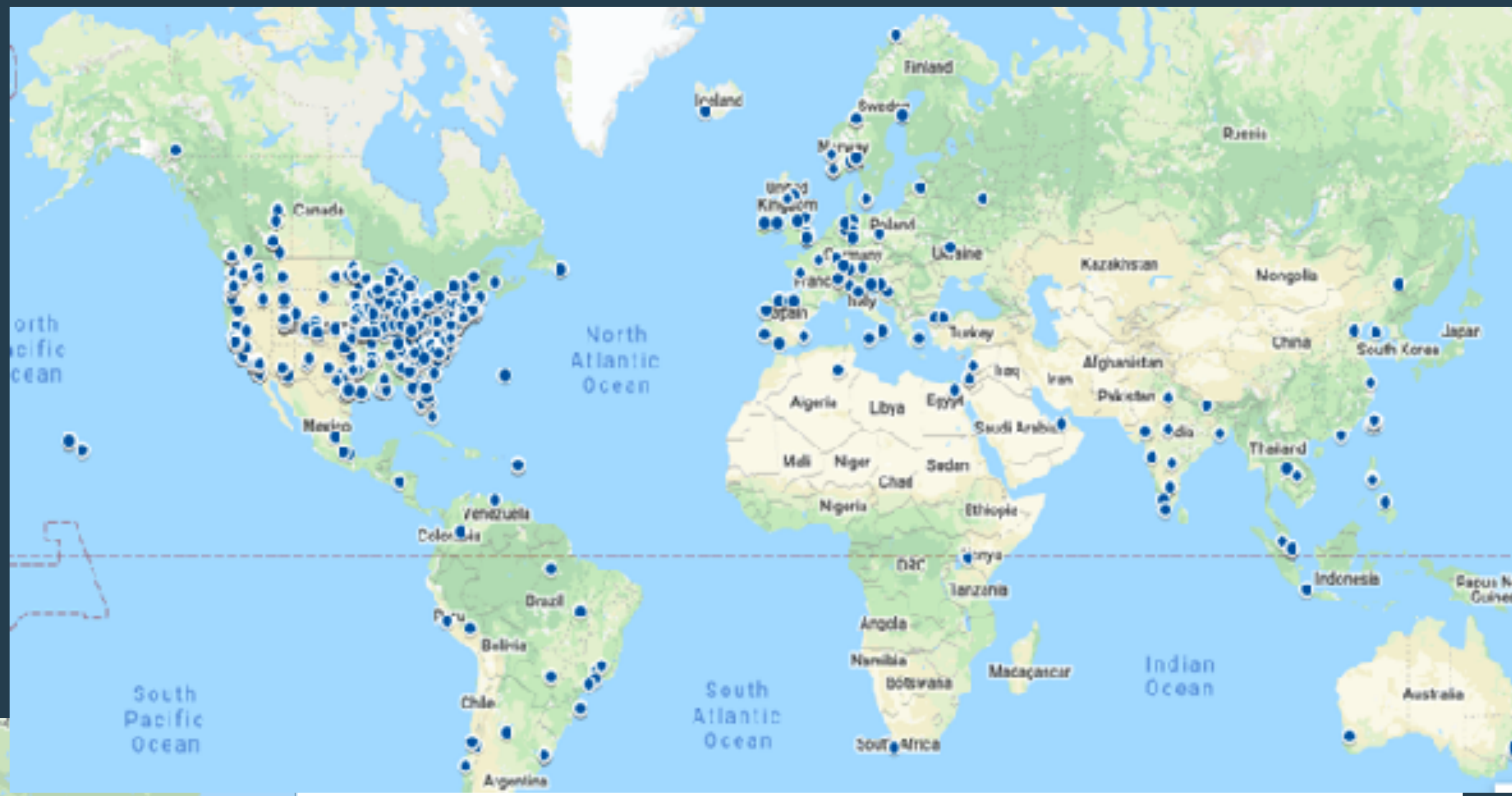
PICUP Community

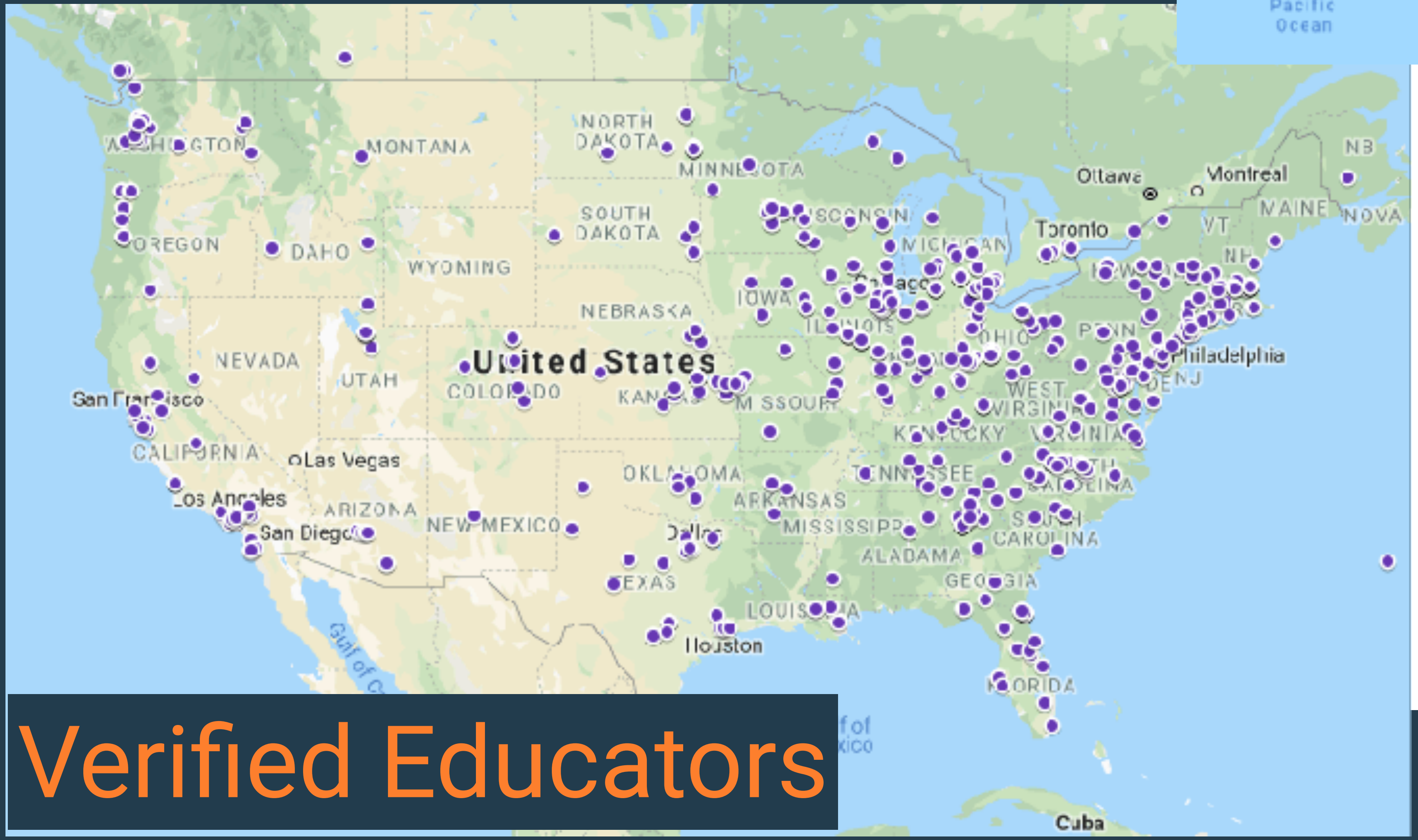
gopicup.org

FDW Participants

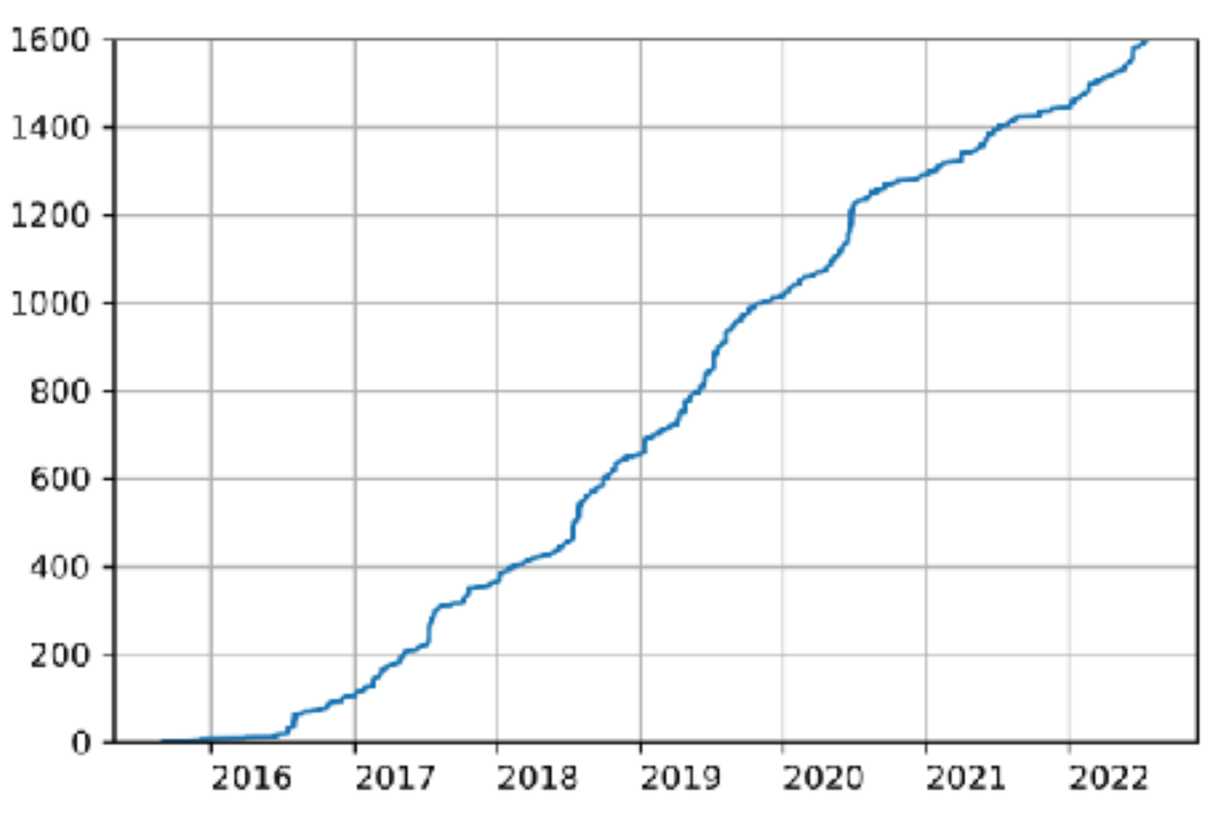
Verified educators submit academic documentation to gain access to:

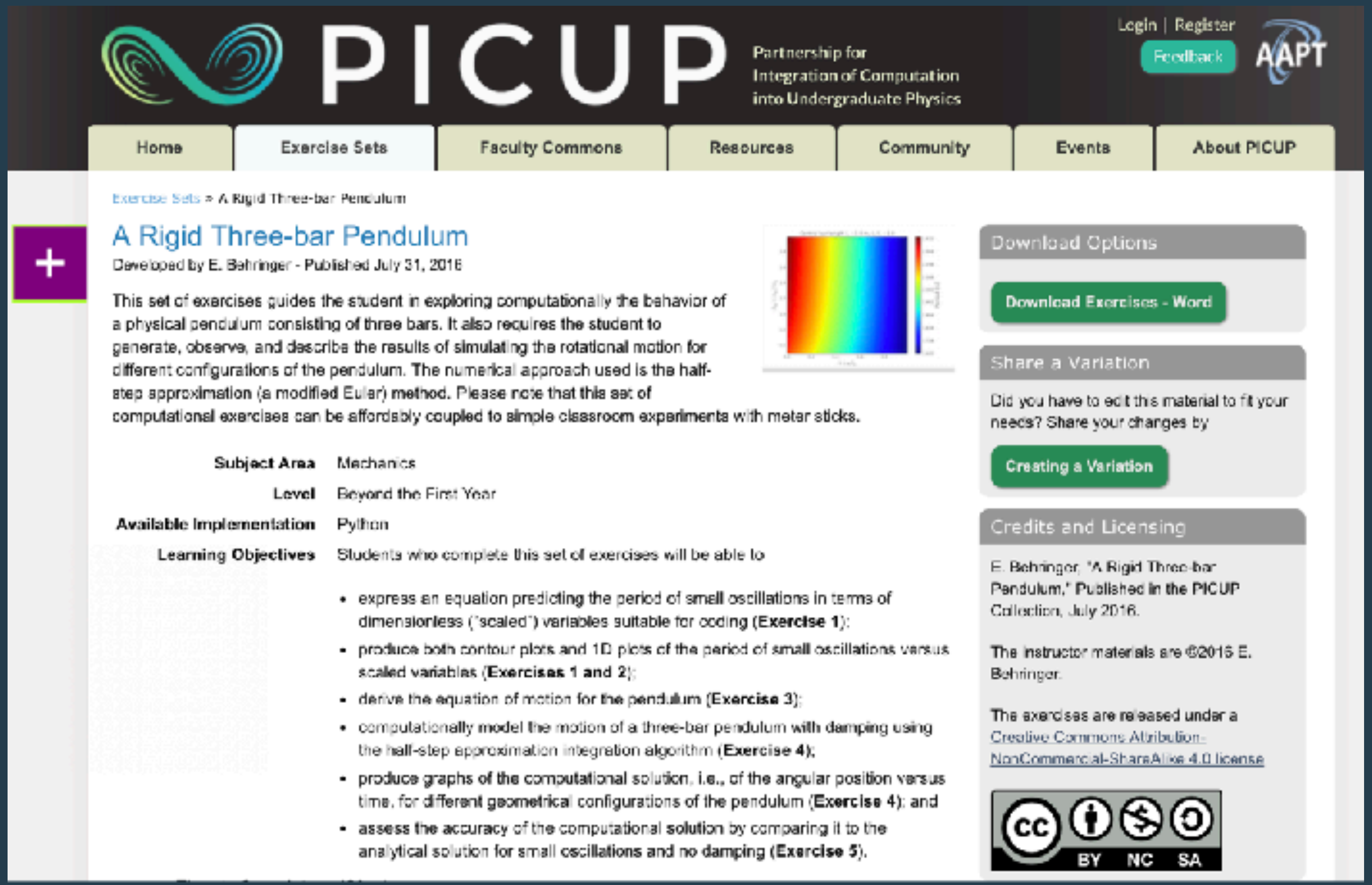
Solutions & Source Codes
Implementation Guides
Additional Materials





Verified Educators





Seemingly necessary but not sufficient conditions for change

How was this effort to integrate computing in physics done?

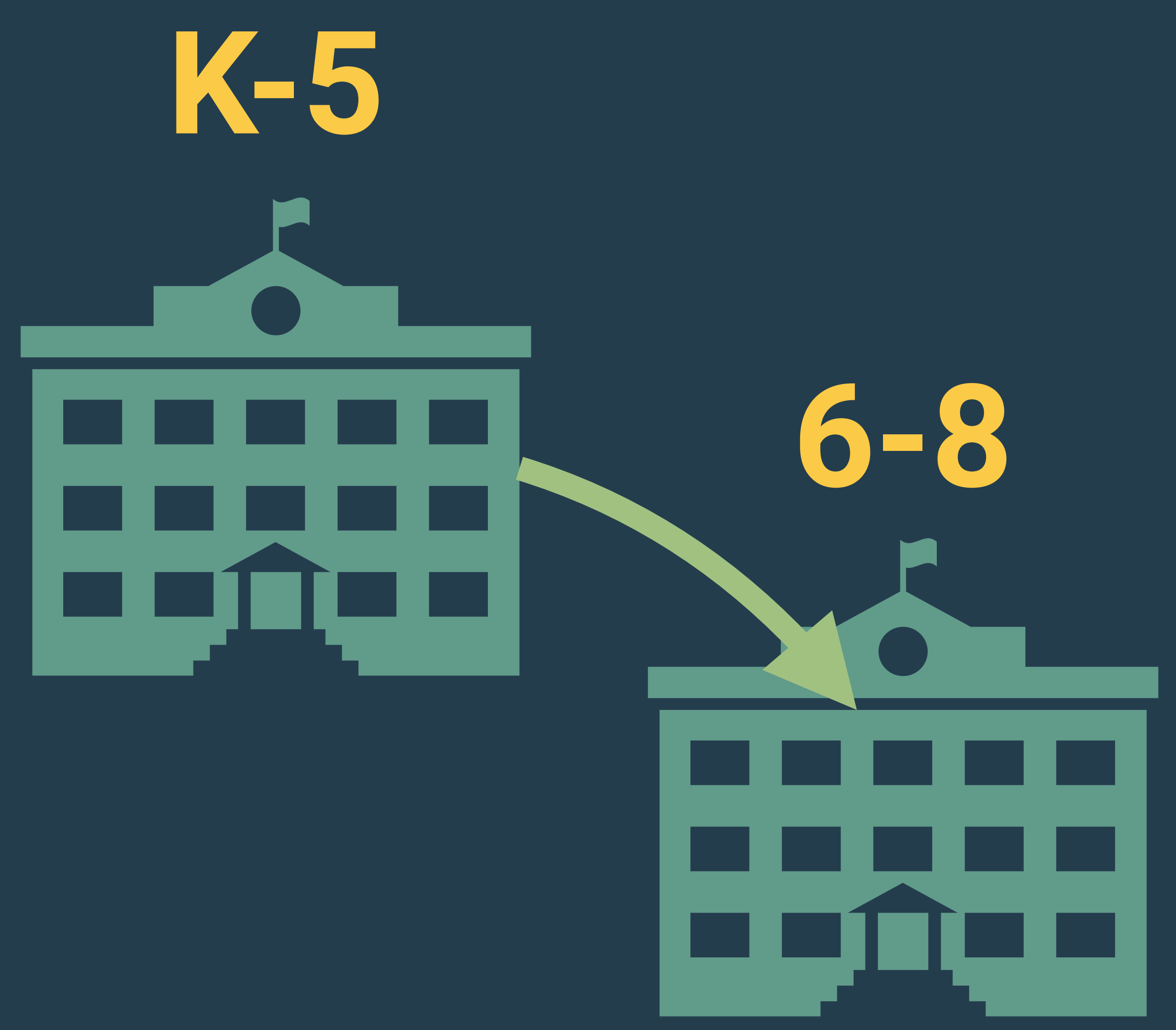
- Define goals and scope collectively
- Build professional development and community
- Respect institutional factors and diversity
- Acknowledge the complexity of the problem
- Collect data on experience and progress
- Share successful cases openly and transparently

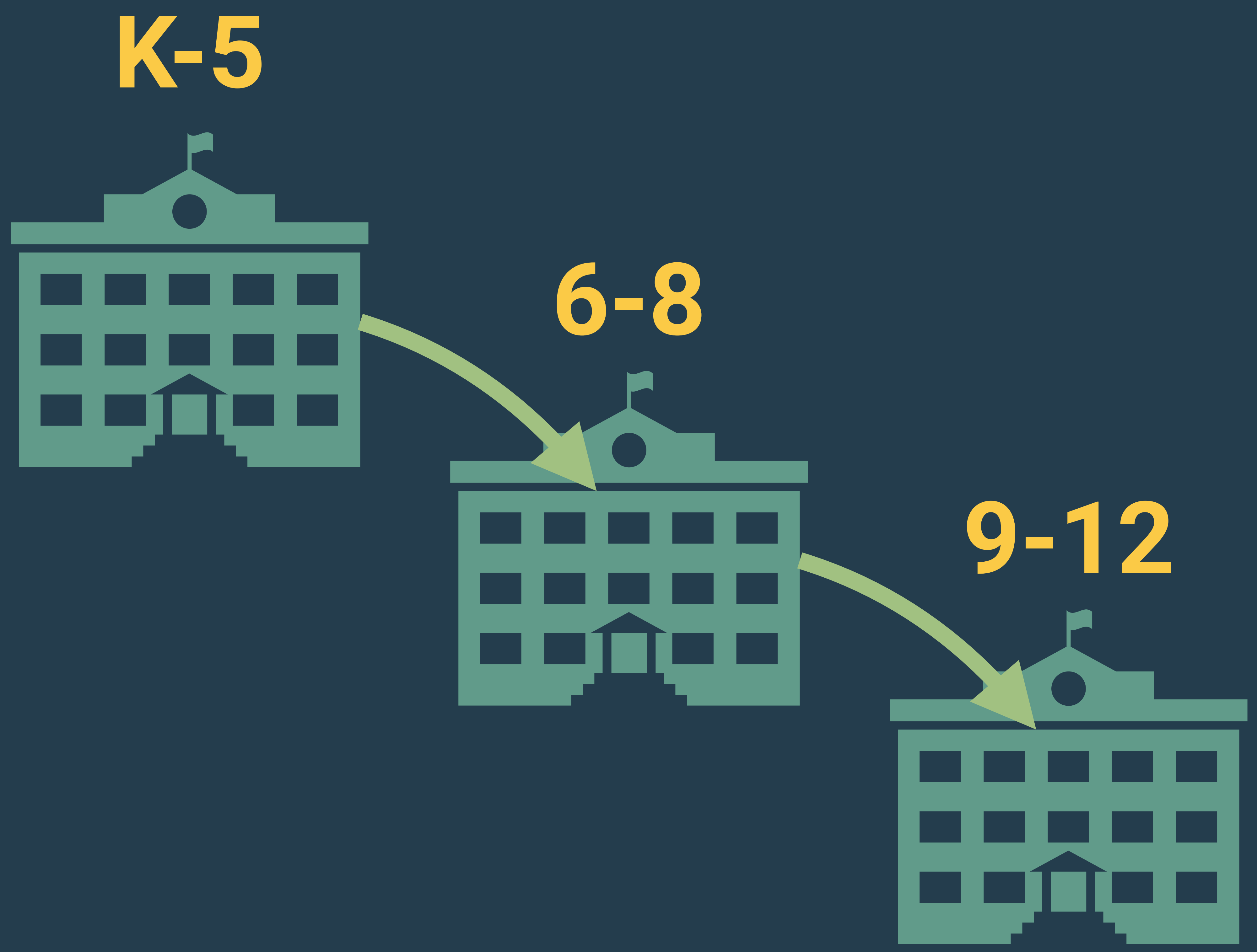
Must happen in disciplinary contexts

Needs scientists, educators, & ed. researchers

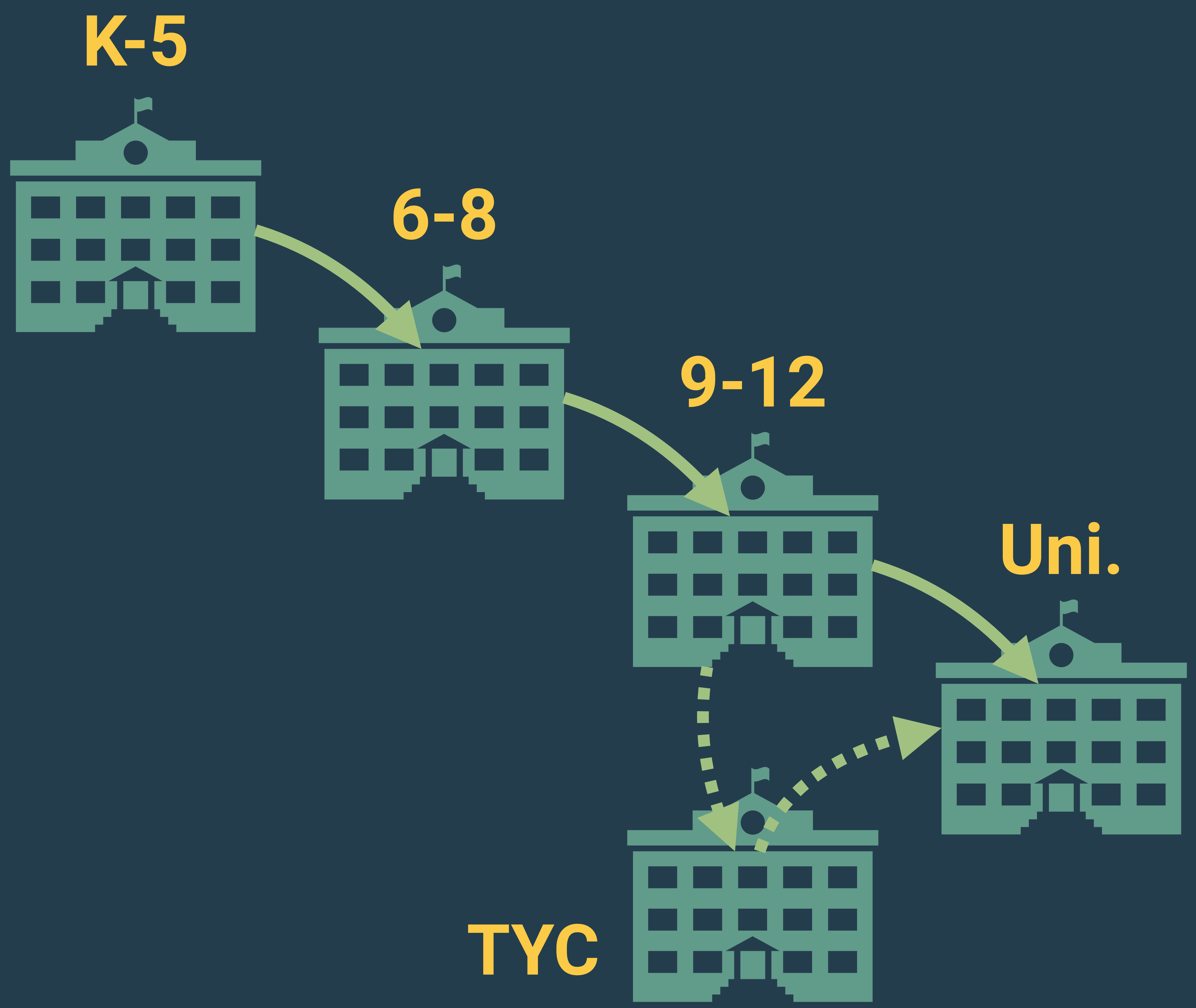
How might we better support students in our computationally enabled STEM courses?

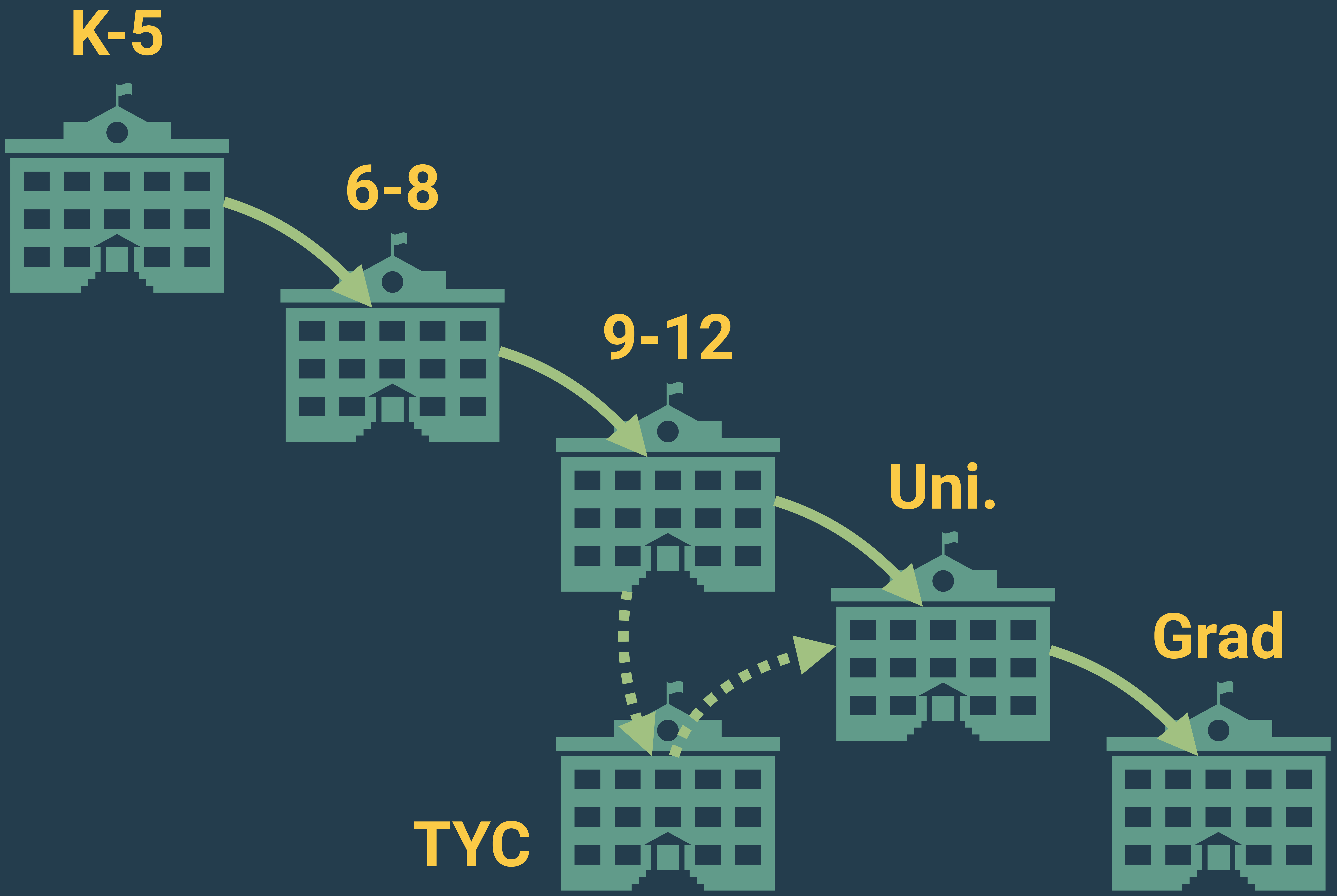
K-5

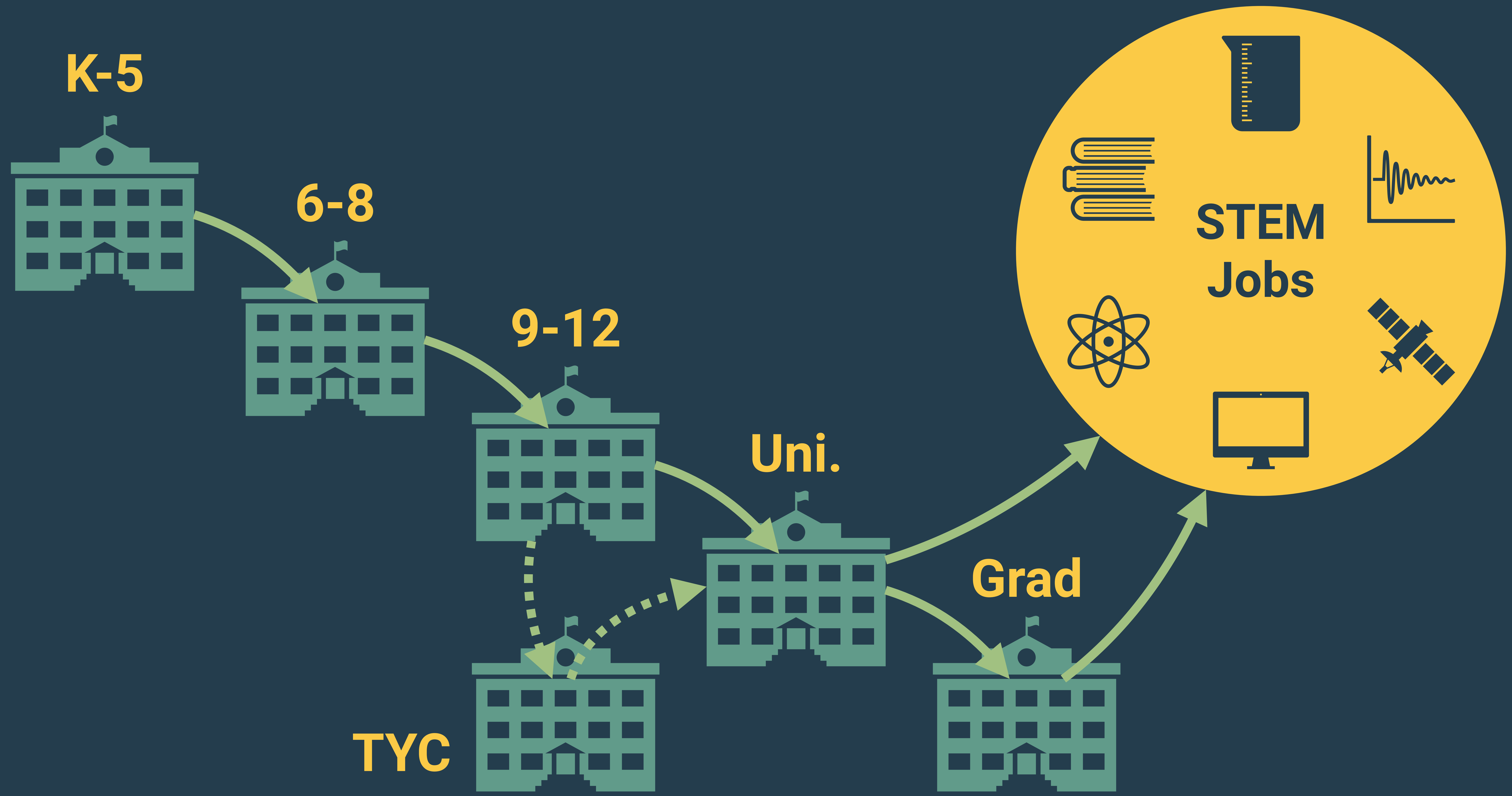

K-5
6-8


K-5
6-8
9-12


K-5
6-8
9-12
Uni.


K-5
6-8
9-12
Uni.
TYC


K-5
6-8
9-12
Uni.
Grad
TYC


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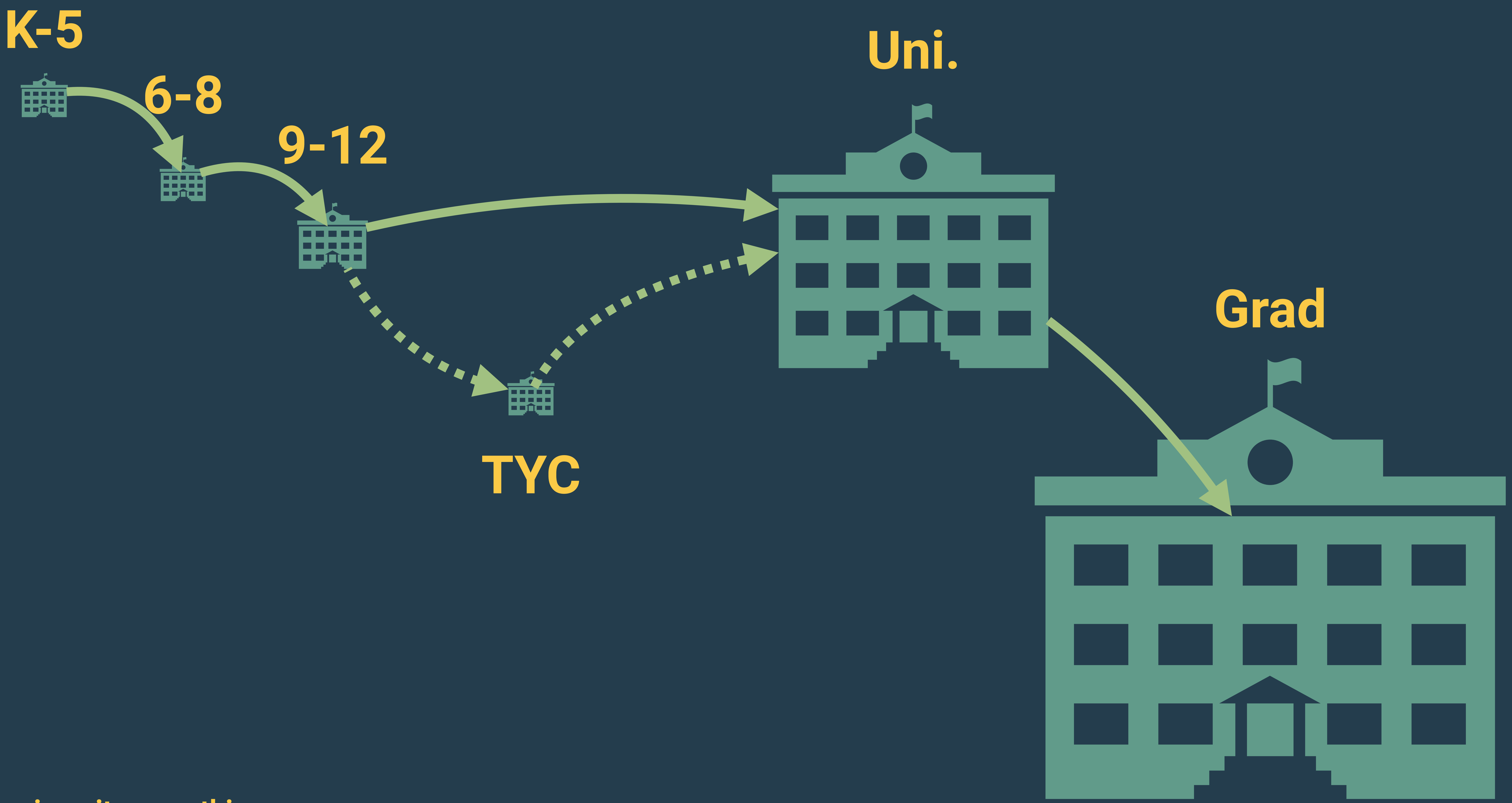
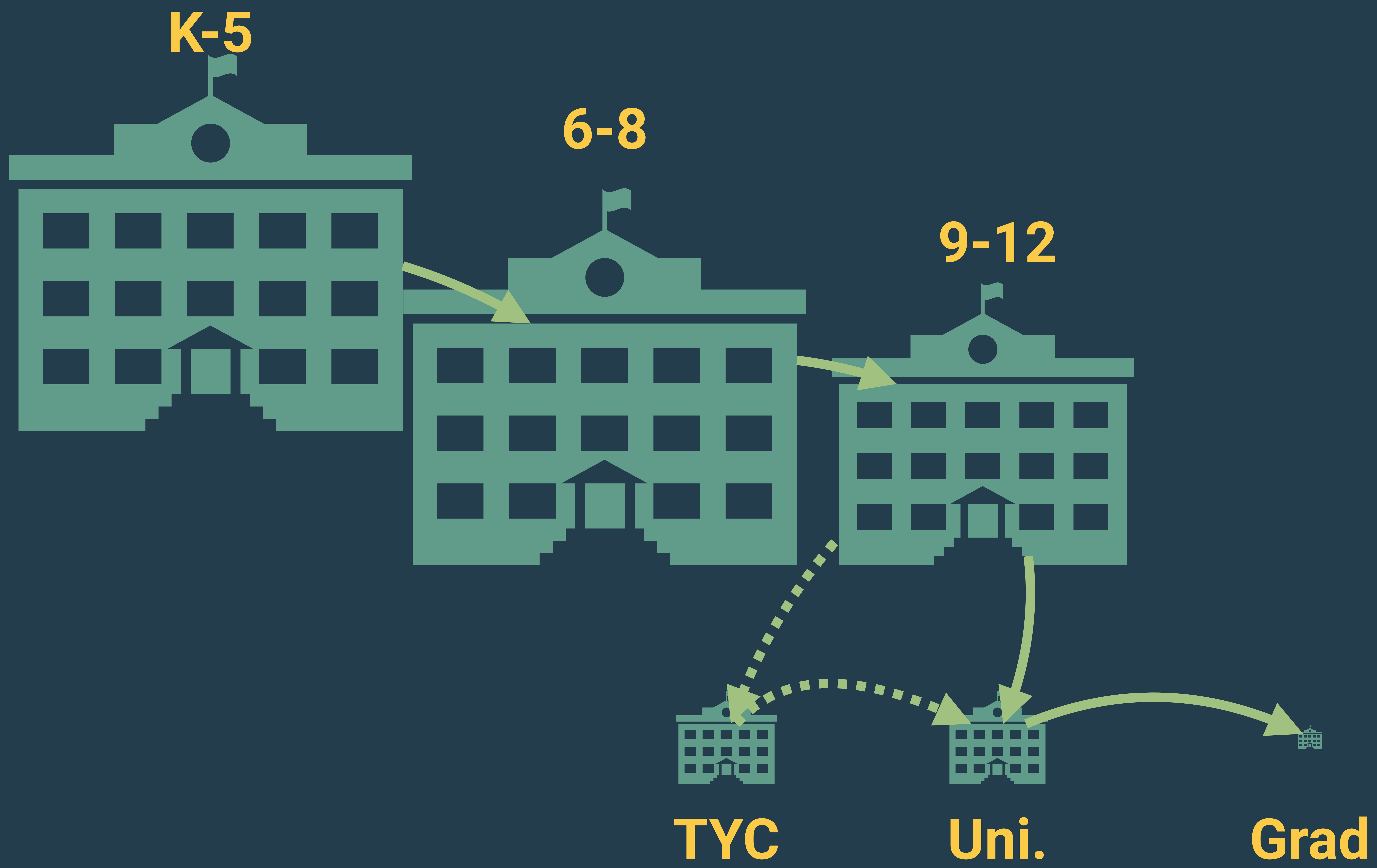
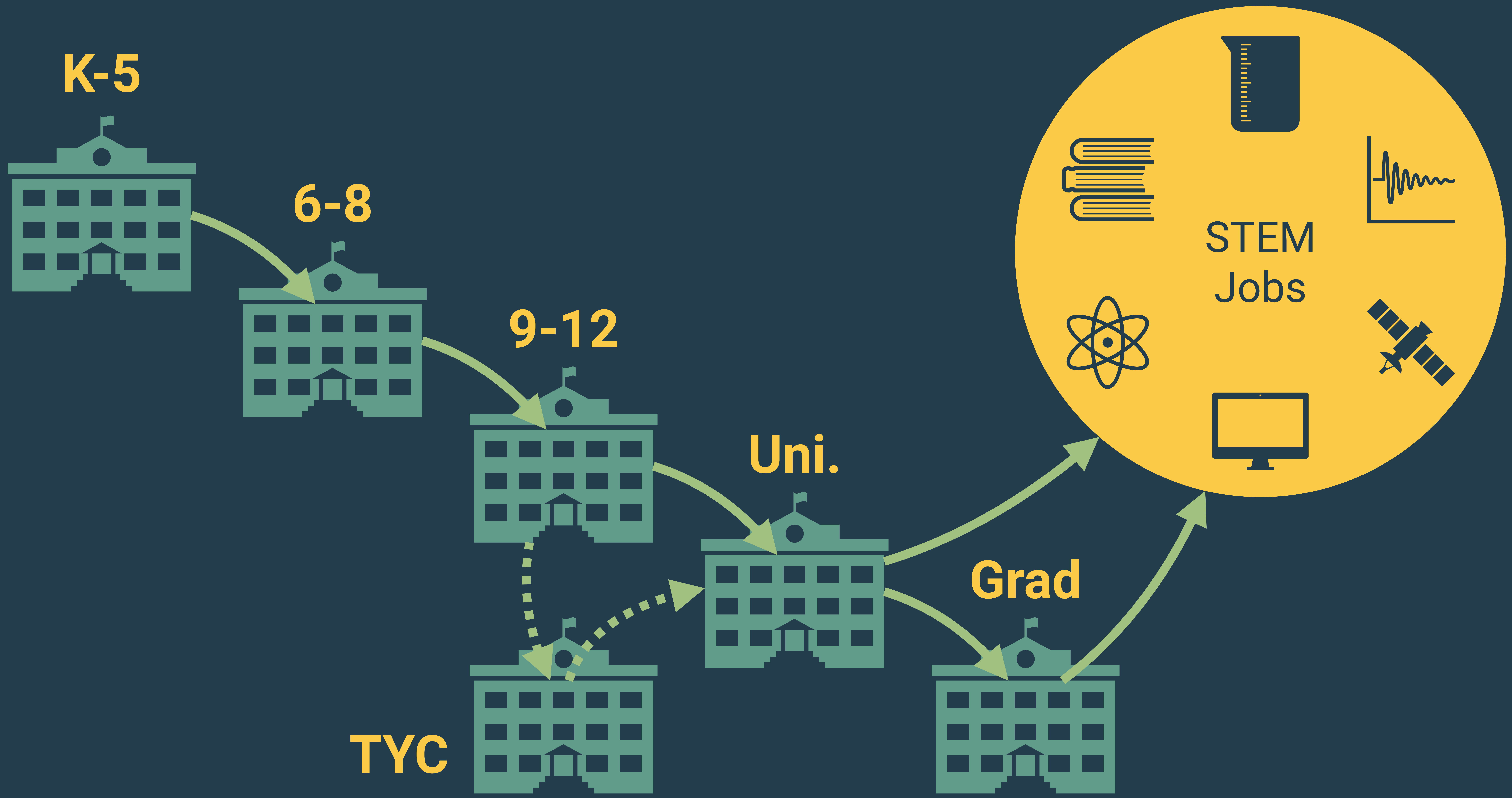
Uni.
Grad
TYC
STEM
Jobs



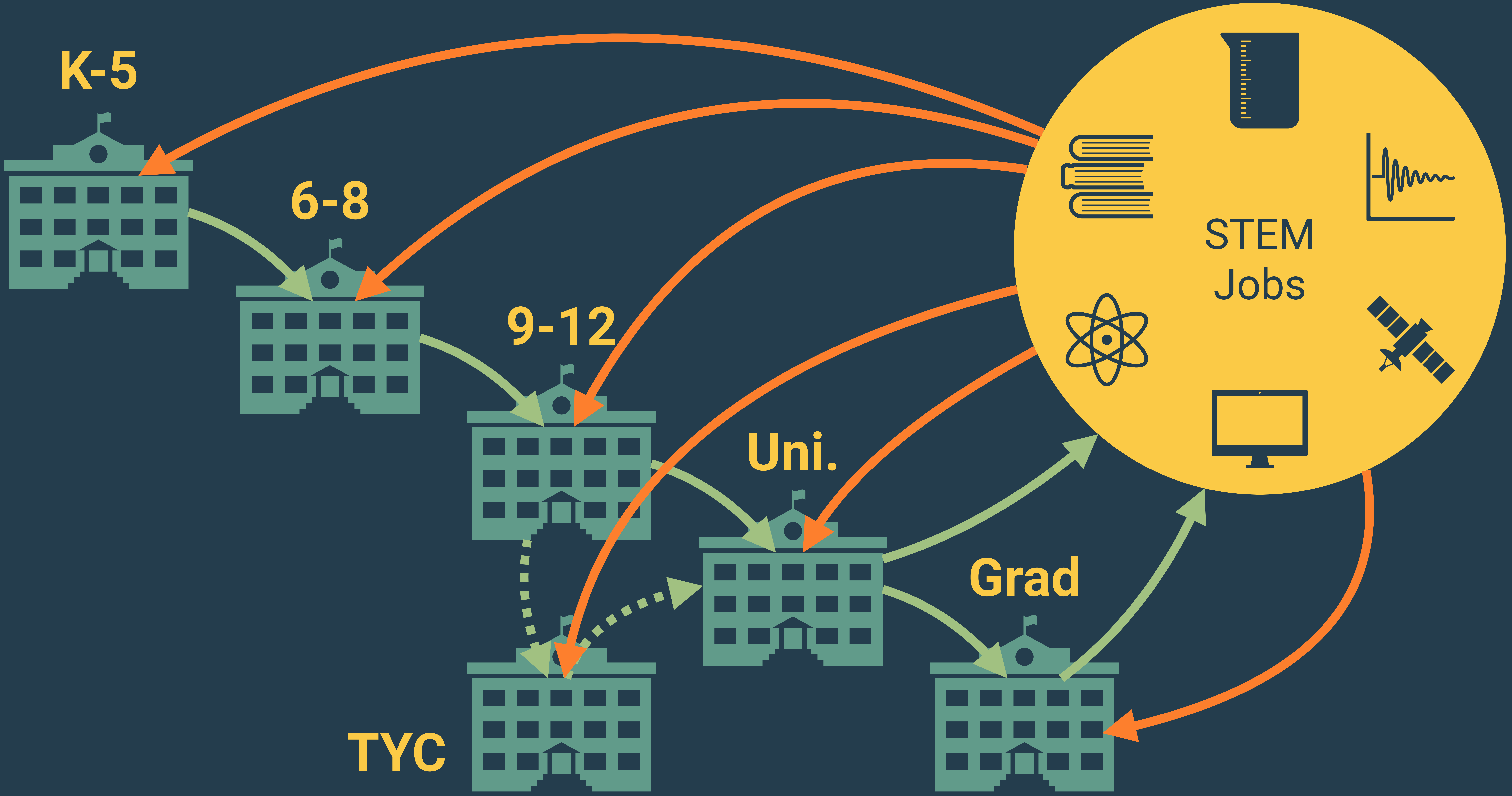
How my university sees things



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

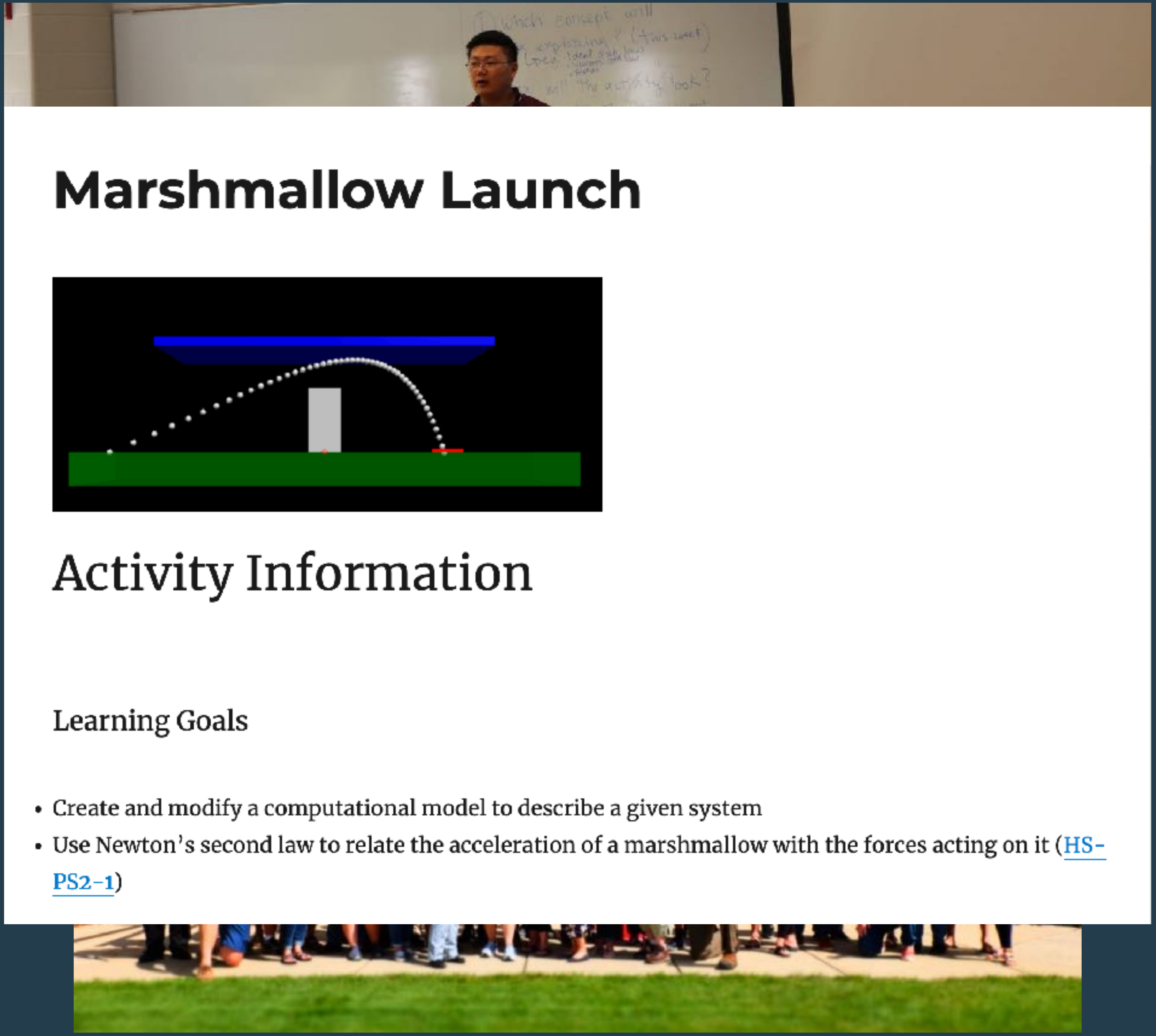
- Introduce computing
- Develop materials
- Grow community
- Focus on equity

Return to MSU (virtual during COVID)

- Addressing problems of practice
- Community building

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

ICSAM Workshop



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!

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

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,[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
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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

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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[nking] about equity in terms of social marker patter[ns in] teaching and learning situations. Then, we illu[strate how] our partner teachers used EQUIP in actio[n ...] sought to build equitable spaces for collabora[tive] computation-based high school physics.

EQUIP: Equity QUantified In Par[ticipation]

Analysis Framework for Computing Practices

Extracting Computational Insight
- Decomposing
- Highlighting and foregrounding

Building Computational Models
- Translating physics into code
- Algorithm building
- Applying conditional logic
- Utilizing generalization
- Adding complexity to a model

Data Practices
- Choosing data representation forms
- Generating data
- Manipulating data
- Analyzing data

- Debugging
- Working in groups on computational models
- Demonstrating affective dispositions towards computation

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

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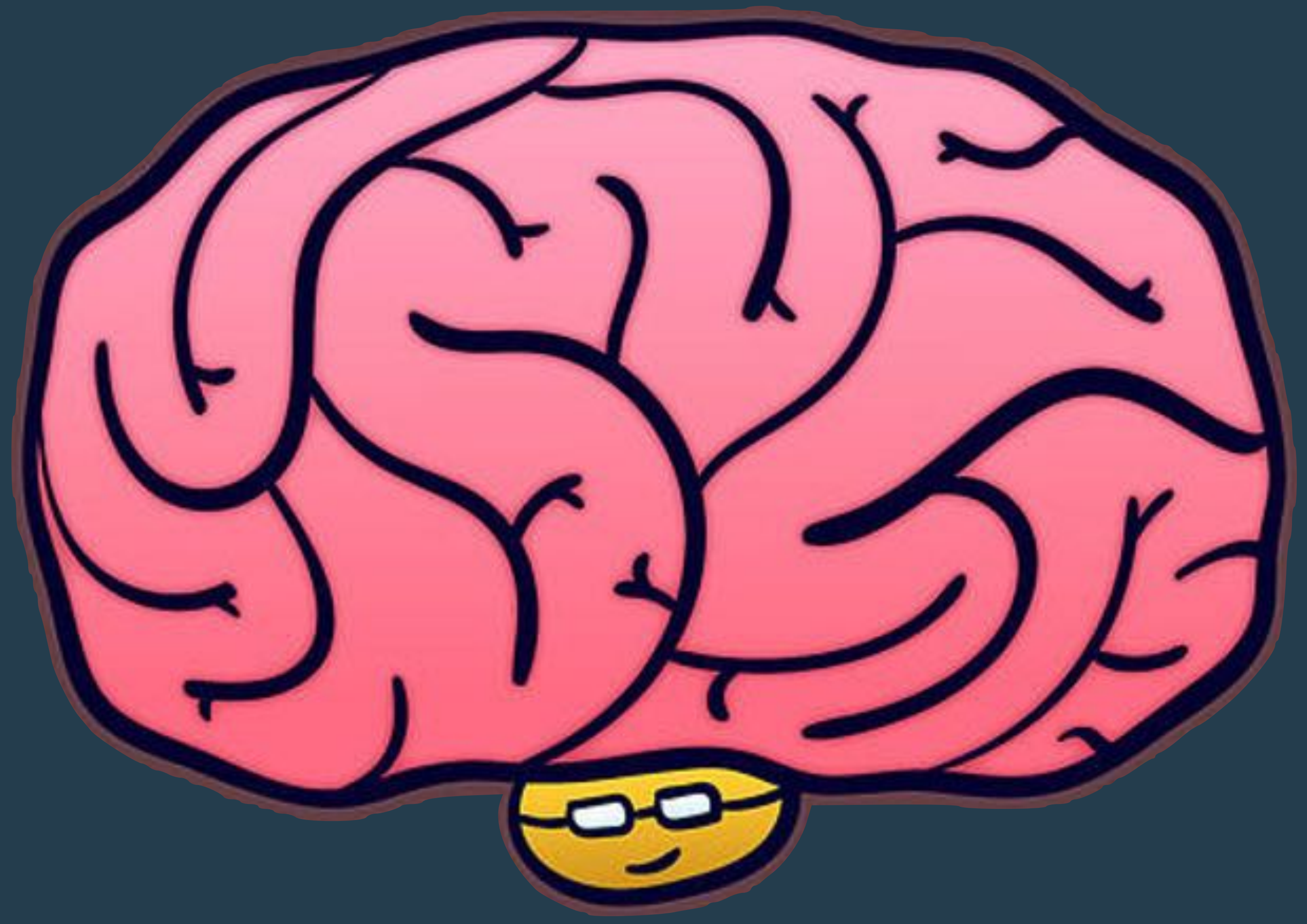
Weller, Bott, et al, Phys Rev PER, 2022


AND NOW FOR SOMETHING COMPLETELY DIFFERENT

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



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?

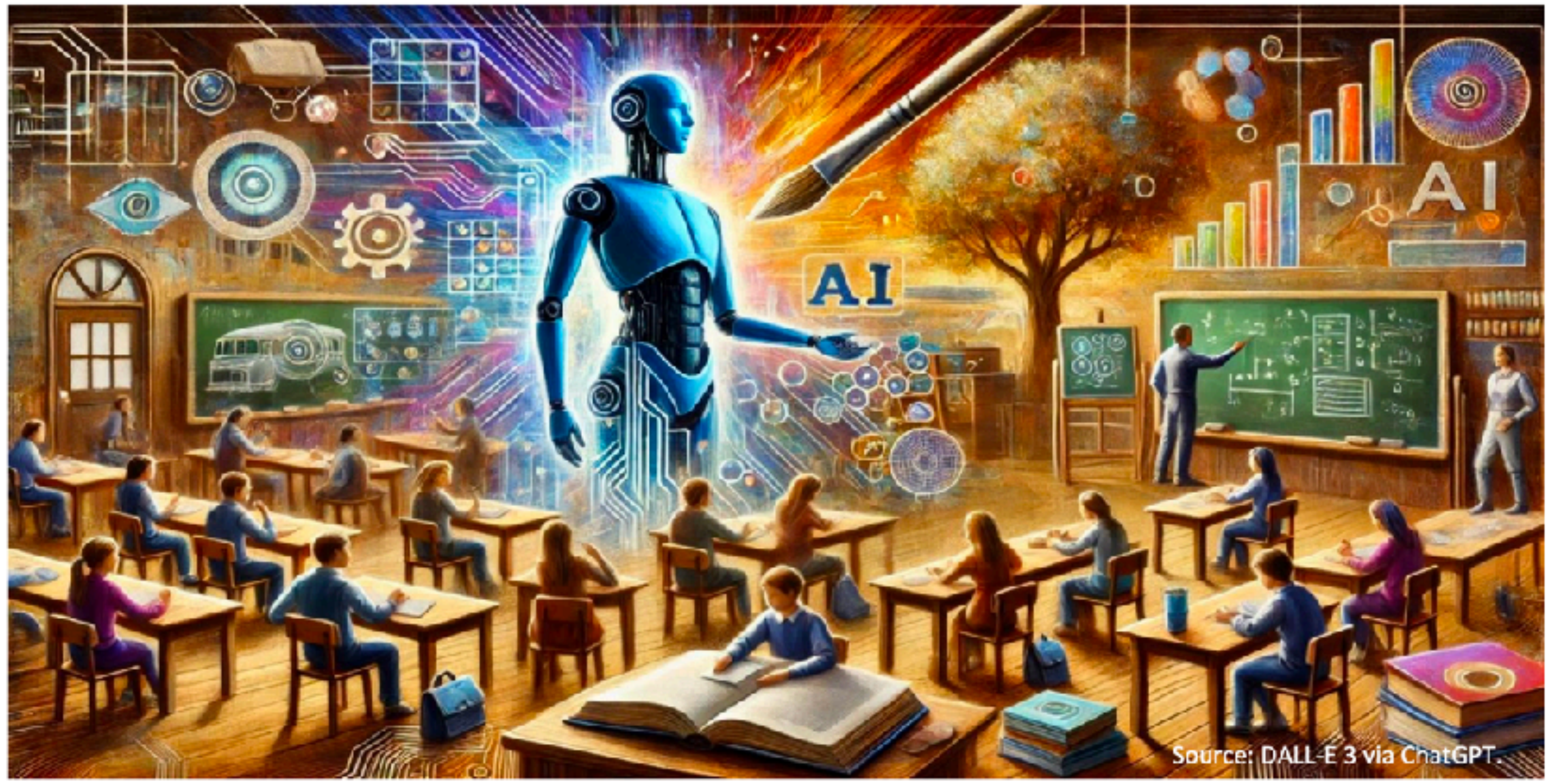
By Ray Schroeder

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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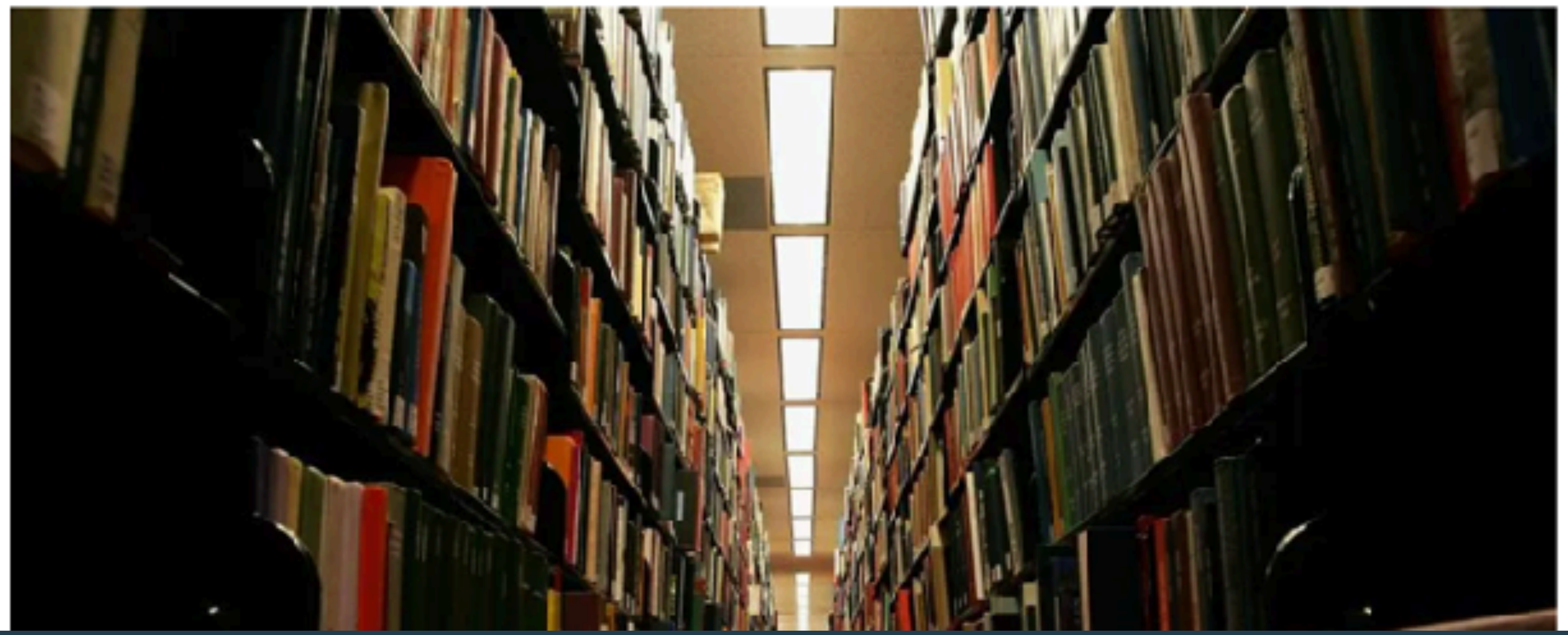


What is being discussed?

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

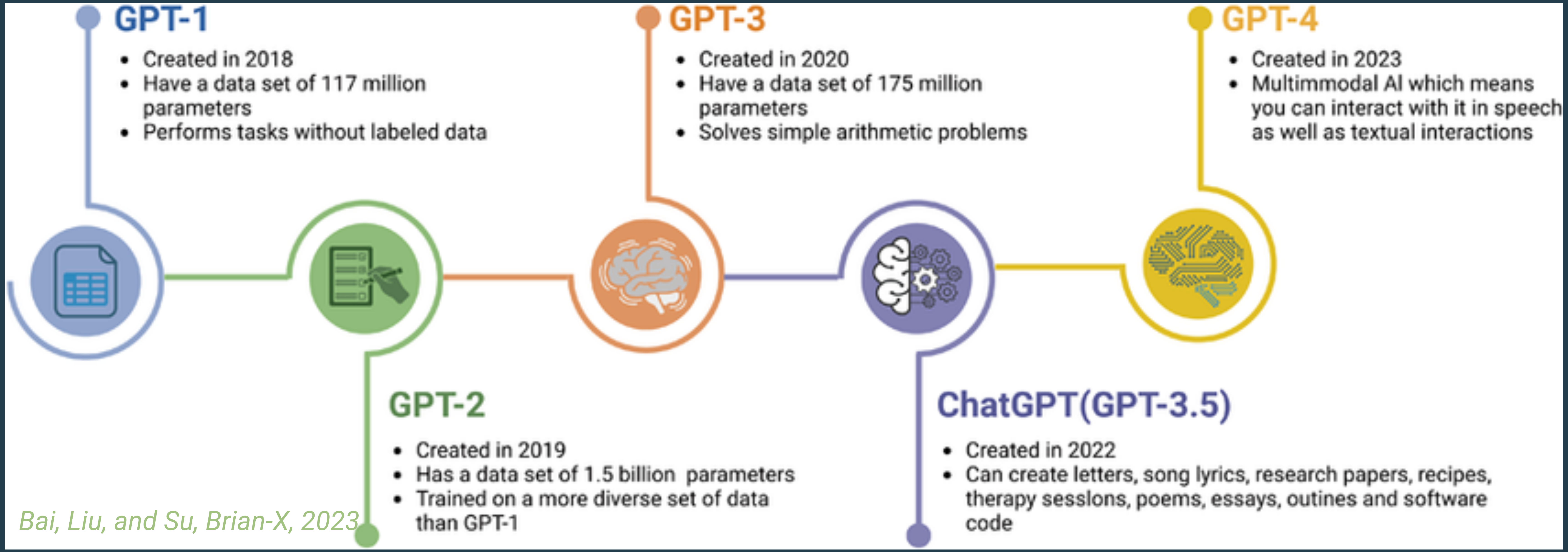
Education as a tool for Justice
education is a political act of liberation

- 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



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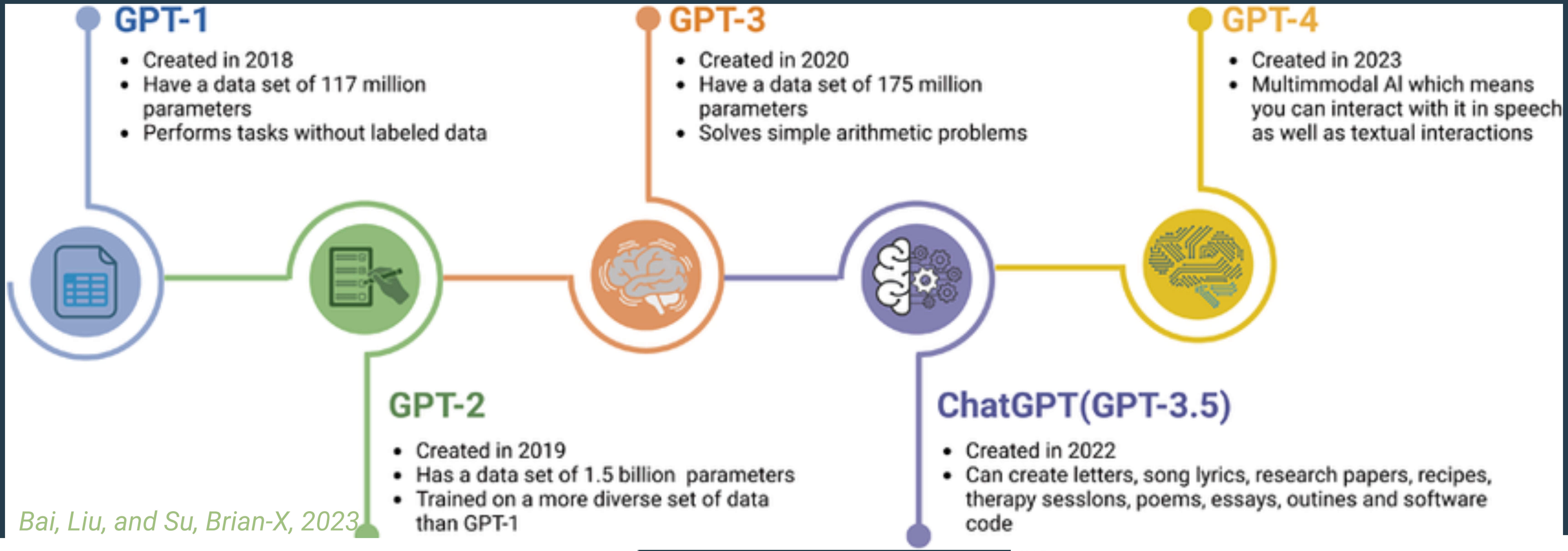
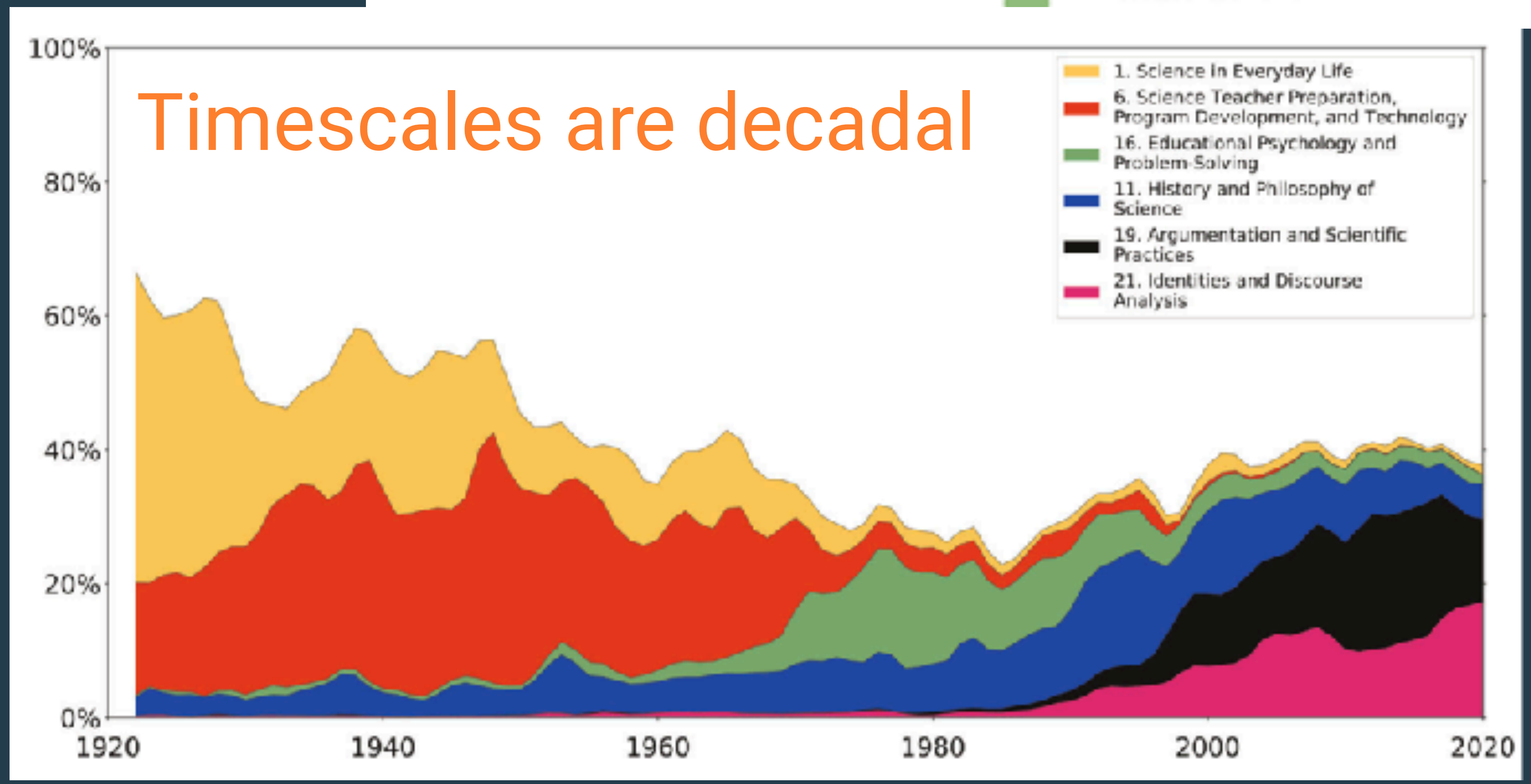
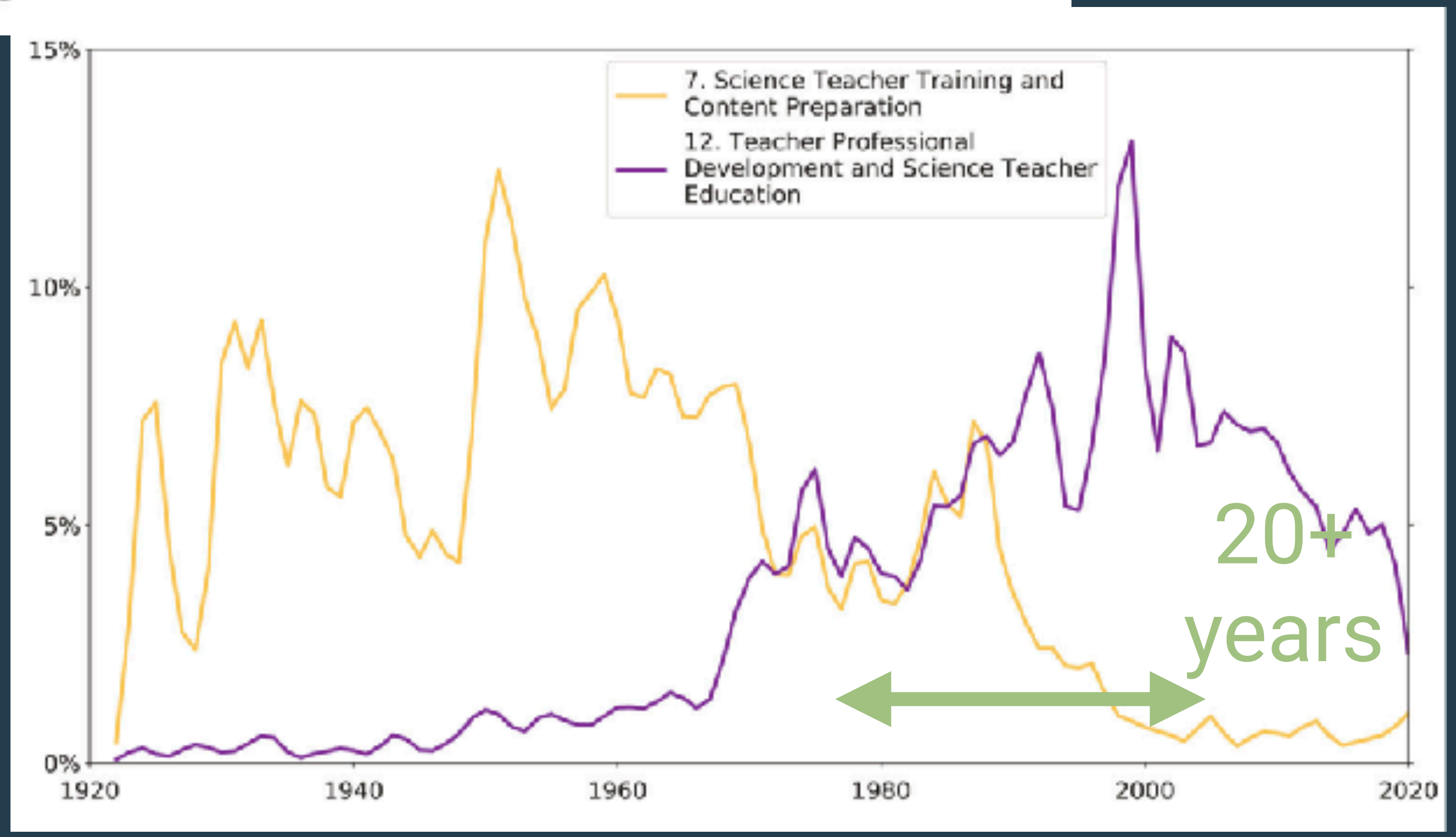


Bai, Liu, and Su, Brian-X, 2023





Odden, Marin, and Rudolph, Science Education, 2021

Computing Education Research Lab

CMSE Research Program

- 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?

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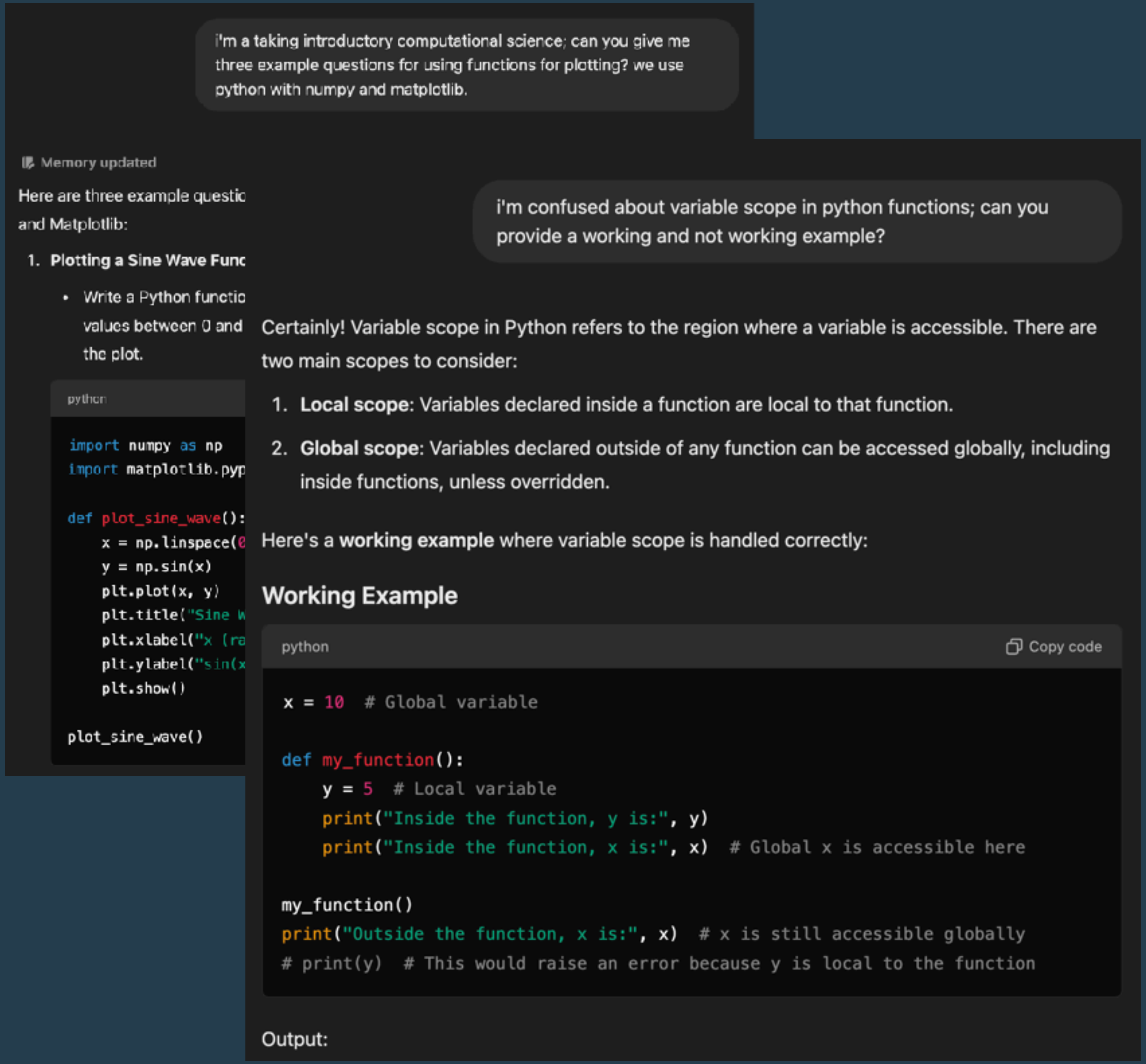
The CERL squirrels

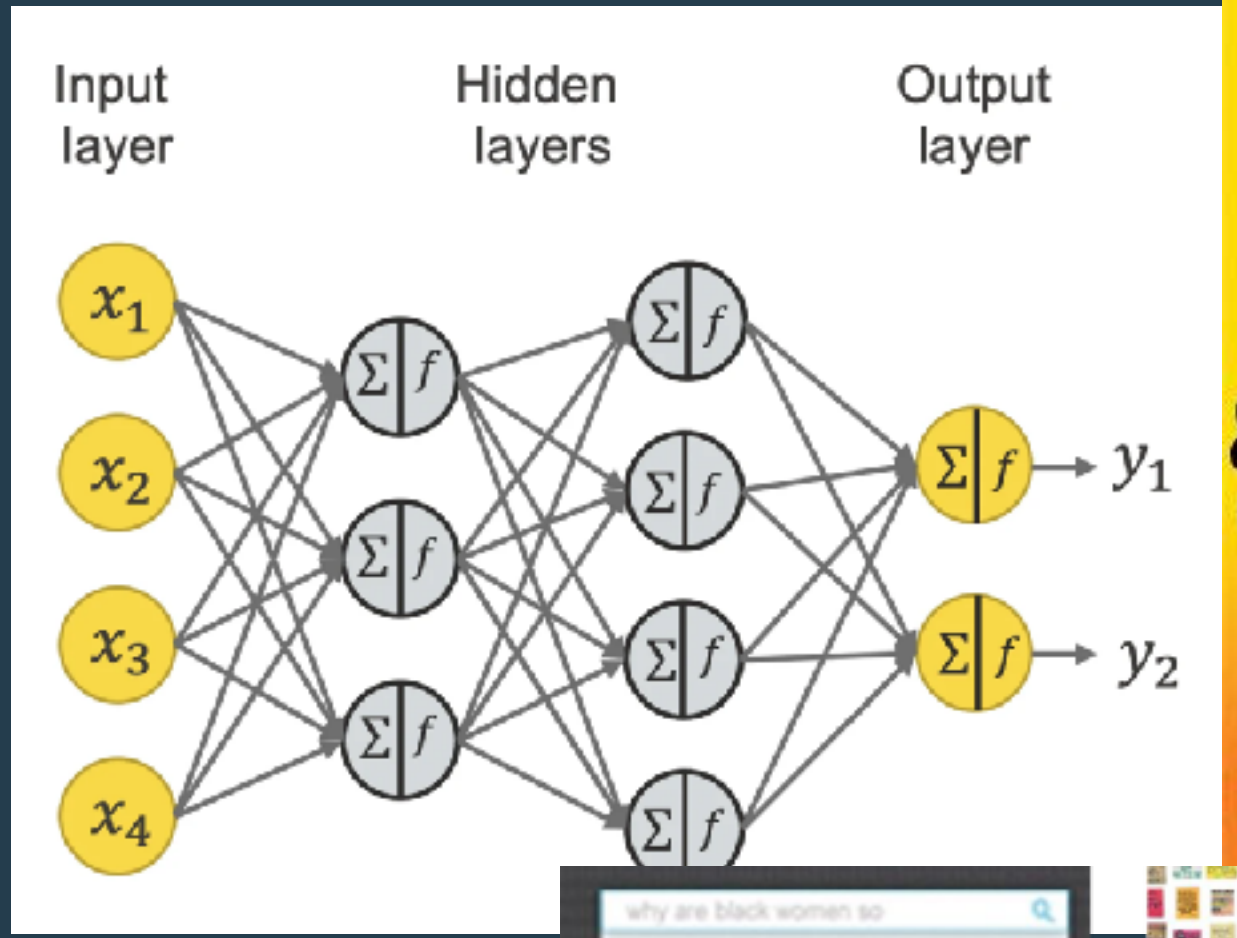
https://msu-cerl.github.io/

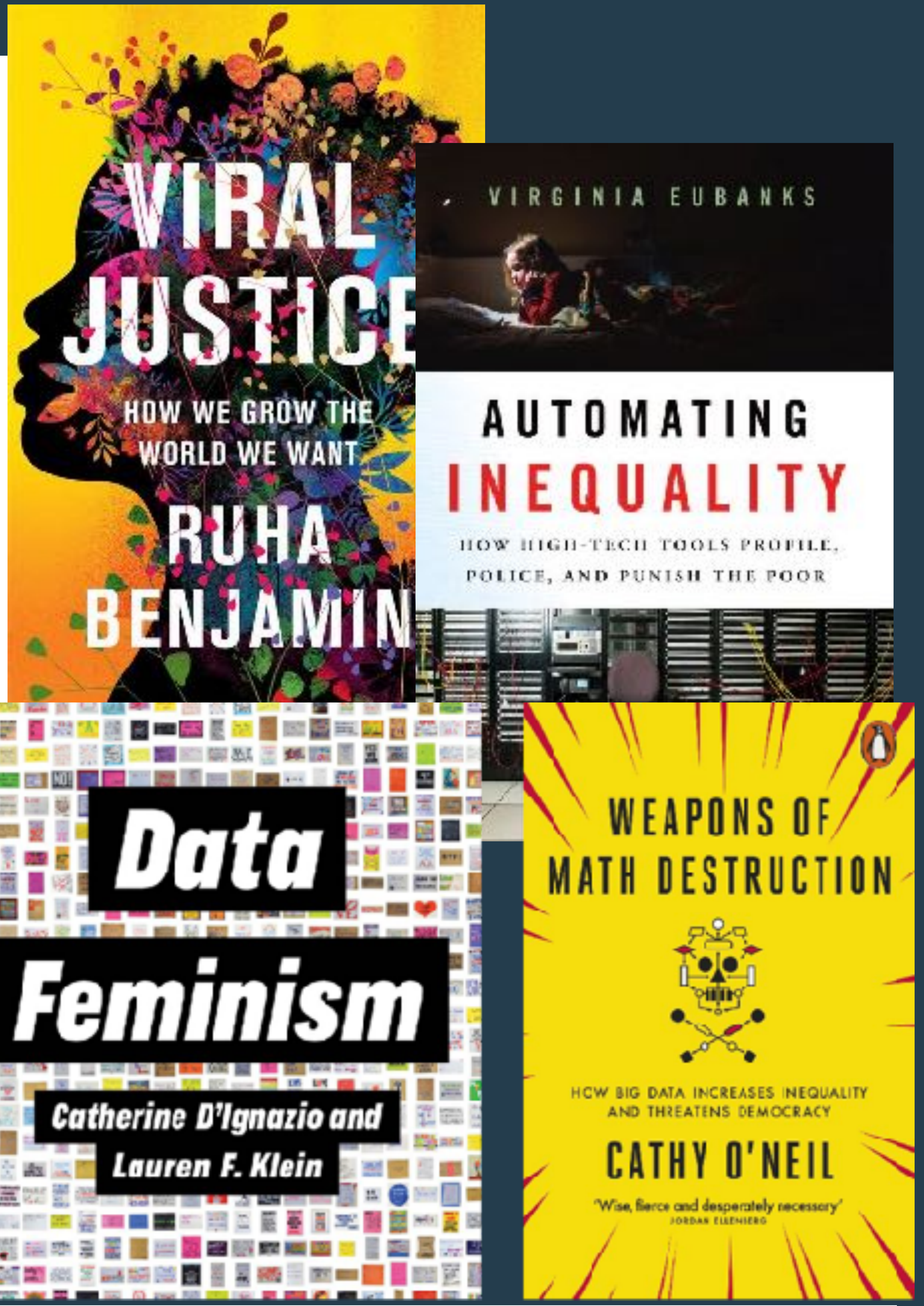
Two Concerns (for now)



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

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

we need more research, but we have some questions to start

How do students develop an understanding of and relationship with AI in science classrooms?

In what ways can science students use AI productively for learning?

How does teaching students science change when AI can write nearly all the code they would use?

How do we engage students in discussions about AI, ethics, and justice?

How does AI exacerbate or mitigate inequities in science learning?

How do we engage a broad cross-section of scientists in this work?

Final Takeaways

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

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- It’s important that we engage with AI and science education. It will require an authentic and collective effort.

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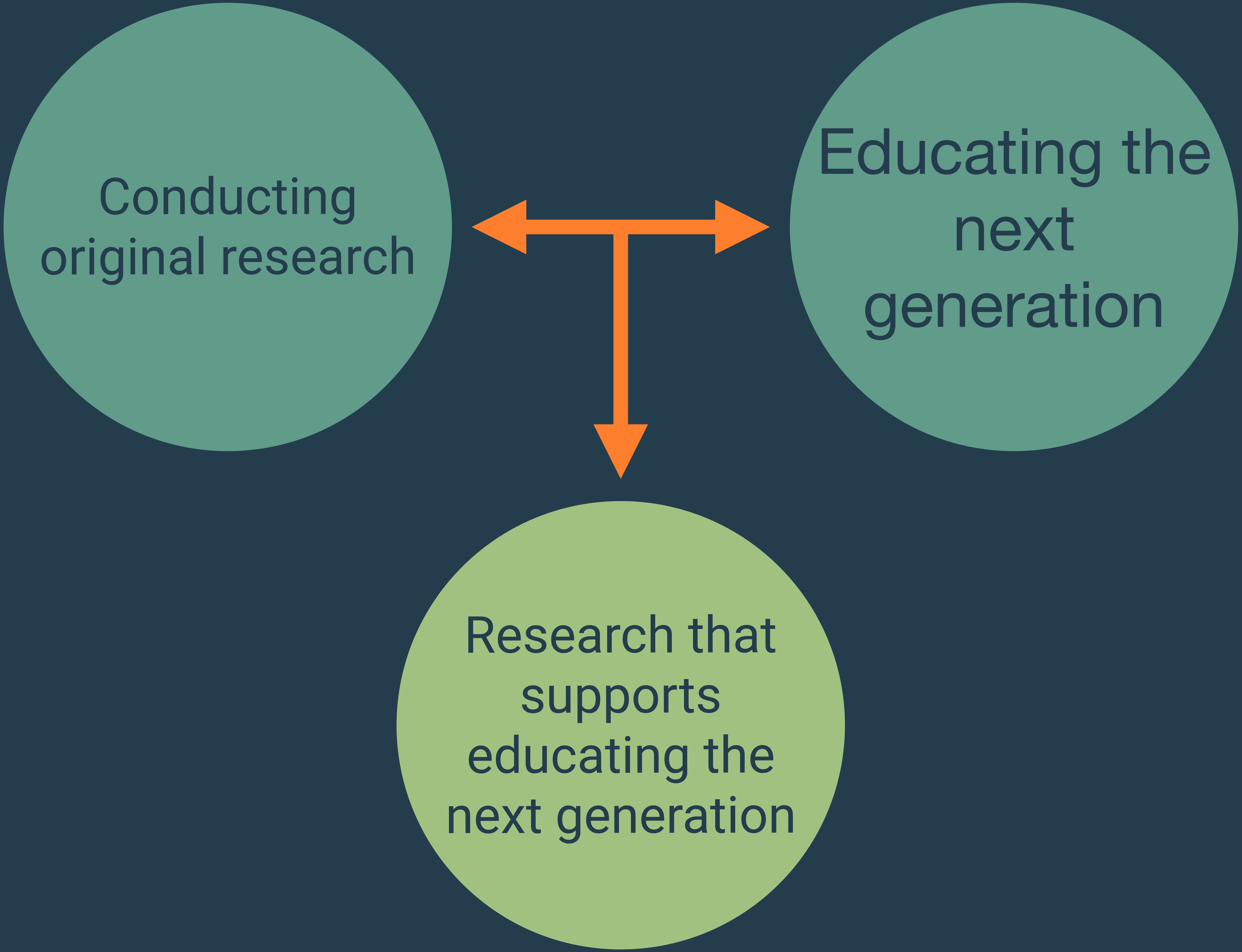
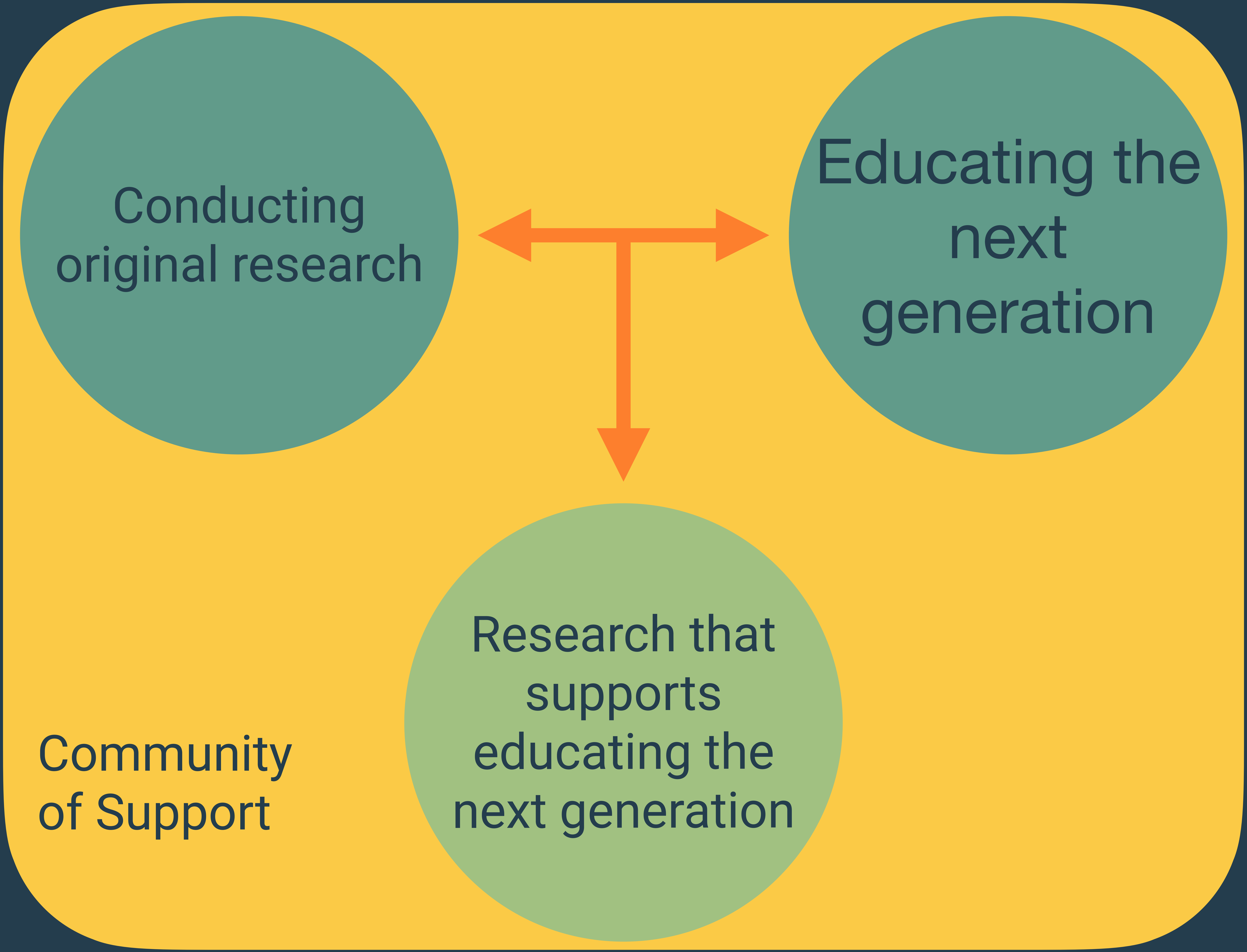
- It’s essential that we design for AI in science classrooms. The future of science appears to demand it.

Final Takeaways

- It's quite possible to integrate computing into a wide variety of physics learning environments. It's hard to do it sustainably.
- It's important that we engage with AI and science education. It will require an authentic and collective effort.
- It's essential that we design for AI in science classrooms. The future of science appears to demand it.
- It's gonna be a lot of work. But a lot of fun, too.


Conducting original research
Educating the next generation
Research that supports educating the next generation


Conducting original research
Educating the next generation
Research that supports educating the next generation
Community of Support

Thank you!

Thank y’all

Questions?

caballero@pa.msu.edu
perl.natsci.msu.edu
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Extra Slides