

Supporting the integration of computing in physics education

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*Department of Physics
Centre for Computing in Science Education*



What do I do with my physics degree?

A few things...

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





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

MICHIGAN STATE
UNIVERSITY



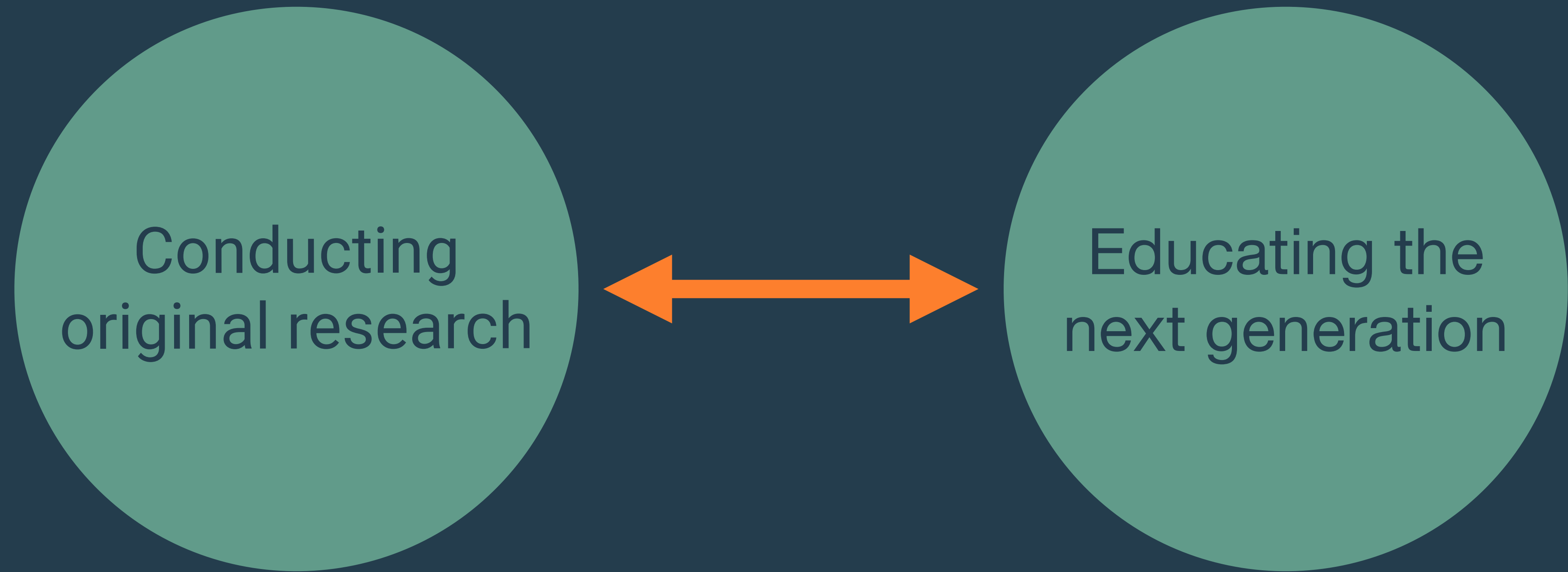
Conducting Original Research

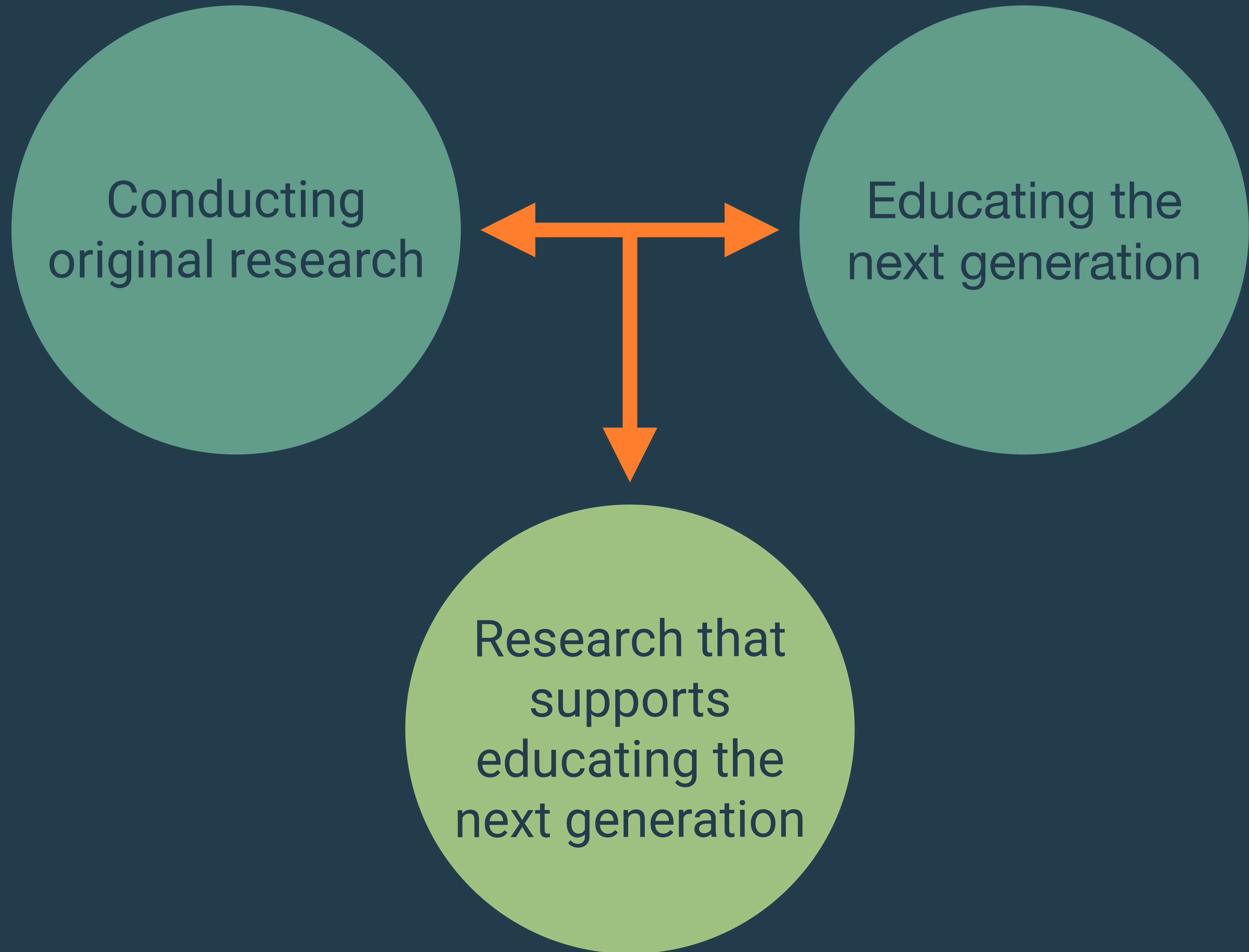
Two students working on
an FRIB experiment



Educating the Next Generation

Students working on introductory physics
lab in Lyman Briggs College





A diagram illustrating the relationship between Classroom Instruction and Education Research. It features two ovals: a yellow one on the left labeled 'CLASSROOM INSTRUCTION' and a teal one on the right labeled 'EDUCATION RESEARCH'. Two curved, dashed orange arrows connect them in a clockwise cycle, indicating a reciprocal relationship.

**CLASSROOM
INSTRUCTION**

**EDUCATION
RESEARCH**

Physics Education Research studies:

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

Theory, Experiment, and Applied



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

Challenges and Opportunities in Physics Education

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

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

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

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

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

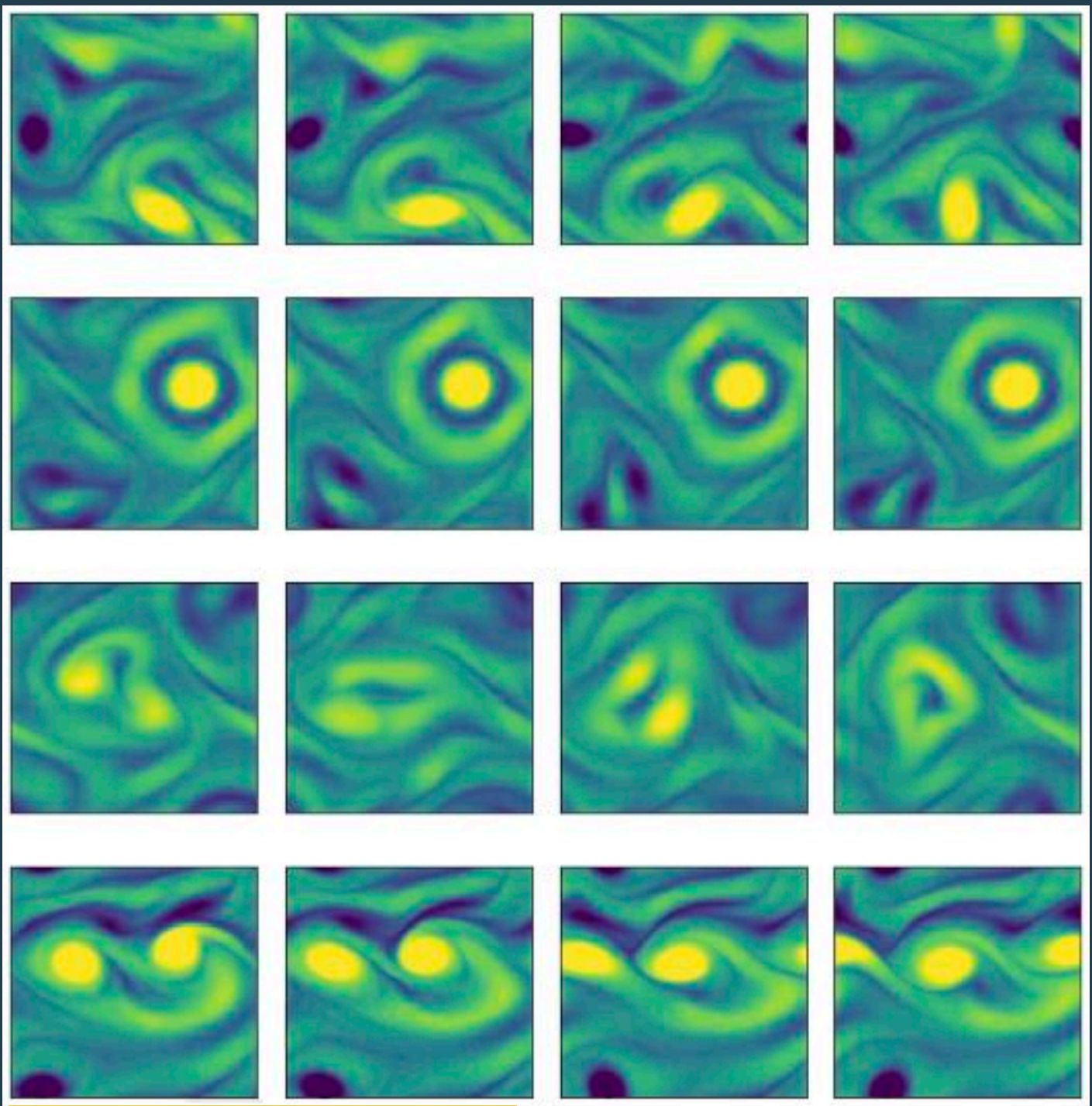
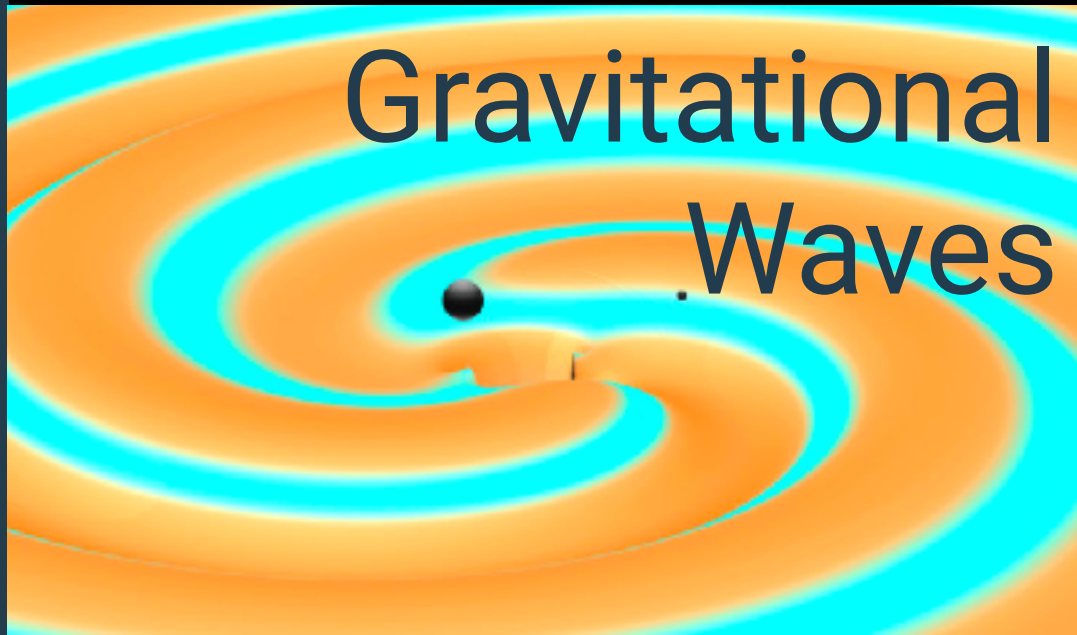
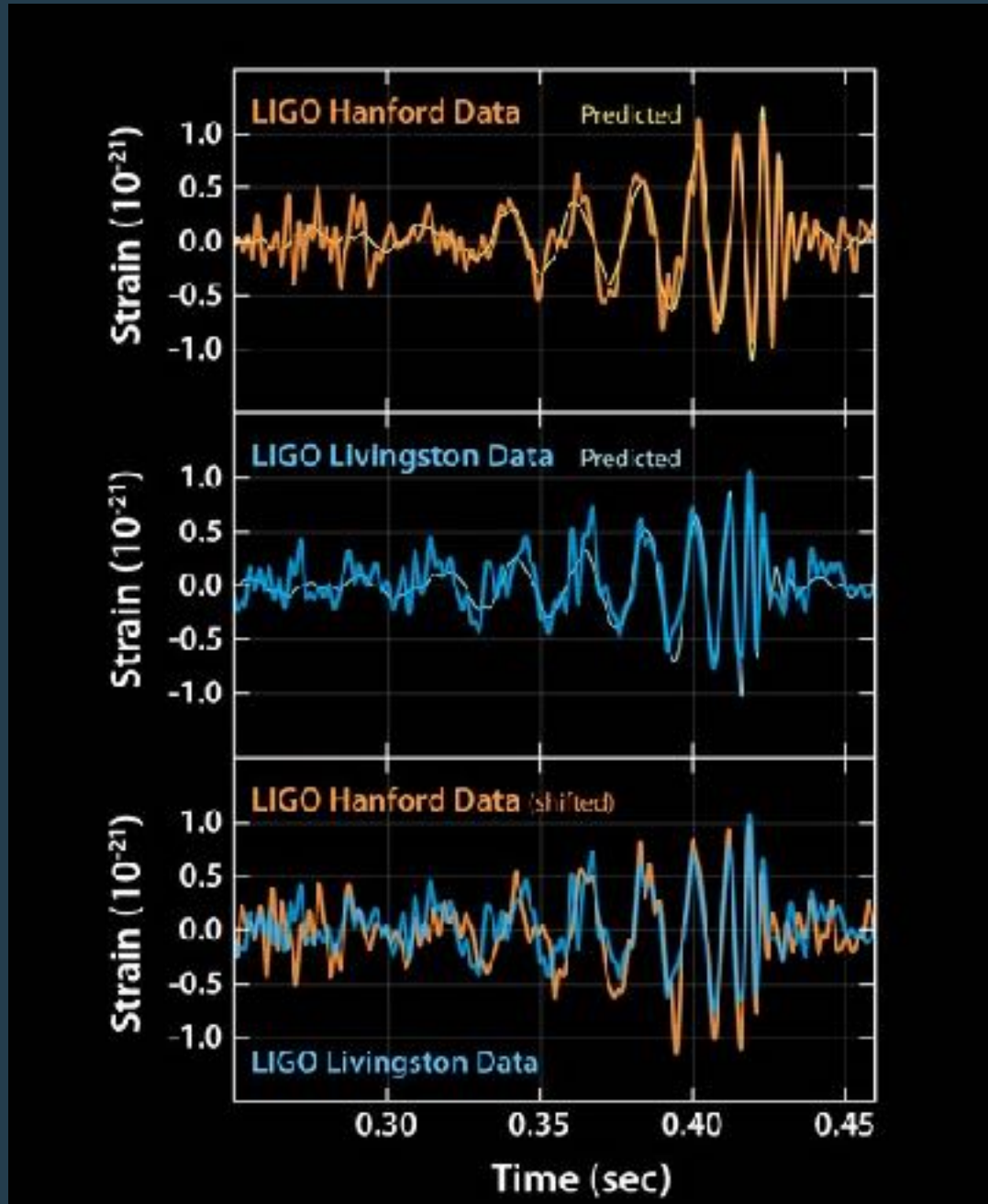
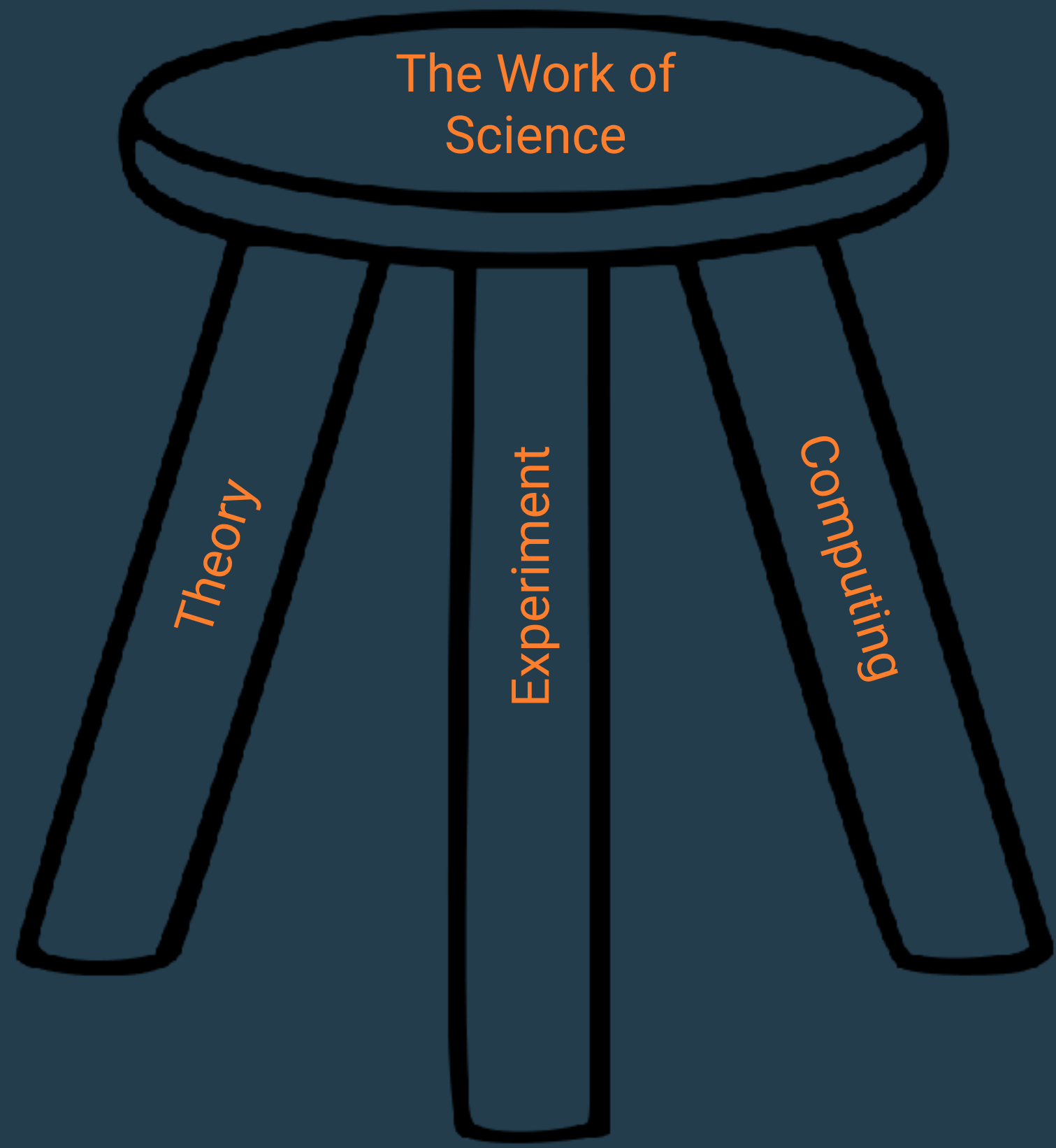
Nicholson and Mulvey (AIP, 2011); White and Chu (AIP, 2014); Porter, Church, and Ivie (AIP, 2024)

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

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

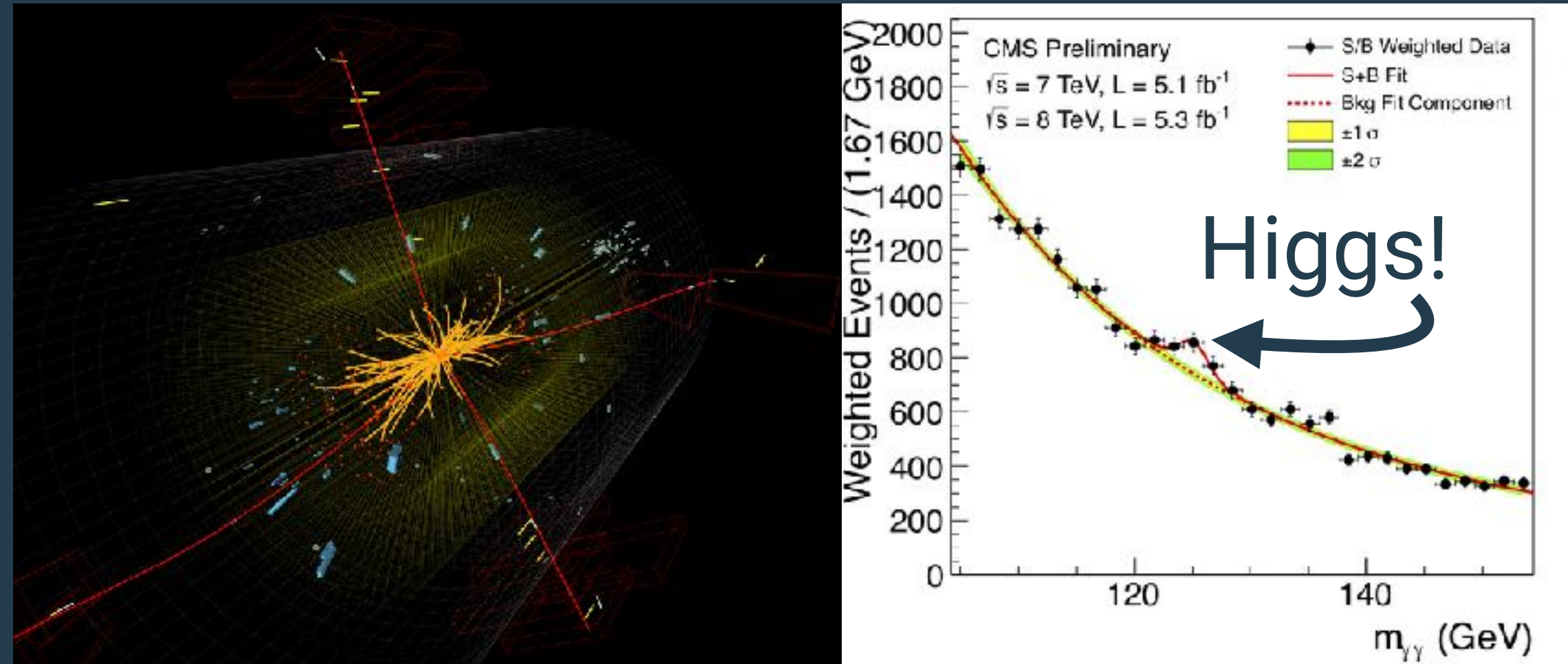
¹This is my position and we can disagree on that. But it also my experience, and that is not up for debate.

Computing is how science is done.

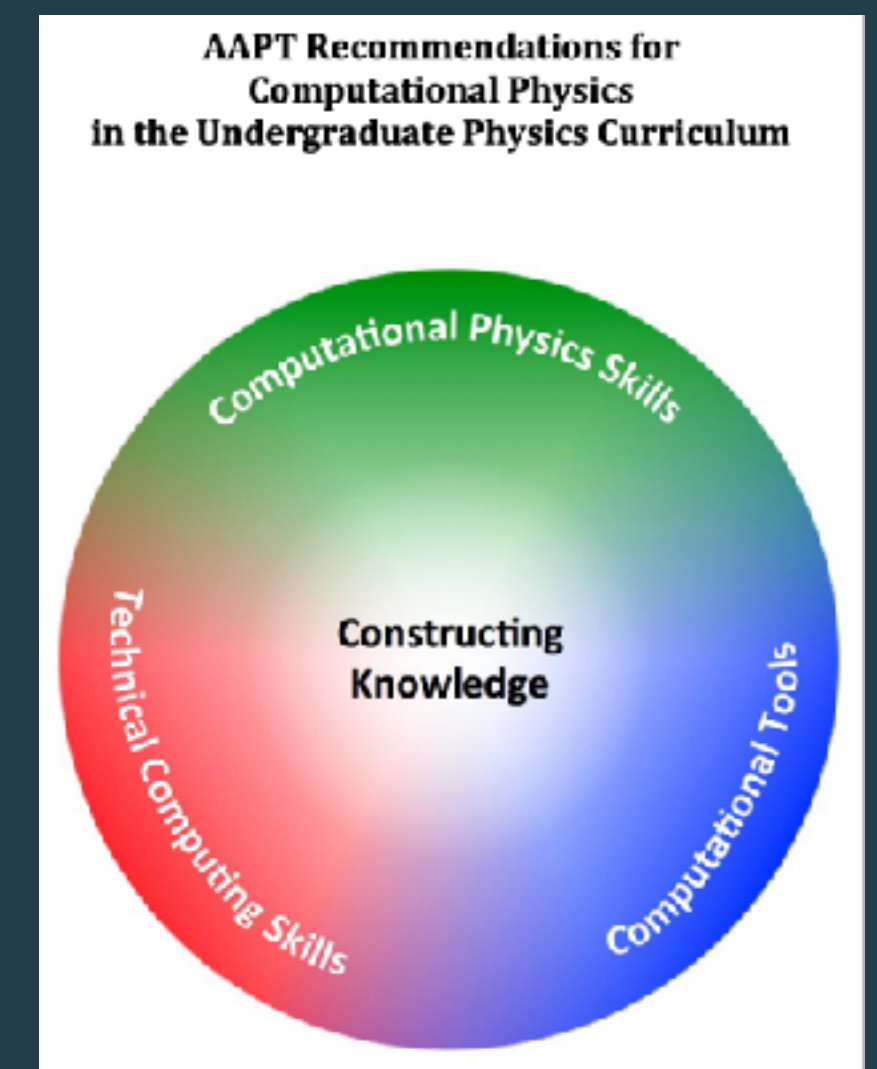
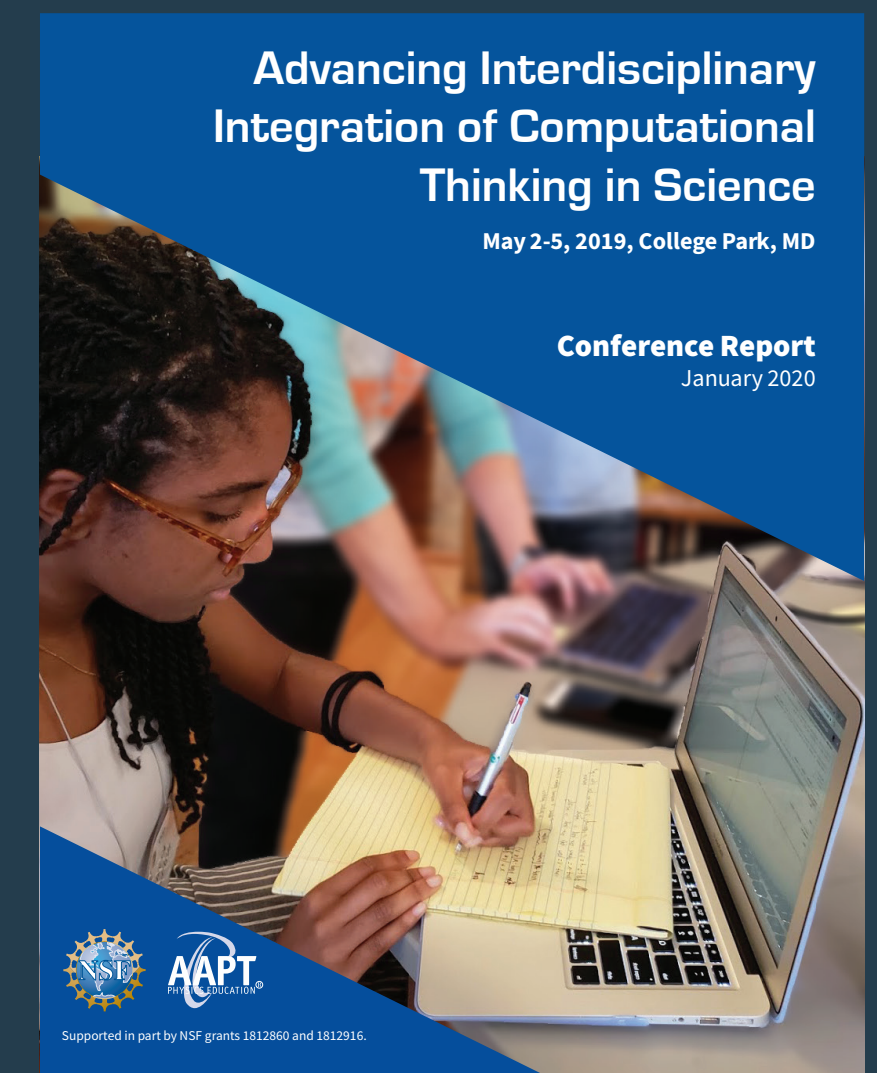
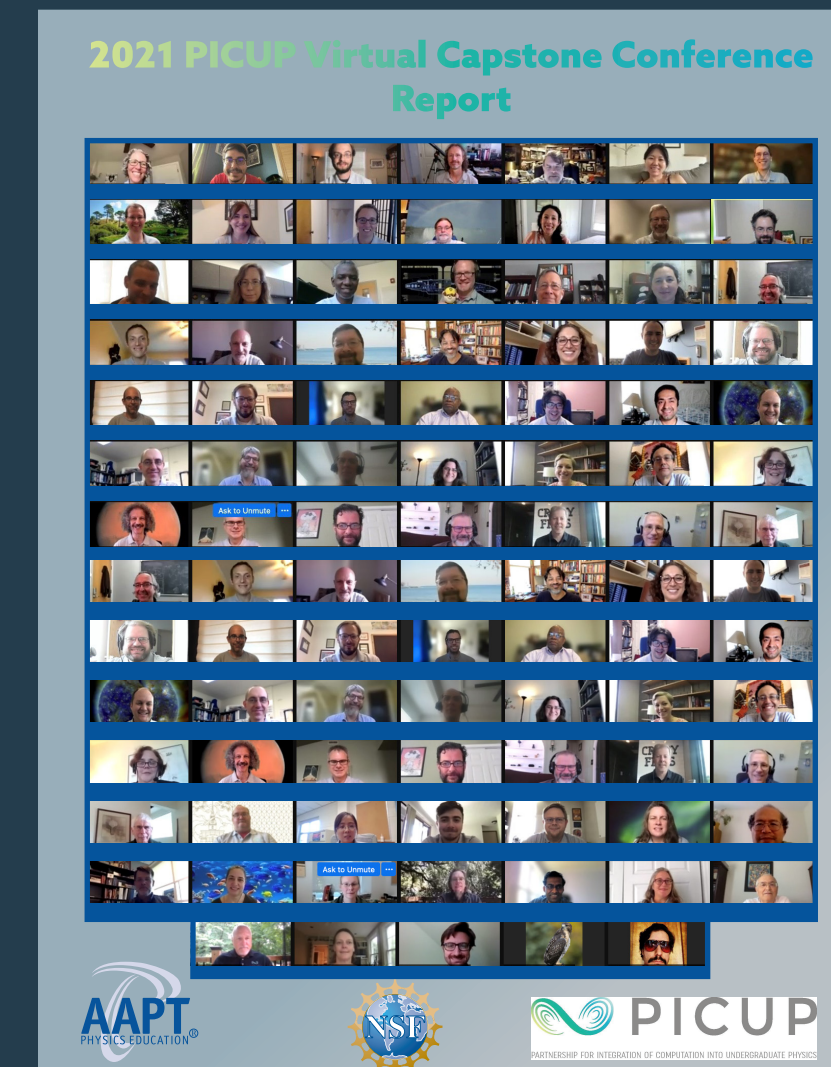
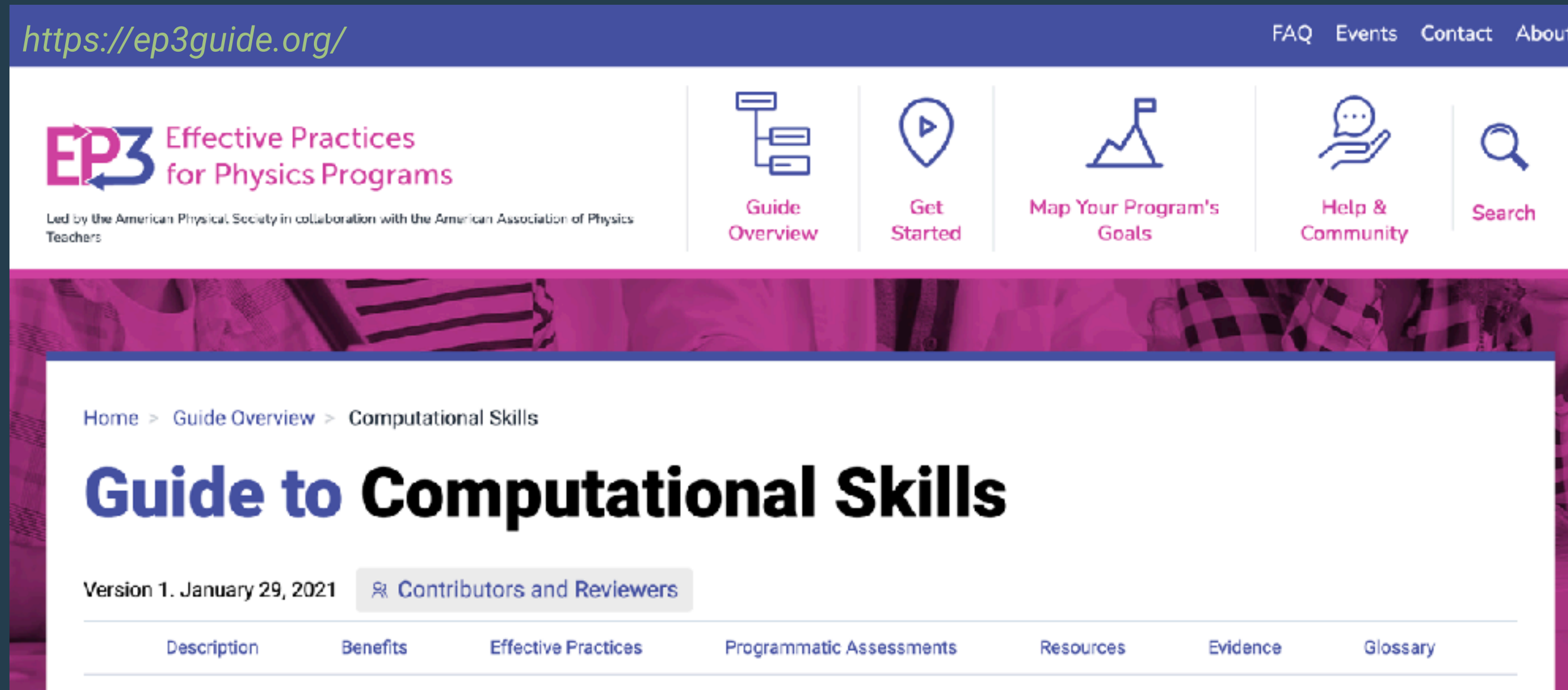


Turbulence

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

$\frac{dQ}{dt} + \left(\frac{\partial Q}{\partial t}\right)$
 $|10\rangle = \frac{1}{\sqrt{2}}(\uparrow\downarrow + \downarrow\uparrow)$
 $|1-1\rangle = \downarrow\downarrow$
 symmetric
 lower energy

singlet
 $i\hbar \frac{\partial \chi}{\partial t} = \hat{H} \chi, \chi(t) = a\chi_+ e^{i\mathbf{B} \cdot \mathbf{S} t / \hbar} + b\chi_- e^{-i\mathbf{B} \cdot \mathbf{S} t / \hbar}, H = -\vec{\mu} \cdot \vec{B} = -\gamma \vec{S} \cdot \vec{B}$
 $\det(A - \lambda I) = 0, H\psi = E\psi, \chi = a\chi_+ + b\chi_-$

$\psi_n^0, \psi_n^1 = \sum_{m \neq n} \frac{\langle \psi_m^0 | H' | \psi_n^0 \rangle}{(E_n^0 - E_m^0)} \psi_m^0, E_n^2 = \sum_{m \neq n} \frac{|\langle \psi_m^0 | H' | \psi_n^0 \rangle|^2}{E_n^0 - E_m^0}, E_{\pm}^1 = \frac{1}{2} [W_{aa} + W_{bb} \pm \sqrt{(W_{aa} - W_{bb})^2 + 4|W_{ab}|^2}]$
 $\begin{pmatrix} \alpha \\ \beta \end{pmatrix} = E_i \begin{pmatrix} \alpha \\ \beta \end{pmatrix}, W_{ij} = \langle \psi_i^0 | H' | \psi_j^0 \rangle$

$H_{\text{hyd}} = \frac{\hbar^2}{2m} \nabla^2 - \frac{e^2}{4\pi\epsilon_0 r}, T = \frac{p^2}{2m} = \frac{\hbar^2}{2m} \frac{d^2}{dx^2}, H_r' = \frac{-p^4}{8m^3 c^2}, E_r^1 = \frac{-1}{2mc^2} [E^2 - 2E$

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

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

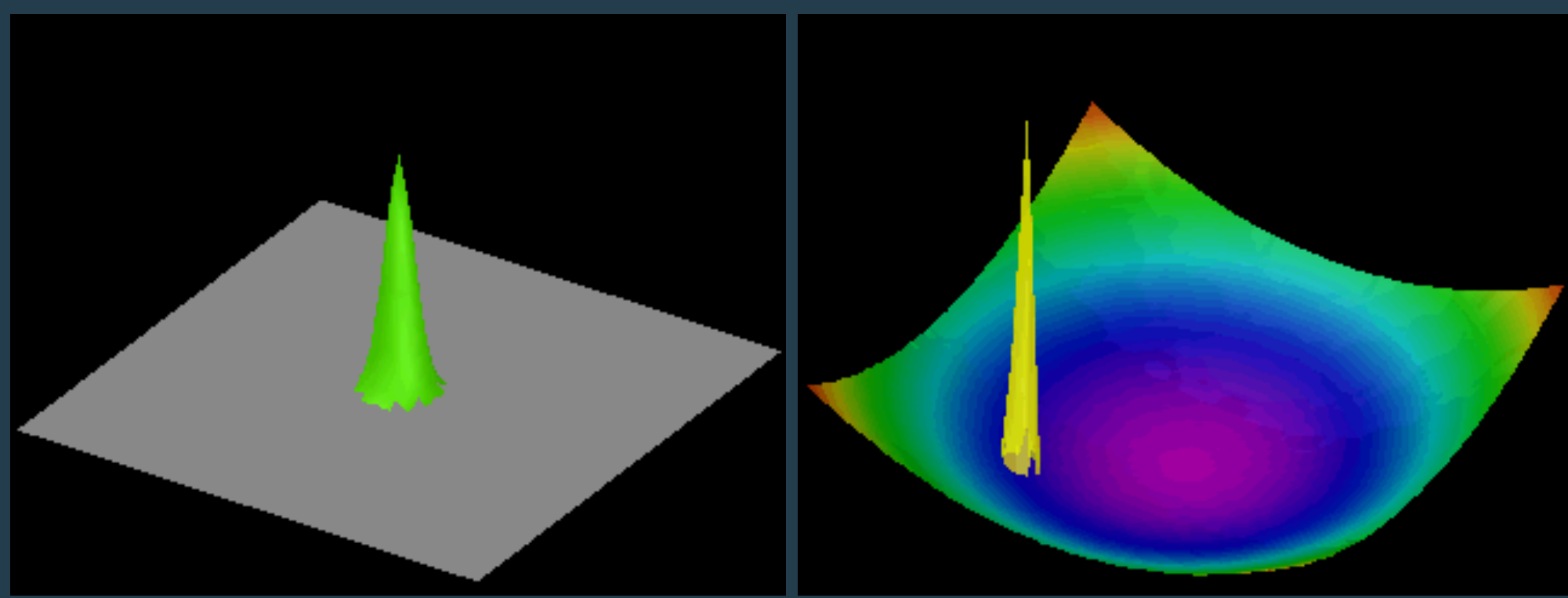
$\underline{Z}: H_Z' = \frac{e}{2m} (\vec{L} + 2\vec{S}) \cdot \vec{B}_{\text{ext}}, \mu_B = \frac{e\hbar}{2m}$

$E_Z^1 = \langle n, l, j, m_j | H_Z' | n, l, j, m_j \rangle \Rightarrow E_Z^1 = \mu_B \left[1 + \frac{j(j+1) - l(l+1) + 3/4}{j(j+1)} \right] B_{\text{ext}} m_j, e \text{ (ii)}, E_{\text{tot}}(2\text{auok}) = \textcircled{i} + \textcircled{ii}$

$\int_a^b f \frac{dg}{dx} dx = f g \Big|_a^b - \int_a^b g \frac{df}{dx} dx$
 $\int_{-\infty}^{\infty} e^{-abx^2} dx = \sqrt{\frac{\pi}{a}}$
 $e^{\pm i\theta} = \cos \theta \pm i \sin \theta$
 $\cos \theta = \frac{1}{2} (e^{i\theta} + e^{-i\theta})$
 $\sin \theta = \frac{1}{2i} (e^{i\theta} - e^{-i\theta})$

$n=0, l=0, m_l=0, m_j=0, m_s=0$
 $j = (l+s), (l-s)$
 fine structure

Physics education requires a computing education

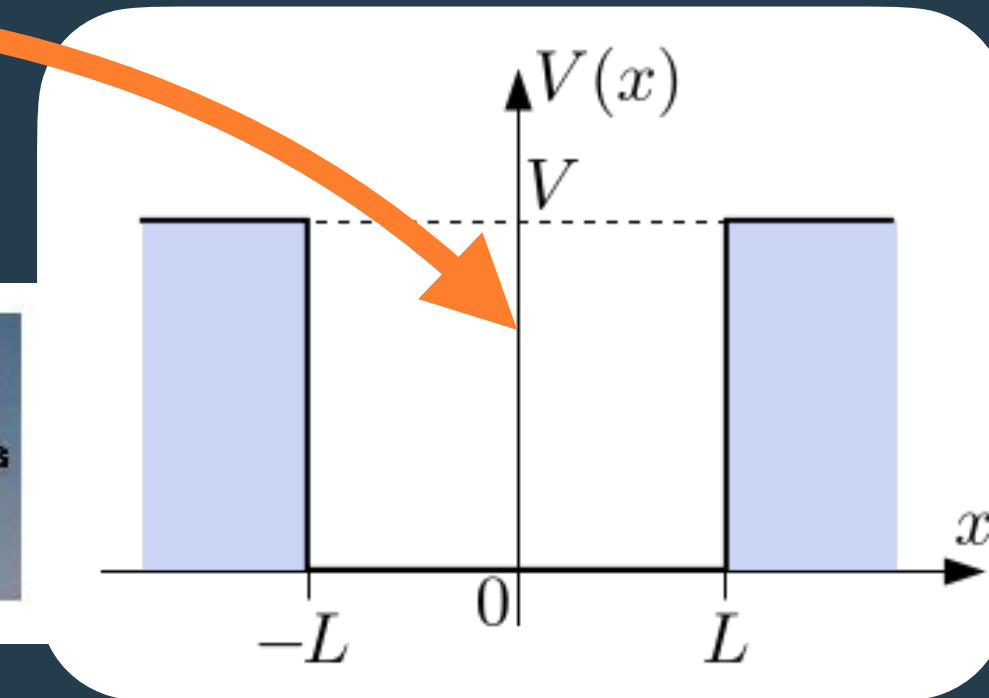
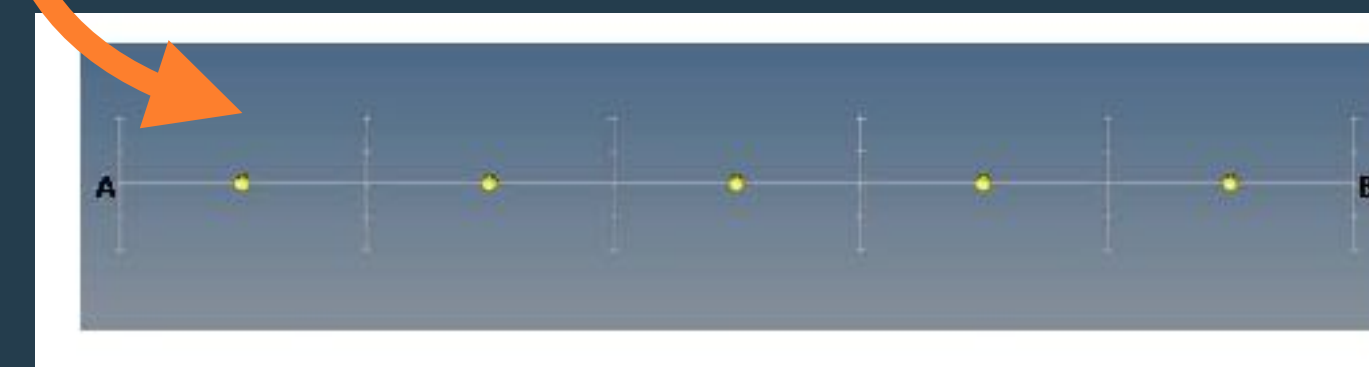
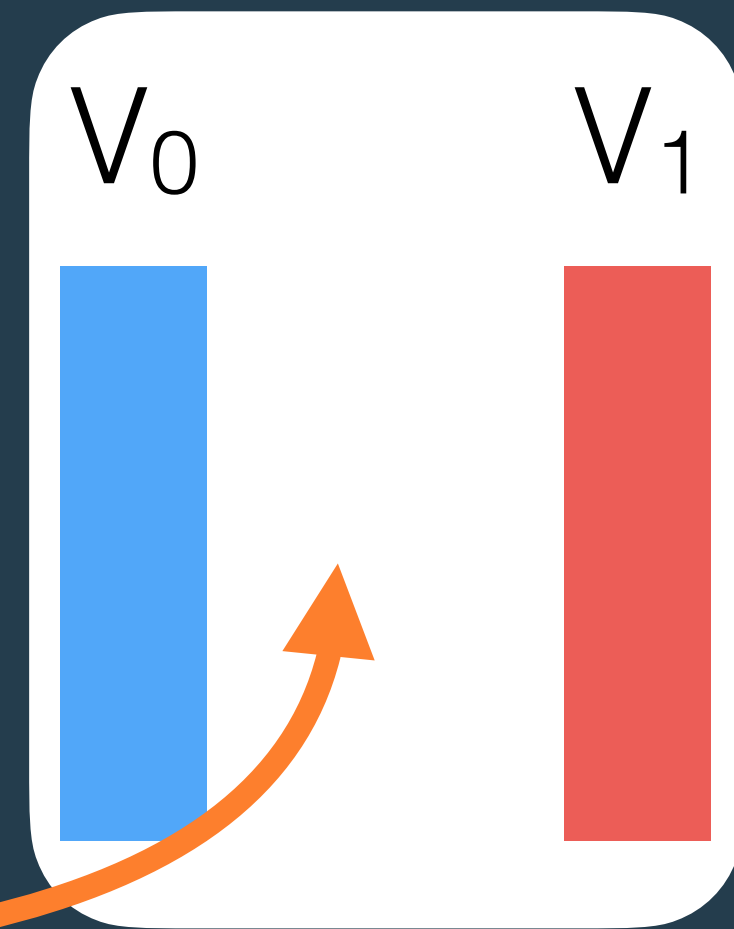
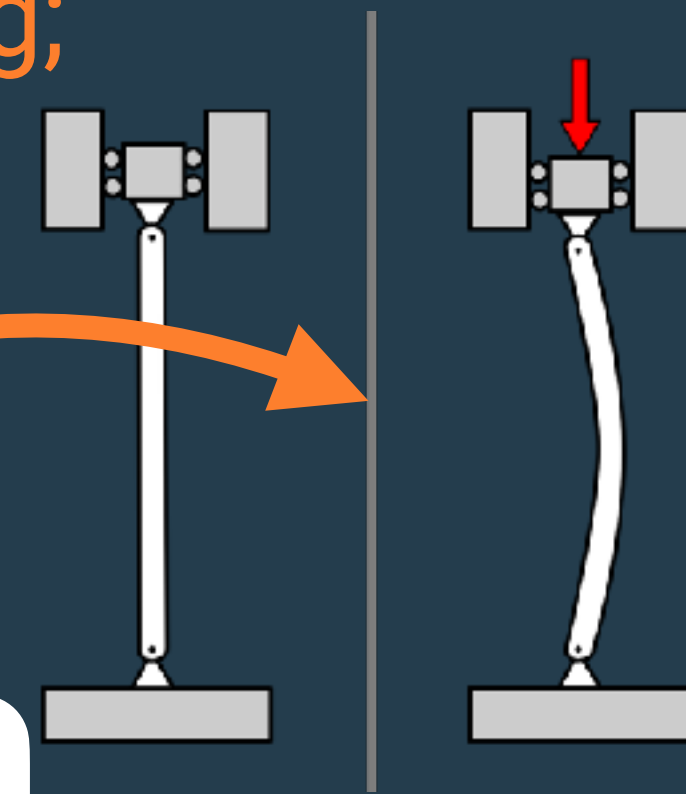


Michielson and De Raedt, 2012

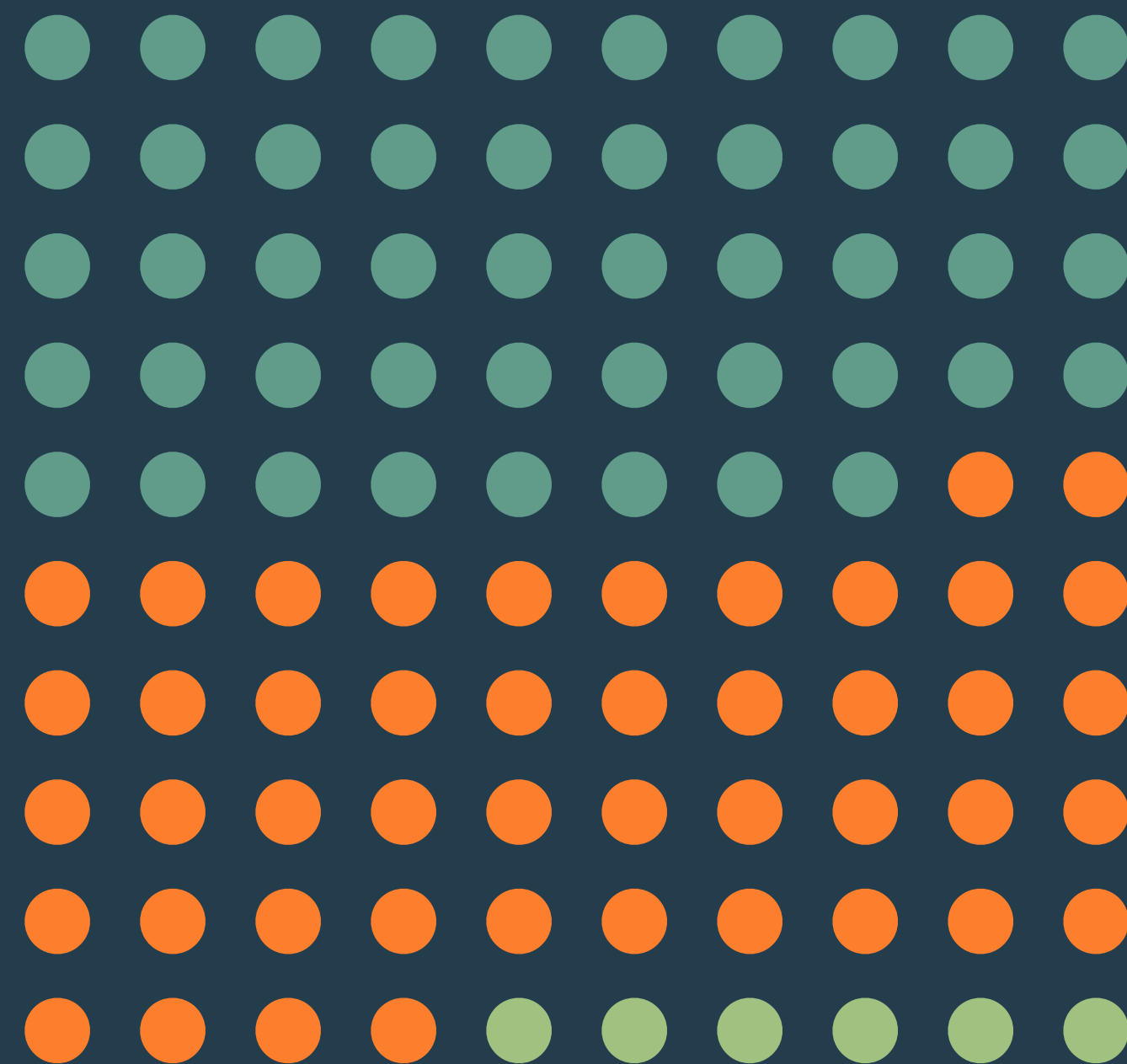
Construct visualizations; develop conceptual understanding

Apply algorithmic thinking; generalize problem solving

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

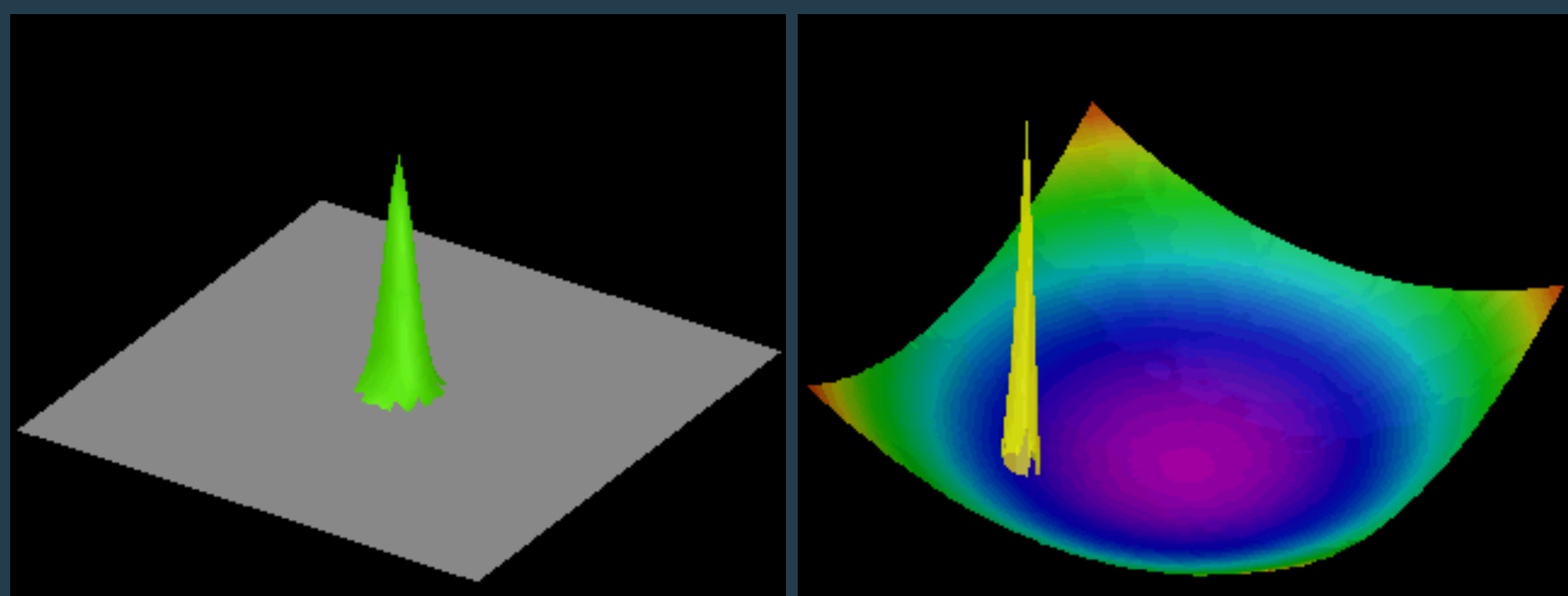


Teach necessary skills; prepare workforce



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

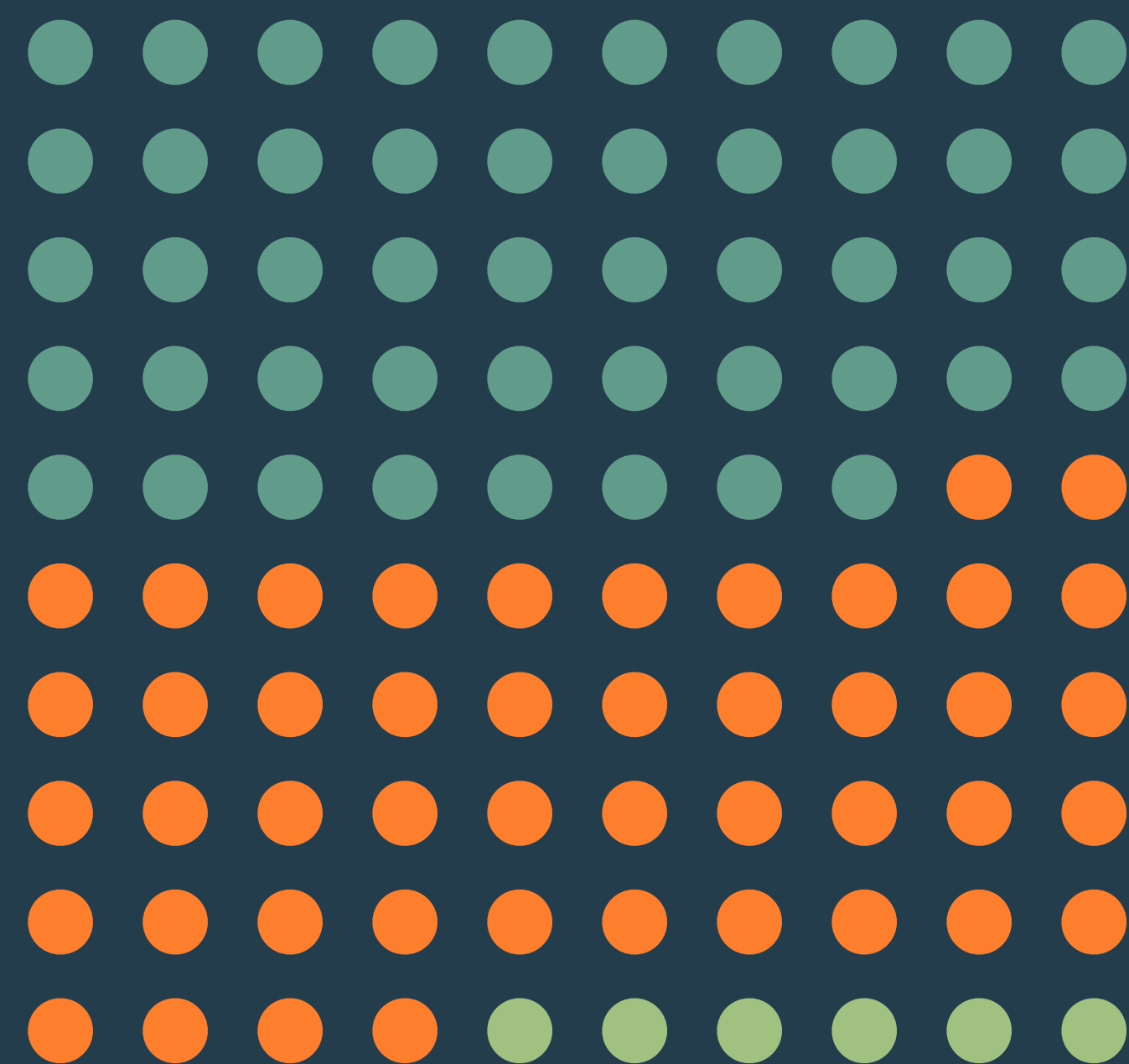
Developing students' computational competencies



Michielson and De Raedt, 2012

Construct visualizations; develop conceptual understanding

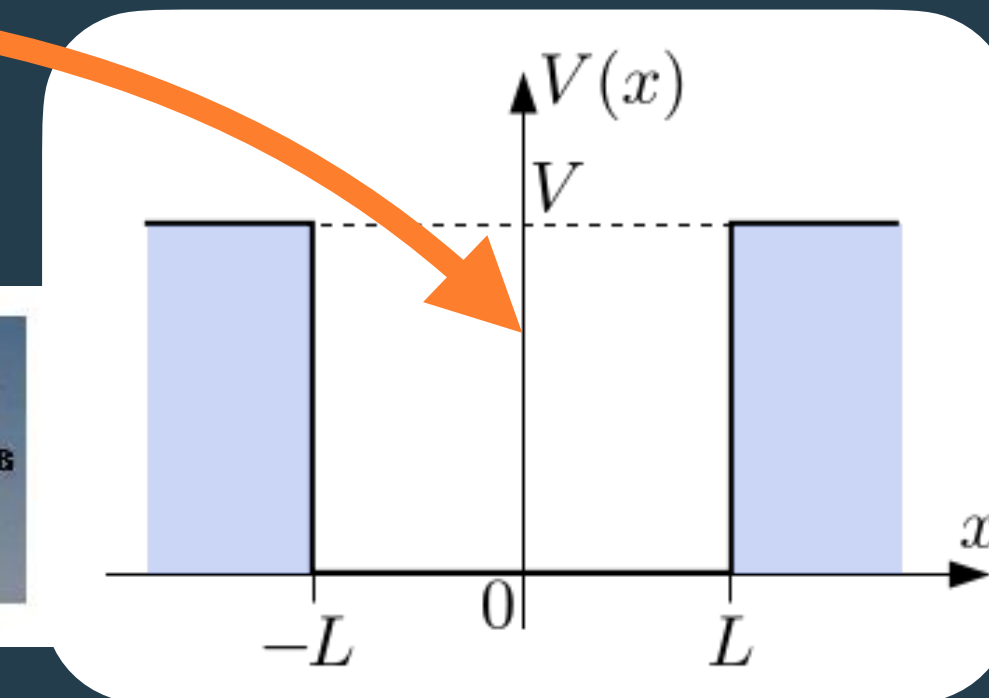
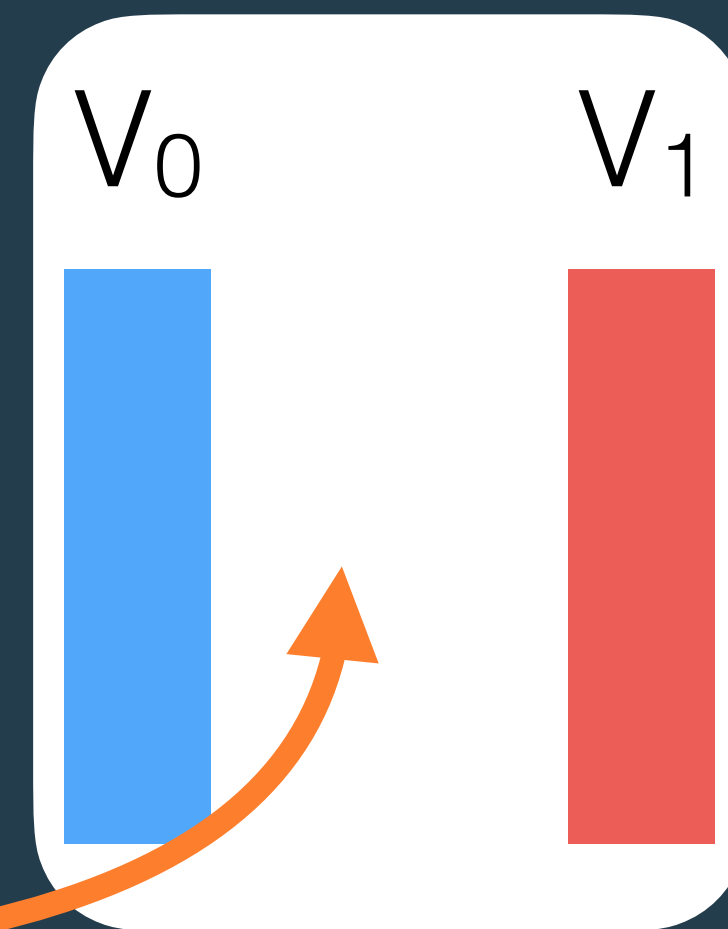
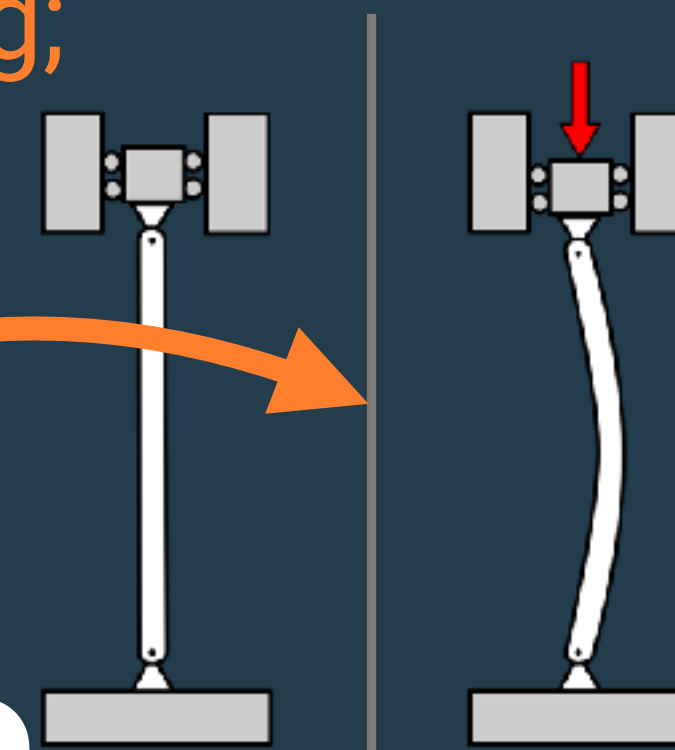
Teach necessary skills; prepare workforce



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

Apply algorithmic thinking;
generalize problem
solving

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



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,‡}

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

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

(Received 26 July 2011; published 14 August 2012)

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

High-level computing languages +
Powerful computers

Some programming is necessary.

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

Initial Conditions

Force Calculation

Newton's Second Law

Position Update

Computing in physics is:



PHYSICAL REVIEW SPECIAL TOPICS - PHYSICS EDUCATION RESEARCH 8, 021006 (2012)

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2012

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6 Earth.color = craft.color
```

Initial Conditions

```
15
16 deltat = 60
17 tf = 365*24*60*60
```

```
18
19 while t < tf:
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```

```
21 r = craft.pos-Earth.pos
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```

Force Calculation

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25 pcraft = pcraft+Fgrav*deltat
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Newton's Second Law

```
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Position Update

```
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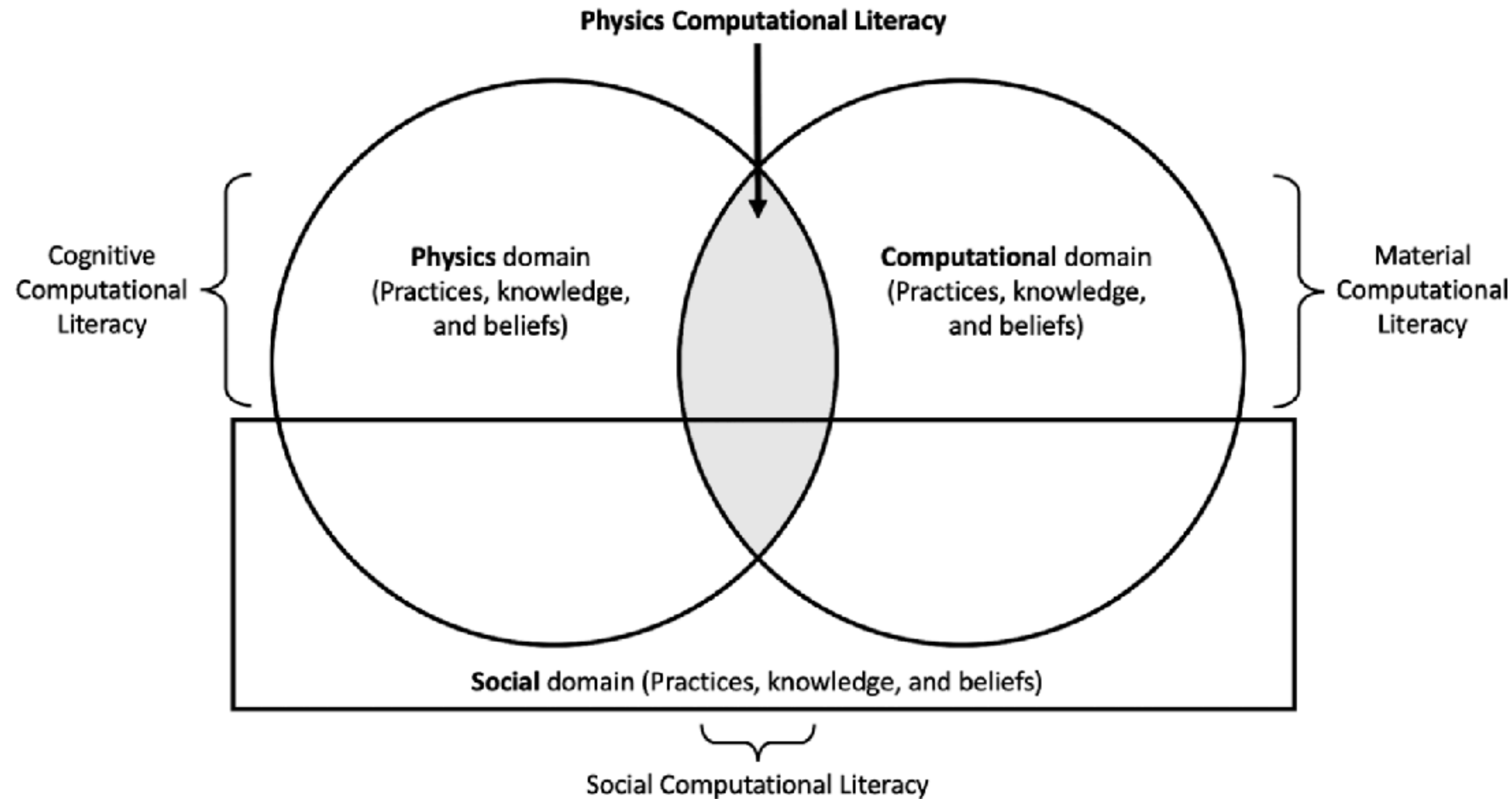

Physics computational literacy: An exploratory case study using computational essays

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

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

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

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



Computational Literacy involves cognitive, material, and social literacies

Overlapping practices, knowledge, and beliefs

Requires further R&D

How Physics Students Develop Disciplinary Computational Literacy

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

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

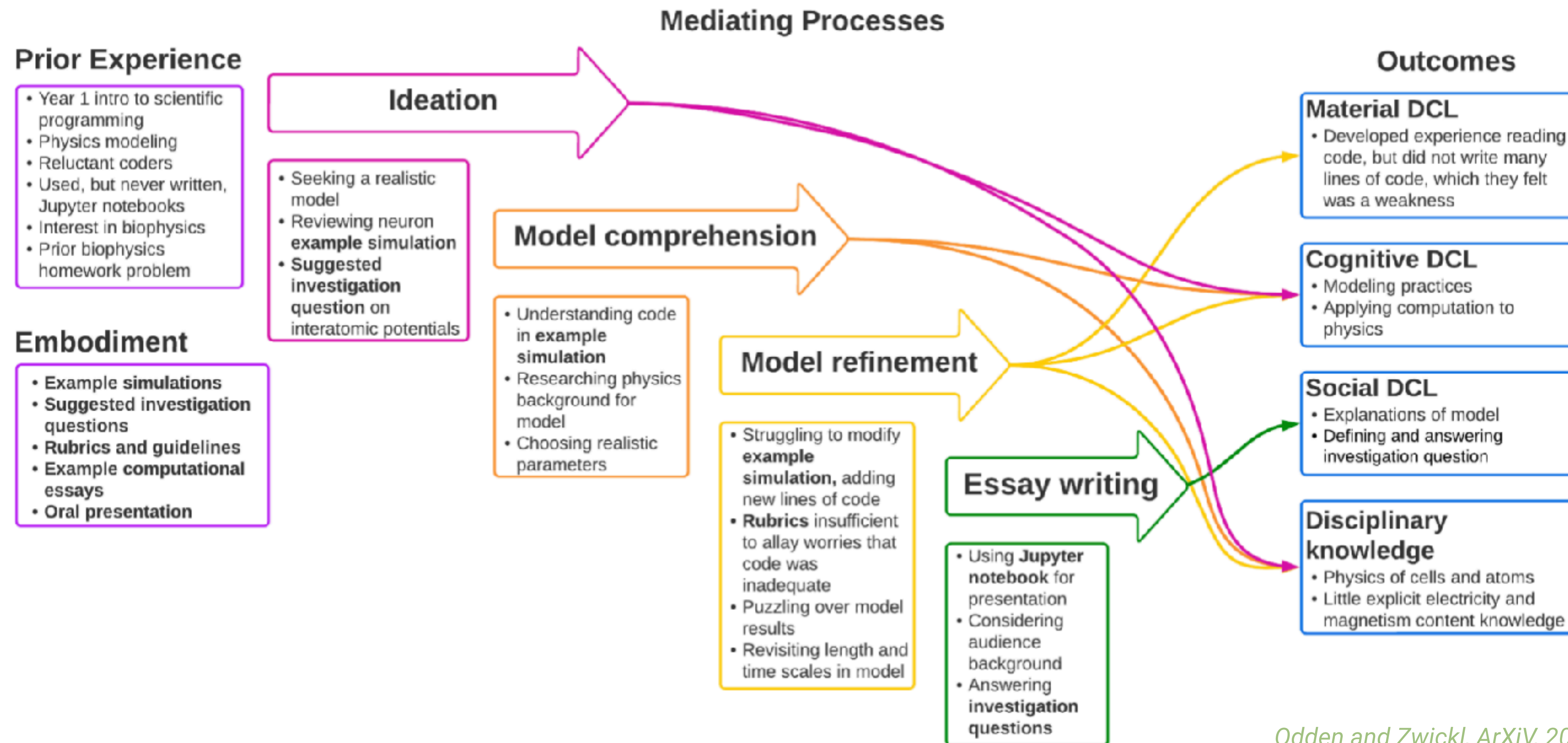
[2] School of Physics and Astronomy, Rochester Institute of Technology, 84 Lomb Memorial Drive, Rochester, NY, 14607

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

PCL is a model that informs activity development & pedagogy



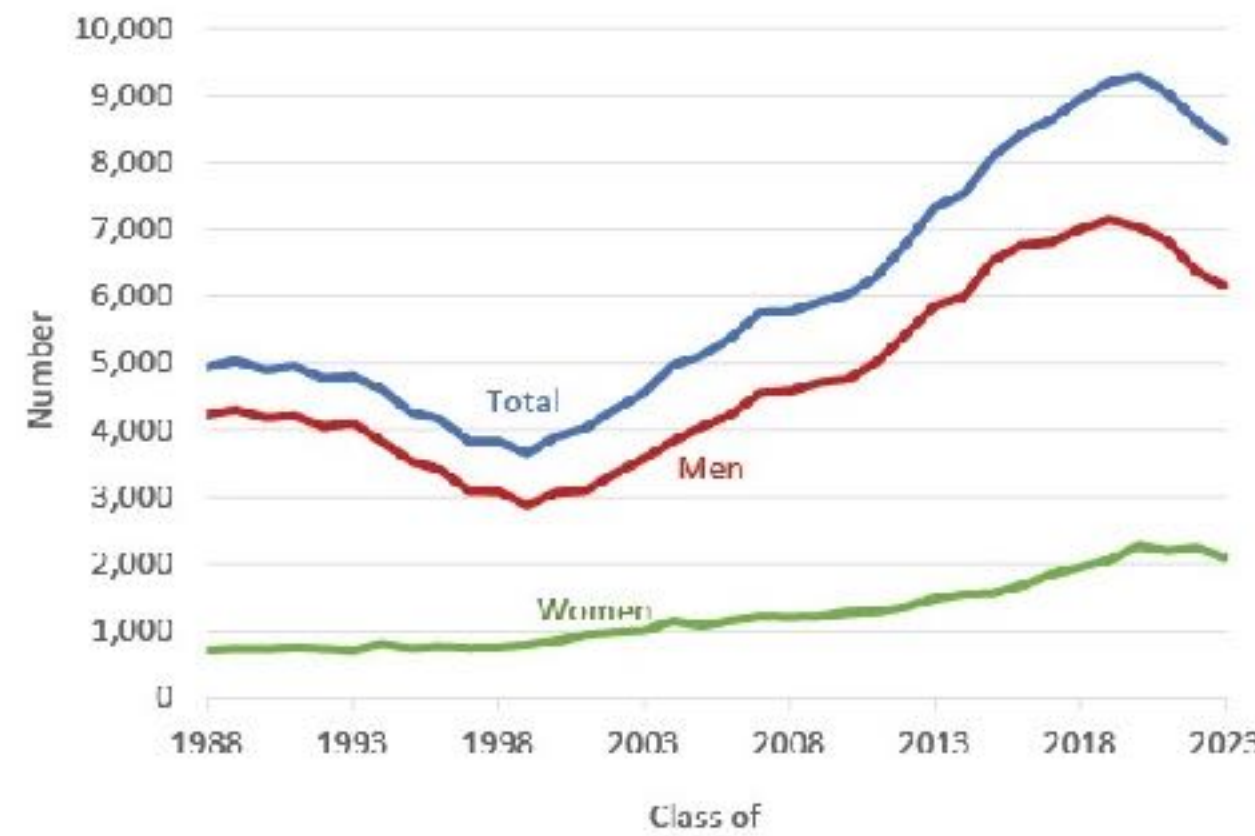
The Research Council
of Norway



Odden and Zwickl, ArXiv, 2024

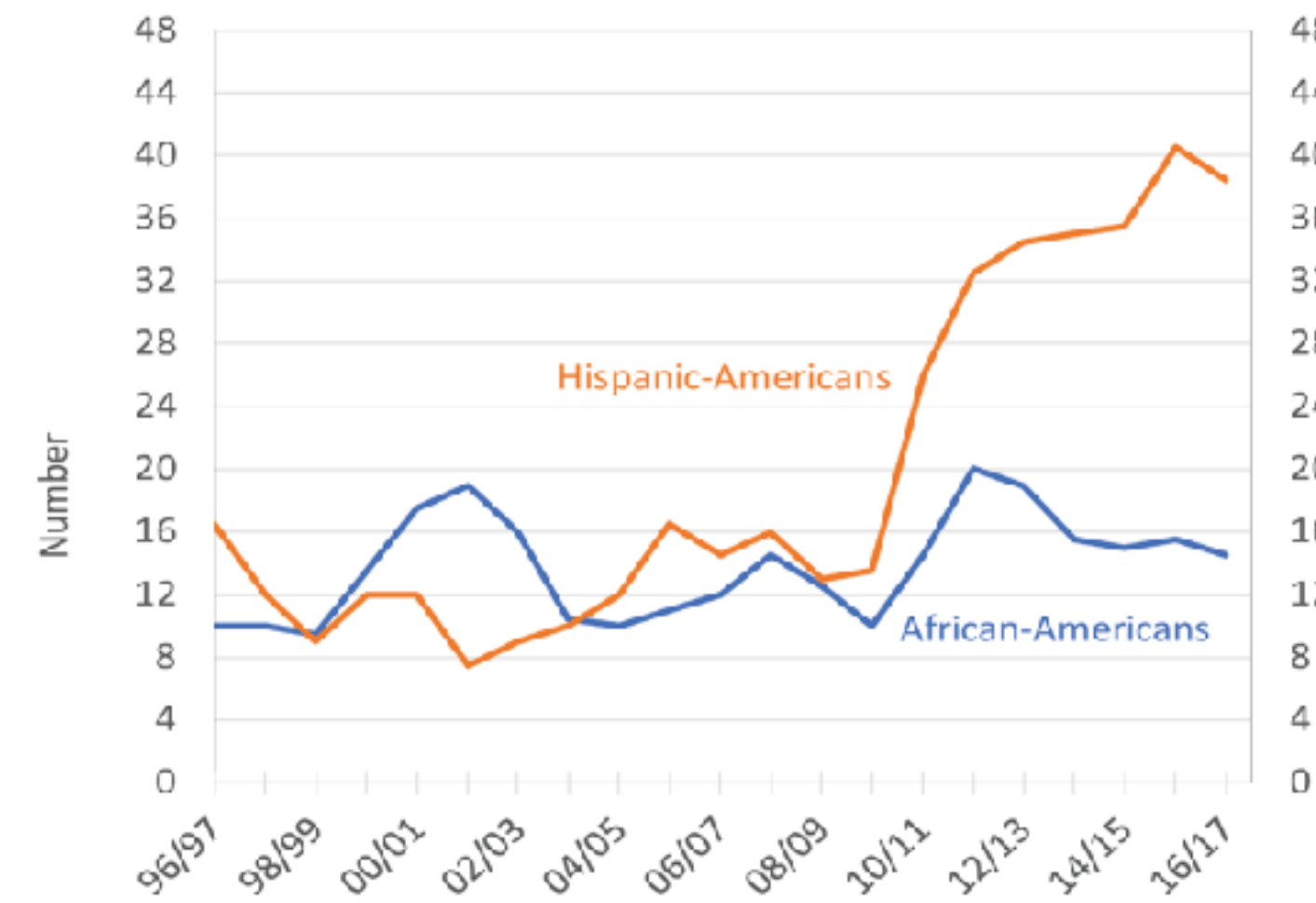
Twelve years have
past between this
paper and the first.

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

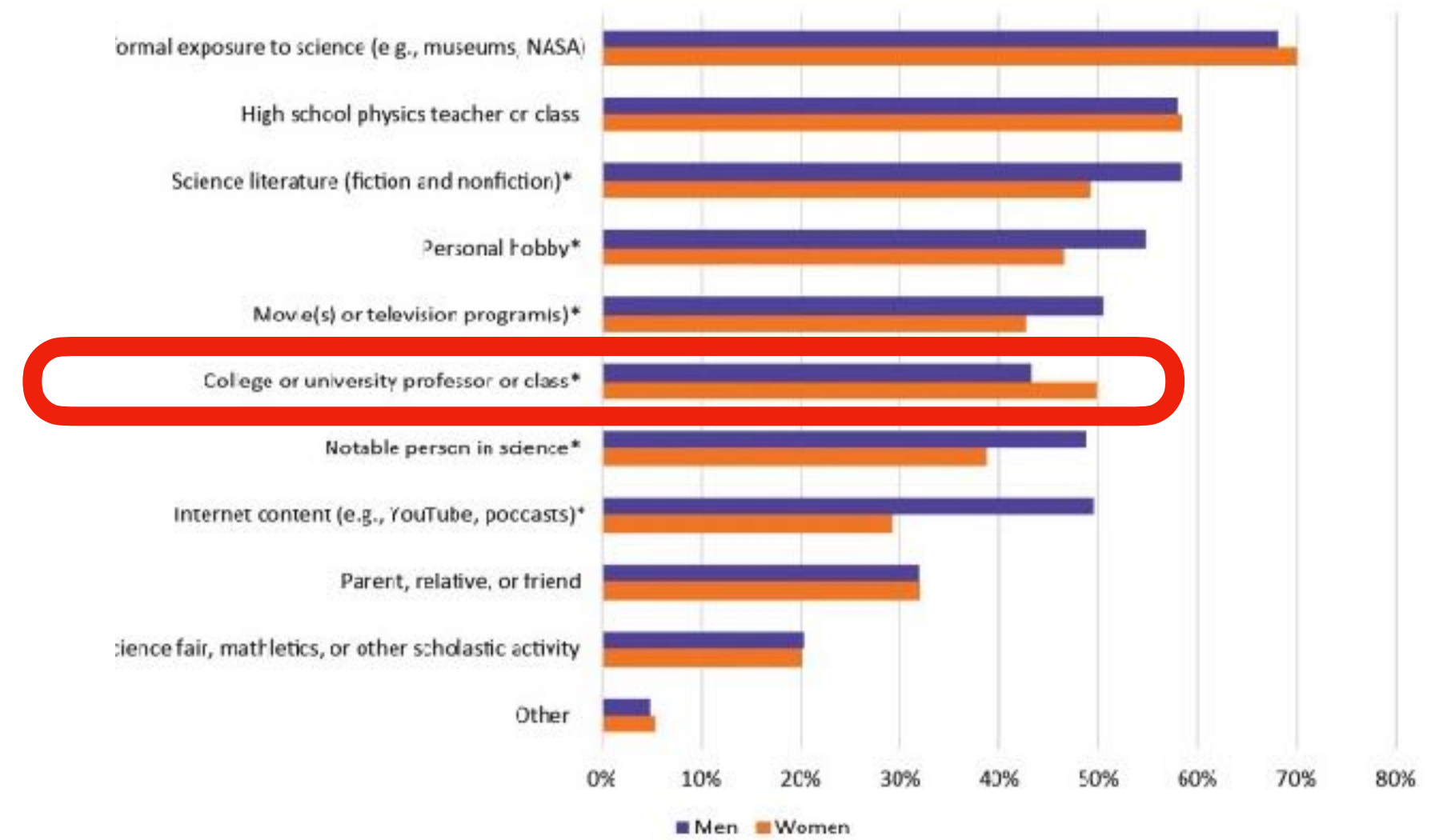


Physics departments reported <1% of their physics bachelor's degree recipients in the class of 2023 identify as a gender other than man or woman.

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

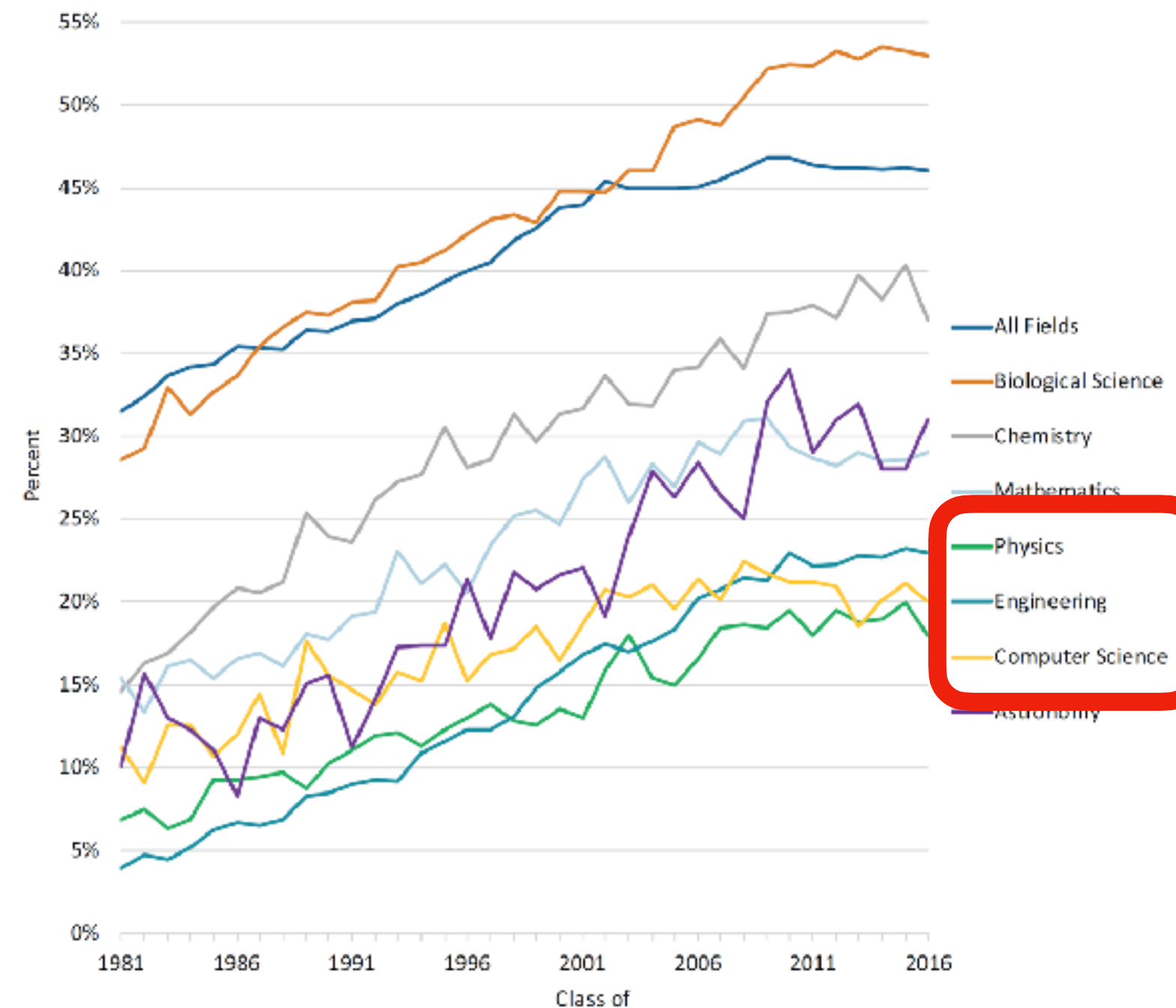


Influences on Physics Bachelors Decision to Pursue Physics,
Classes of 2021 and 2022 Combined



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

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



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

aip.org/statistics



aip.org/statistics

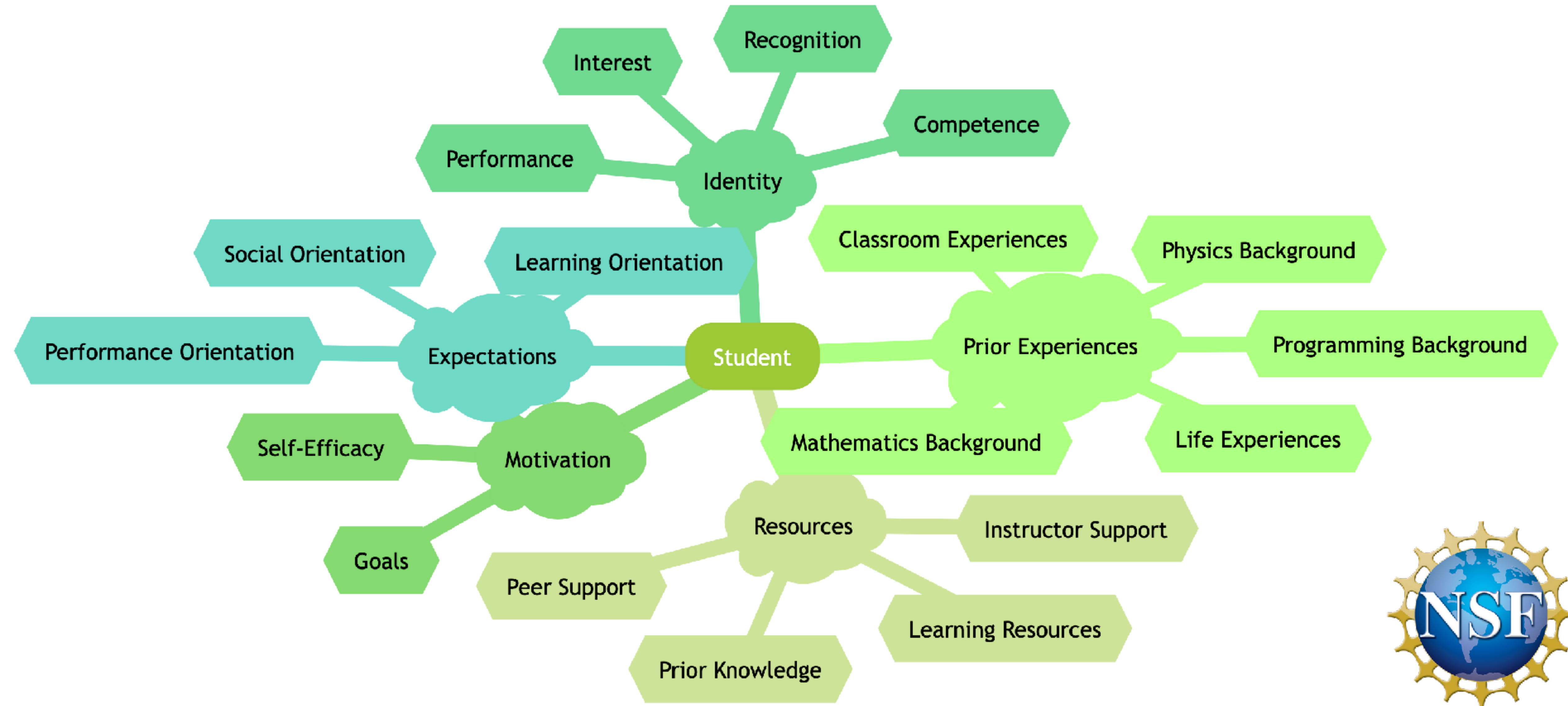
Women, LGBTQIA+, folks of color, the disabled, veterans, first generation students, and folks with these and other intersecting identities have been systematically excluded from physics

Our work does not exist in a vacuum

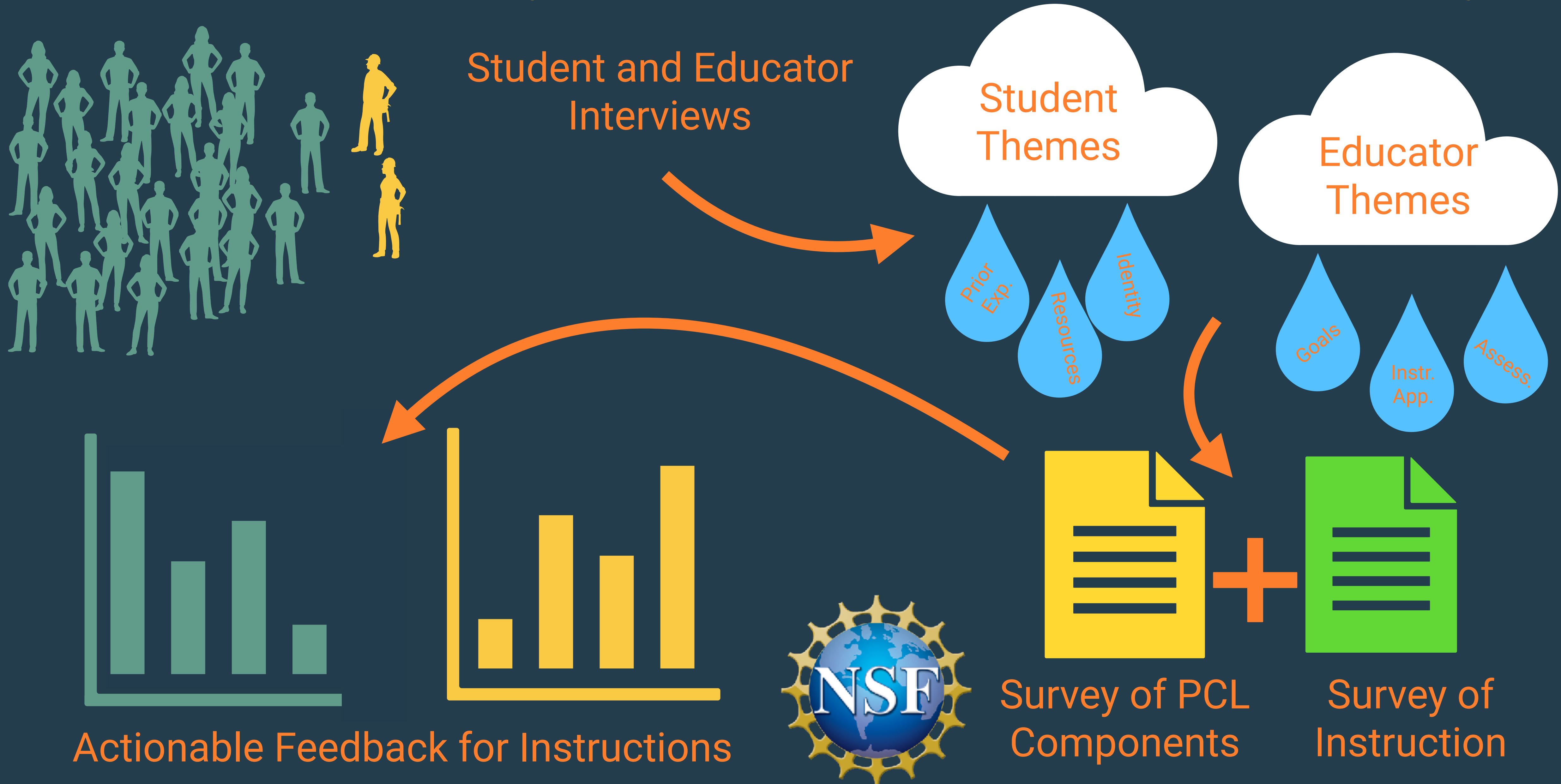
Investigating Physics Computational Literacy



Student Dimension



Investigating Physics Computational Literacy




What can computational
instruction look like?

A diagram on a dark blue background featuring two ovals. The left oval is yellow and contains the text 'CLASSROOM INSTRUCTION'. The right oval is teal and contains the text 'EDUCATION RESEARCH'. Two orange dashed curved arrows connect them: one from the top of the yellow oval to the top of the teal oval, and another from the bottom of the teal oval to the bottom of the yellow oval, forming a cycle.

**CLASSROOM
INSTRUCTION**

**EDUCATION
RESEARCH**

Projects and Practices in Physics



Projects & Practices in Physics
a community-based learning environment

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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 orbit of the satellite. To truly convince Carver, the simulation should include representations of the net force acting on the spacecraft, which has a mass of 15×10^3 kg. Your simulation should be generalized enough to model other types of orbits including elliptical ones.

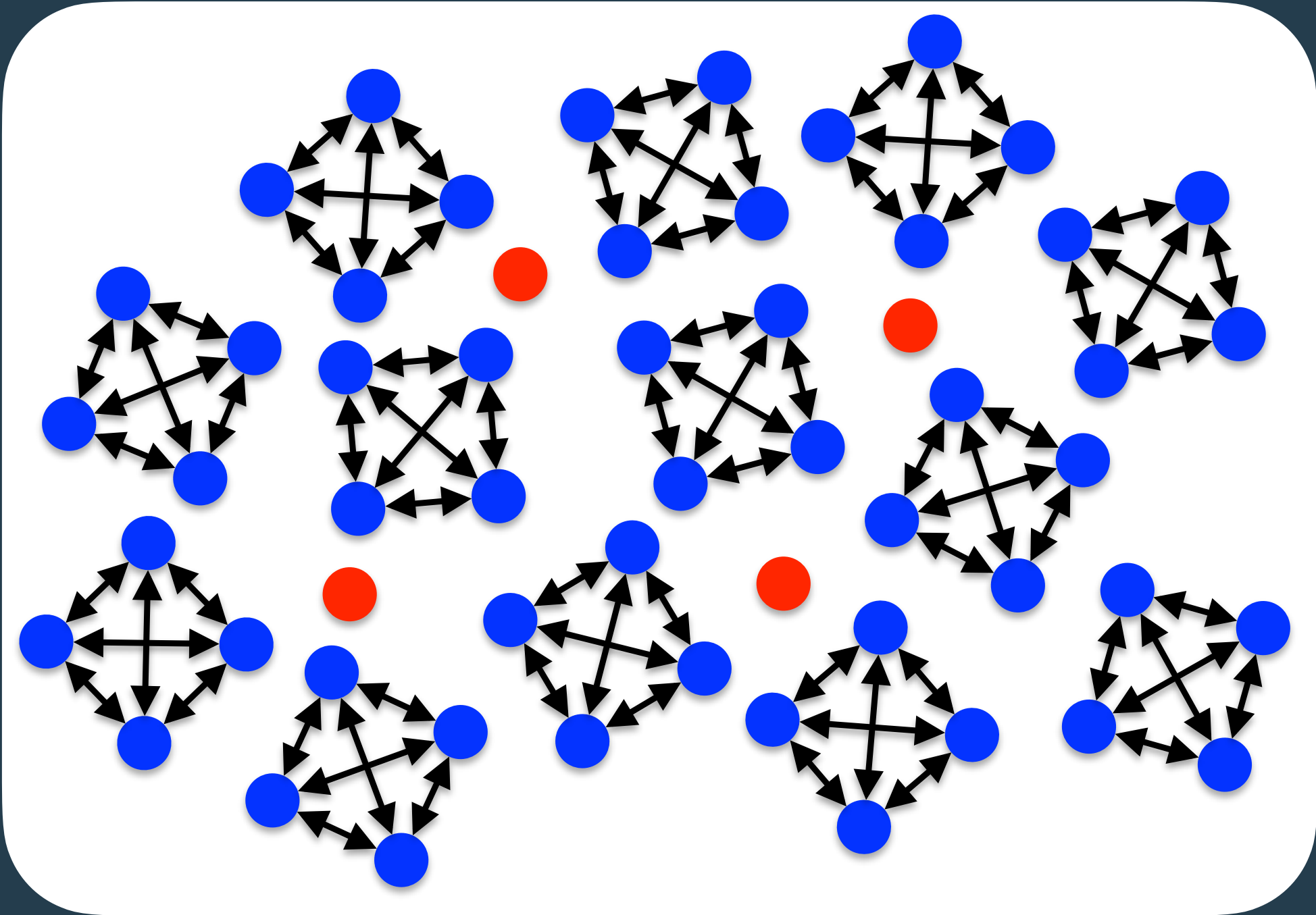
Code for Project 3:

 geosync.py

 PhysUtil Module

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

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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 |

Results

12 LAs Interviewed

Theme and Variation

| 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 |
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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 |
| Category of Description | | | |
| 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 |

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

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

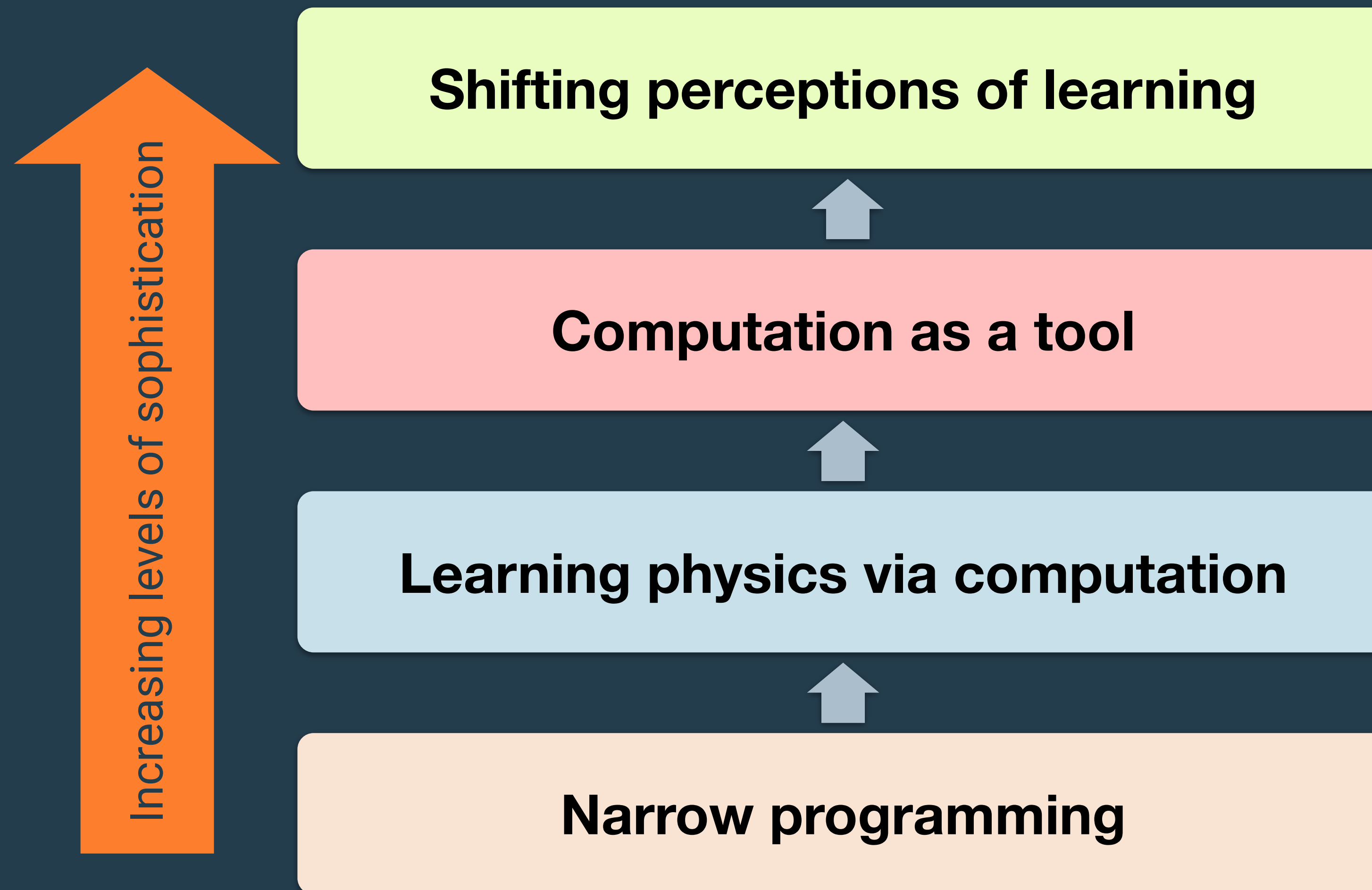
Encourage reflection on coding

Leverage collaboration

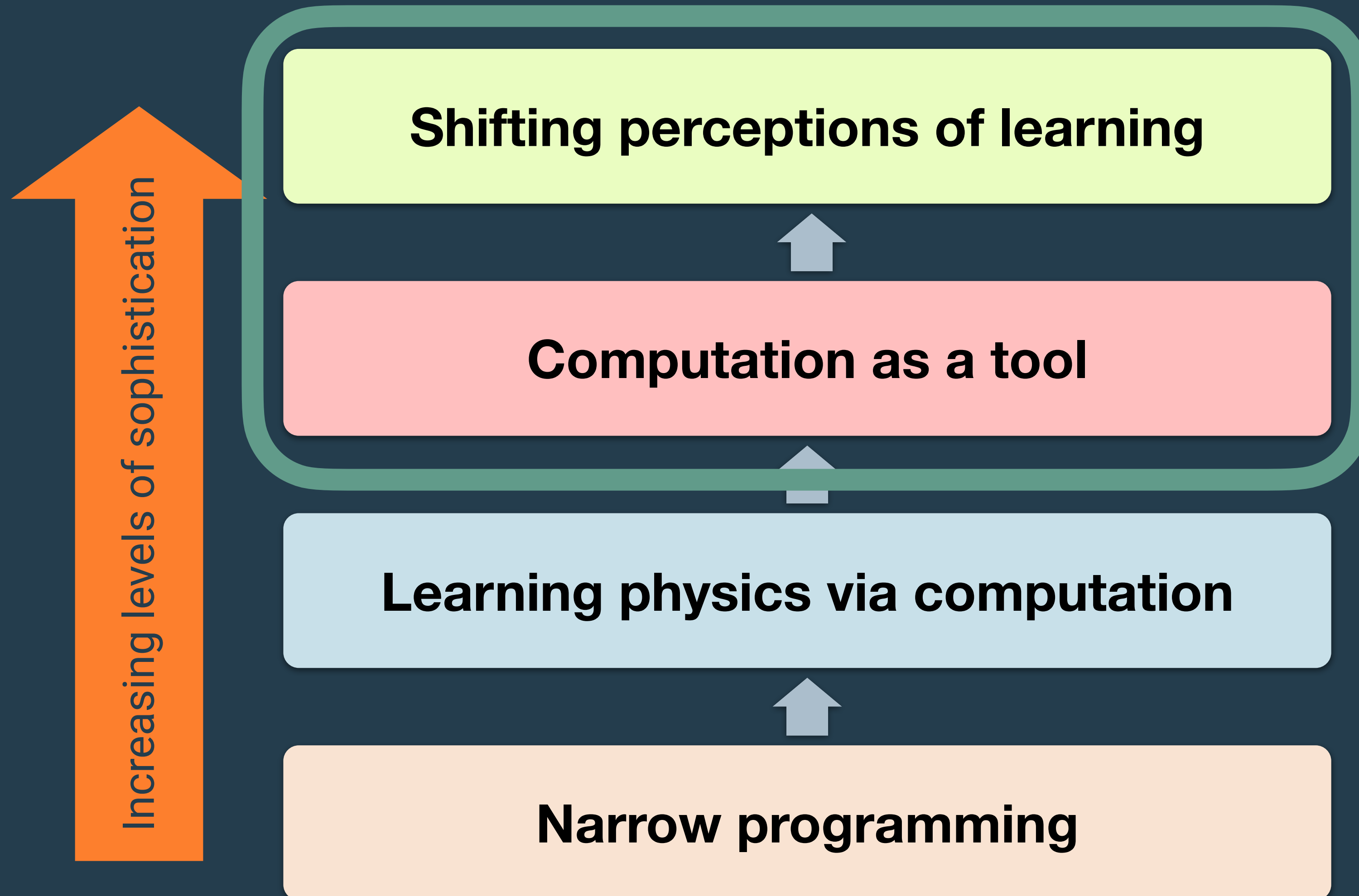
Categories of description

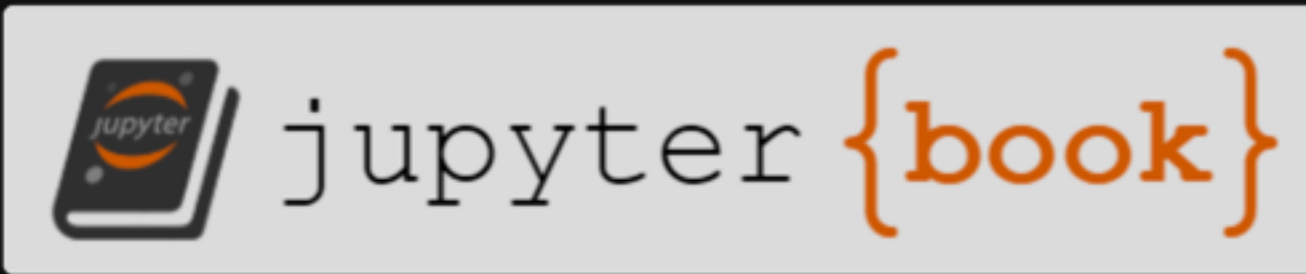
| Category of Description | Utility of coding | Teaching outcome | Characteristic to moderate | Teaching strategy |
|---------------------------------------------|---------------------------------------------|-----------------------------|------------------------------------------|------------------------------------------------|
| 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 |

Outcome space



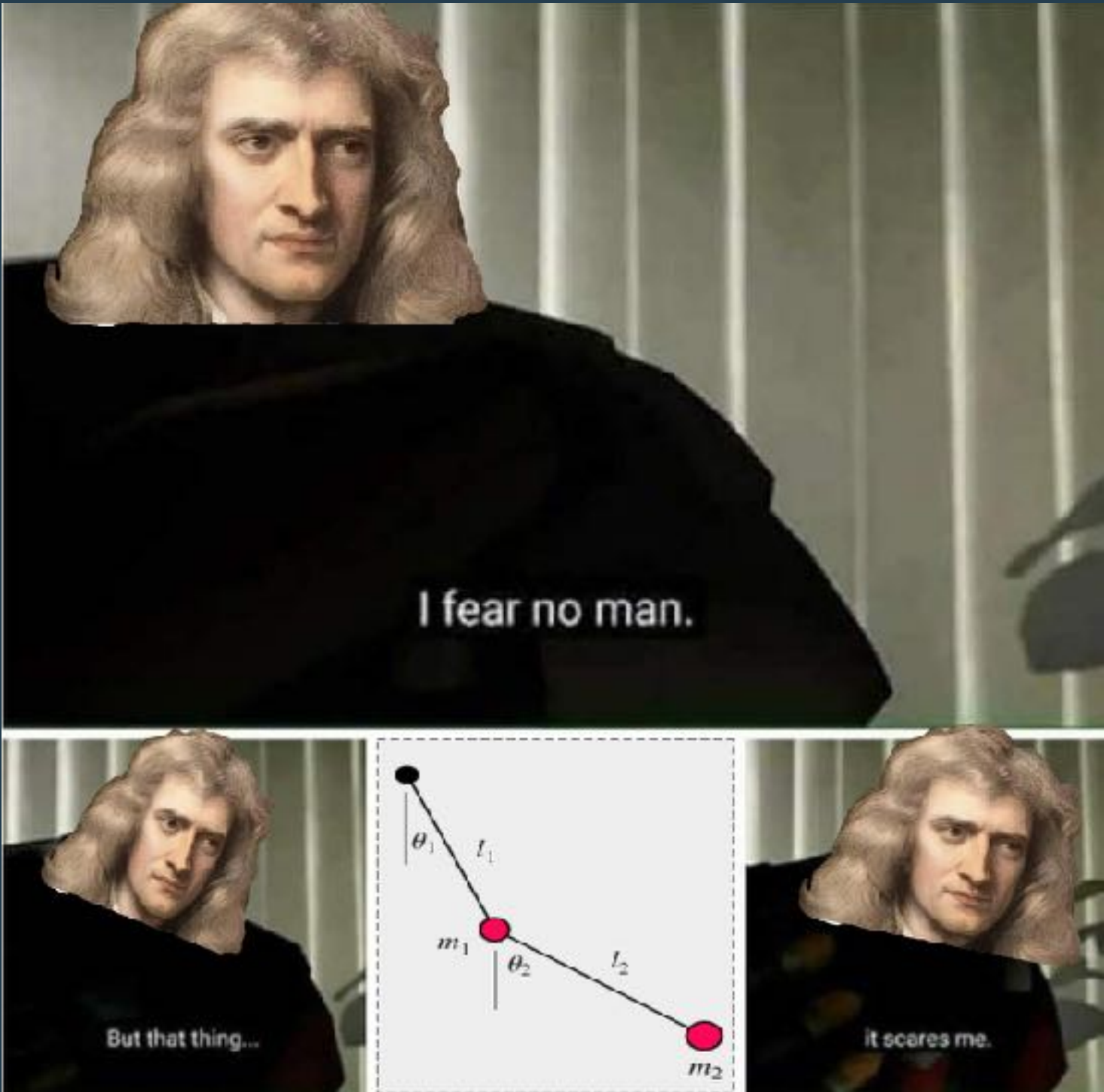
Outcome space





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



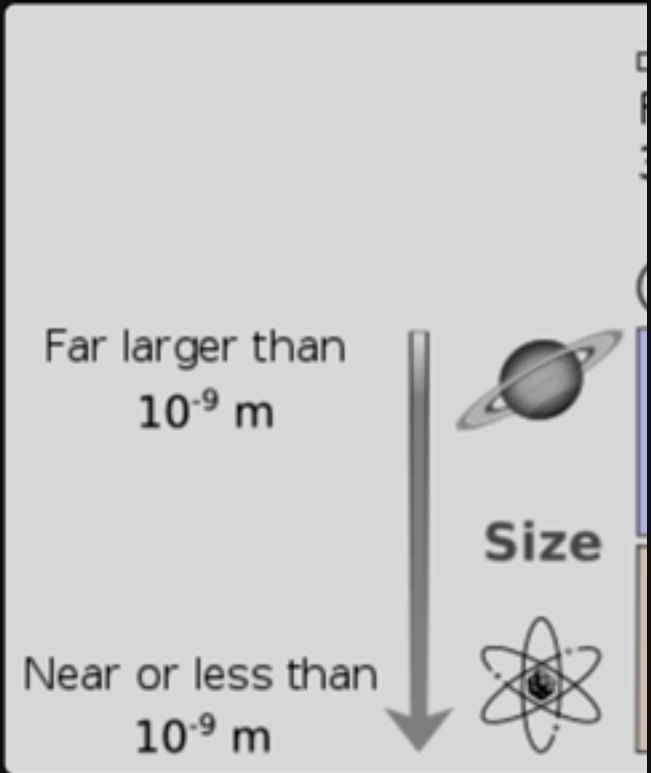
| | Narrative text | Computer Code |
|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
| Title and Introduction | <p>Introduction: What is a Railgun?</p> <p>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 magnetic fields of the rails, which accelerates it.</p> <p>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?</p> <p>In this notebook, we aim to estimate how much current one would need in order to use such a railgun to launch a 1 kg 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.</p> | |
| Pictures and Diagrams | | |
| Pictures and Diagrams | <p>The US Navy's Electromagnetic Railgun (From popular mechanics)</p> <p>Initial Simulation of the Railgun</p> <p>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</p> <pre>In [1]: import sympy as sp import numpy as np import matplotlib.pyplot as plt</pre> <p>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.</p> <p>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.</p> <pre>In [2]: D = .15 #separation of the rails and width of the bar. Set to 15cm L = 10 #length of the rails. Set to 10m m = 1 #set mass to 1kg I = 10000 #starting current. Set to 10000 Amps</pre> | <p>Importing packages</p> <p>Model parameters</p> |

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 mecl](#)
- [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 l



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 ok 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 scienc [crystals and other optical system](#) in [fluid dynamics](#), [plasma physics](#) with nonlinear dynamics and is a where the Hamiltonian is nonlinea chaotic systems.

Nonlinear Differ

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 behi 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 o

Chaotic systems exhibit several k [systems](#)

Sensitive Depend

One of the hallmark features of cl differences in the starting state o cases this means that we cannot make accurate short-term predic flapping its wings in Brazil can ca reaching effects. But it is true the

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.

"Textbook": Interactive JupyterBook

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

60-100 Students take PHY 321

Interactive Lecture with Clickers

Clicker Question 31-1

We completed this derivation with the following mathematical statement:

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

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

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

5 / 9

Clicker Question 6-2

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

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

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

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

9 / 13

Clicker Question 34-1

For this plane pendulum, the mathematical statement

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

is equivalent to what statement? Is it true?

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

7 / 10

60-100 Students take PHY 321

Group Activities

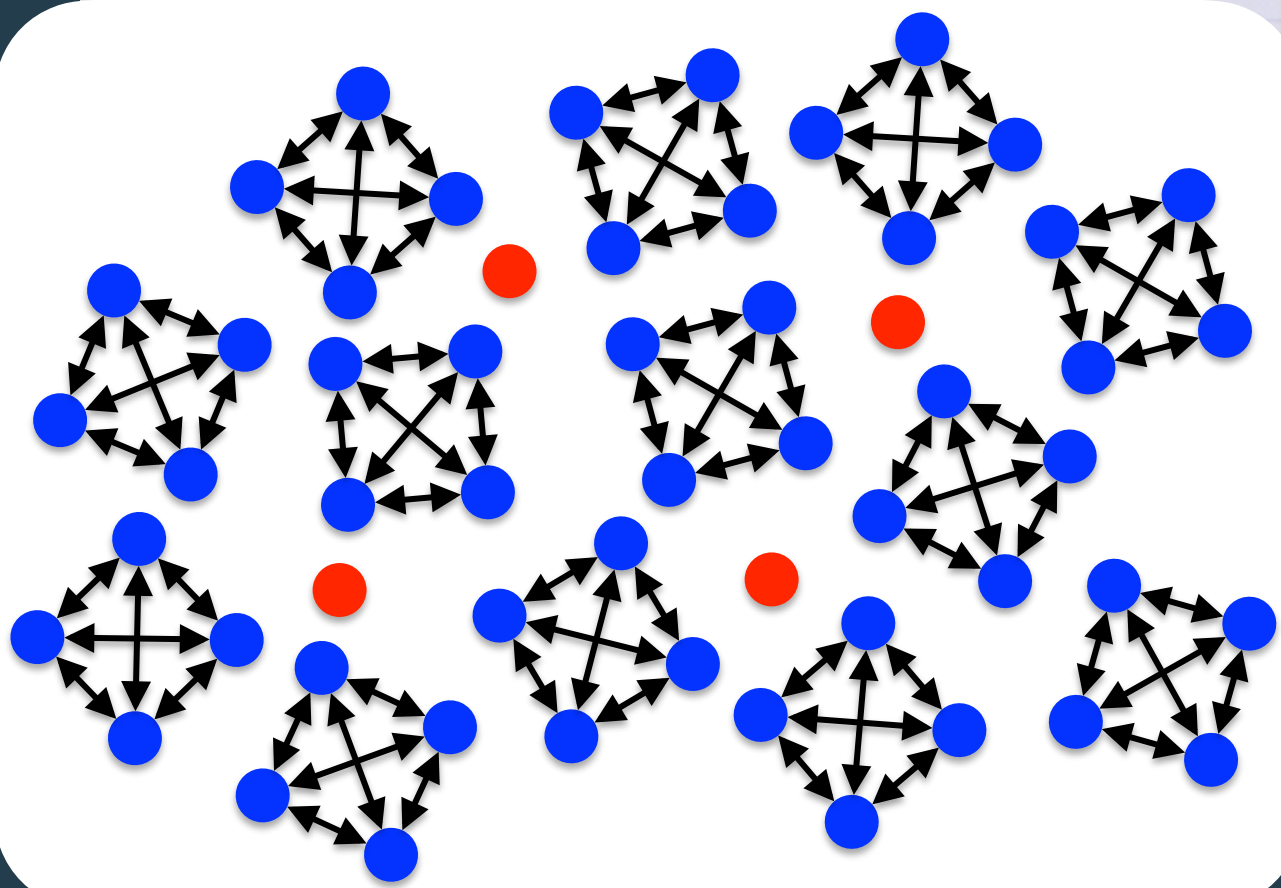
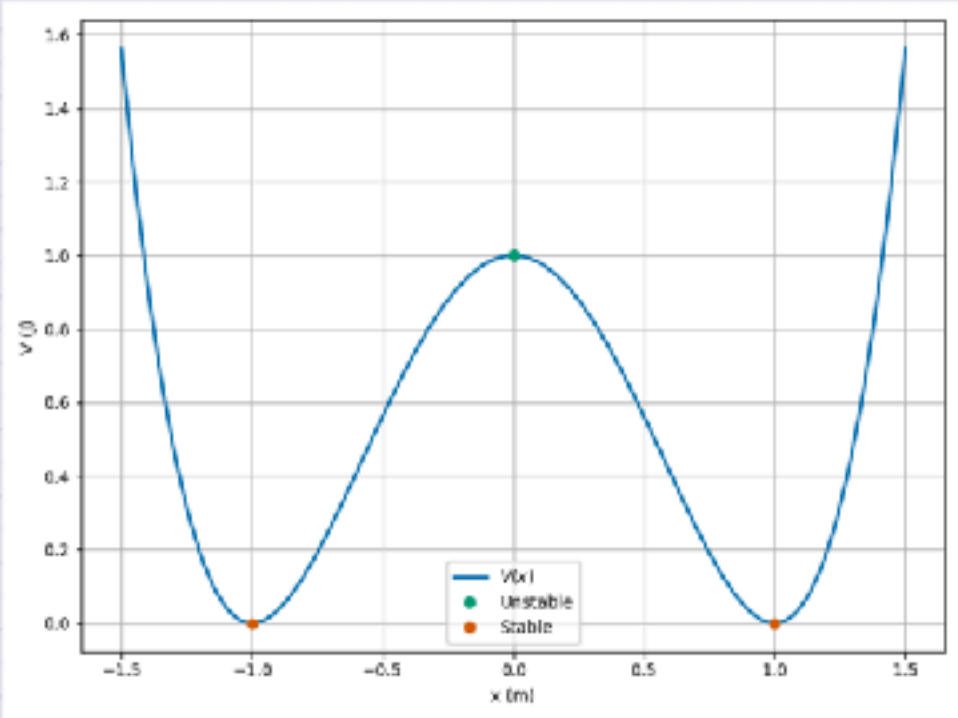
Clicker Question 15-5

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

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

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

Click when done.



Clicker Question 18-4

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

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

That yields the following solution (🤔🤔🤔):

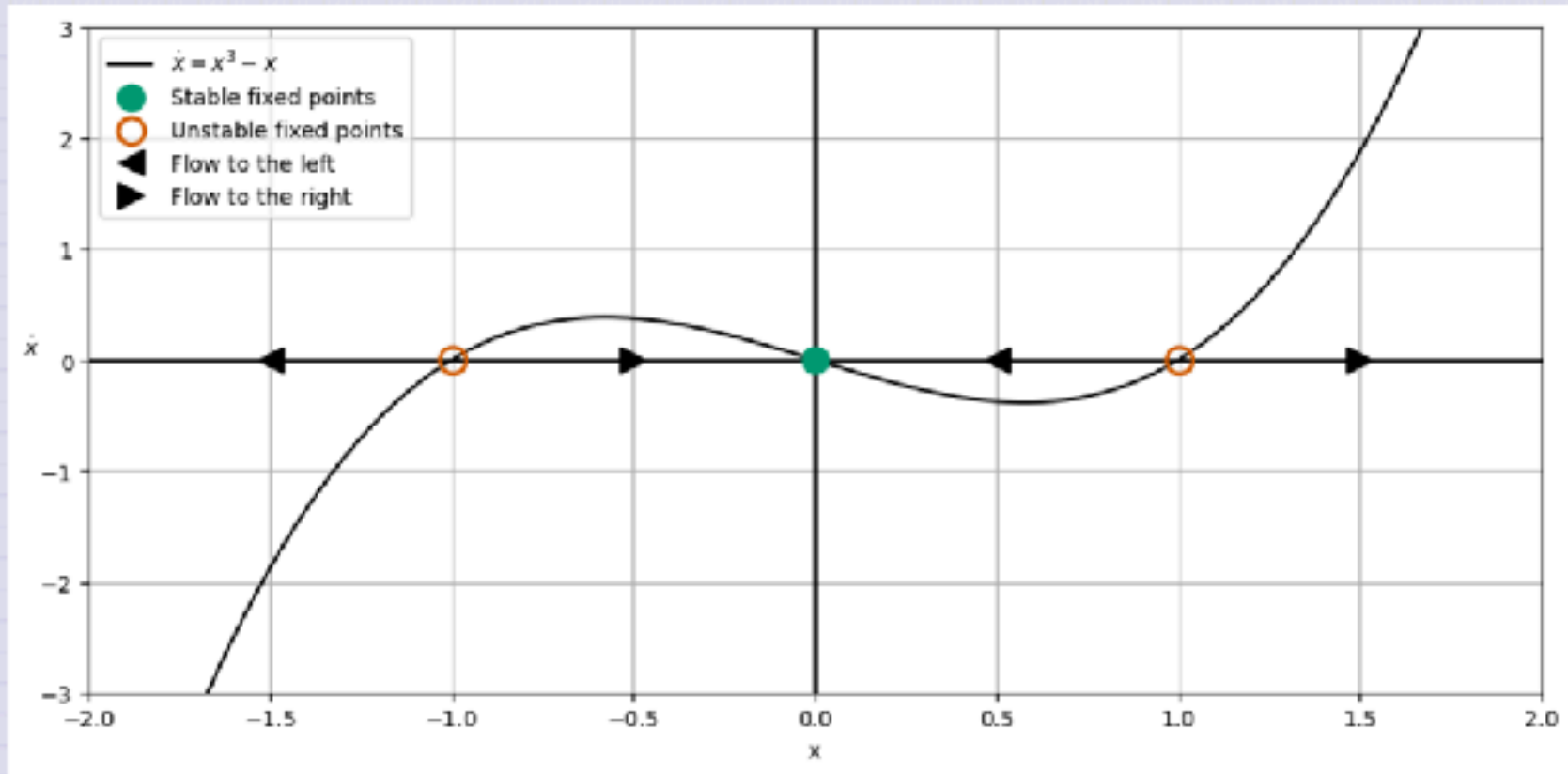
$$t(x) = \left(\frac{1}{2} \ln(1 - x^2) - \ln(x) \right) - \left(\frac{1}{2} \ln(1 - x_0^2) - \ln(x_0) \right)$$

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

Click when you and your table are done.

14 / 17

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



15 / 17

Midterms help develop agency

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_3-colorblind')
```

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

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

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

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

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

Part 2, model your own system (50 points)

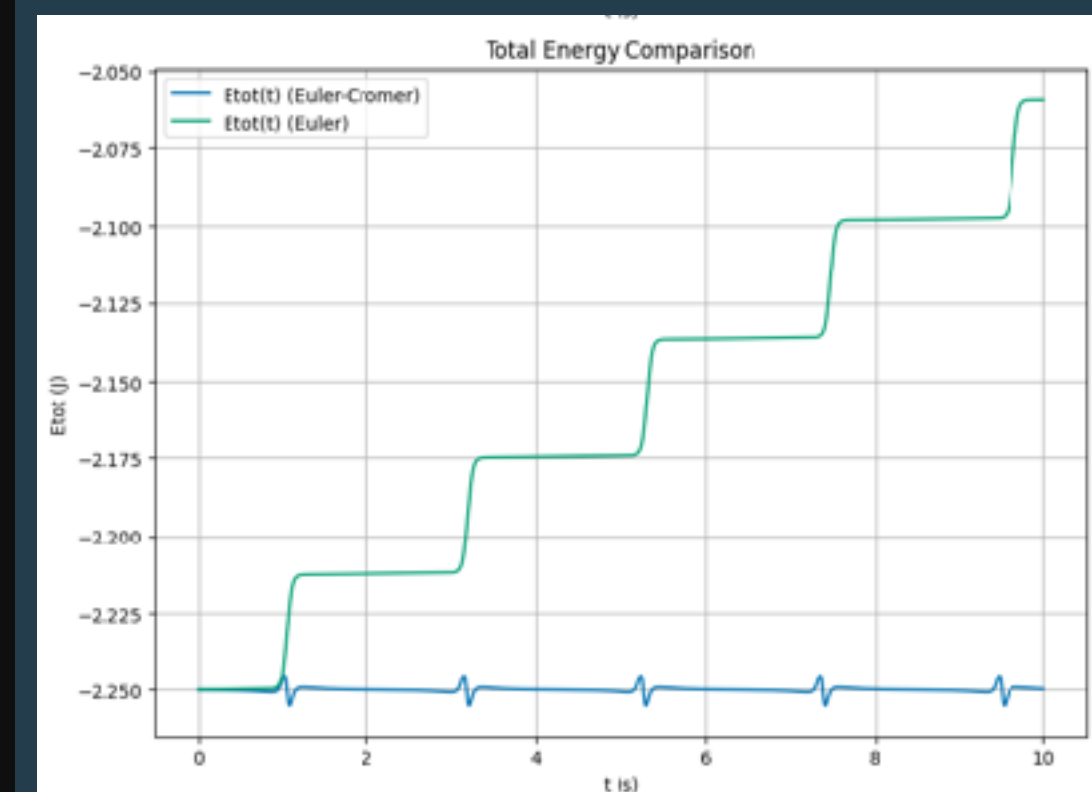
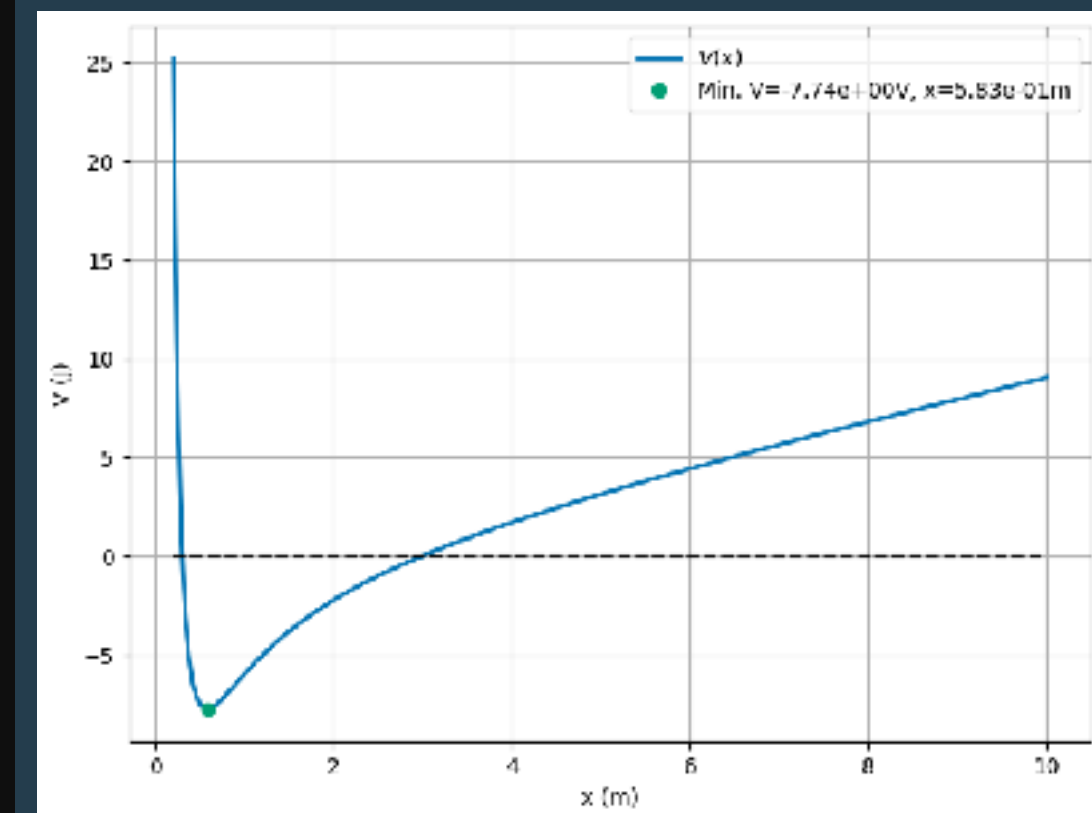
In this problem, you will choose a one dimensional system of your own. You may choose a known potential, or you may invent your own. Your potential must:

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

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

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

1D quark confinement model



Midterms help develop agency

In-class Modeling Activity

The Lorenz model is given by:

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

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

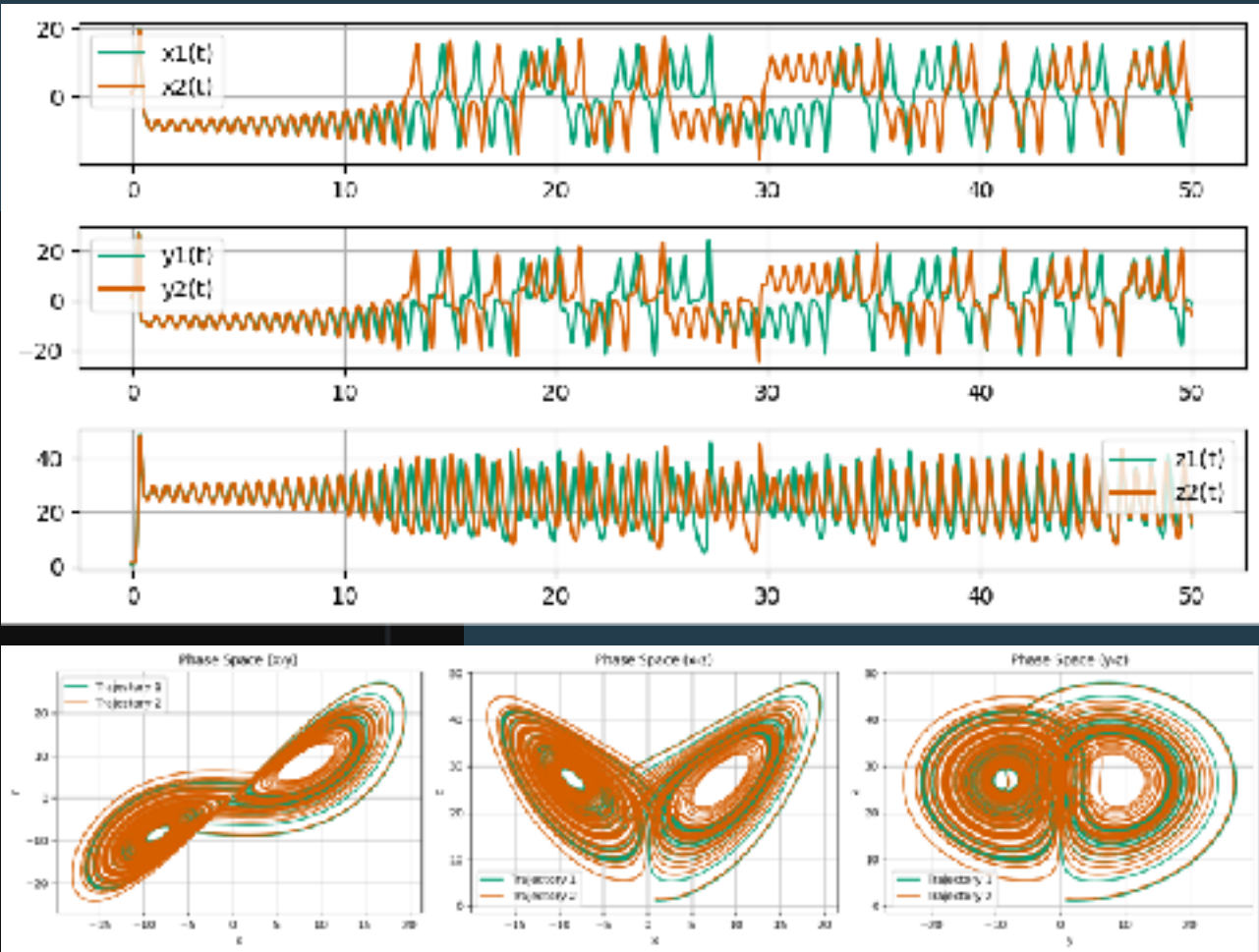
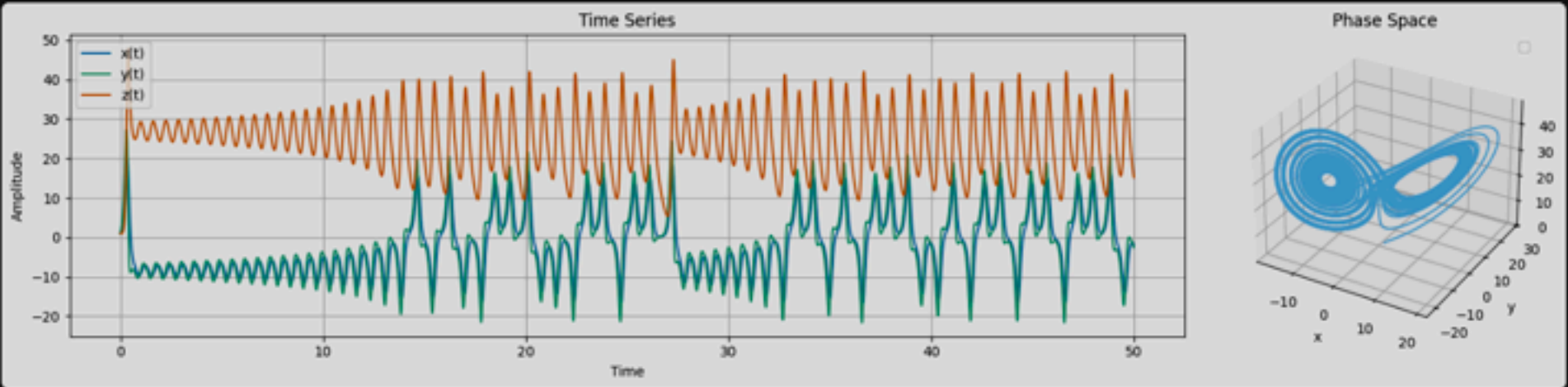
$$\frac{dz}{dt} = xy - \beta z$$

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

Numerically Integrate the Lorenz Attractor

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

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



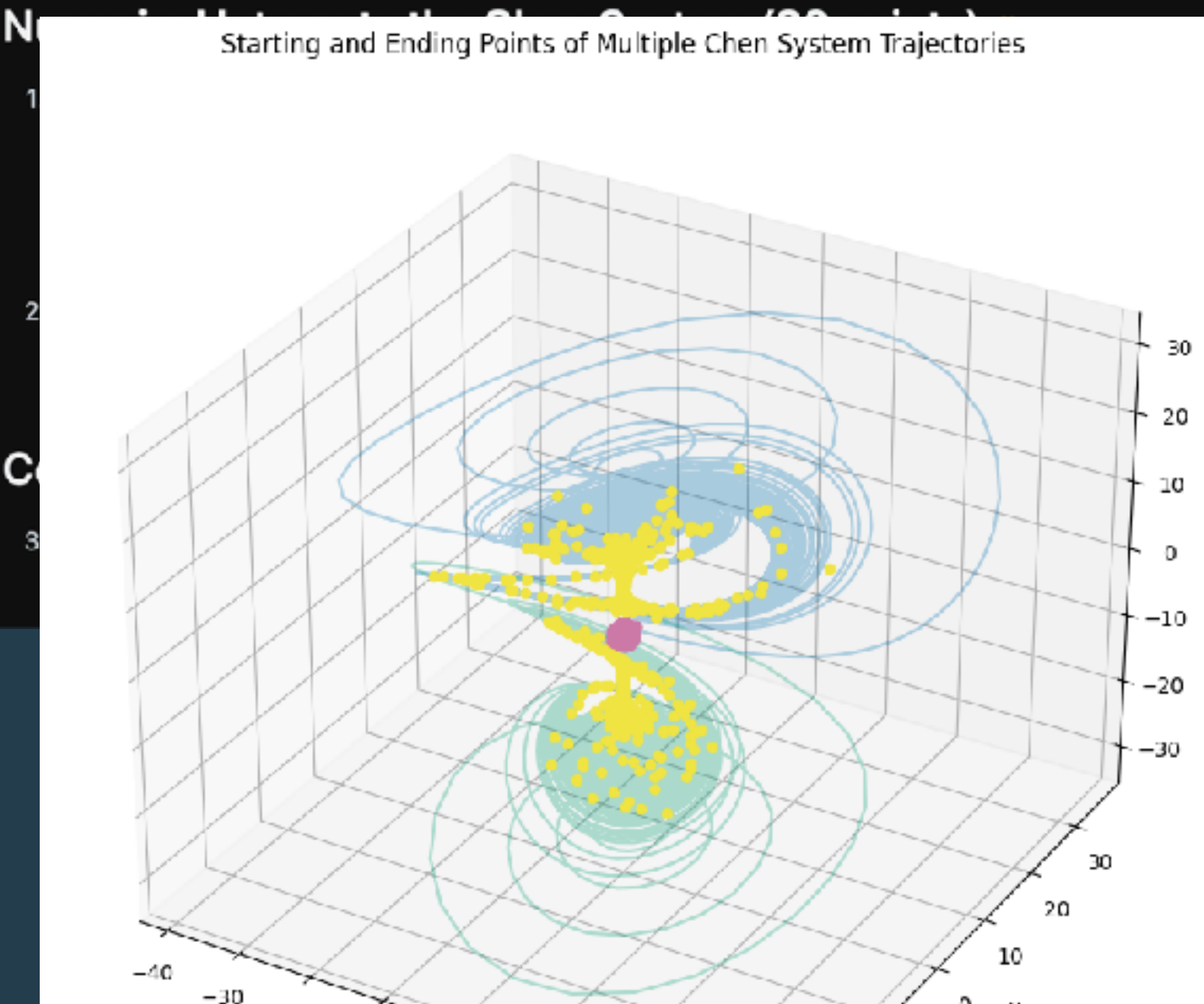
Part 2, Strange Attractor (40pt)

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

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

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

| Parameter | Value |
|-----------|-------|
| α | 5.0 |
| β | -10.0 |
| δ | -0.38 |



Student's illustration of initial condition sensitivity

Timeline of Integrating Computation at MSU

Typical Course Progression



Five years



Ten years



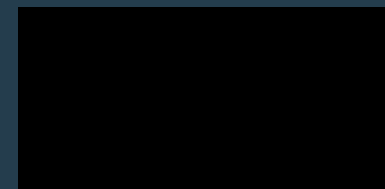
| | F13 | S14 | F14 | S15 | F15 | S16 | F16 | S17 | F17 | S18 | F18 | S19 | F19 | S20 | F20 | S21 | F21 | S22 | F22 | S23 | F23 | S24 | F24 | | F2X |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|-----|
| 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 | | | | | | | | | | | | | | | | | | | | | | | | | |



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

Instruction in computation (some sections)

Instruction in computation

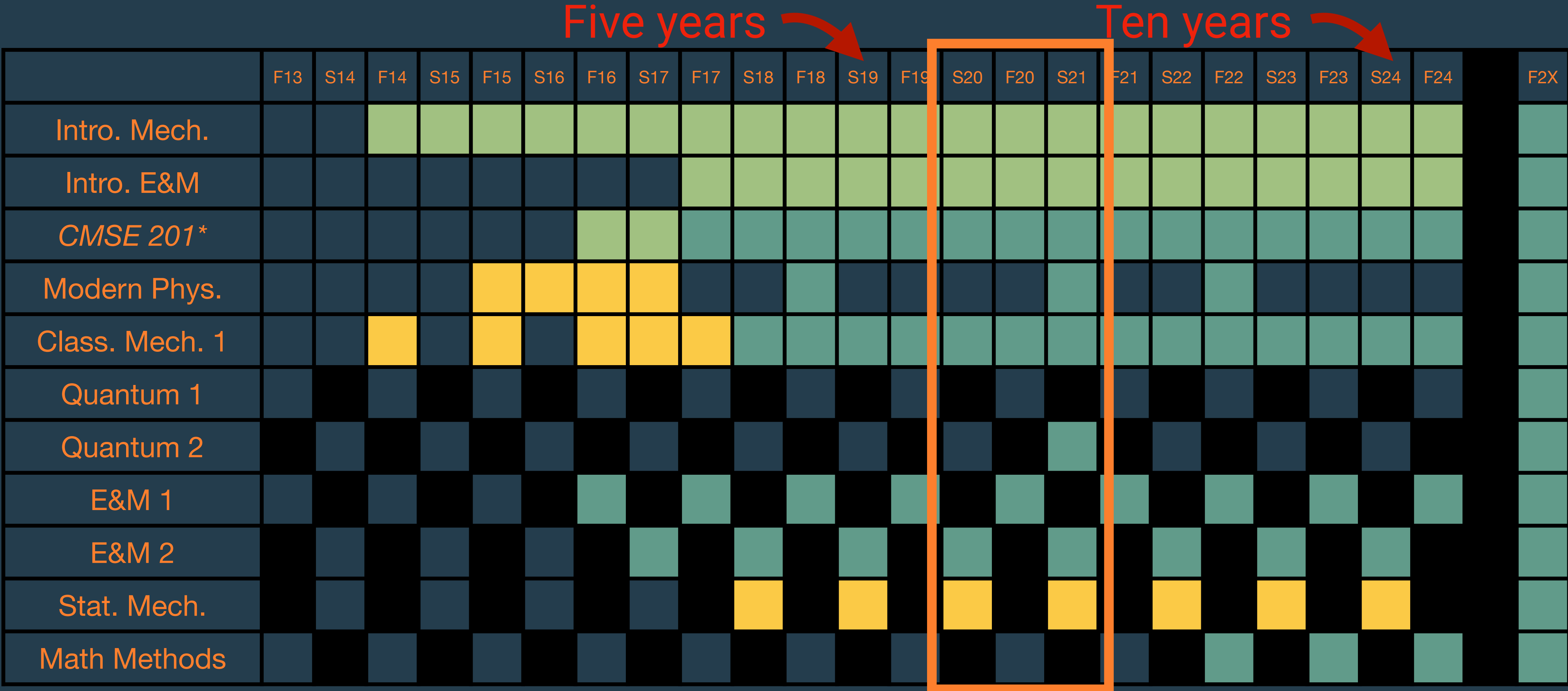


Not offered

We are 11 years into a five year plan. 🤗💧

Timeline of Integrating Computation at MSU

Typical Course Progression



Use of computational environment (e.g., plotting)
Instruction in computation (some sections)
Instruction in computation
Not offered

COVID-19
Pandemic

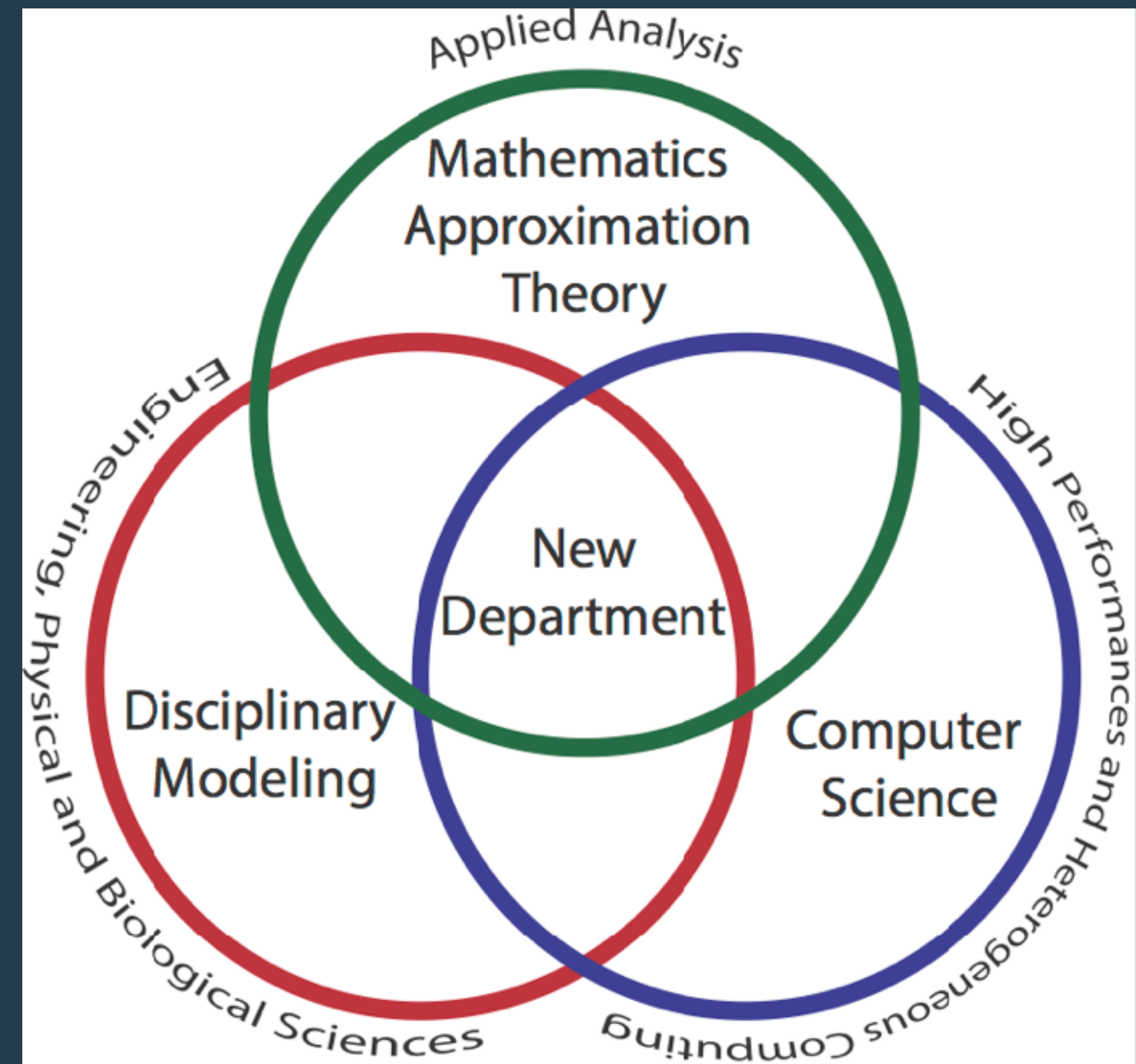
We are 11 years into a five year plan. 🤗💧

External support can help
accelerate the process of
integration.

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

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

BS, MS, and PhD granting department



Introductory Computational Science

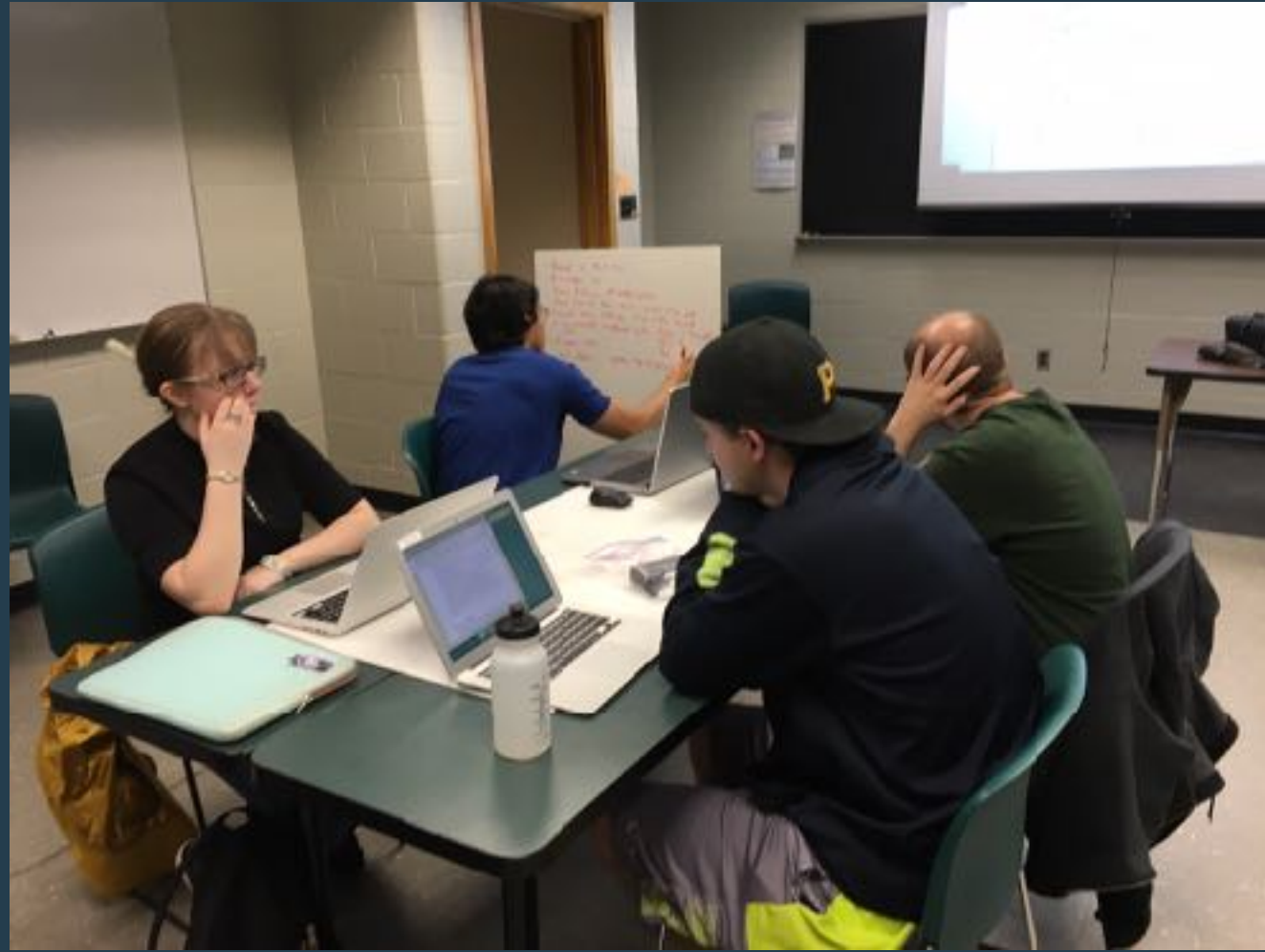
Learning Goals for CMSE 201



1. Gain insight into physical, biological, and social systems through the use of computational algorithms and tools.
2. Write programs to solve common problems in a variety of disciplines.
3. Identify salient features of a system that can be codified into a model.
4. Manipulate, analyze, and visualize datasets and use to evaluate models.
5. Understand basic numerical methods and use them to solve problems.
6. Synthesize results from a scientific computing problem and present it both verbally and in writing.

For any STEM major - pre-req: Calculus 1

Intro. Comp. Modeling (CMSE 201)

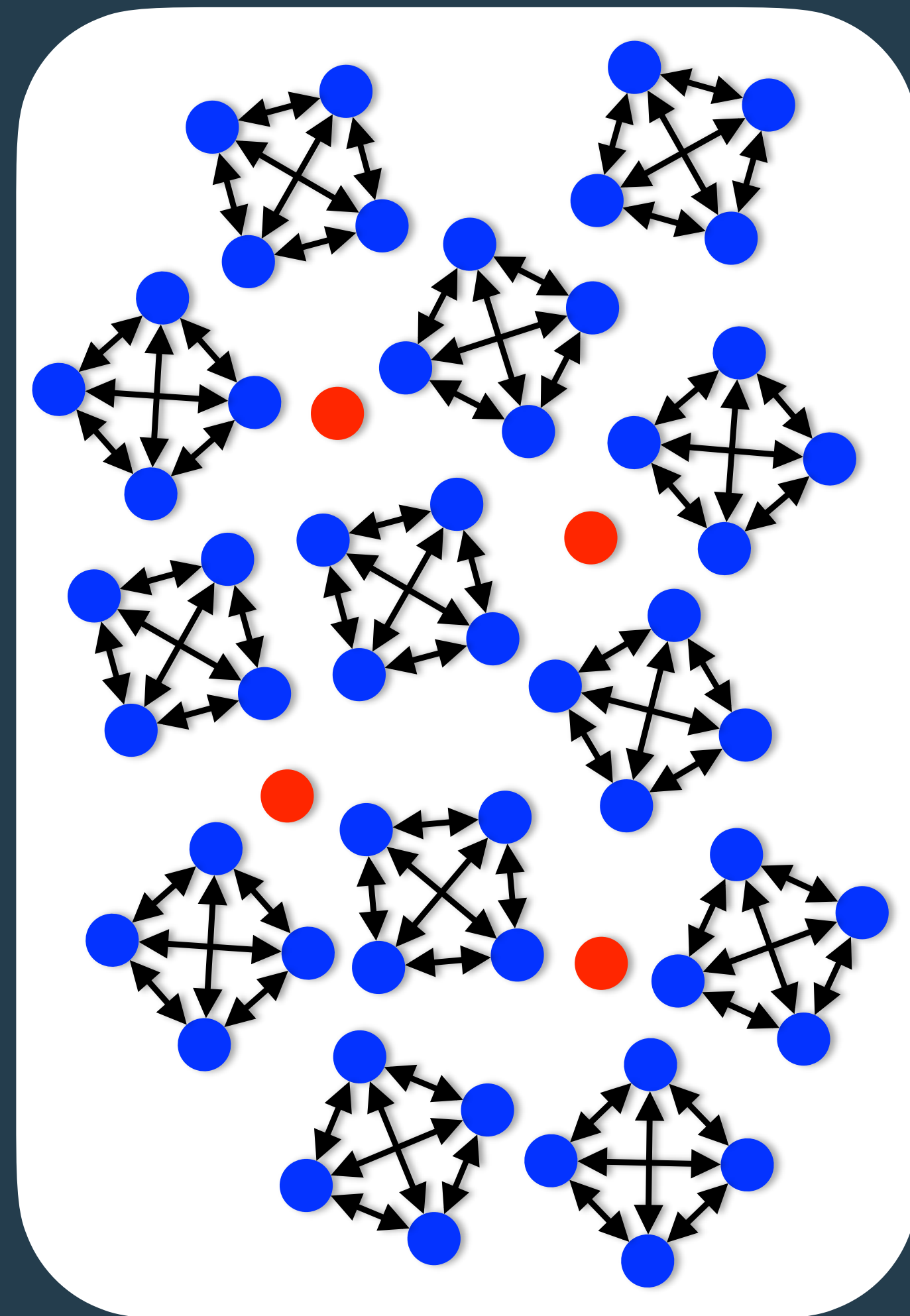


Introductory course in data analysis and modeling
Taken by STEM majors (Calc 1 pre-req)
Required for Physics and Astronomy majors

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



50-70 students/section



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

Integrated Progression

Modeling, Context, and Programming work together

Time



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

and so on...

Day 8: In-class Assignment: Modeling extreme sports

Goals for Today's In-Class Assignment

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

- Use functions to define derivatives that model the evolution of a physical system.
- Use loops to update the state of an evolving system.
- Use `matplotlib` to plot the evolution of the system.
- Use NumPy when necessary to manipulate arrays or perform mathematical operations



Modeling the motion of a skydiver

Part 1: Modeling a falling skydiver without air resistance

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

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

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

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

Part 2: The falling skydiver meets air resistance

Part 3: Opening the parachute

Part 4: Modeling a bungee jumper

Required for PA majors
before Classical Mechanics





PICUP



PARTNERSHIP FOR INTEGRATION OF COMPUTATION INTO UNDERGRADUATE PHYSICS



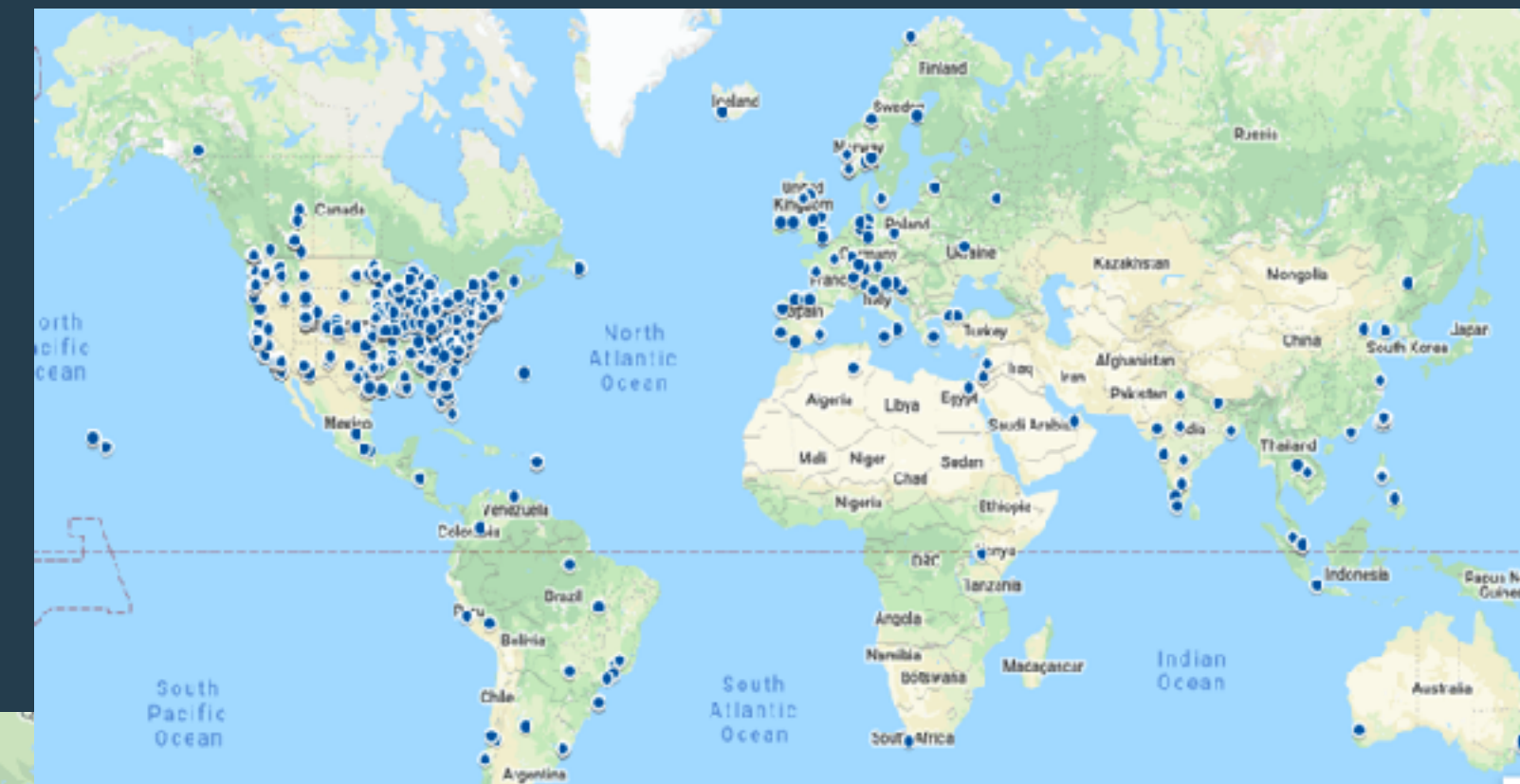
PICUP Community

gopicup.org




Verified educators submit
academic documentation
to gain access to:

Solutions & Source Codes
Implementation Guides
Additional Materials



FDW Participants





Partnership for
Integration of Computation
into Undergraduate Physics

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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

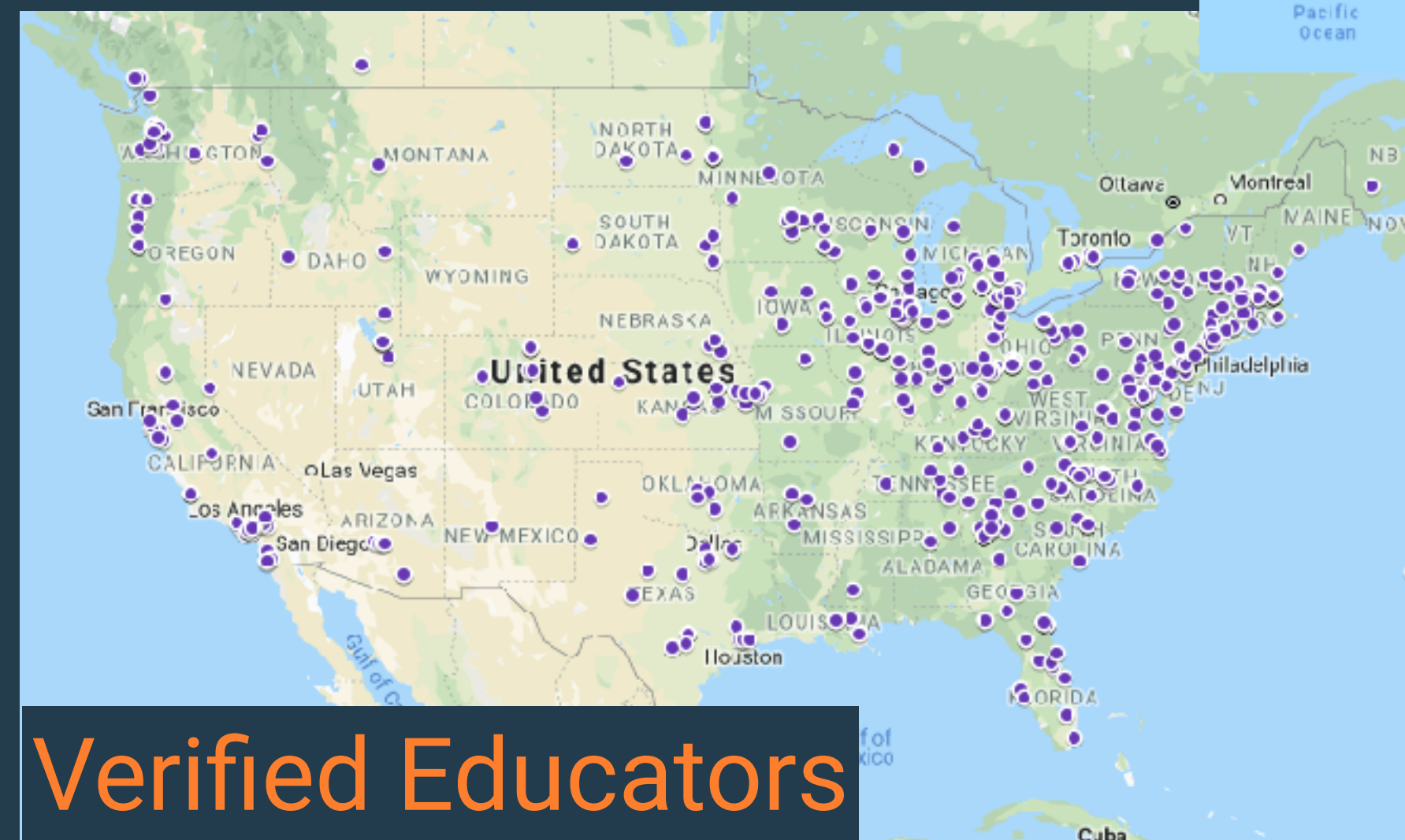
Credits and Licensing

E. Behringer, "A Rigid Three-bar Pendulum," Published in the PICUP Collection, July 2016.

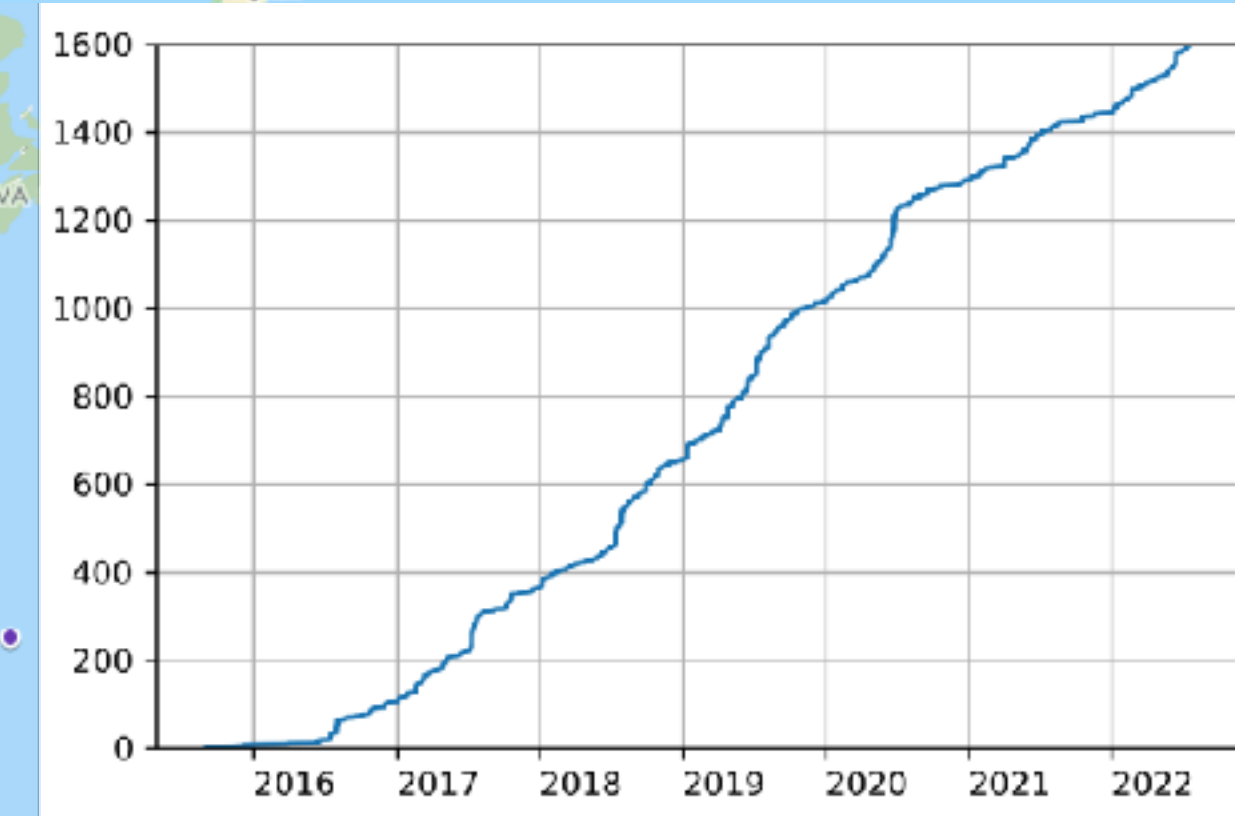
The instructor materials are ©2016 E. Behringer.

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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



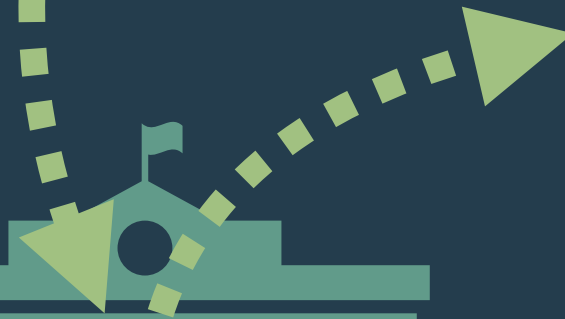
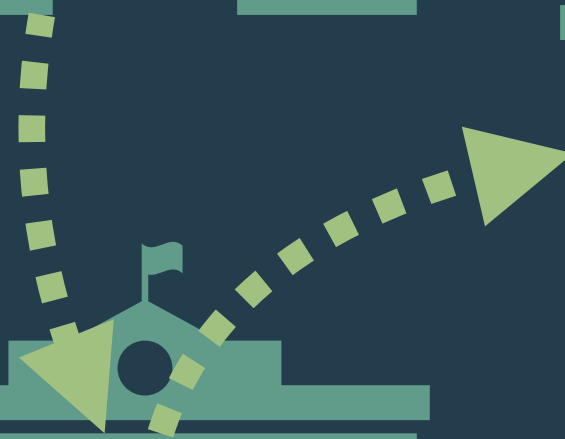
9-12

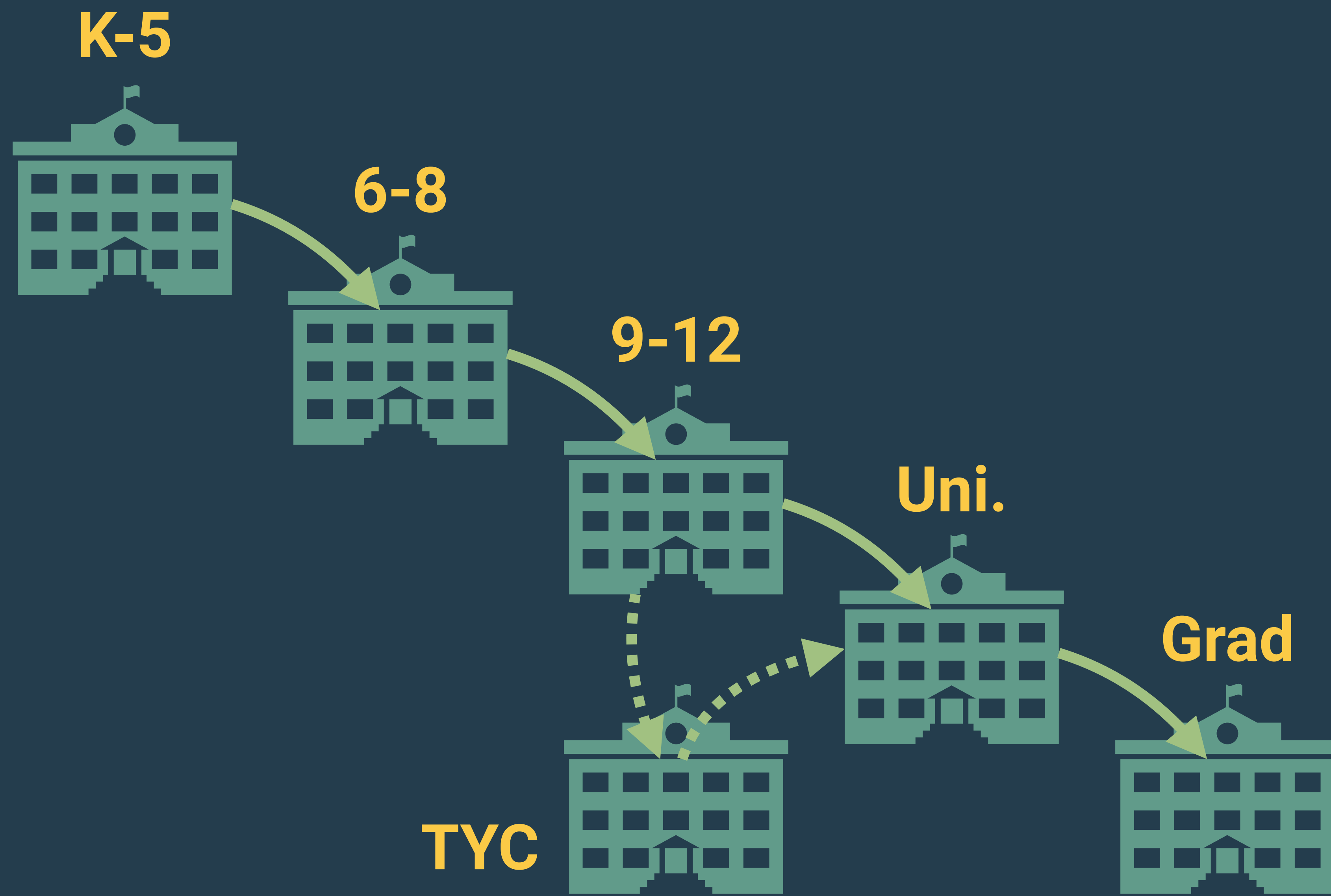


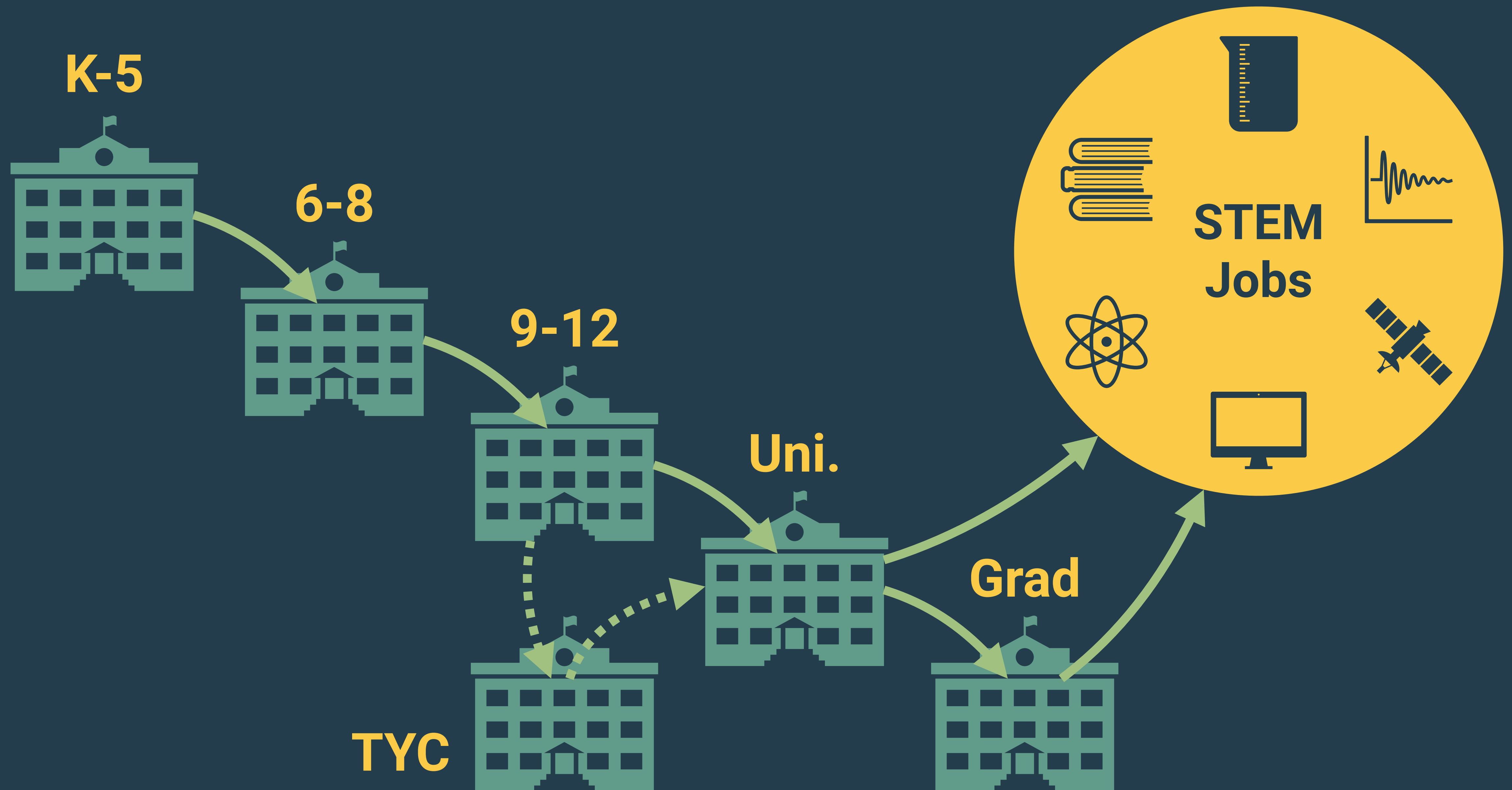
Uni.



TYC







K-5



6-8



9-12



Uni.



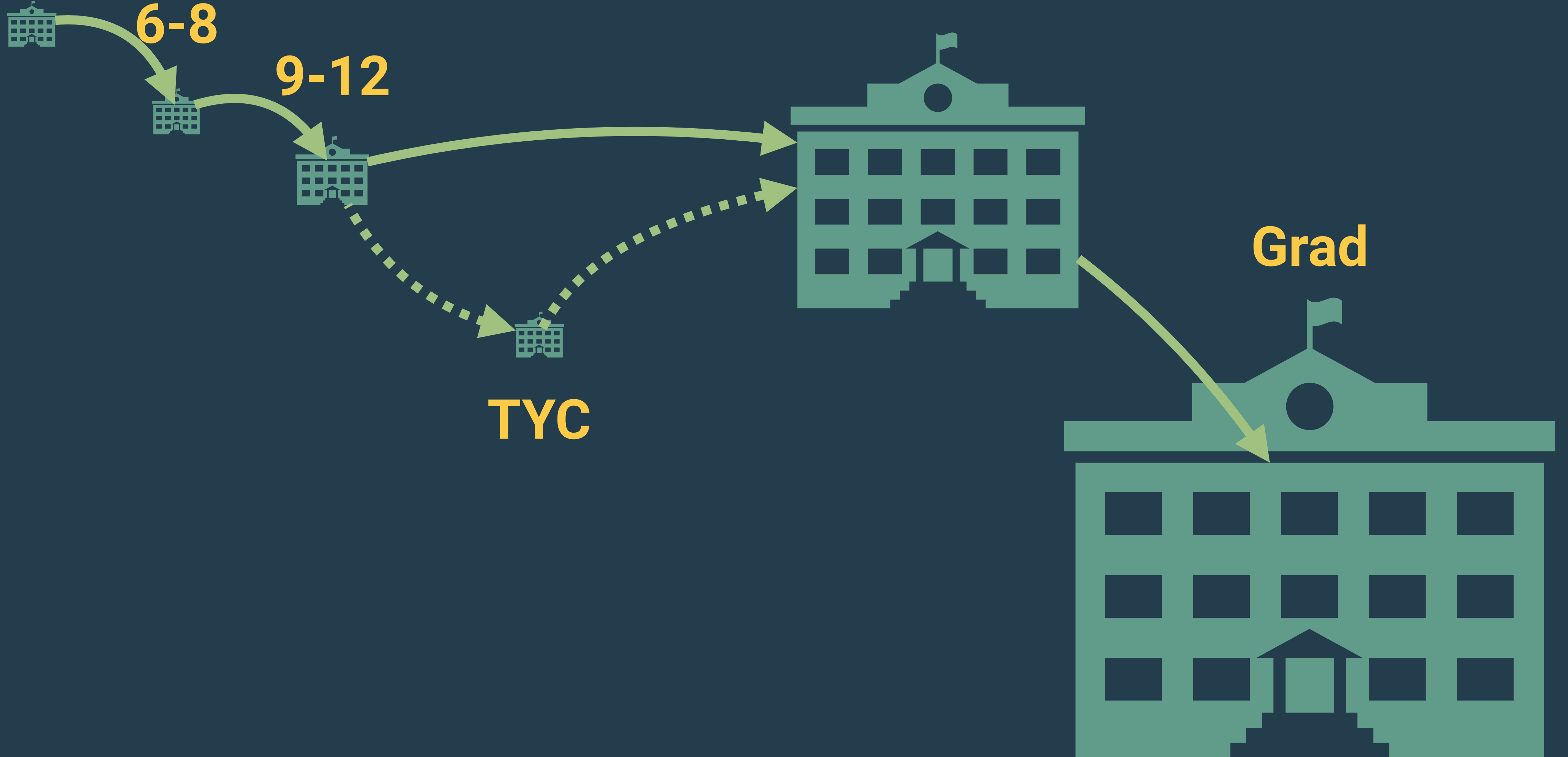
Grad

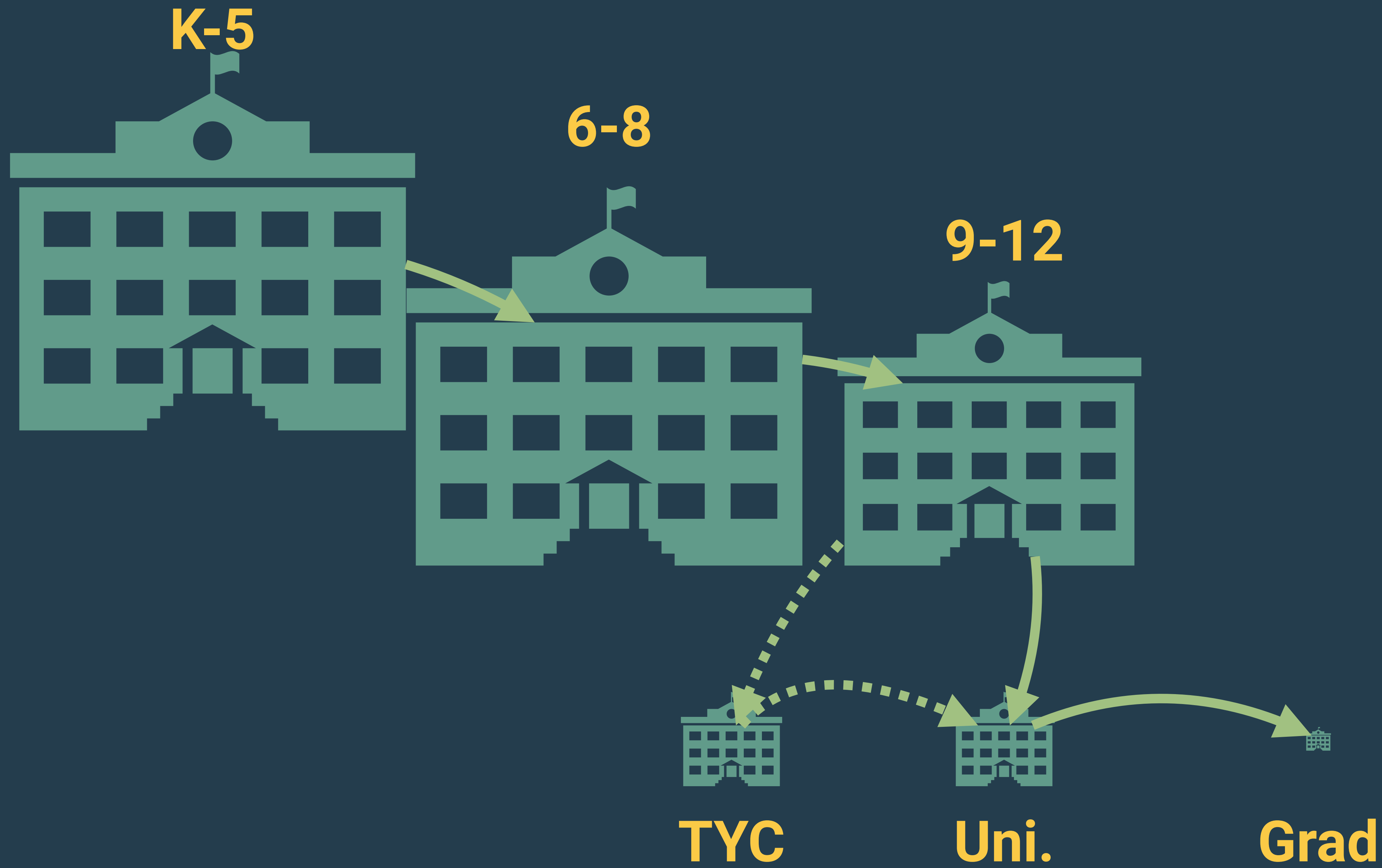


TYC

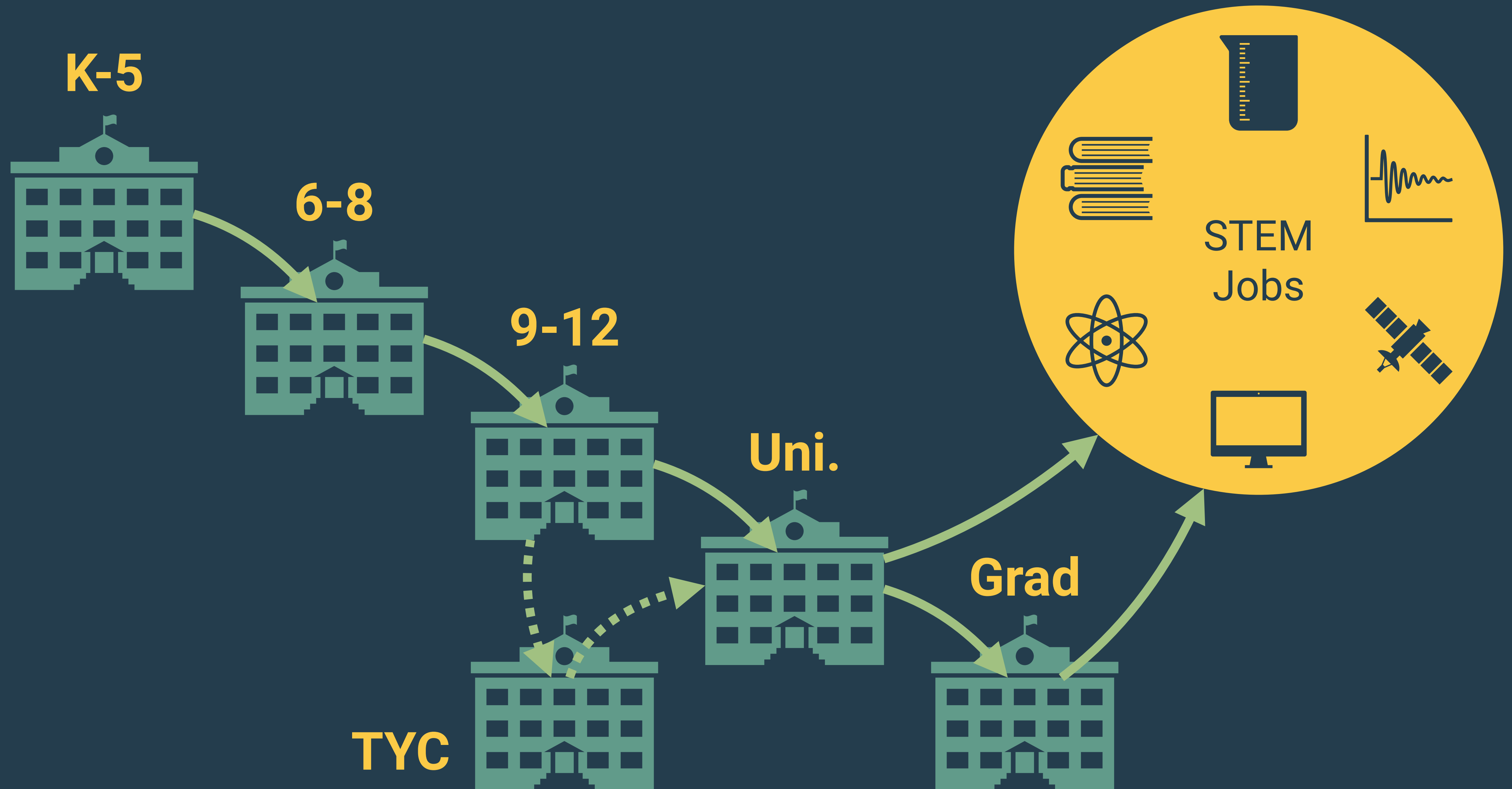


How my university sees things

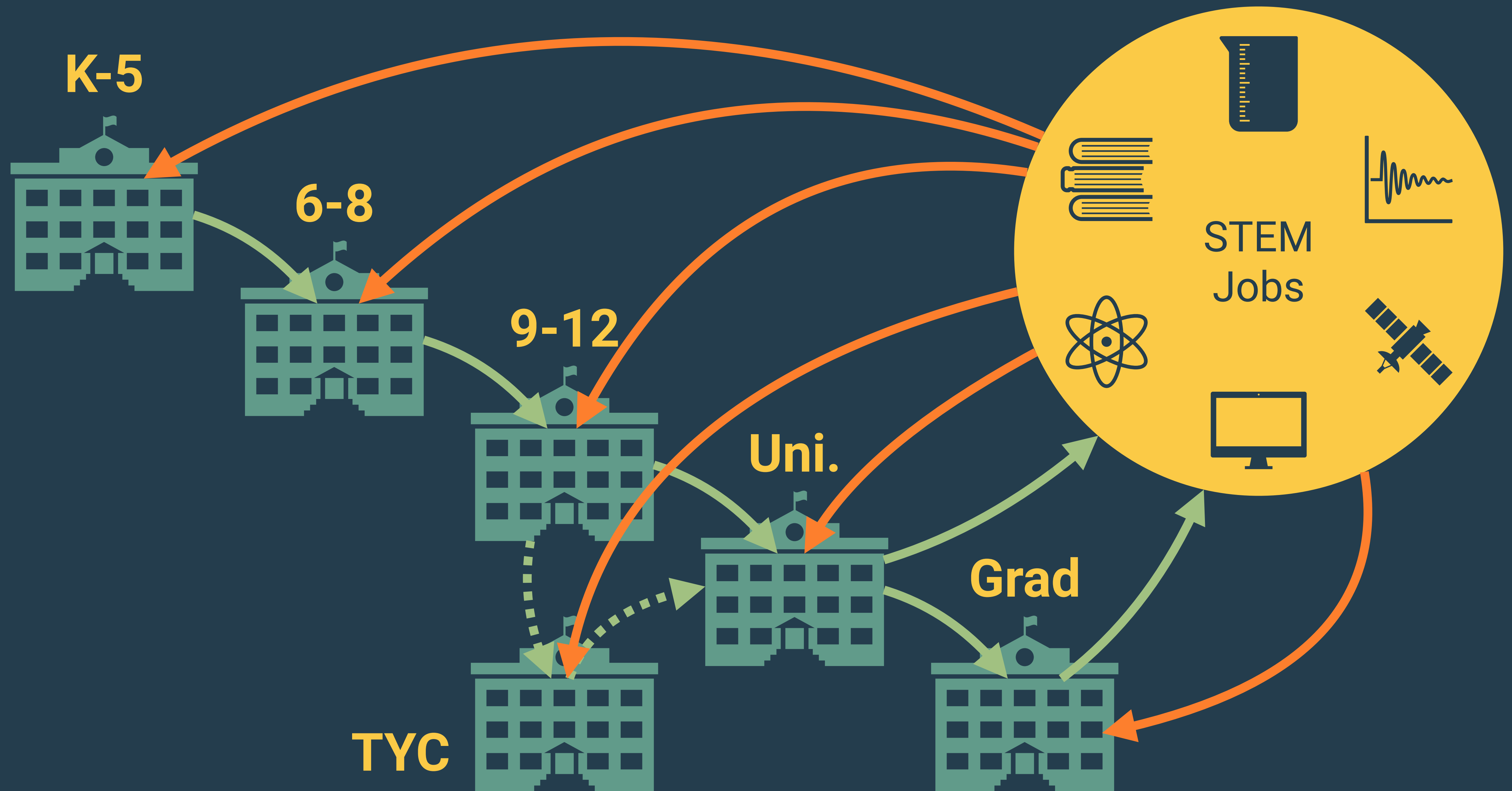




How numbers of students are distributed



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



Create a **computational model** to calculate...

Use mathematical and/or **computational representations** to support explanations of factors...

Use mathematical or **computational representations** to predict the motion...



ICSAM Workshop



Weeklong Summer Camp for High School Teachers

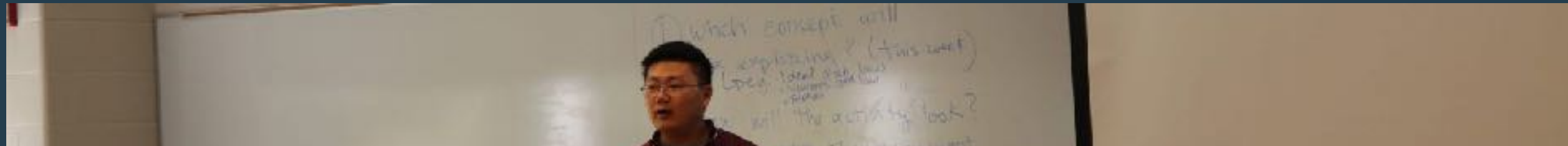
- Introduce computing
- Develop materials
- Grow community
- Focus on equity

Return to MSU (virtual during COVID)

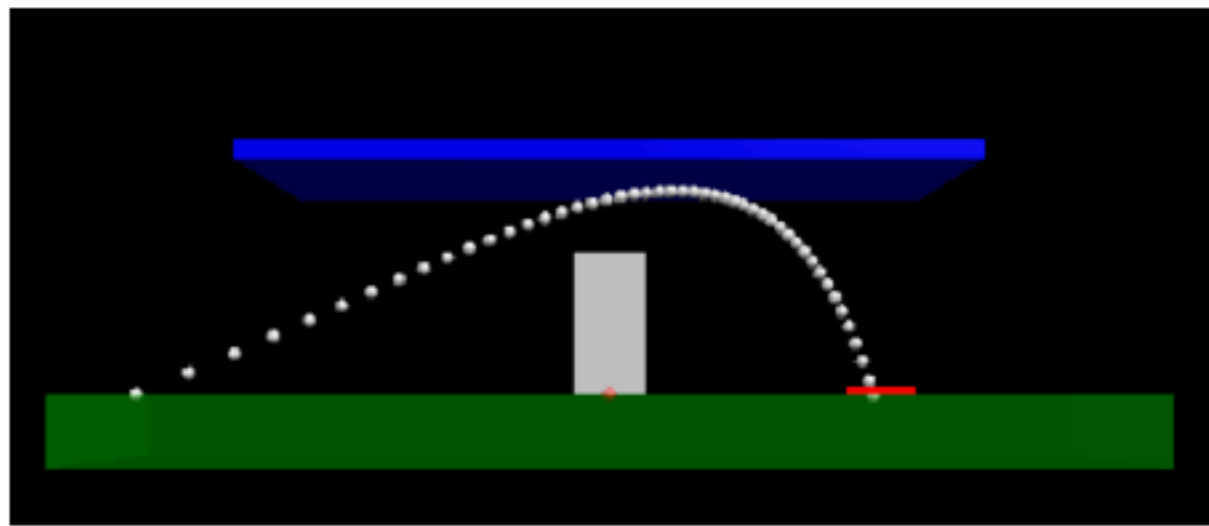
- Addressing problems of practice
- Community building



ICSAM Workshop



Marshmallow Launch



Activity Information

Learning Goals

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

Weeklong Summer Camp for High School Teachers

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

Return to MSU (virtual during COVID)

- Addressing problems of practice
- Community building

Many teacher-developed materials!



ICSAM is also a research lab

PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH 18, 020109 (2022)

Editors' Suggestion

Students' perspectives on computational challenges in physics class

Patti C. Hamerski¹, Daryl McPadden¹, Marcos D. Caballero^{1,2} and Paul W. Irving¹

¹Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA

²Department of Physics and Center for Computing in Science Education,
University of Oslo, N-0316 Oslo, Norway

PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH 18, 020106 (2022)

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

Daniel P. Weller^{1,2}, Theodore E. Bott¹, Marcos D. Caballero^{1,3,4} and Paul W. Irving¹

¹Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA

²School of Mathematical and Physical Sciences, University of New England,
Biddeford, Maine 04005, USA

³Department of Computational Mathematics, Science, and Engineering and CREATE for STEM Institute,
Michigan State University, East Lansing, Michigan 48824, USA

⁴Department of Physics and Center for Computing in Science Education, University of Oslo,

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

 **Routledge**
Taylor & Francis Group



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

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

ABSTRACT

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

ARTICLE HISTORY

Received 31 October 2019
Accepted 31 July 2020

KEYWORDS

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

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

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

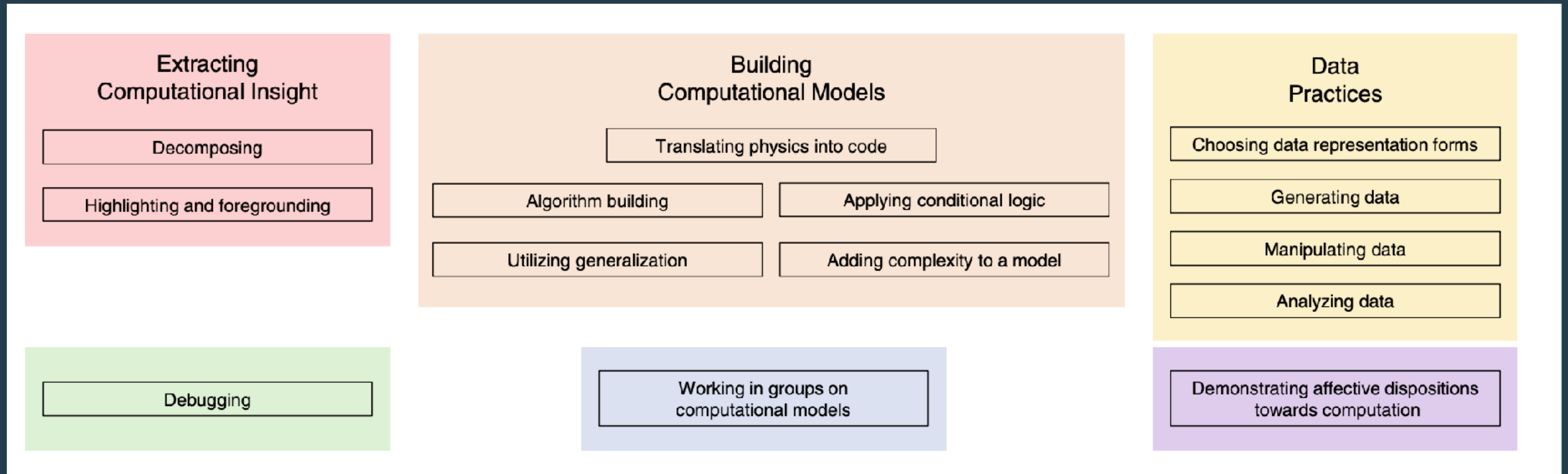
learners.^{12,13} Therefore, we encourage teachers to consider past and contemporary forms of marginalization when determining standards of fairness. In other words, we recommend a “reparations-type” view when defining equity.

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

EQUIP: Equity QUantified In Part



Analysis Framework for Computing Practices



Analysis Framework for Computing Practices

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

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

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



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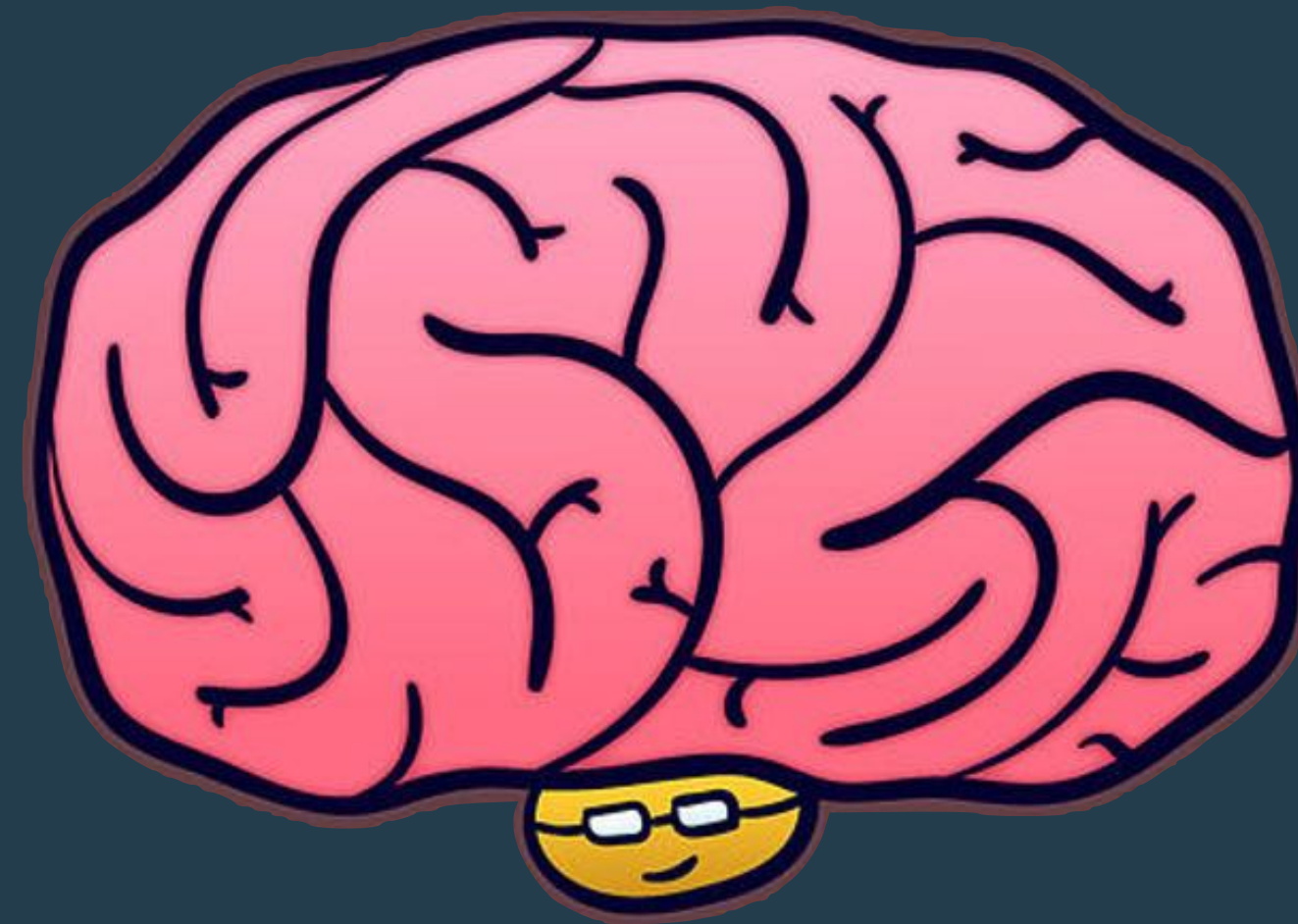
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AND NOW FOR
SOMETHING
COMPLETELY
DIFFERENT

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

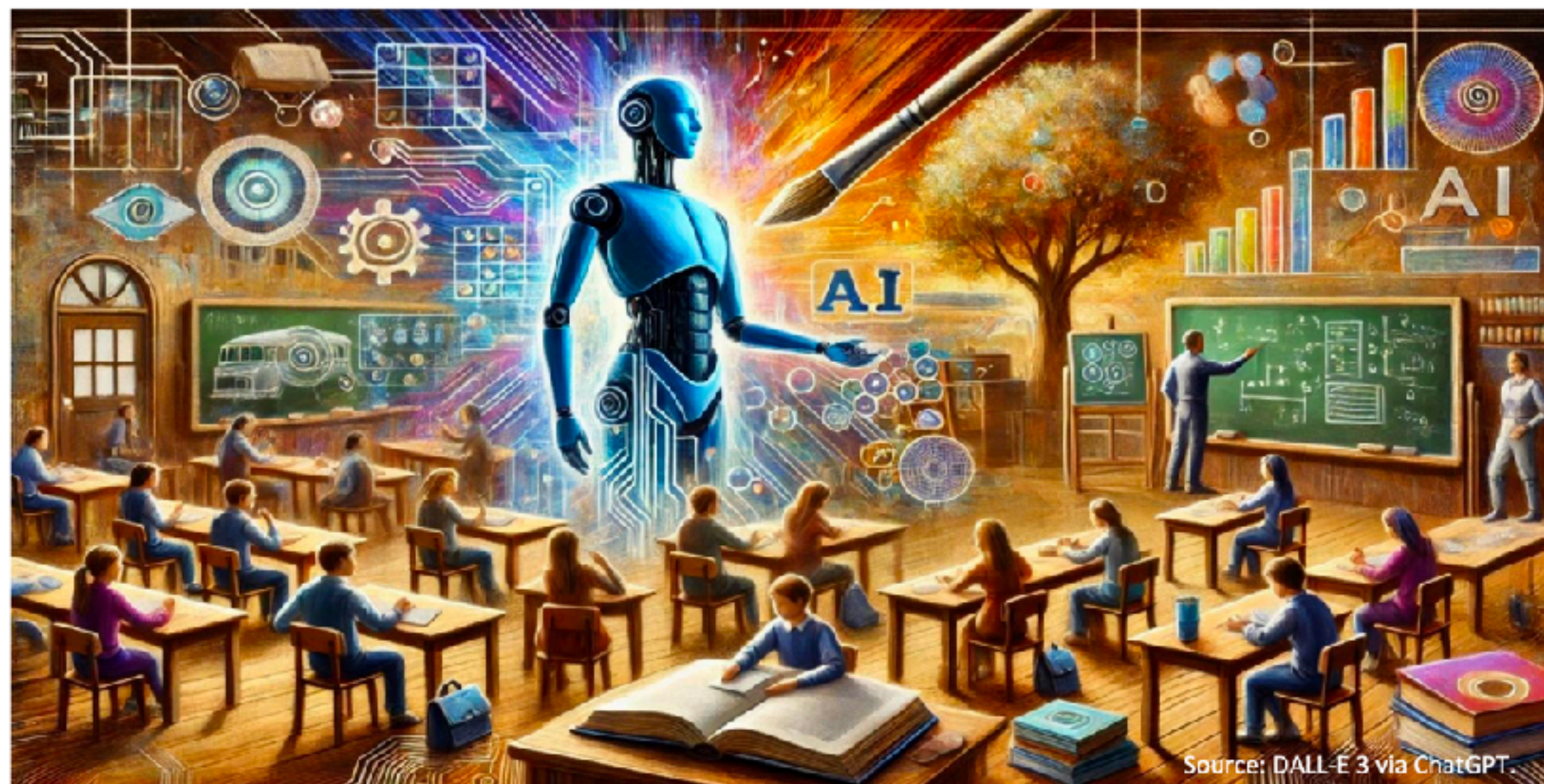
No. 10 | 2024

13 August 2024

AI is Disrupting Education – For Better or Worse

Challenges and Strategies for Sustainable Learning and Institutional Resilience

Anselm Küsters



Forbes

FORBES > LEADERSHIP > LEADERSHIP STRATEGY

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

Nicole Serena Silver Contributor @

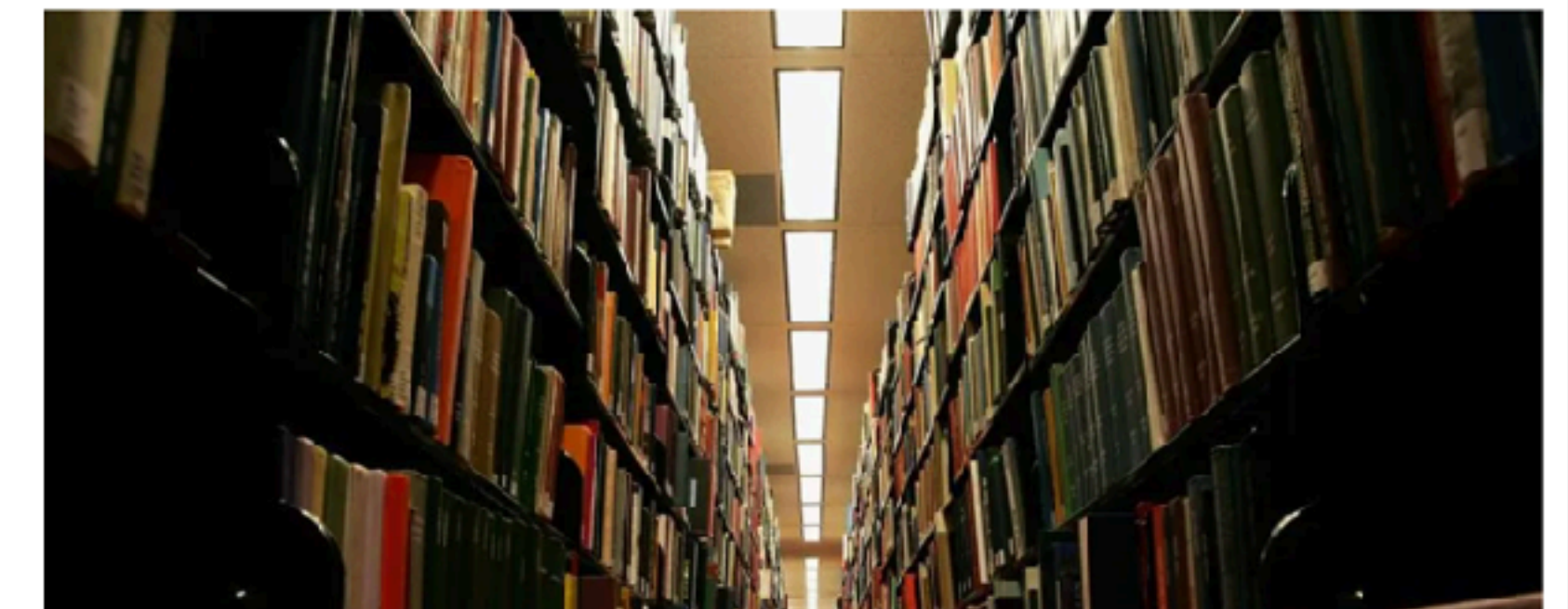
Nicole Serena Silver covers entrepreneurship and the future of work.

Follow



Jun 5, 2023, 09:25pm EDT

Updated Jun 20, 2023, 01:29am EDT



What is being discussed?

AI has several potential benefits

Benefits

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

What is being discussed?

AI has several potential benefits & numerous concerns:

Benefits

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

Concerns

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

Framing the AI issue

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

Technological Solutionism:
tech can provide the necessary solutions

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

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

Human-centered Education:
social relationships are paramount

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

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

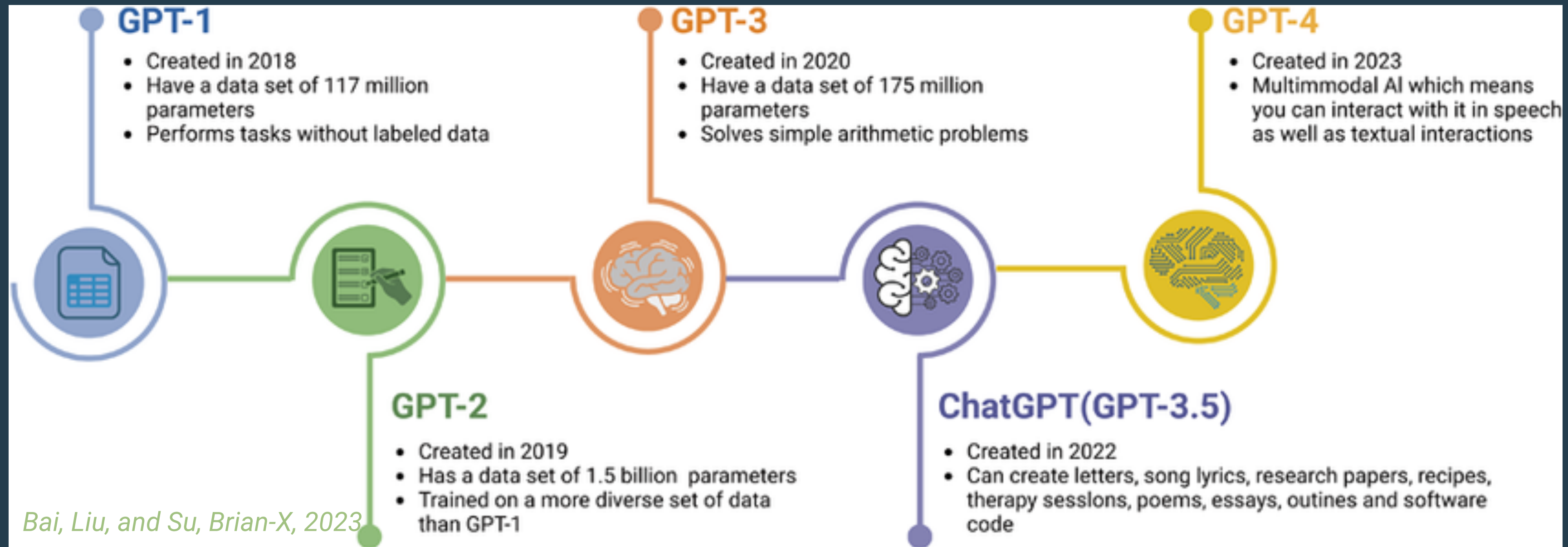
Education as a tool for Justice
education is a political act of liberation

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

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

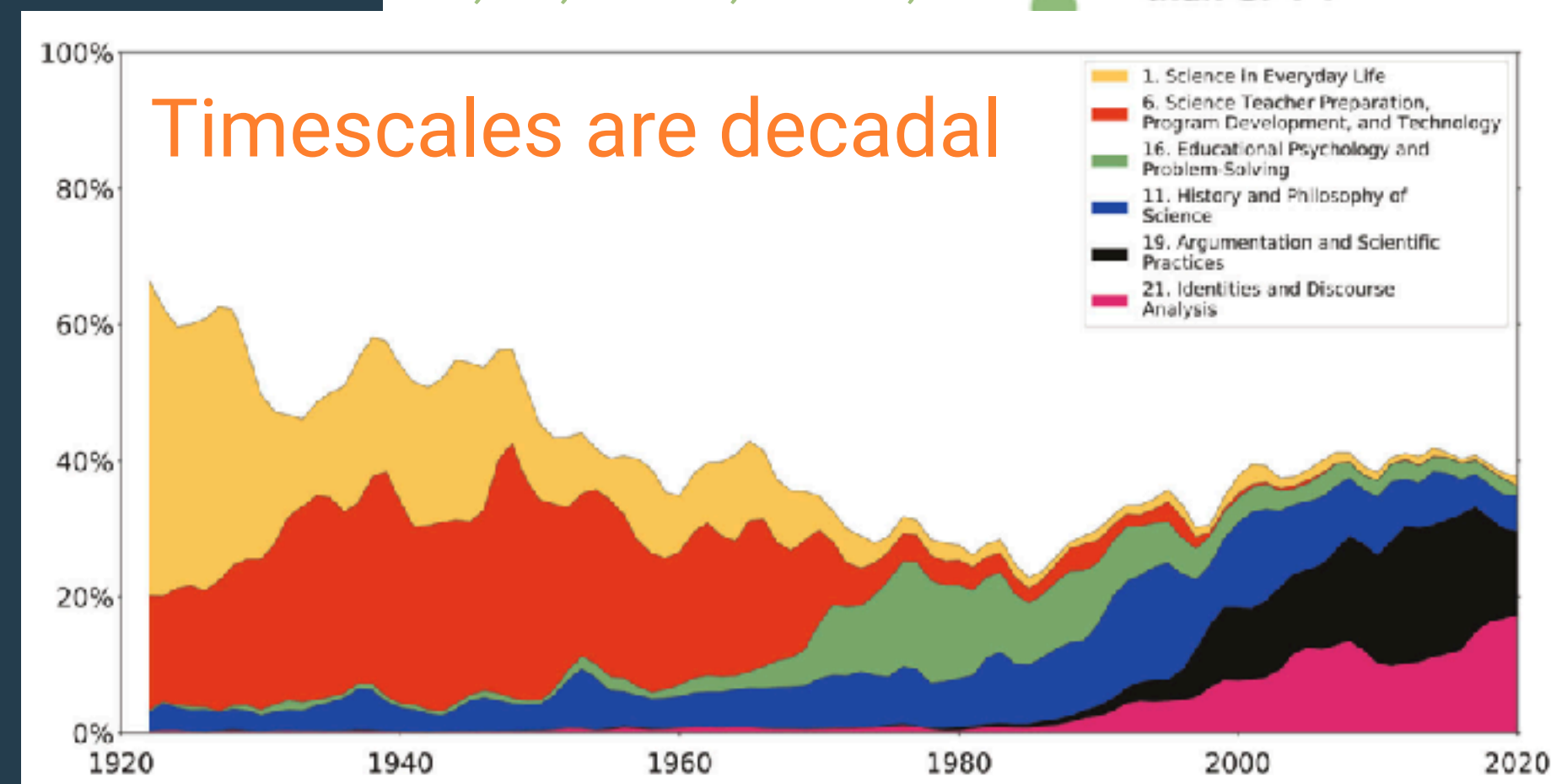
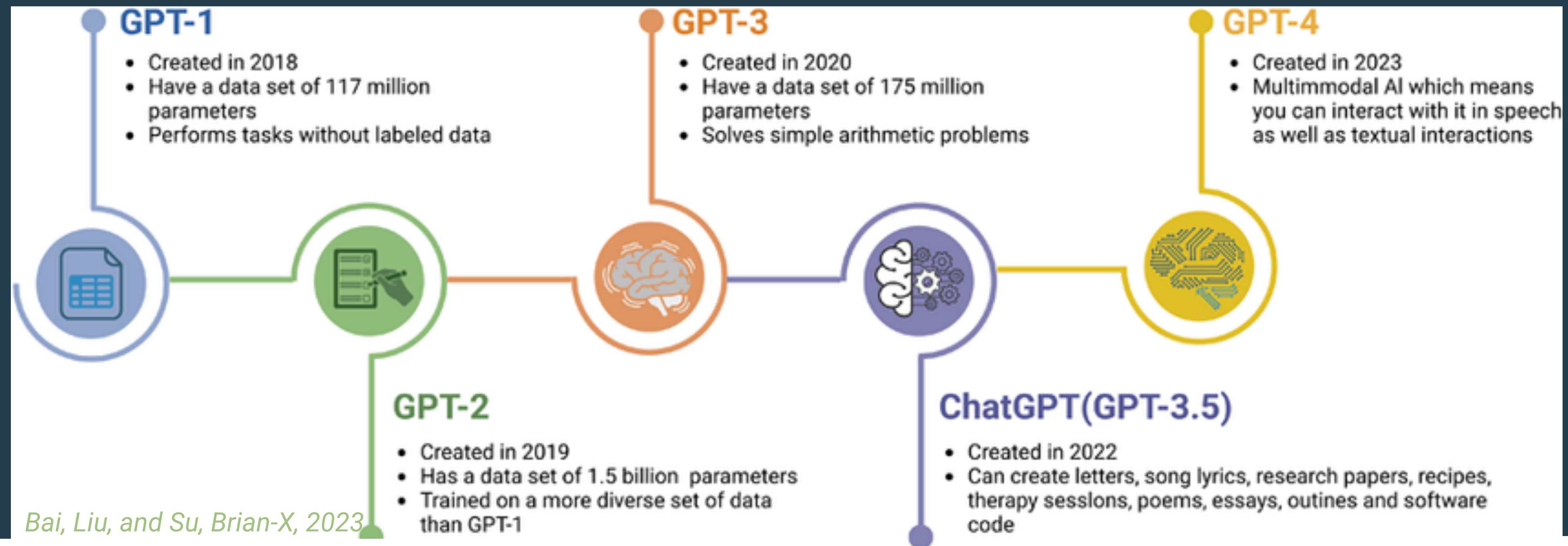
Rapid development

Development is too rapid for education research capacity and pace

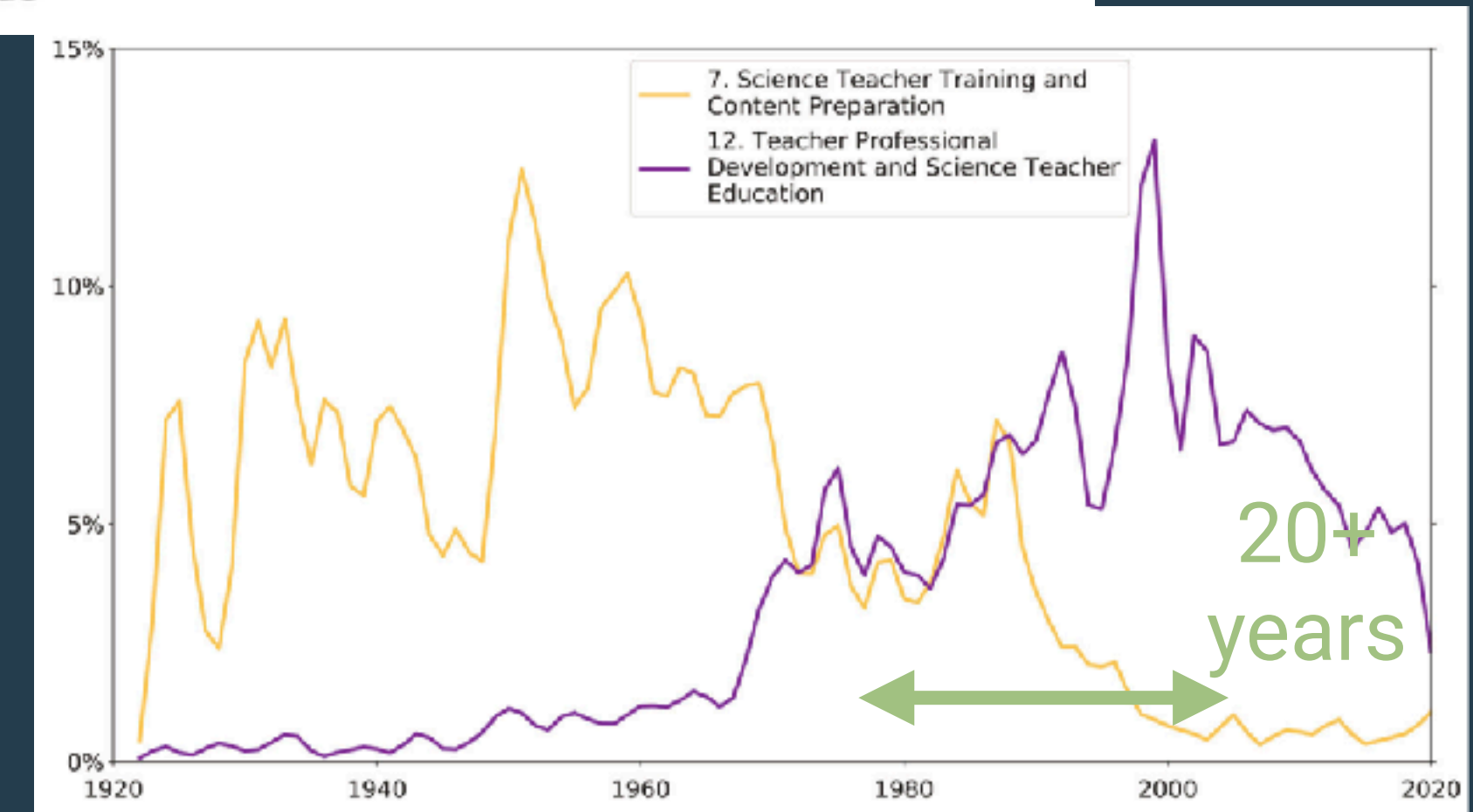


Rapid development

Development is too rapid for education research capacity and pace



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?



The CERL squirrels

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

Two Concerns (for now)

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

Memory updated

Here are three example questions and Matplotlib:

1. Plotting a Sine Wave Function

- Write a Python function that takes values between 0 and 2π and plots the sine wave.

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

def plot_sine_wave():
    x = np.linspace(0, 2*np.pi, 100)
    y = np.sin(x)
    plt.plot(x, y)
    plt.title("Sine Wave")
    plt.xlabel("x (radians)")
    plt.ylabel("sin(x)")
    plt.show()

plot_sine_wave()
```

i'm confused about variable scope in python functions; can you provide a working and not working example?

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

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

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

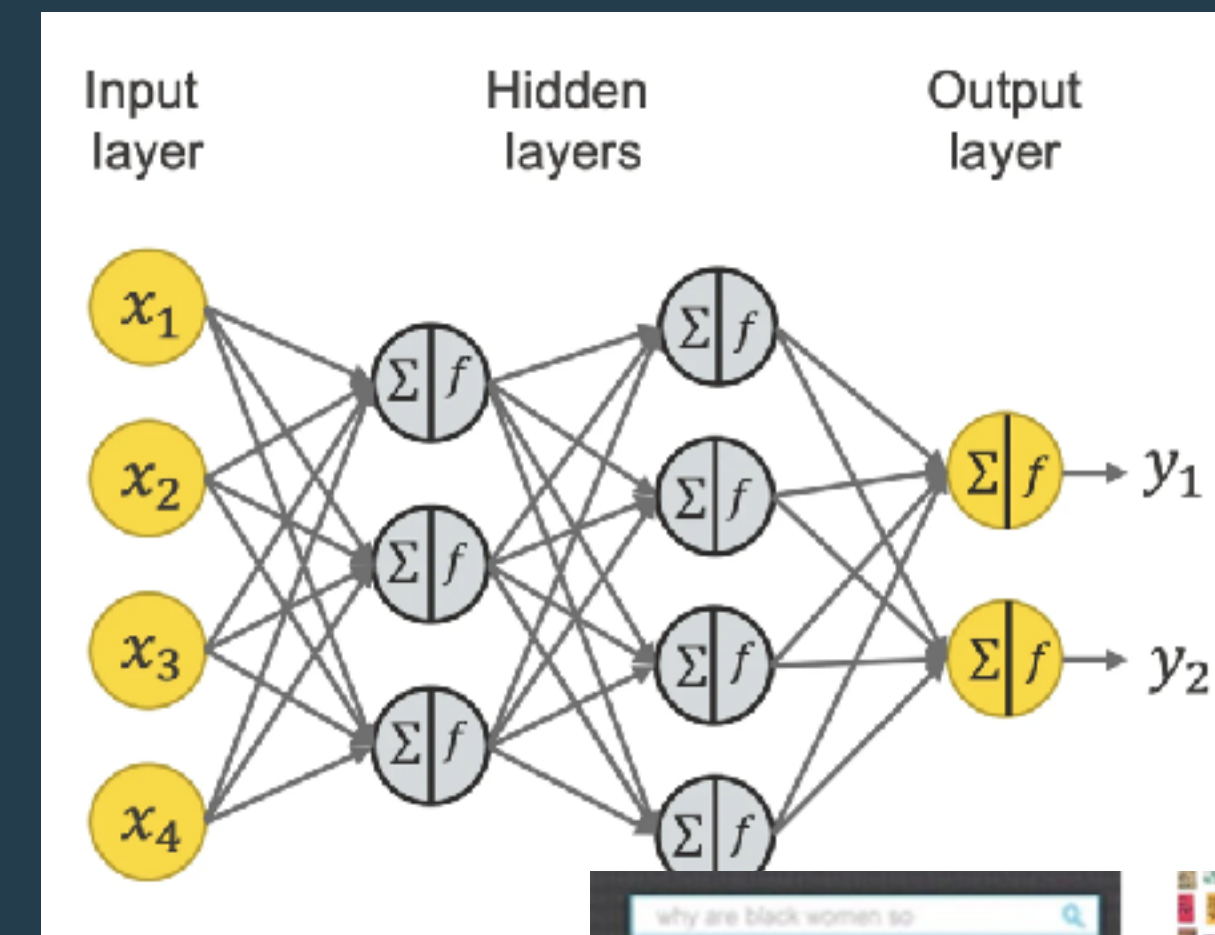
Working Example

```
python
x = 10 # Global variable

def my_function():
    y = 5 # Local variable
    print("Inside the function, y is:", y)
    print("Inside the function, x is:", x) # Global x is accessible here

my_function()
print("Outside the function, x is:", x) # x is still accessible globally
# print(y) # This would raise an error because y is local to the function
```

Output:



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

ORIGINAL PAPER

Racial Justice Amidst the Dangers of Computing Creep: A Dialogue

Niral Shah¹ · Aman Yadav²

The Use of AI in CMSE classrooms

Let's test it out

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

Final Takeaways

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

Final Takeaways

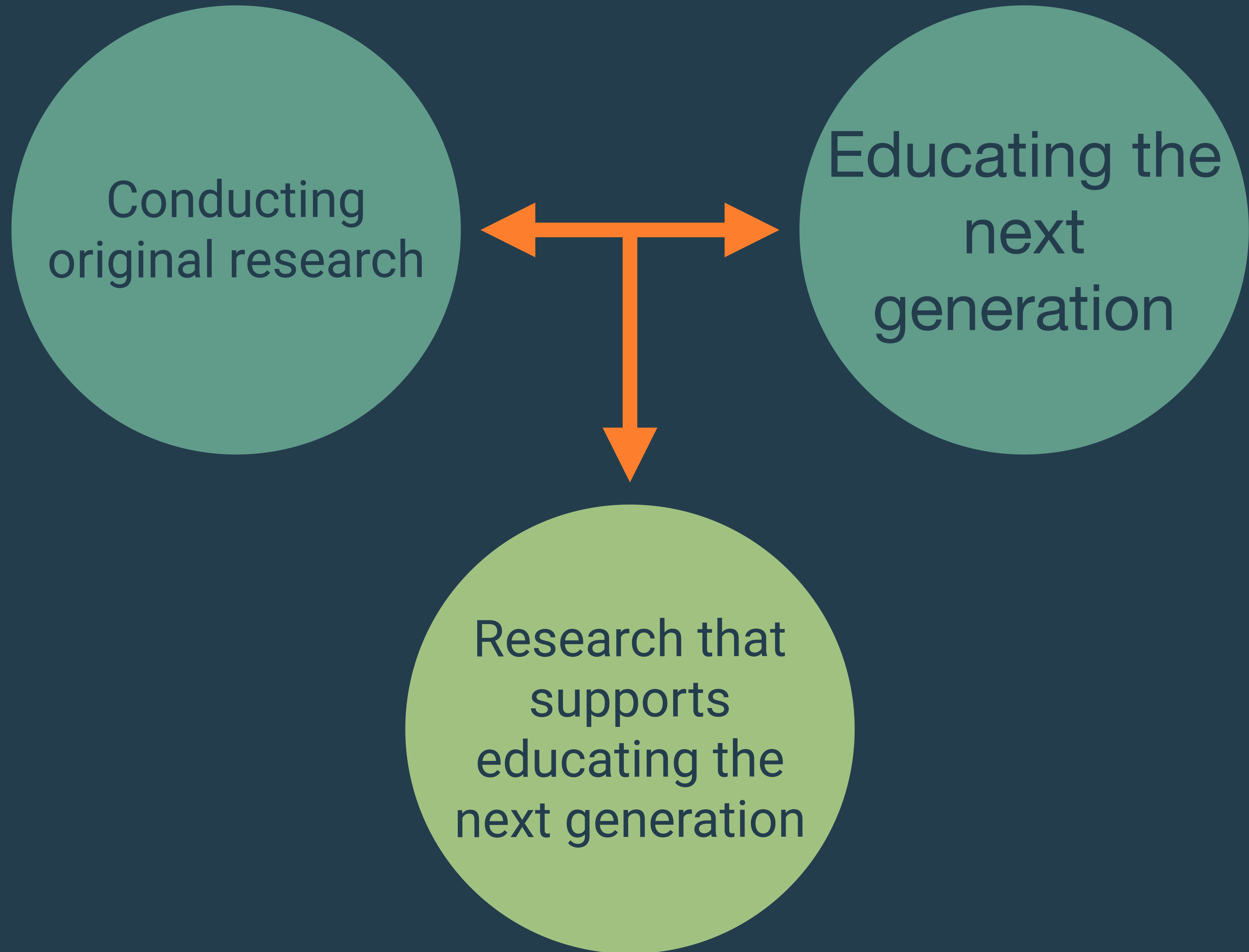
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Final Takeaways

- 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.

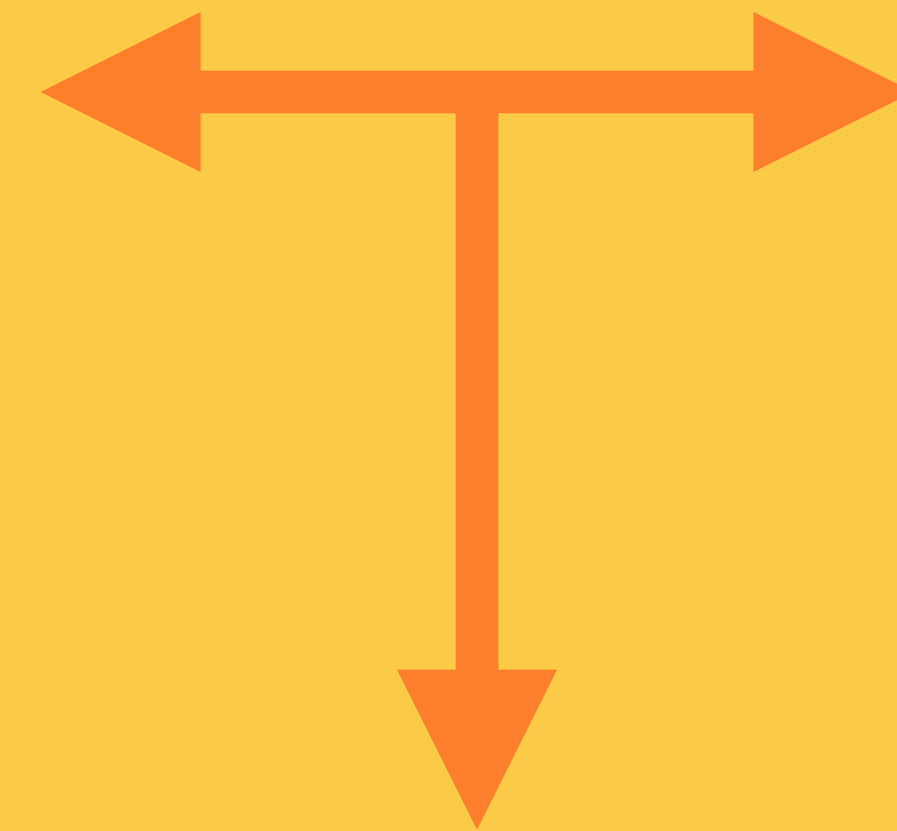
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- It's quite possible to integrate computing into a wide variety of physics learning environments. It's hard to do it sustainably.
- It's important that we engage with AI and science education. It will require an authentic and collective effort.
- 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

Community
of Support



Thank you!

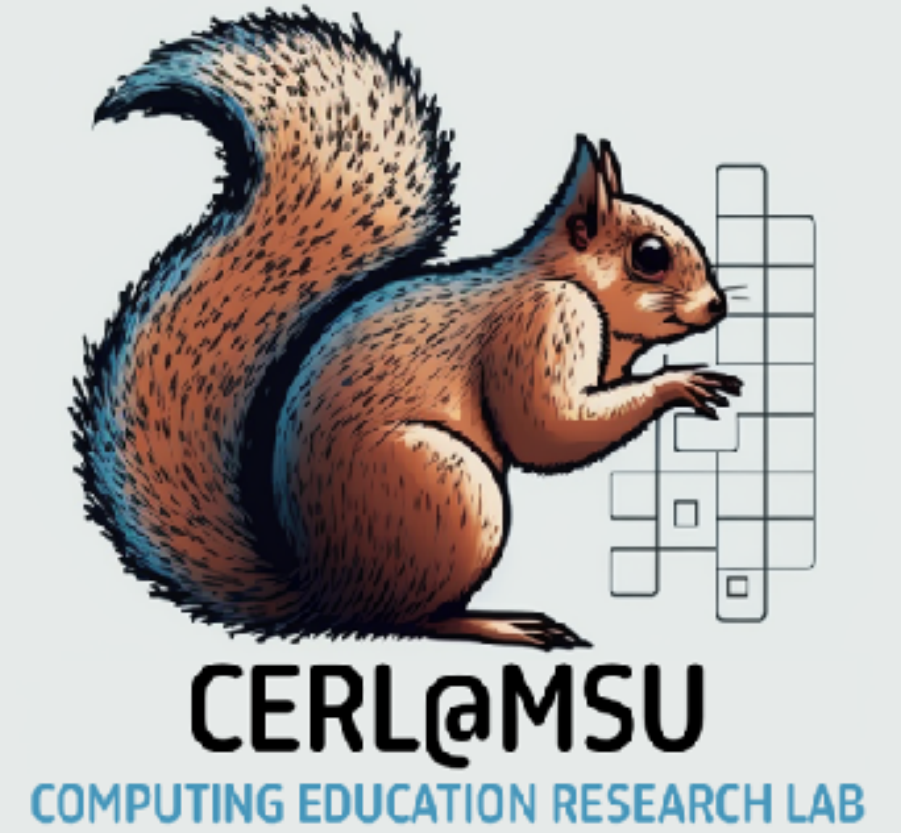
Thank y'all



Questions?

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Extra Slides

