Computing in Science, Technology, Engineering, and Mathematics Education

Kazakhstan Higher Education Delegation

28 July 2022

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Department of Physics and Astronomy
Department of Computational Mathematics, Science, and Engineering
CREATE For STEM Institute

Plans for Today

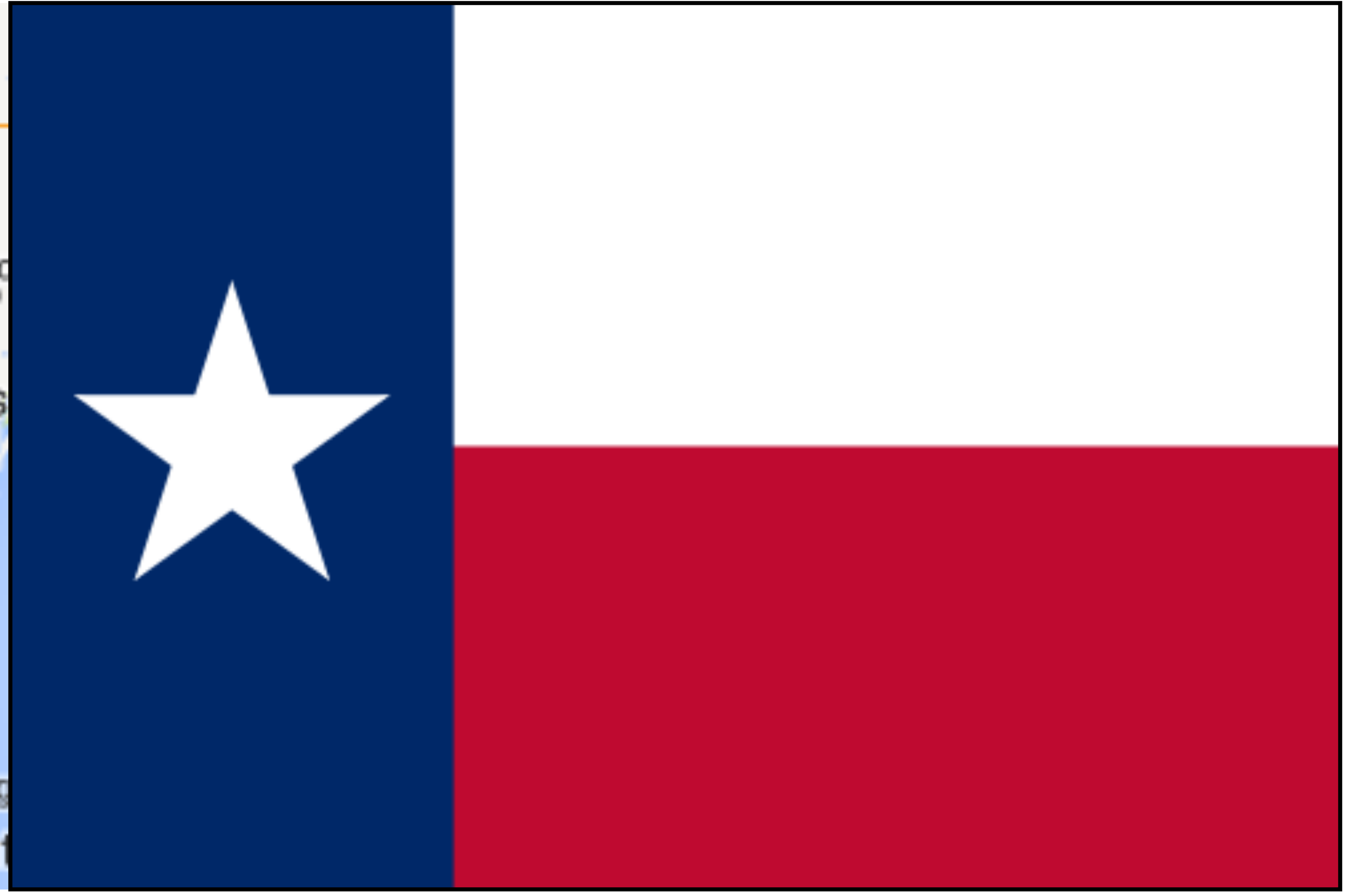
- Introductions
- Brief Discussion
- Presentation: Computing in STEM Education
- Hands-on Activity: Making a Python model of a sliding block
- Presentation: Education Research
- Discussion and Q&A

INTRODUCTORY PHYSICS MODEL
SATELLITE ORBIT

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

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

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

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

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

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

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

sepgraph = gcurve(color=color.red)

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

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

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

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

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

        t = t +deltat
```

MICHIGAN STATE
UNIVERSITY


Ciudad
Acuña
San Antonio
Piedras
Negras
Corpus
Christi
Nuevo
Laredo
A
Reynosa
Monterrey




Ciudad Acuña
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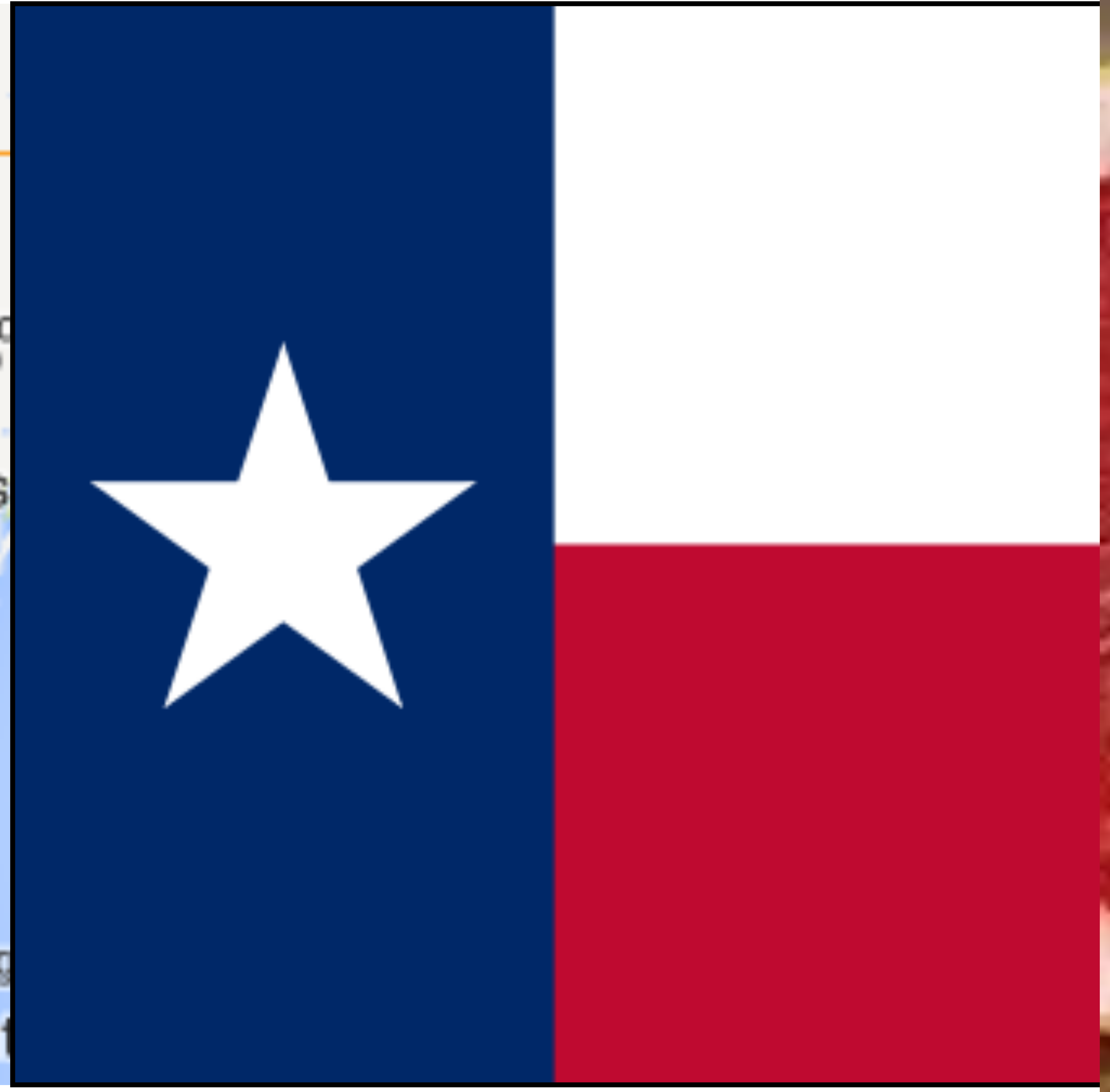


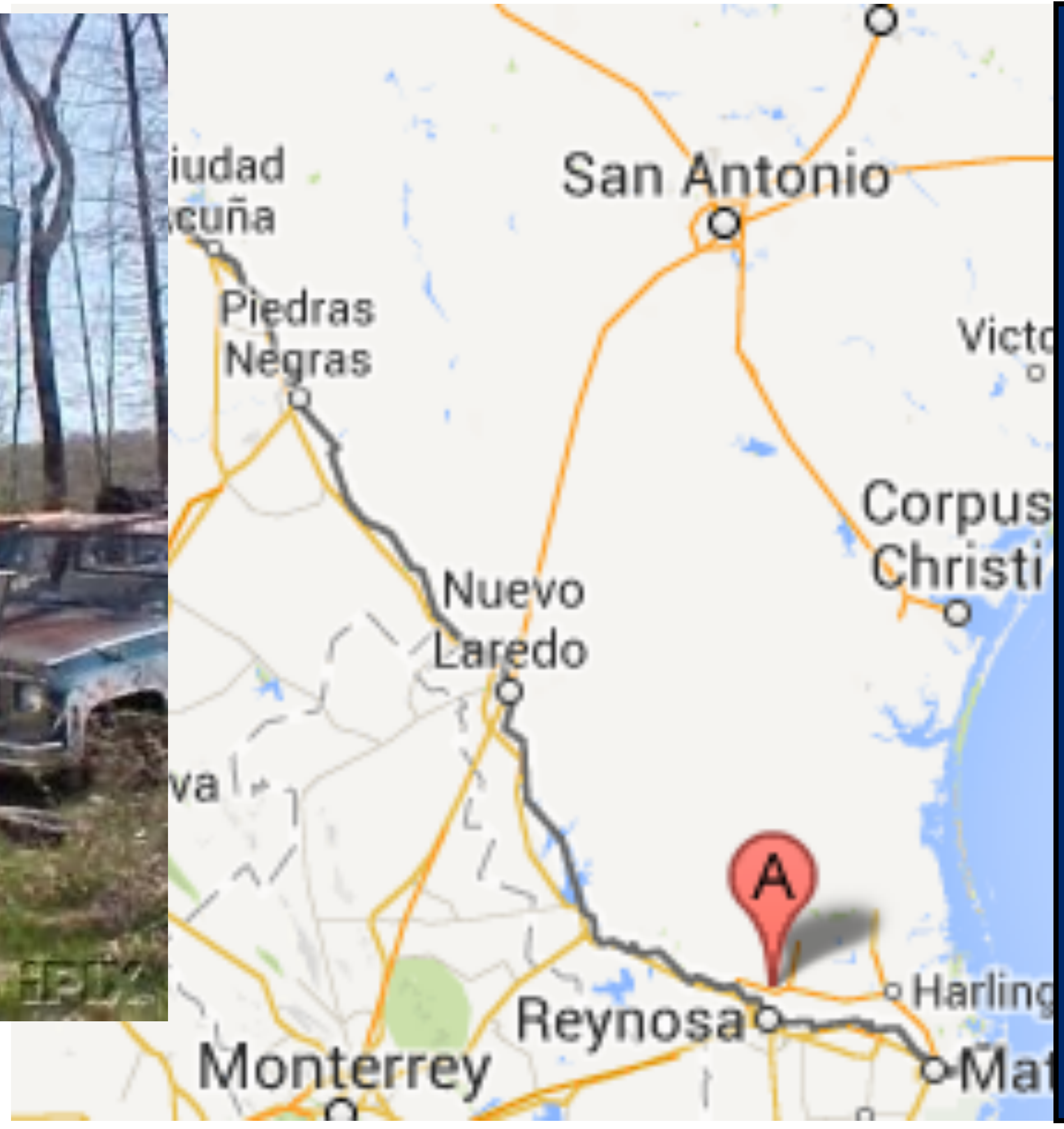
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Piedras Negras
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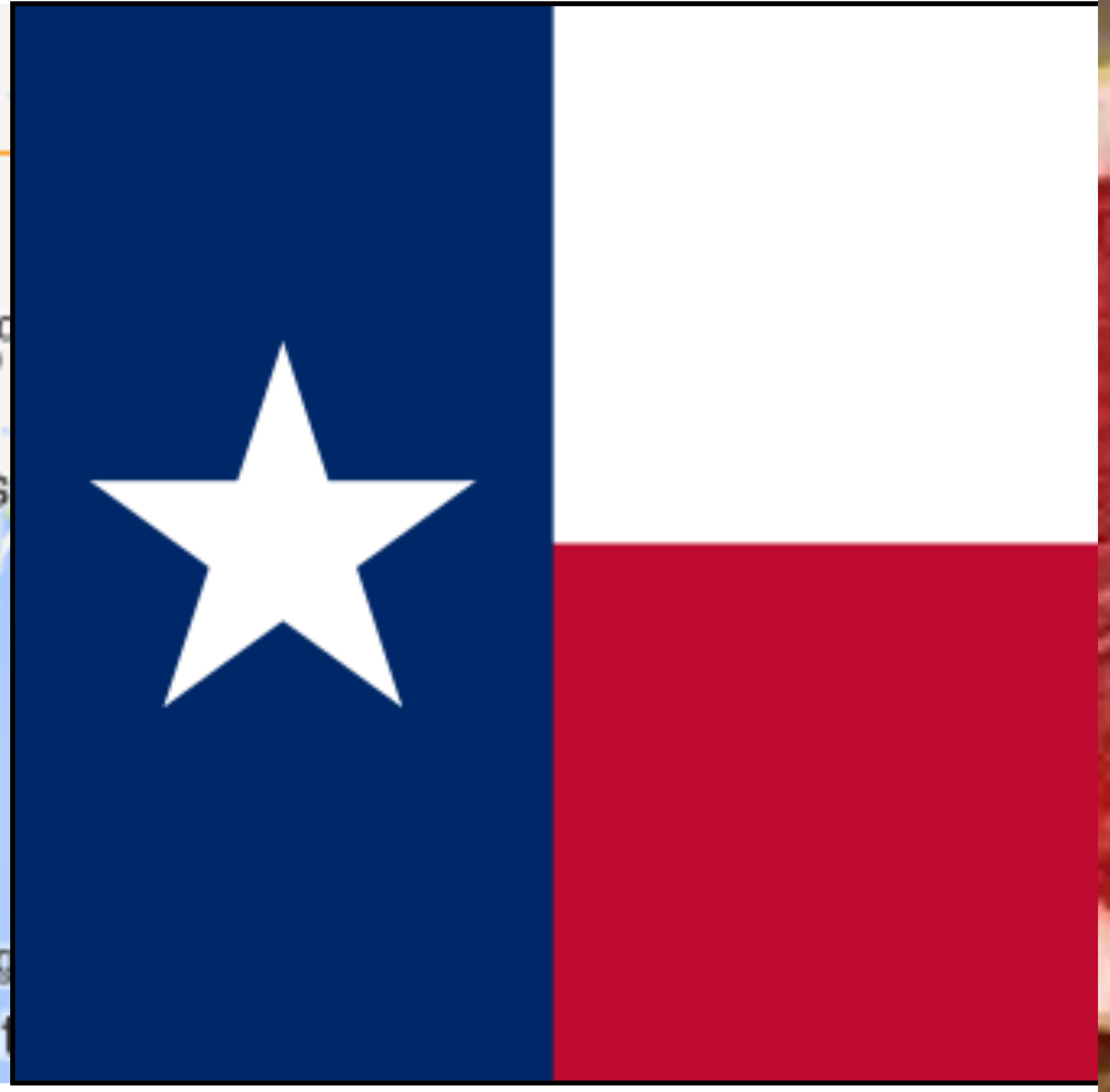


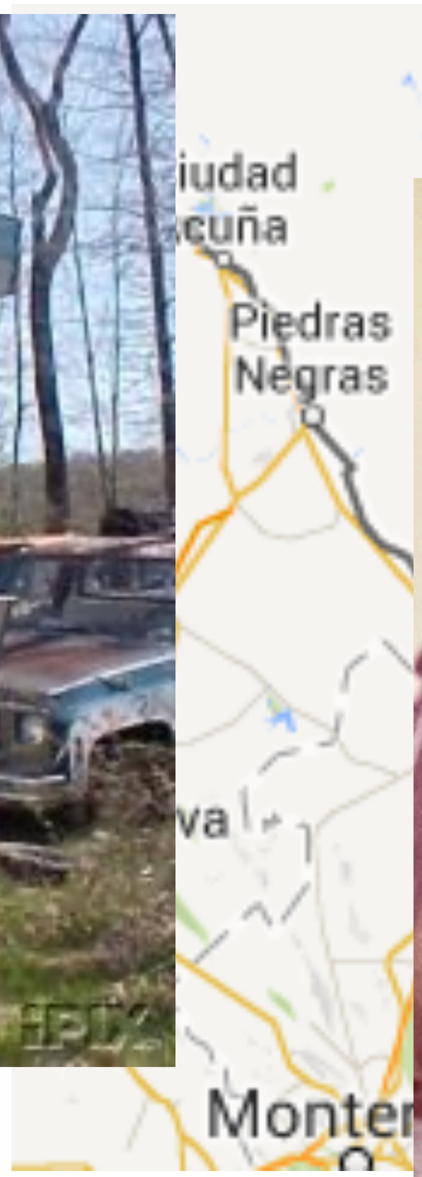
Piedras
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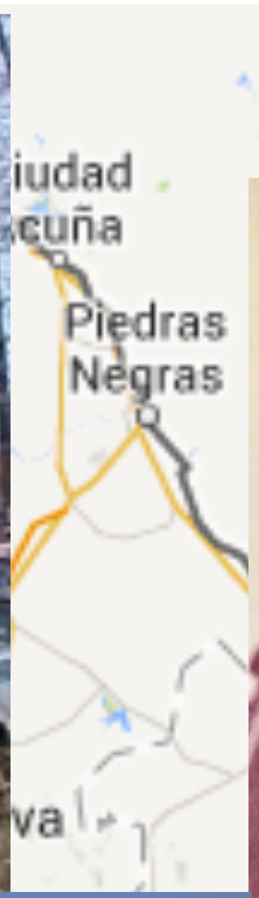
Piedras
Negras


Piedras
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Piedras
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Piedras
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SAMUEL ADAMS


Piedras
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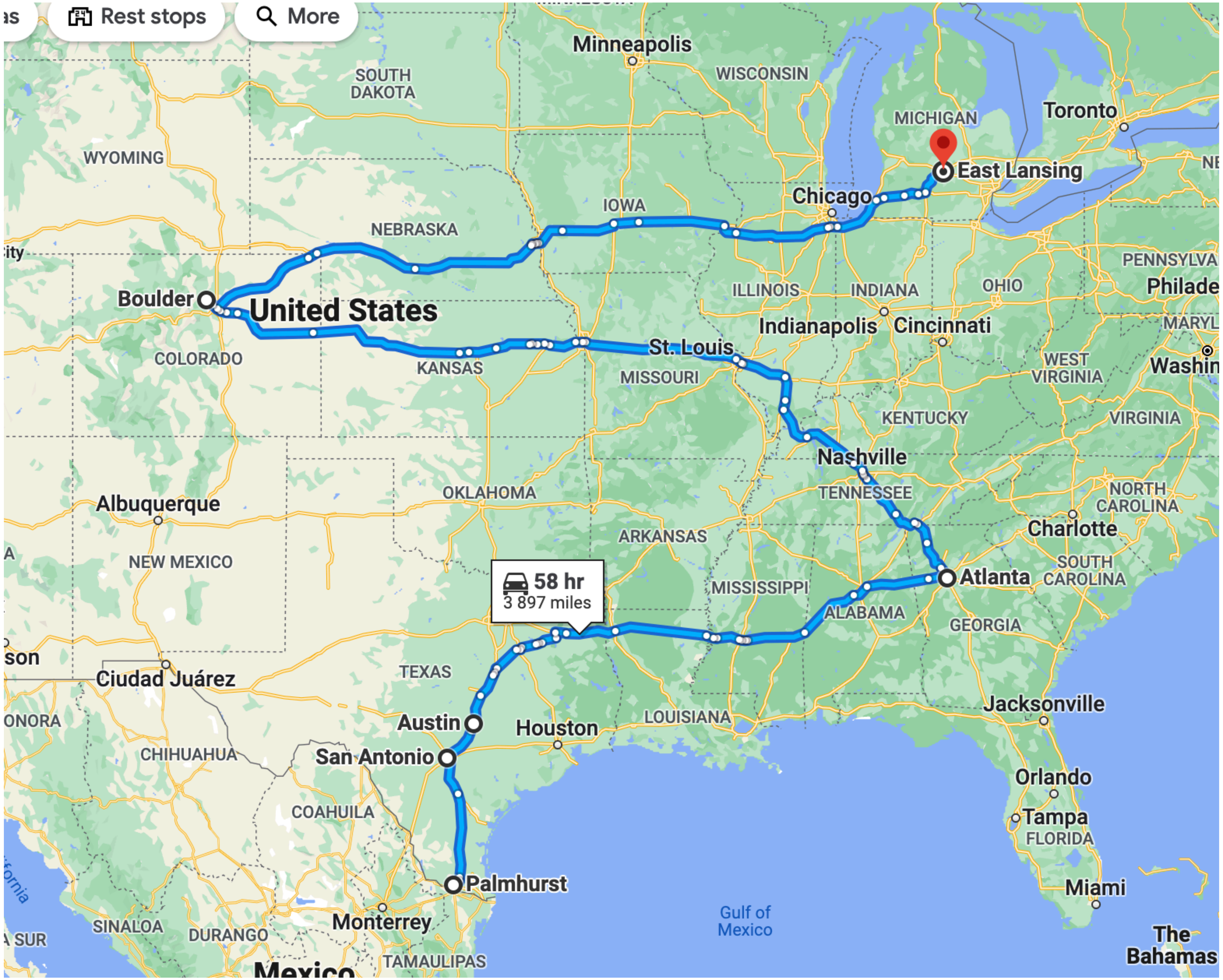
MICHIGAN STATE
UNIVERSITY

In summary…


Rest stops
More
58 hr
3 897 miles
Minneapolis
WISCONSIN
SOUTH DAKOTA
MICHIGAN
Toronto
East Lansing
WYOMING
Chicago
IOWA
NEBRASKA
PENNSYLVA
Philade
Boulder
United States
ILLINOIS
INDIANA
OHIO
Indianapolis
Cincinnati
COLORADO
KANSAS
St. Louis
MISSOURI
WEST VIRGINIA
Washin
KENTUCKY
VIRGINIA
Nashville
TENNESSEE
NORTH CAROLINA
Albuquerque
OKLAHOMA
ARKANSAS
Charlotte
SOUTH CAROLINA
NEW MEXICO
MISSISSIPPI
Atlanta
ALABAMA
GEORGIA
Ciudad Juárez
TEXAS
Austin
Houston
LOUISIANA
Jacksonville
San Antonio
CHIHUAHUA
COAHUILA
Orlando
Tampa
FLORIDA
Palmhurst
Miami
SINALOA
DURANGO
Monterrey
Gulf of Mexico
TAMAULIPAS
The Bahamas
Mexico

What has changed about your discipline in the last ~50 years that students need to know about?

That is, what would need to be changed in your undergraduate major to better represent your discipline?


Finder File Edit View Go Window Help

SCIENCE

Physicists Find Elusive Particle Seen as Key to Universe

By **DENNIS OVERBYE** JULY 4, 2012

122

Scientists in Geneva on Wednesday applauded the discovery of a subatomic particle that looks like the Higgs boson. Pool photo by Denis Balibouse

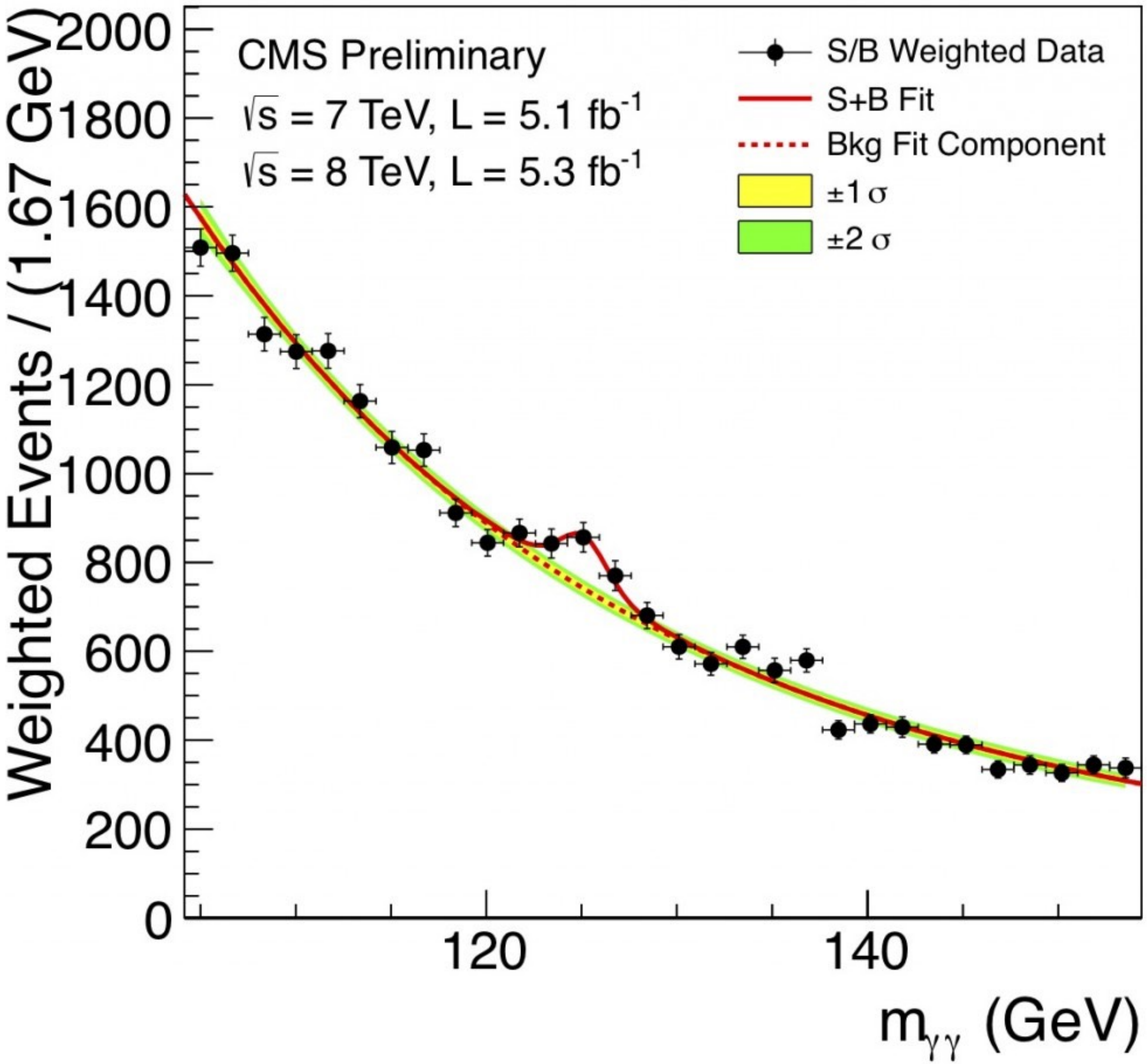
RELATED COVERAGE

THE LEDE BLOG
What in the World Is a Higgs Boson?
JULY 4, 2012

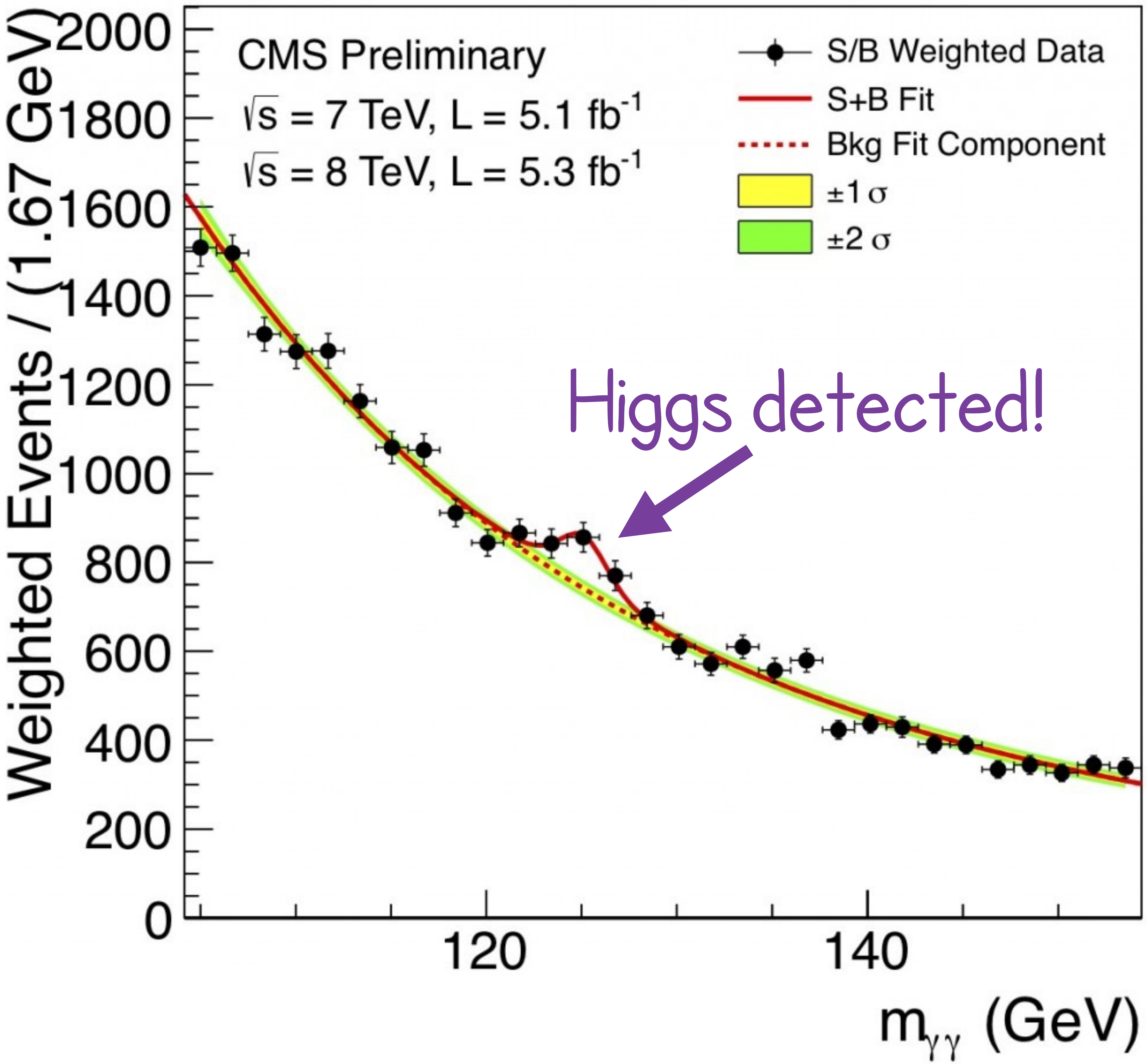
Opinion | Op-Ed Contributor
Why the Higgs Boson Matters JULY 13, 2012

RECENT COMMENTS

Robert L. Oldershaw July 5, 2012



CMS Preliminary
√s = 7 TeV, L = 5.1 fb⁻¹
√s = 8 TeV, L = 5.3 fb⁻¹
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1 σ
±2 σ
Weighted Events / (1.67 GeV)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
120
140
$m_{\gamma\gamma}$ (GeV)



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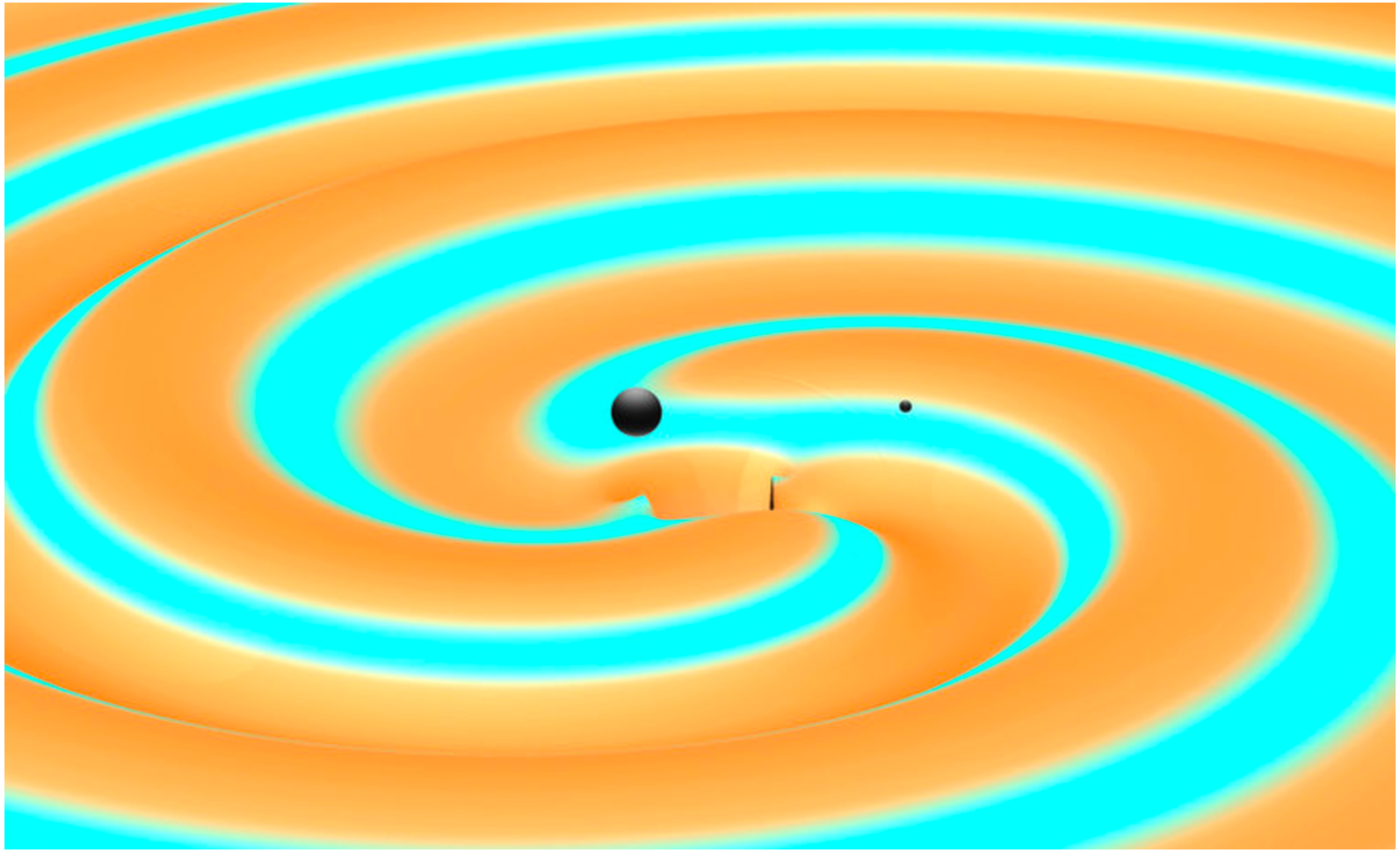
Bkg Fit Component
±1 σ
±2 σ
Higgs detected!
Weighted Events / (1.67 GeV)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
120
140
mγγ (GeV)

SCIENCE

Scientists Hear a Second Chirp From Colliding Black Holes

By DENNIS OVERBYE JUNE 15, 2016

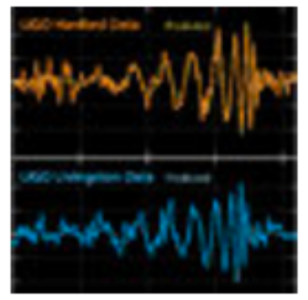


A depiction of two black holes just moments before they collided and merged with each other, releasing

RELATED COVERAGE

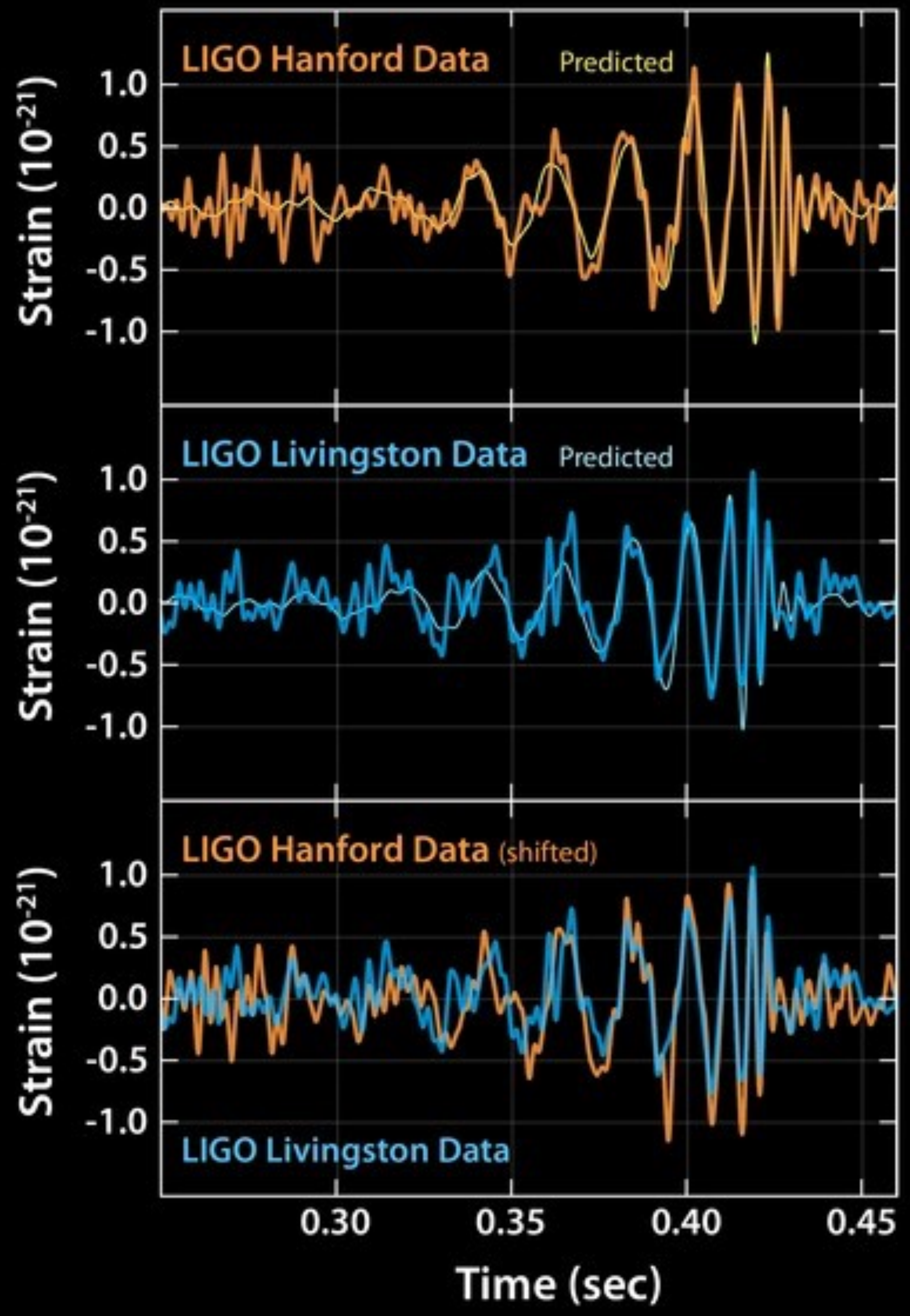
OUT THERE
Short Answers to Your Good Questions About Black Holes JUNE 15, 2016

OUT THERE
Gravitational Waves Detected, Confirming Einstein's Theory FEB. 11, 2016

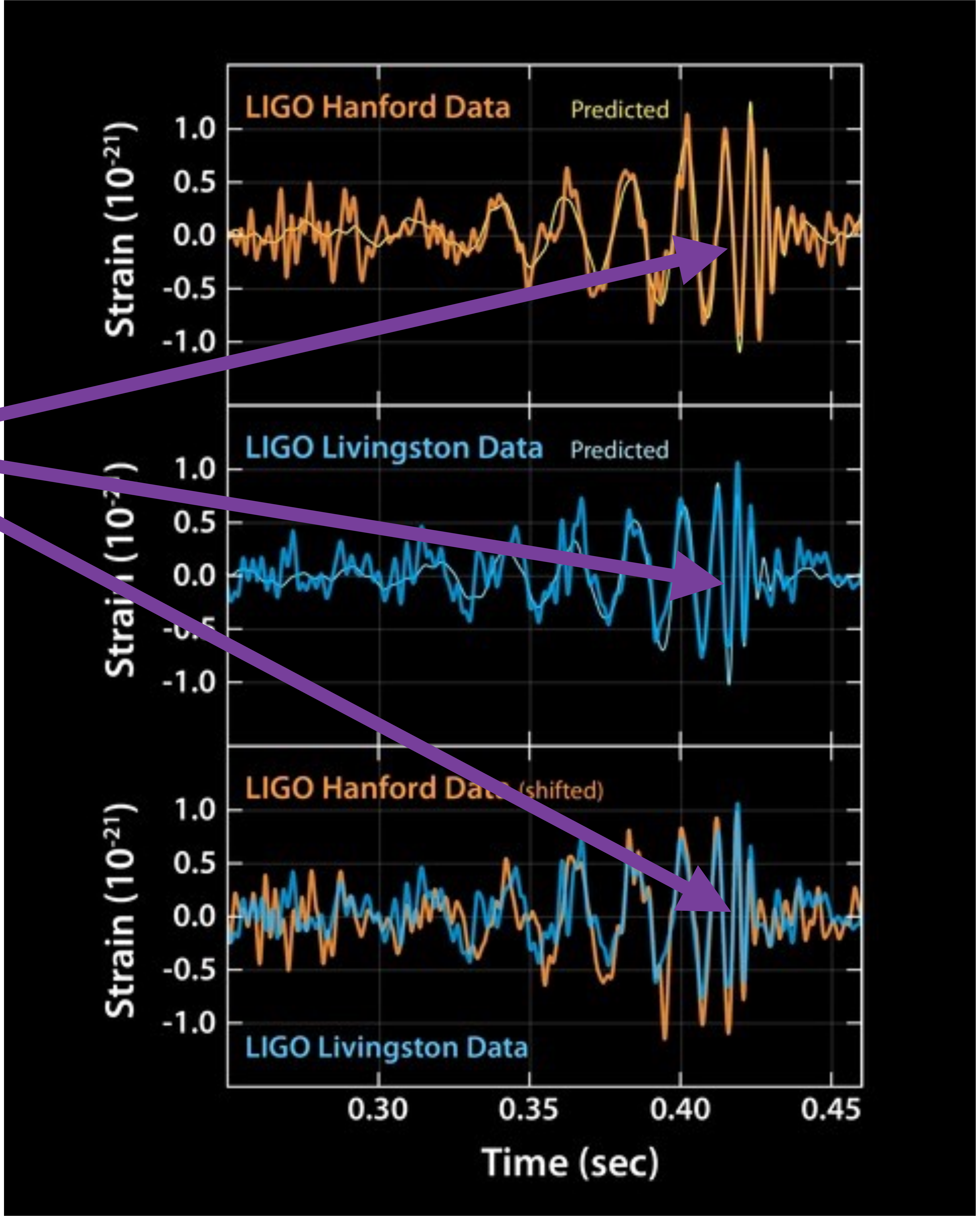


TRILOBITES
Scientists Chirp Excitedly for LIGO, Gravitational Waves and Einstein
FEB. 11, 2016

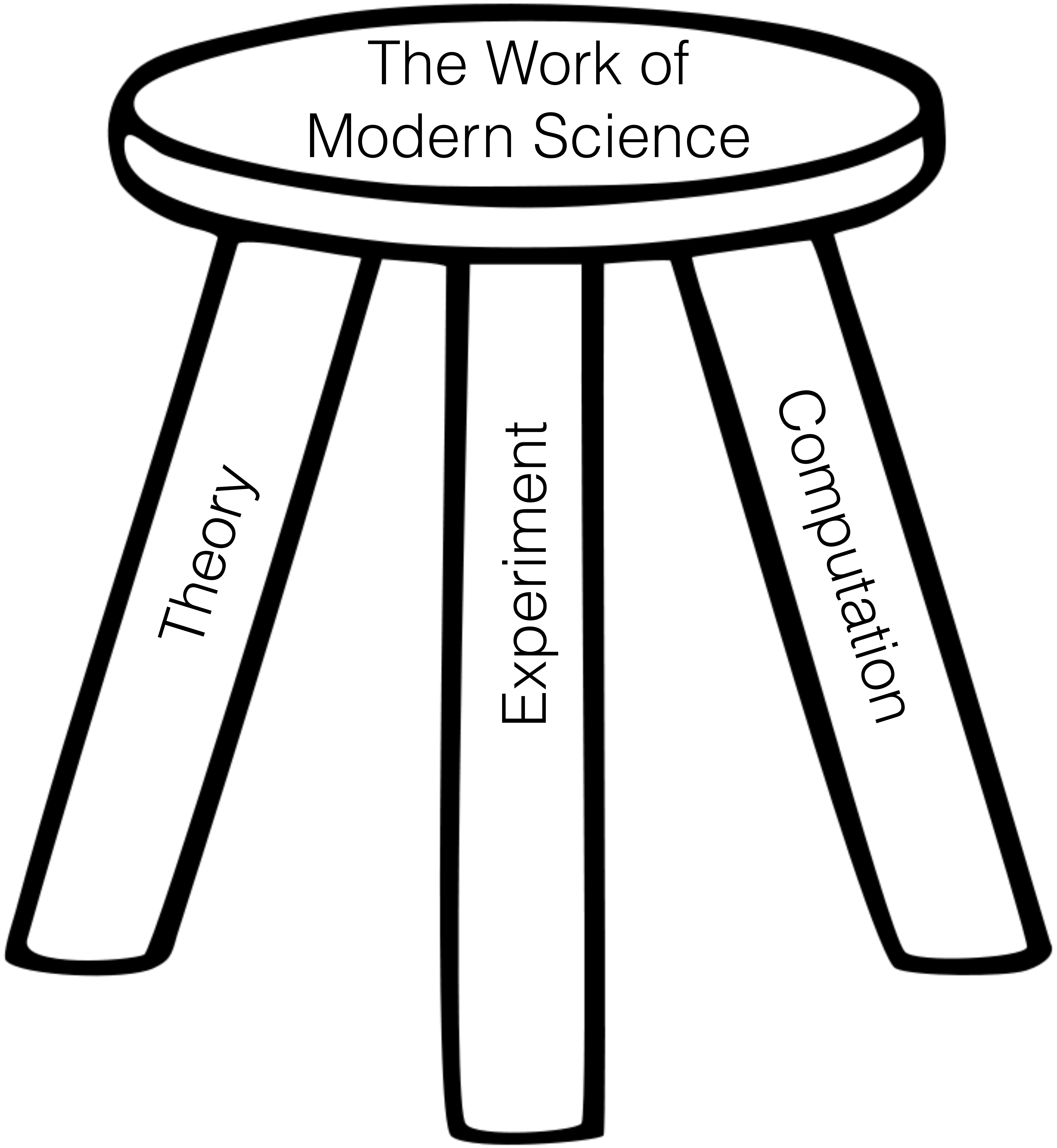
No Escape From Black Holes? Stephen Hawking Points to a Possible Exit JUNE 6, 2016


LIGO Hanford Data
Predicted
LIGO Livingston Data
Predicted
LIGO Hanford Data (shifted)
LIGO Livingston Data
Strain (10^{-21})
1.0
0.5
0.0
-0.5
-1.0
0.30
0.35
0.40
0.45
Time (sec)

Black hole
Merger
Ringdown!



Computation
is how
modern science
is done.



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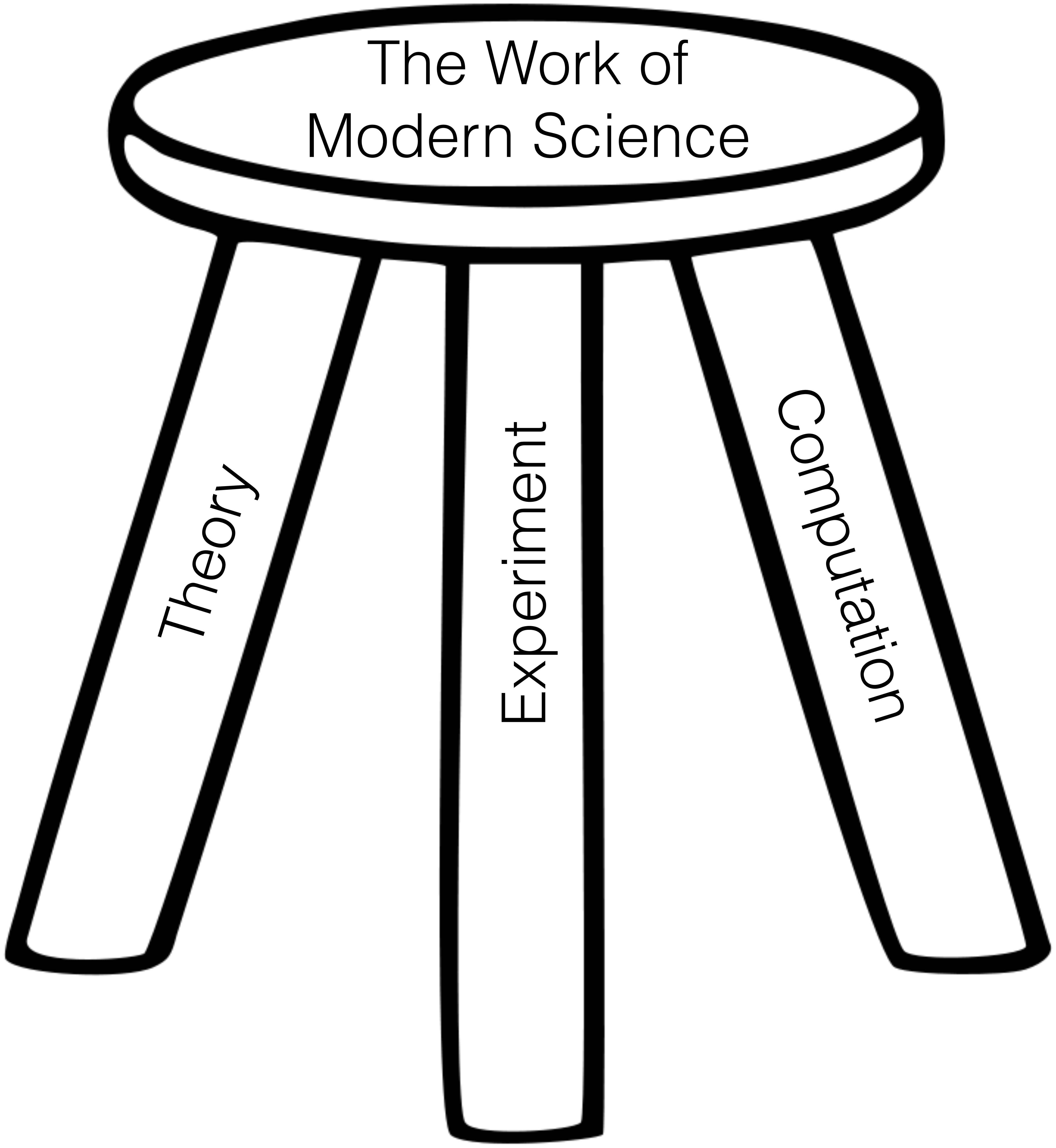


But, what has changed in
physics education?

Twin goals of a physics department

ELSEVIER

Nuclear Physics A718 (2003) 247c–254c

NUCLEAR PHYSICS A

www.elsevier.com/locate/npe

Nuclear physics in normal X-ray bursts and superbursts

Hendrik Schatz[a], Lars Bildsten[b], Andrew Cumming[c] and Michelle Ouellette[a]

[a]Dept. of Physics and Astronomy and National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI 48824, USA

[b]Kavli Institute for Theoretical Physics and Department of Physics, Kohn Hall, University of California, Santa Barbara, CA 93106, USA

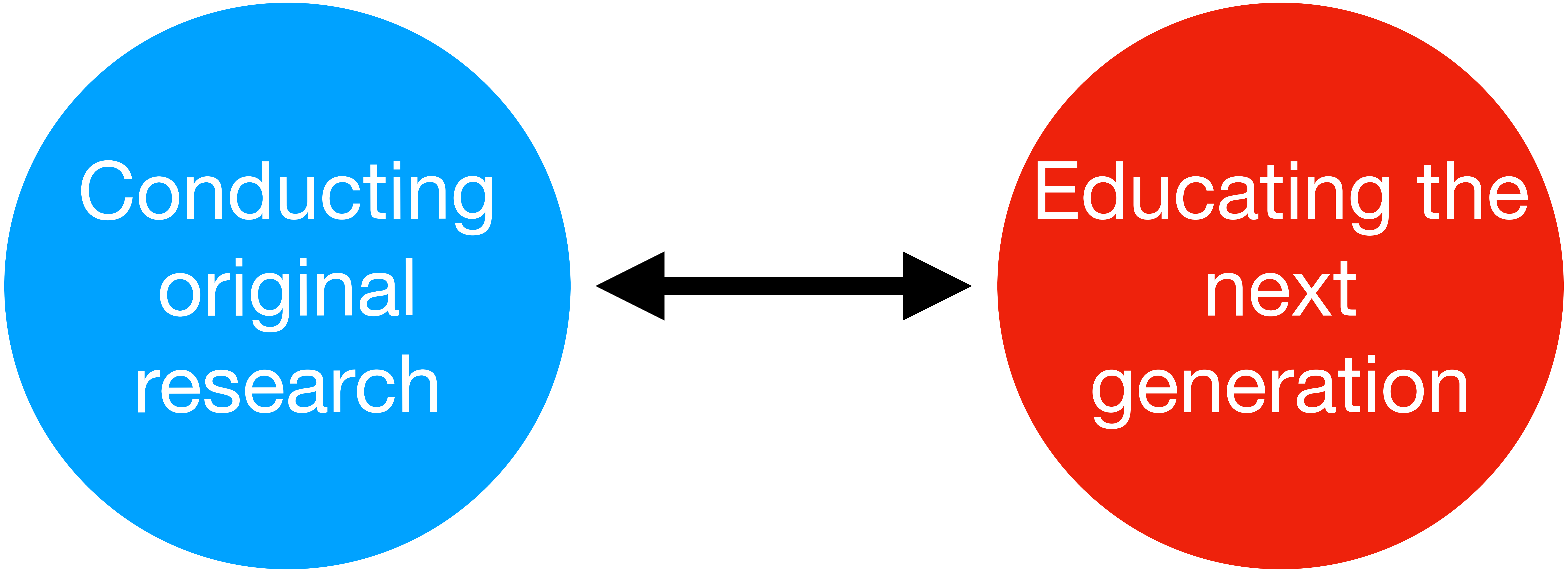
[c]Dept. of Astronomy and Astrophysics, University of California, Santa Cruz, CA 95064, USA

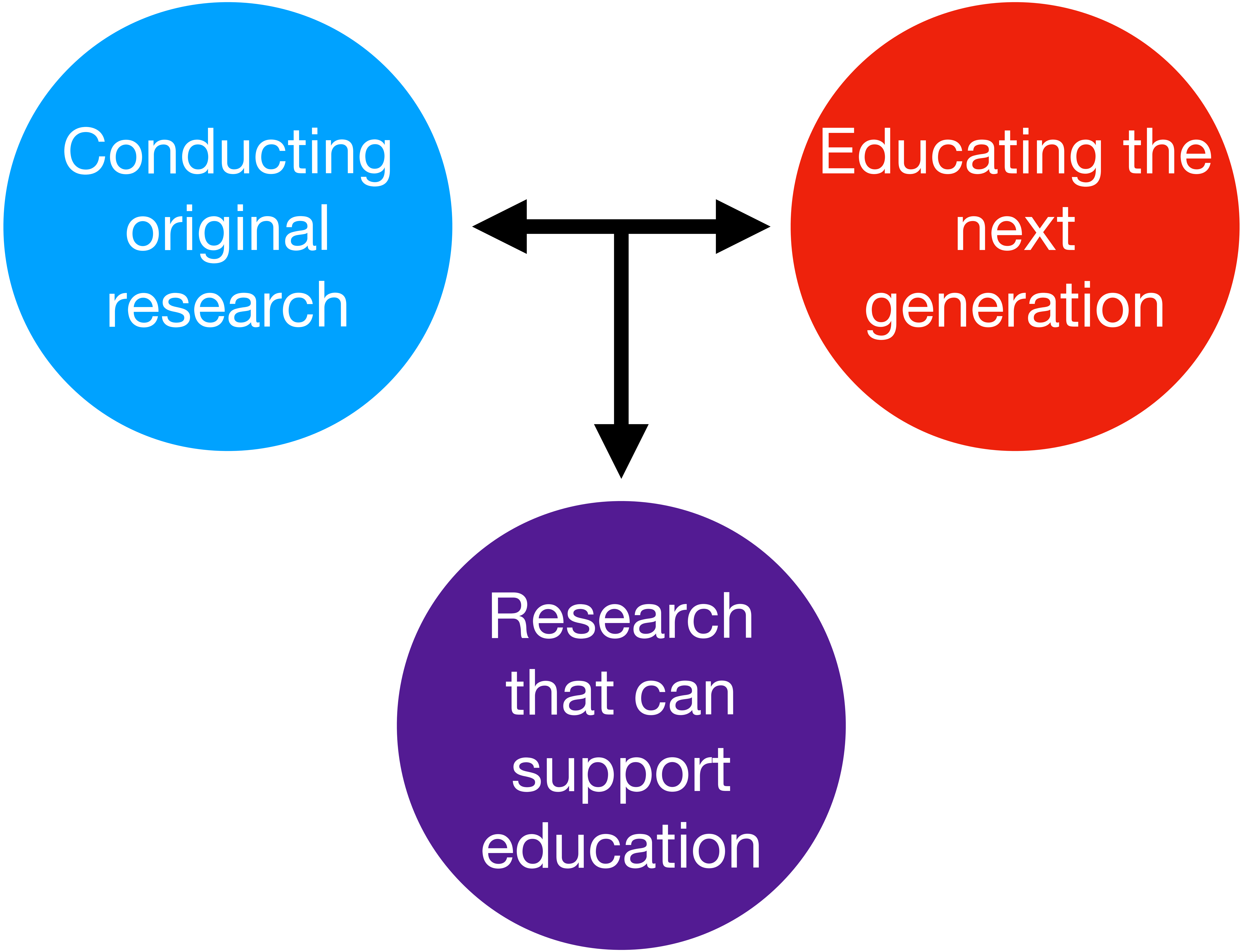
1. Introduction

Normal type I X-ray bursts are powered by unstable burning of accumulated H and He on the surface of an accreting neutron star [1–3] (see also the reviews [4–6]). These burning processes take place in the atmosphere of accreted gas surrounding the neutron

Conducting original research

Educating the next generation


Conducting original research
Educating the next generation


Conducting original research
Educating the next generation
Research that can support education

Physics Education Research studies:

Physics Education Research studies:

- student learning and engagement

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- pedagogical and curricular impacts

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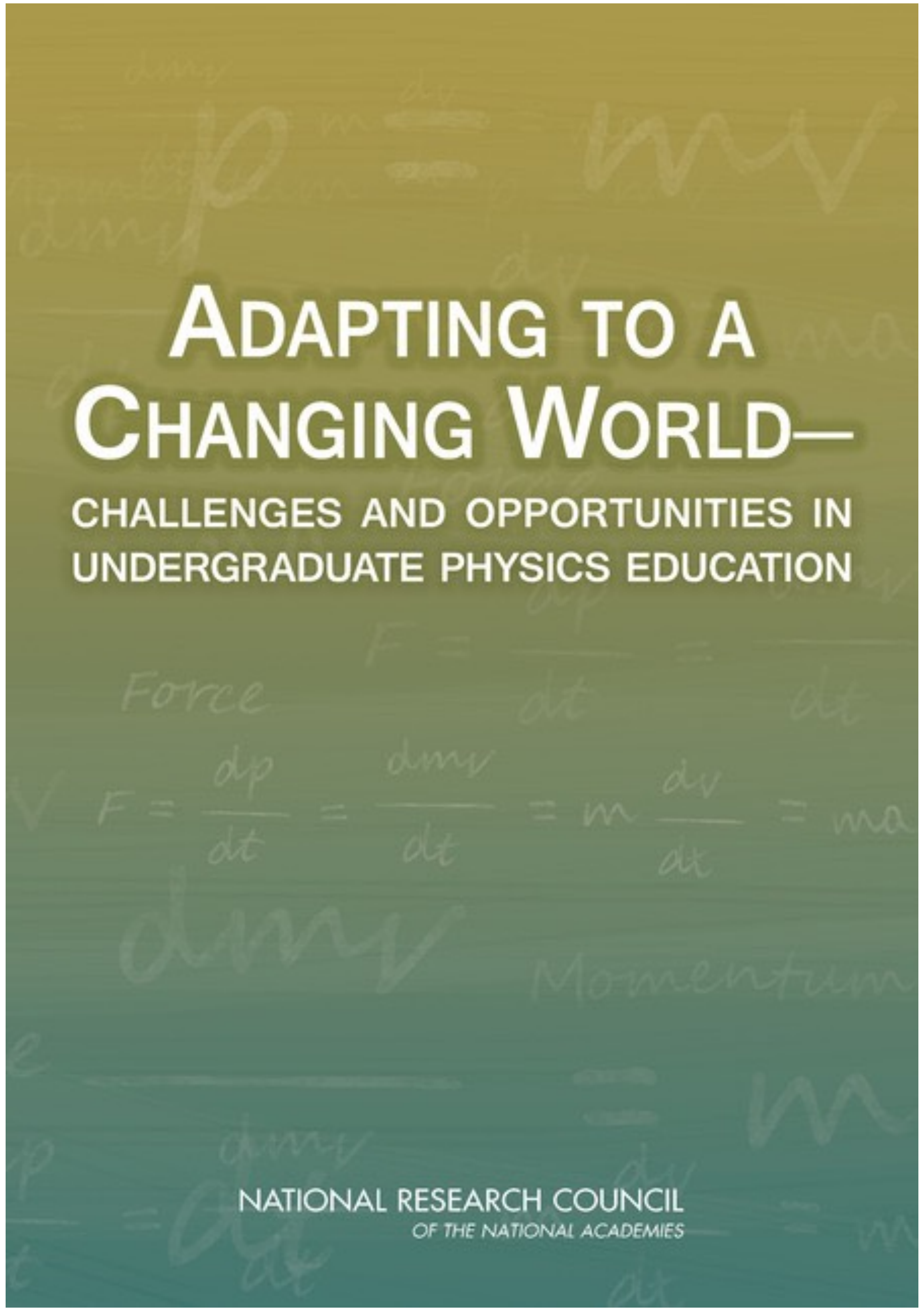
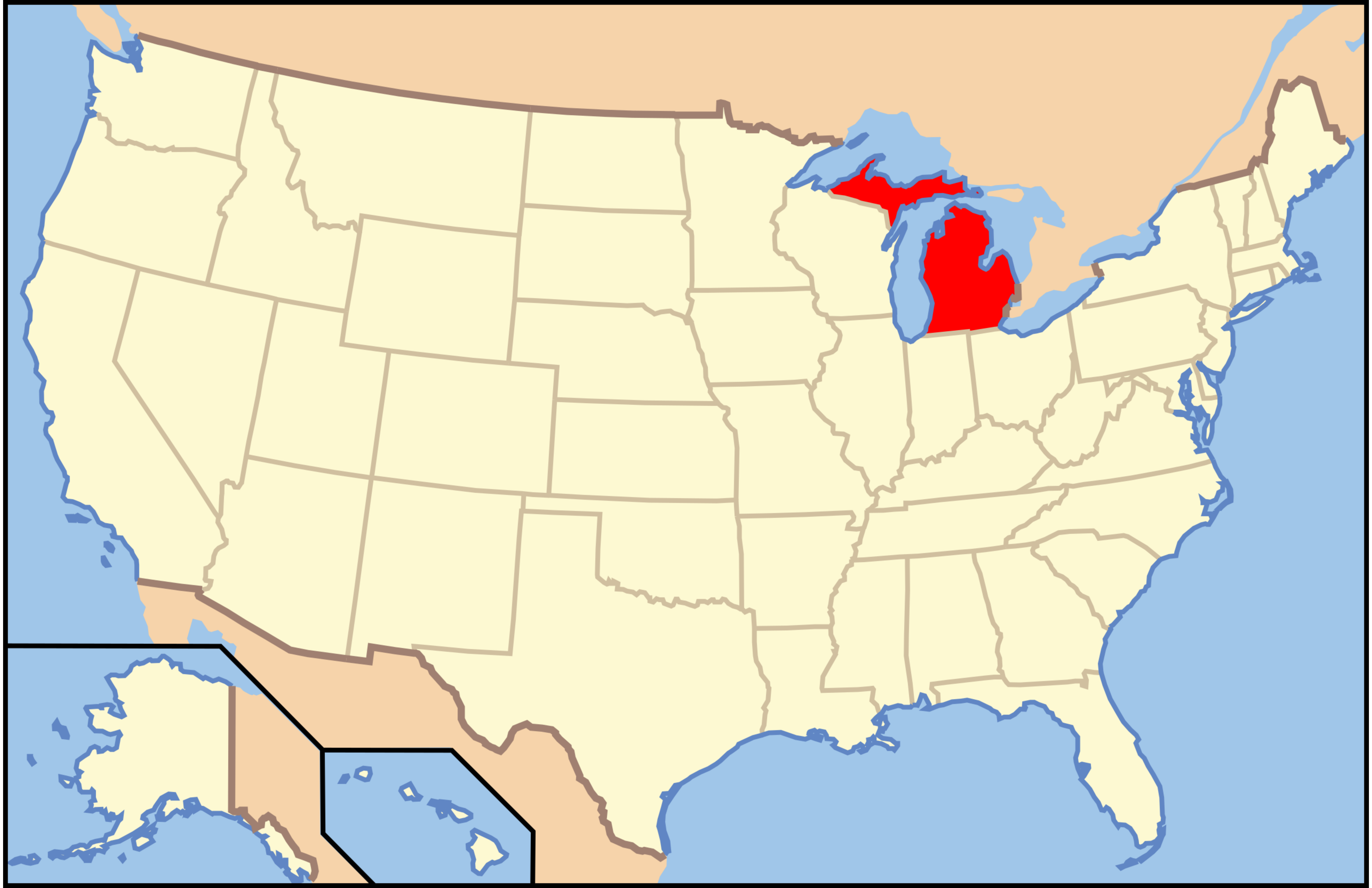


Physics Education Research (around the world)

Physics Education Research (US Programs)

Physics Education Research (US Programs)



State of Michigan

Population: 9.9 million
(Kazakhstan - 19.1 million)

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Major cities (all in the Southern Peninsula):

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- Detroit
- Flint
- Grand Rapids
- Lansing (Michigan state green/white; state capital)

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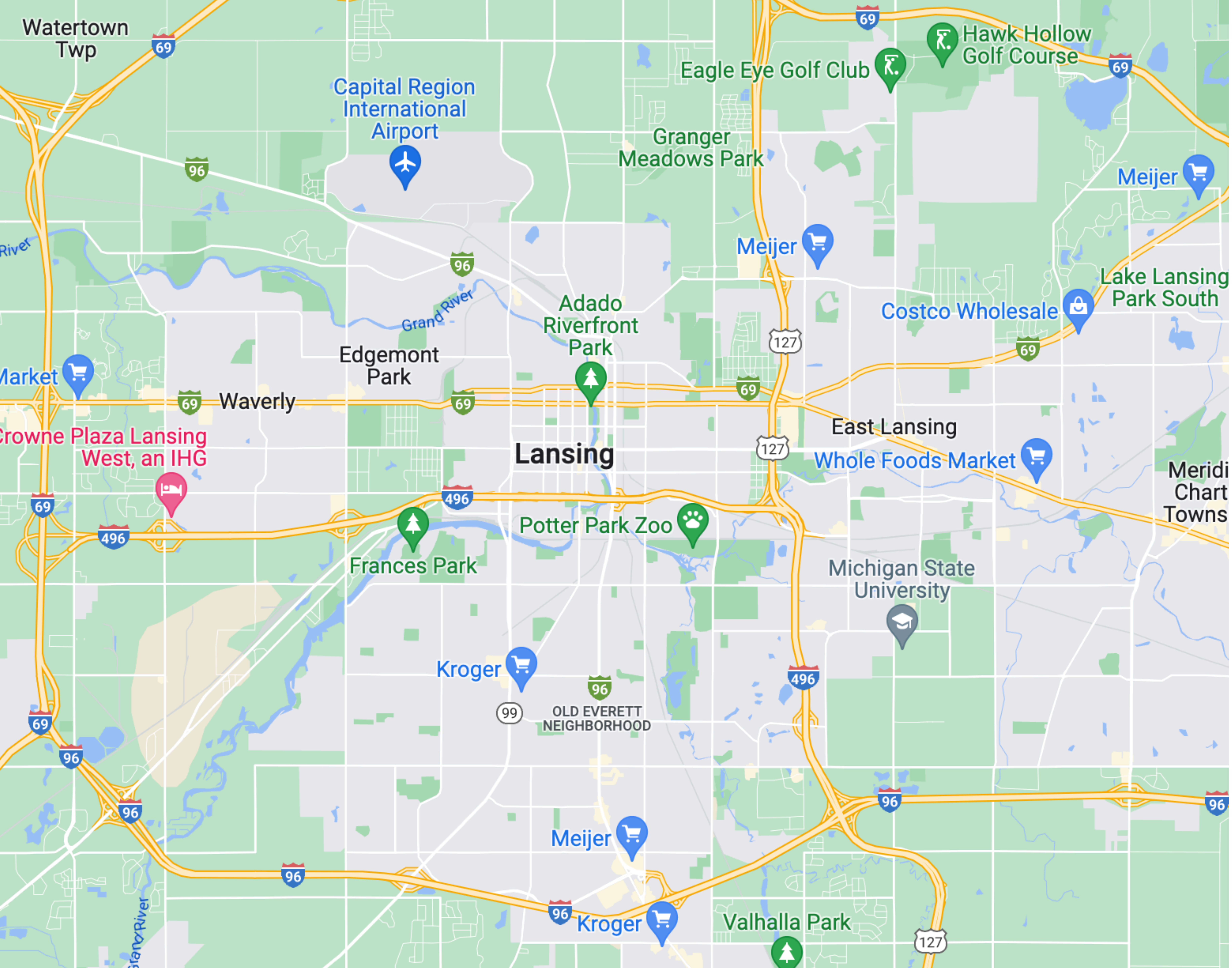
Major industries:

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



Greater Lansing Area

Population: 540k
Nur-Sultan: 1.2M

Major industries:

- The State of Michigan
- Michigan State University
- Sparrow Health Systems
- McLaren Healthcare
- General Motors
  - We build the Cadillac CT4 and CT5, Chevy Camaro, Buick Enclave, and Chevy Traverse

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UNIVERSITY

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

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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** - widest breath of DBER in US; largest PER faculty in US

STEM in Michigan

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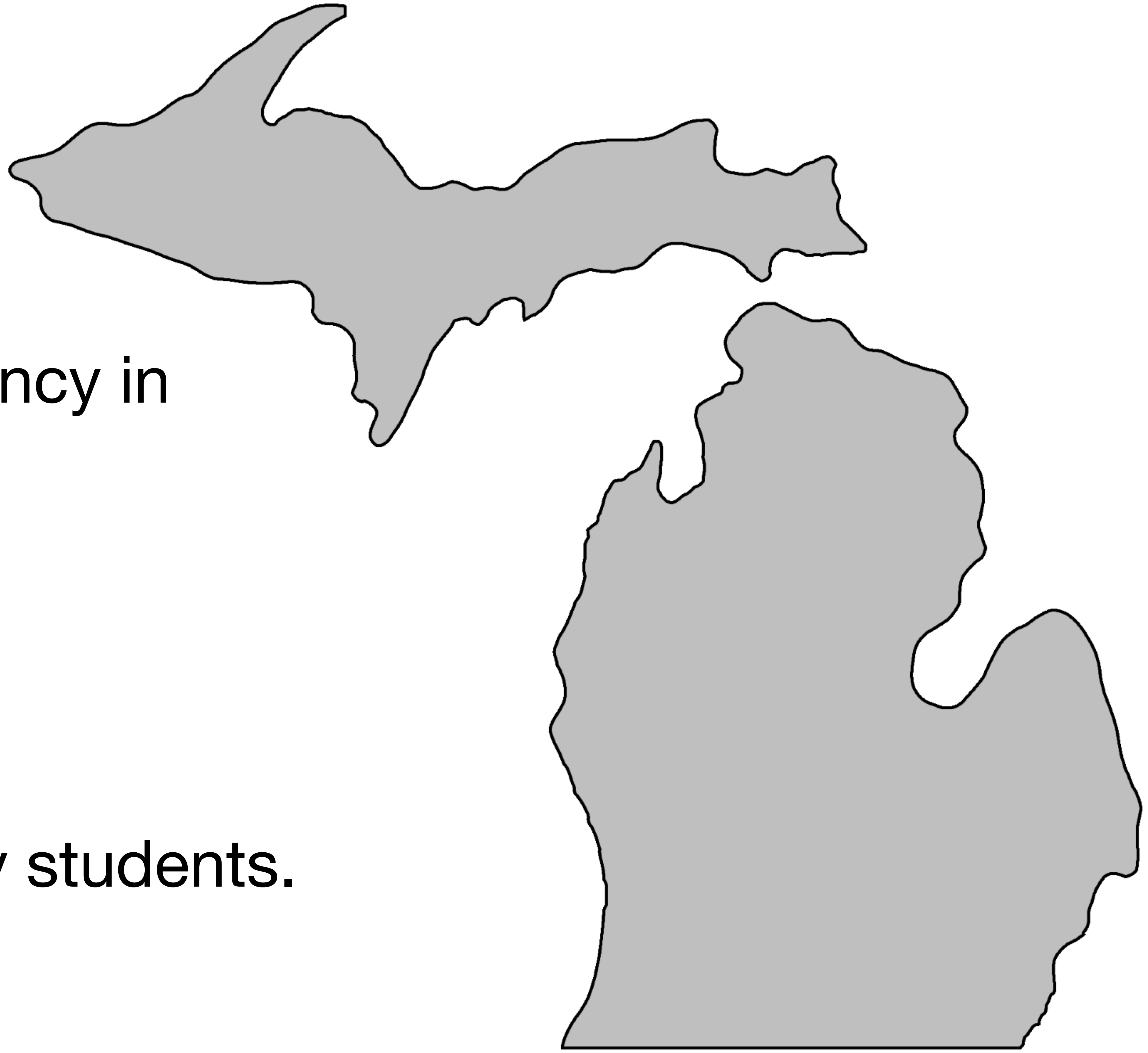

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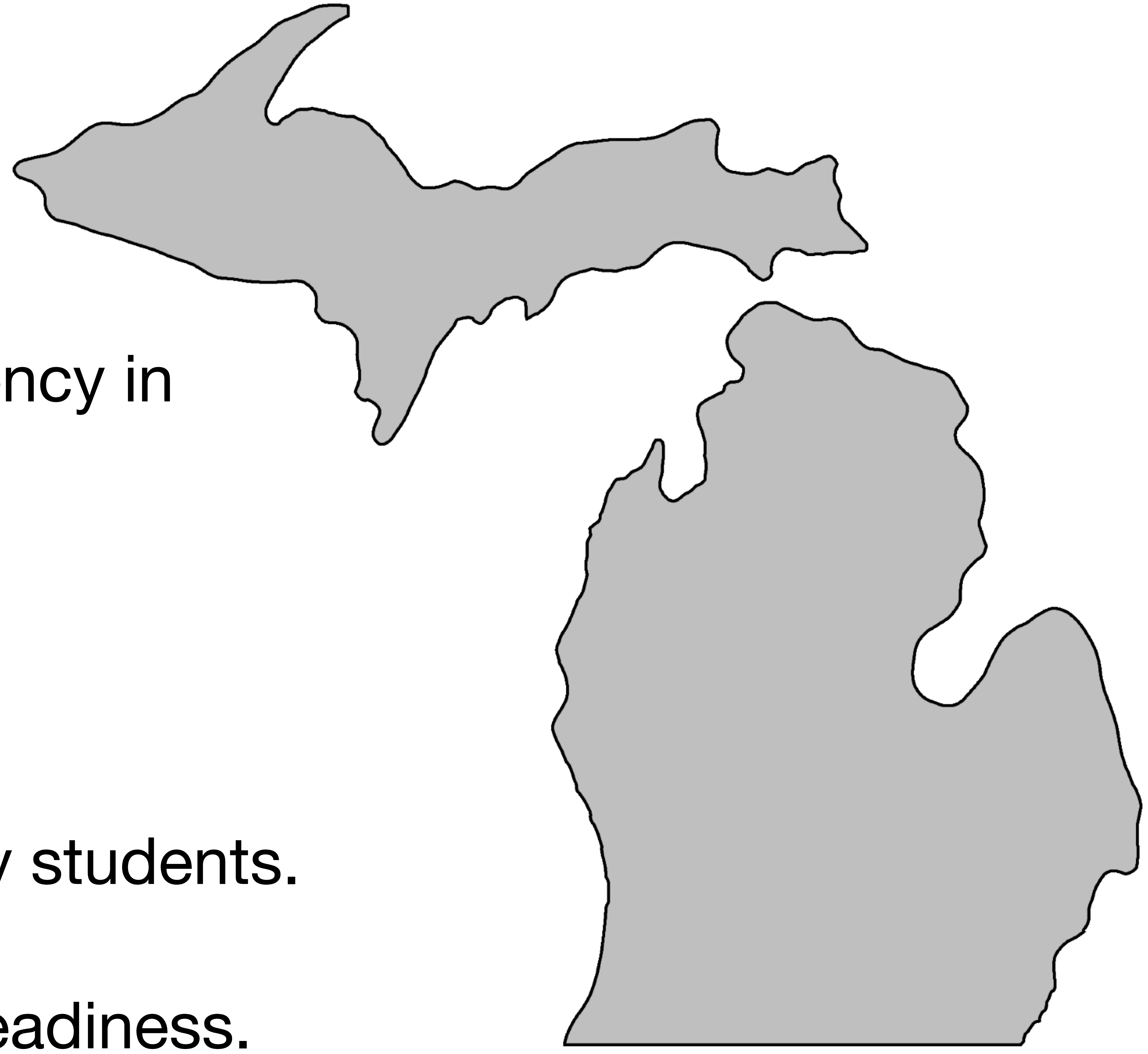

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> 75% of MSU students are Michiganders.

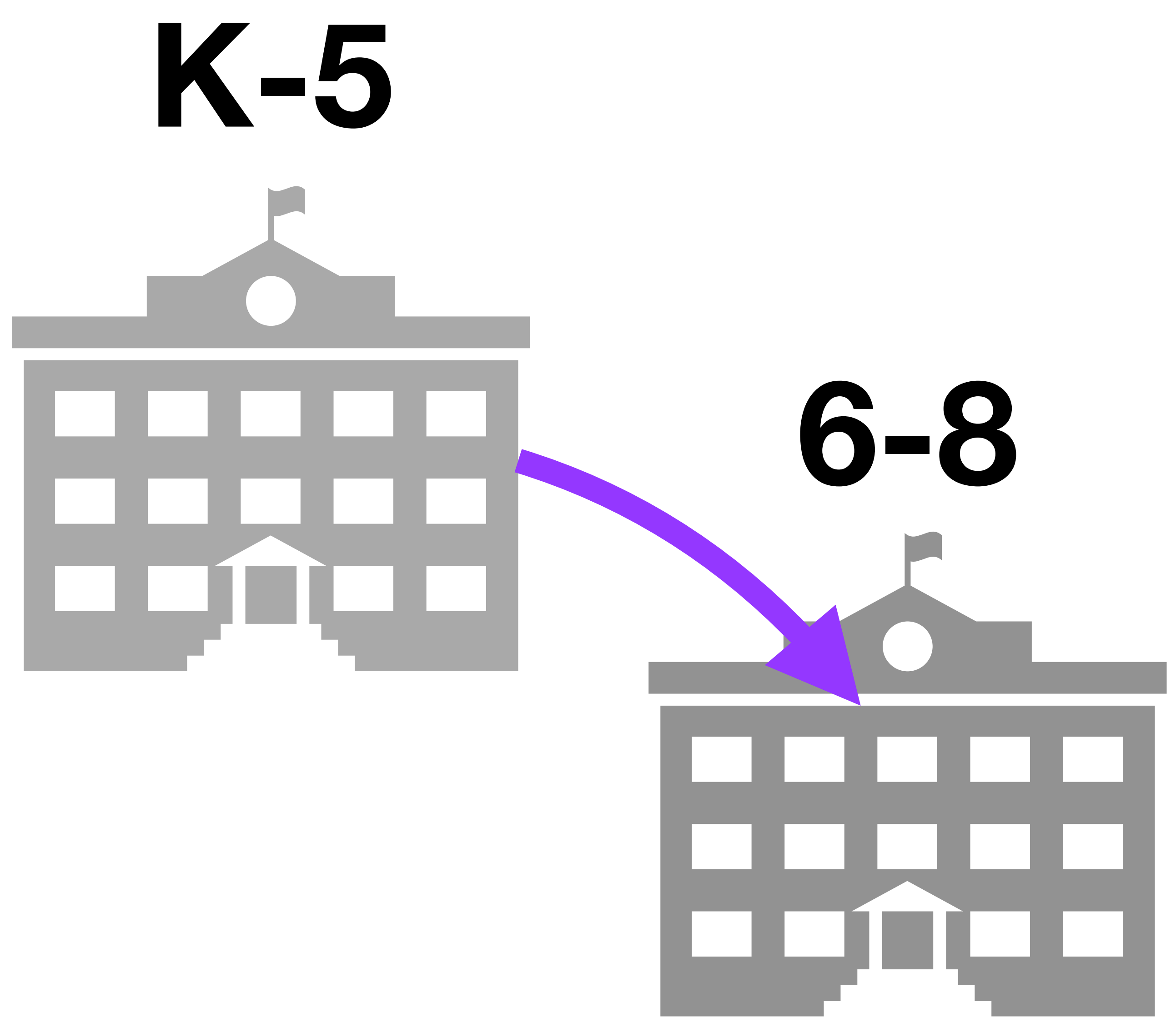
Michigan State as a Case for Change

~70 Academic and Teaching Staff
~450 majors
~300 PhD students

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

Michigan State hosts the top nuclear physics program in the US.

K-5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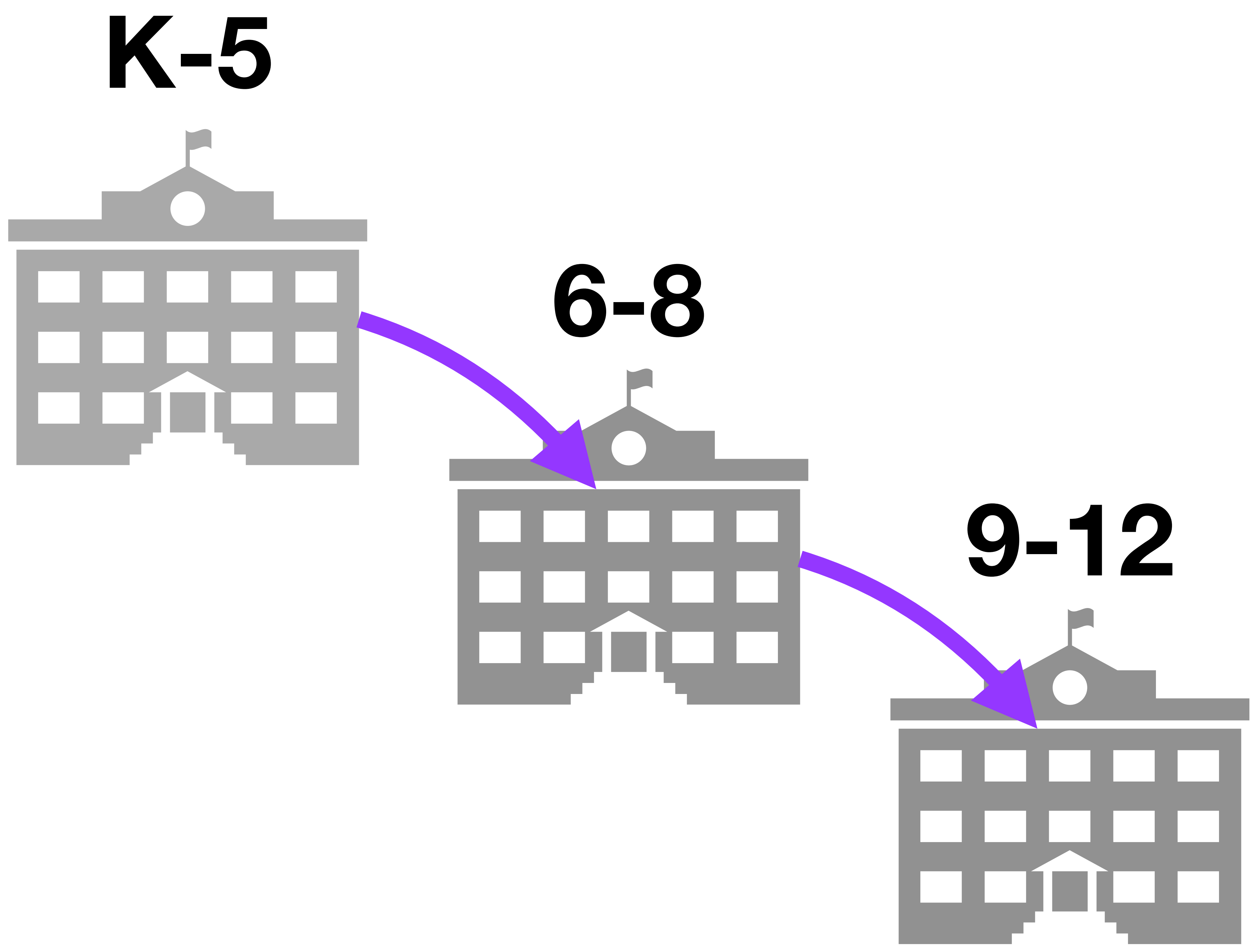
6-8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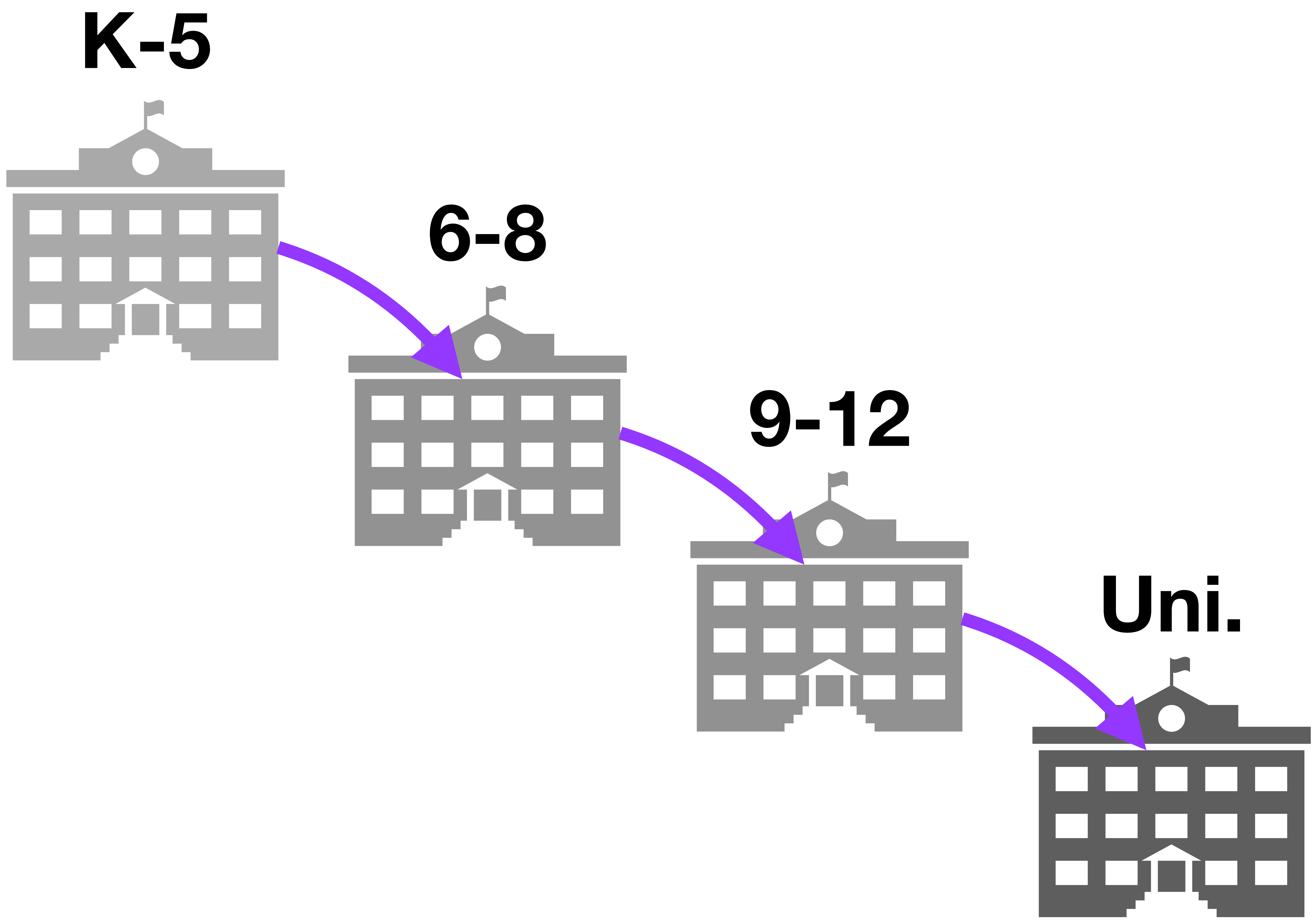
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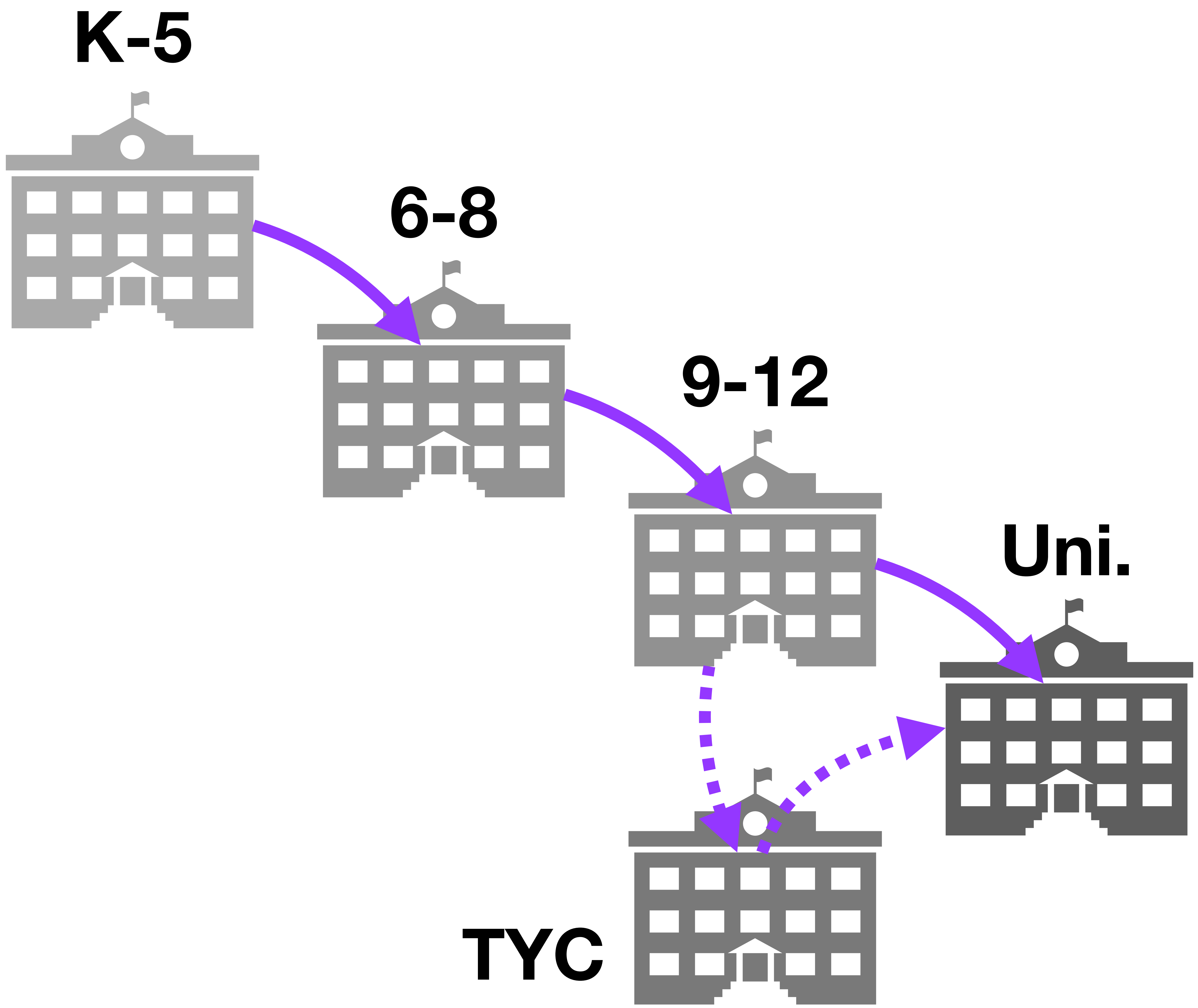
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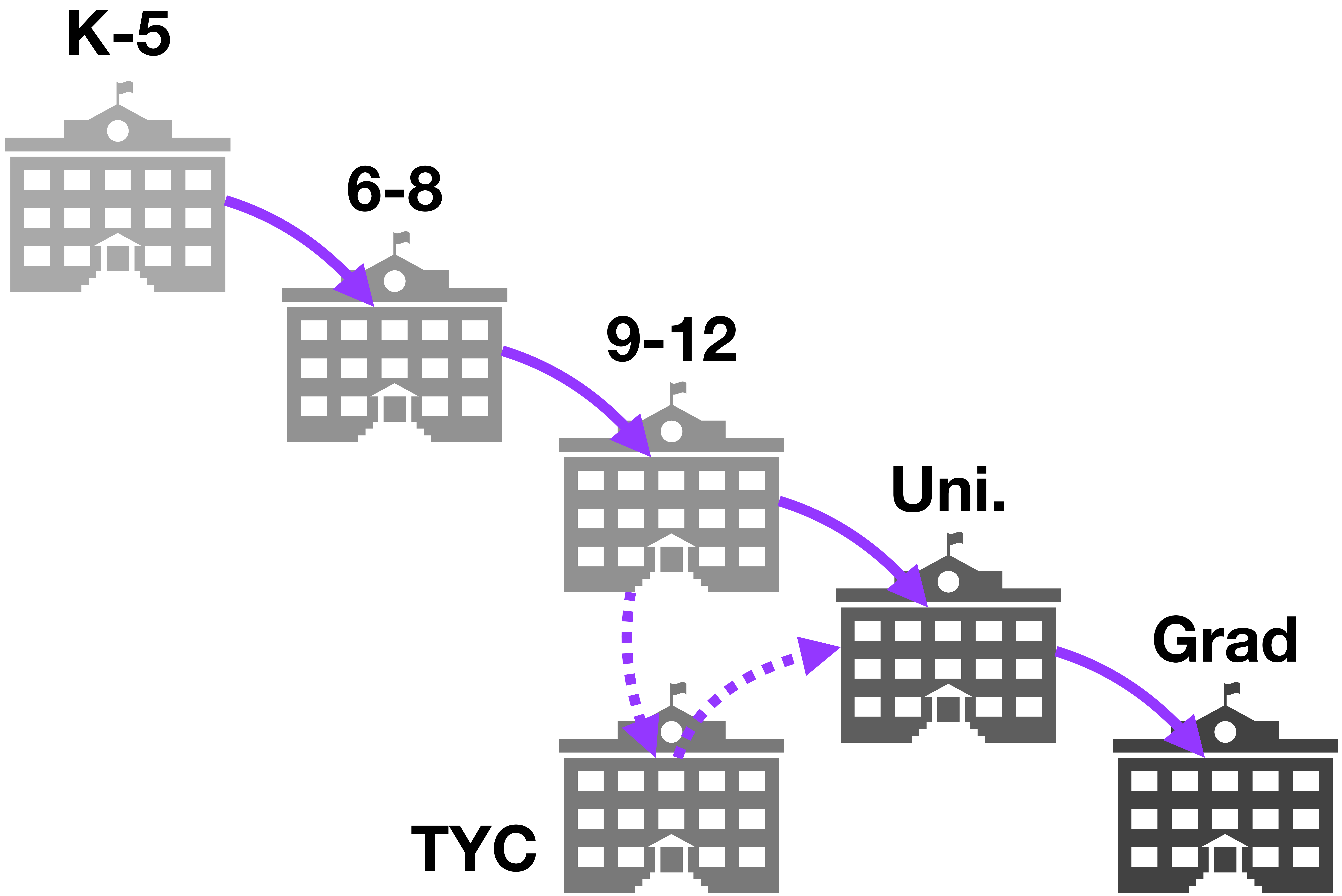
TYC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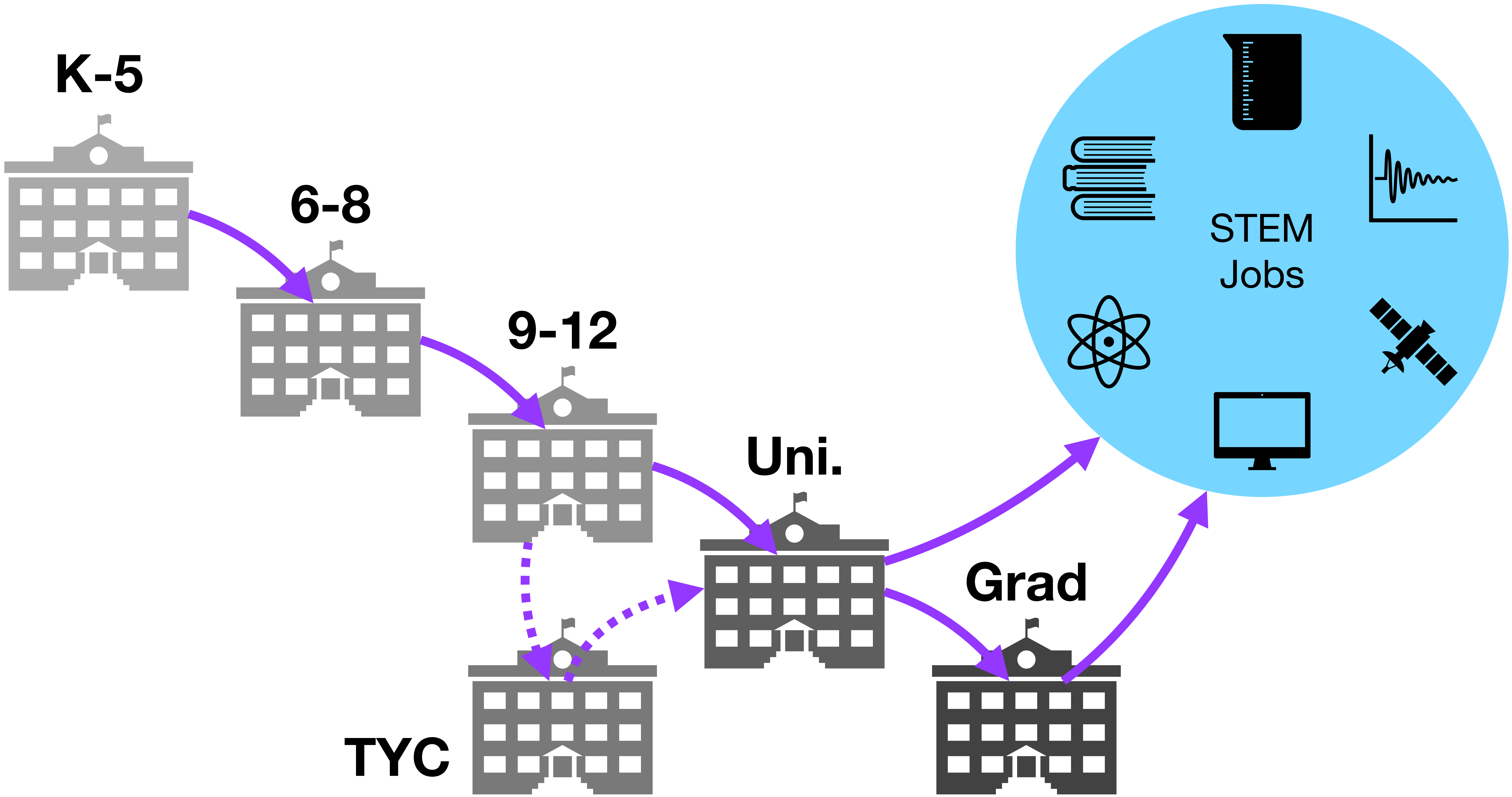
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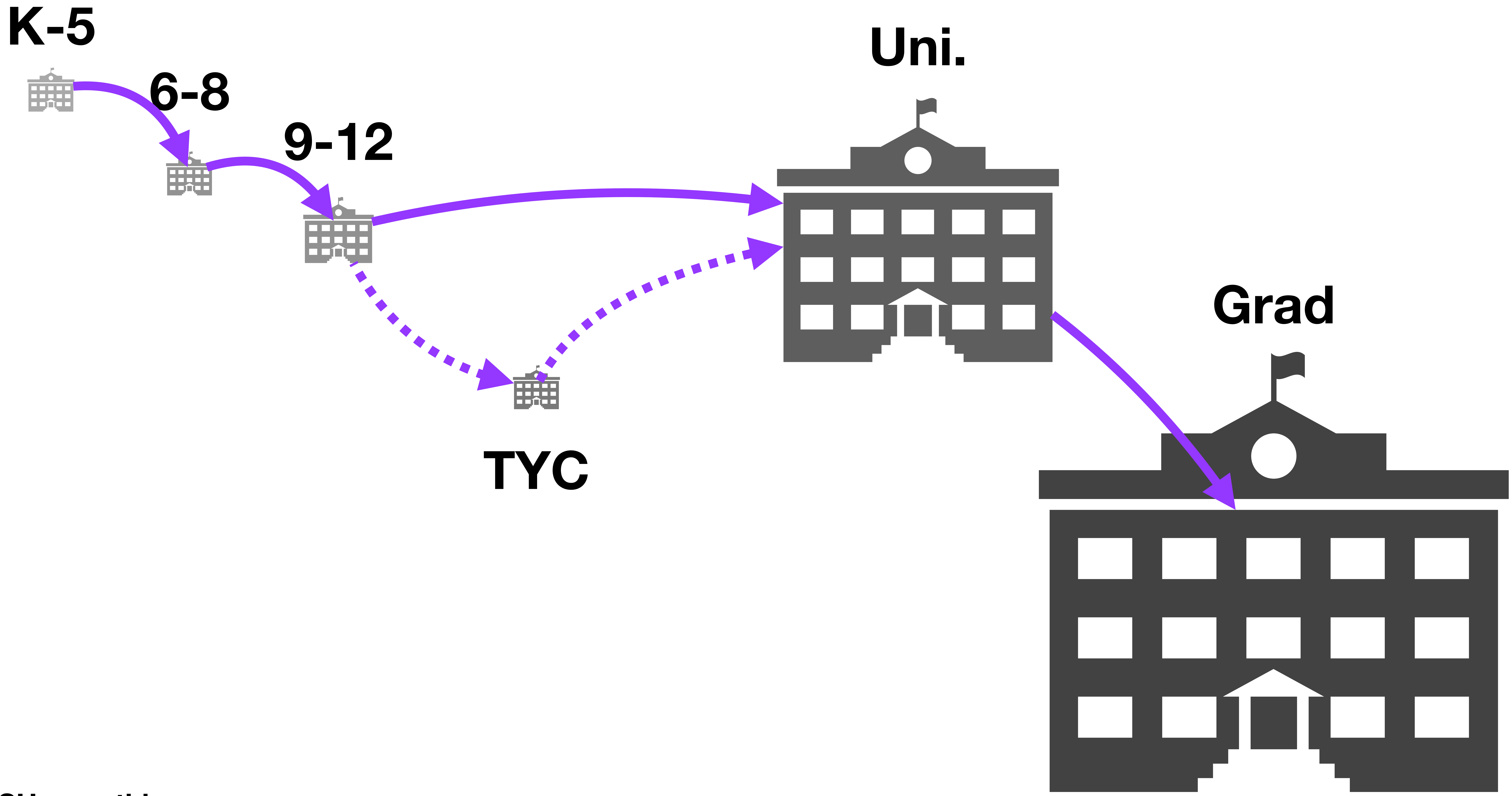
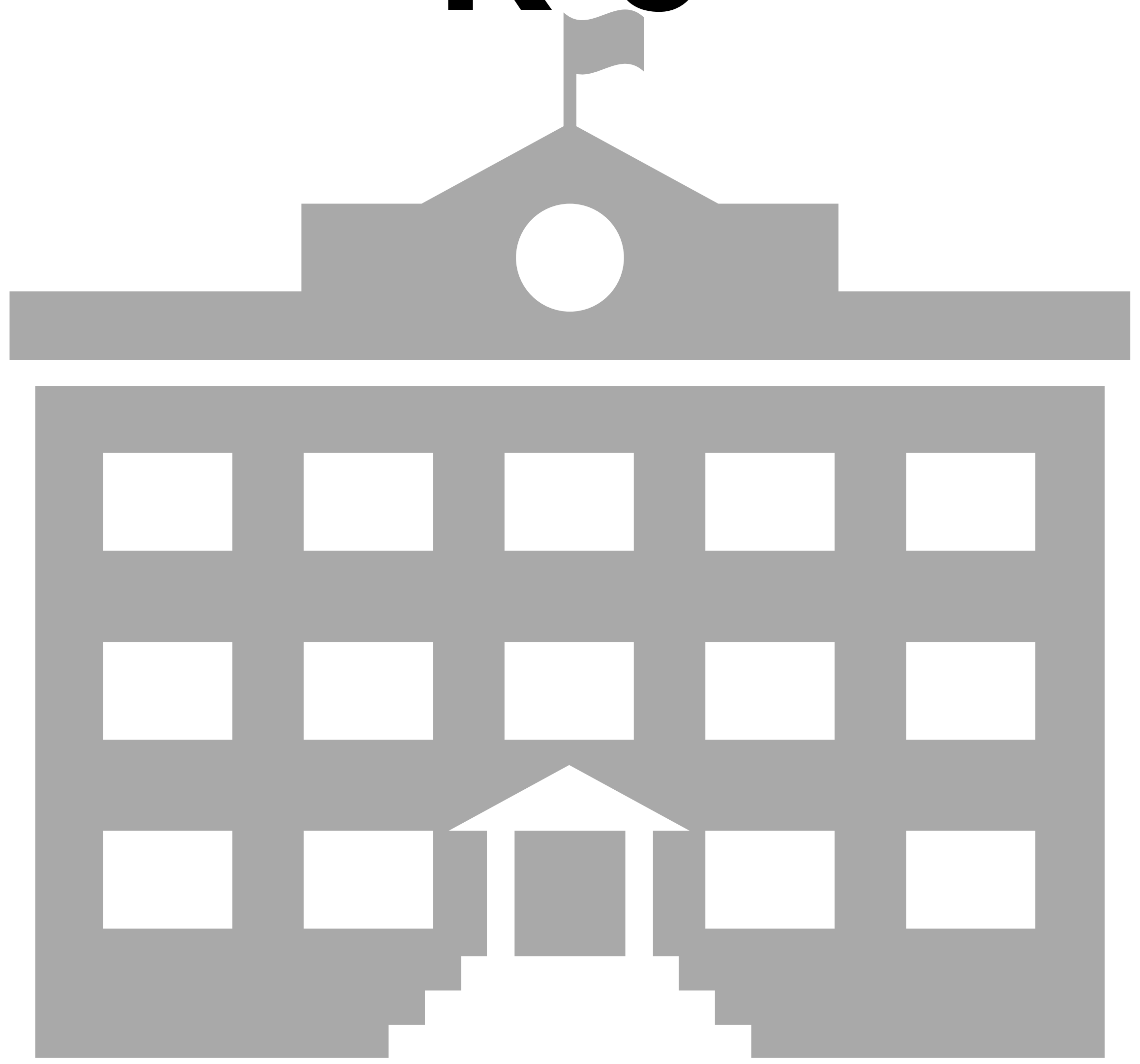
Grad
STEM
Jobs

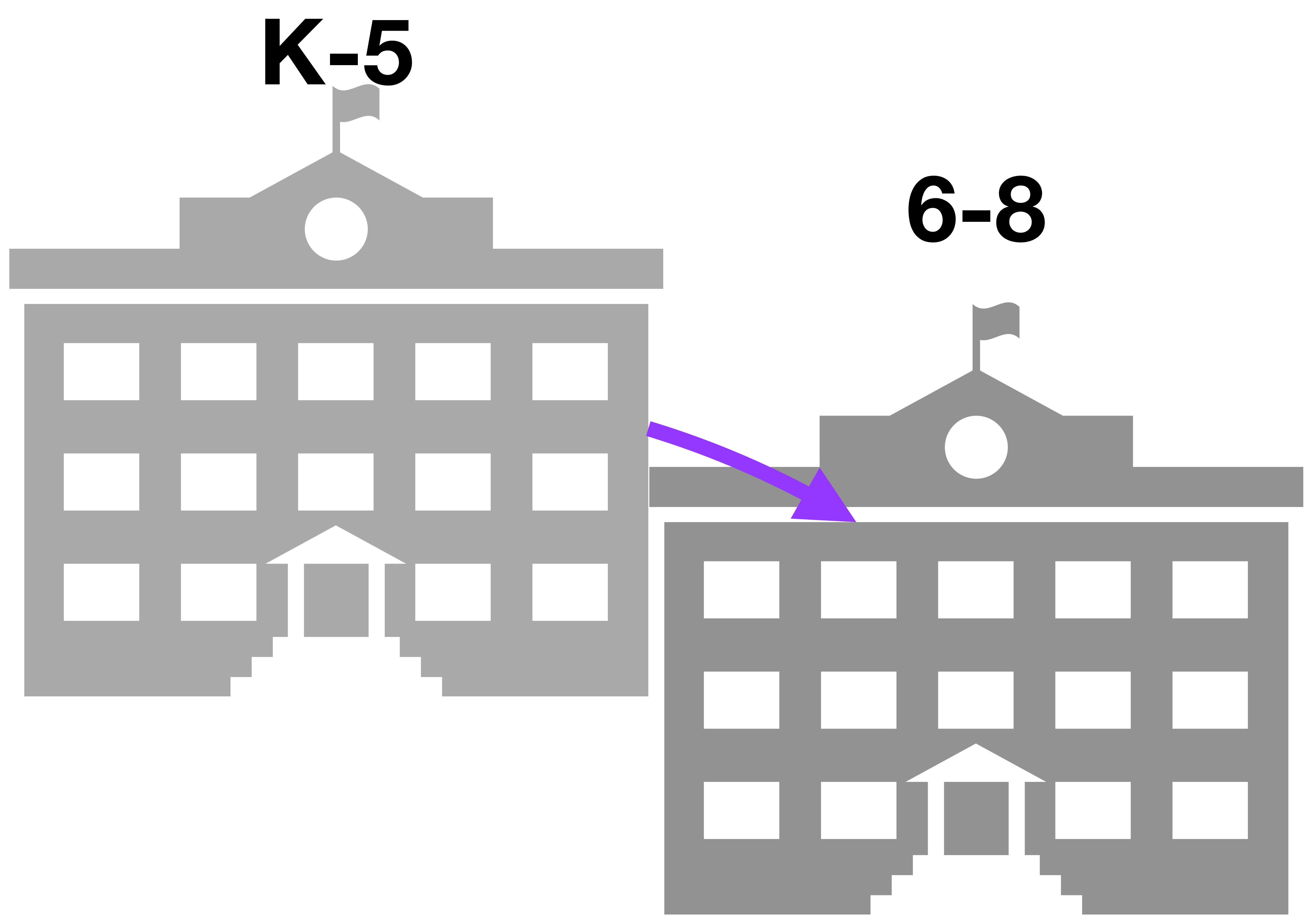


How MSU sees things

K-5



How numbers of students are distributed



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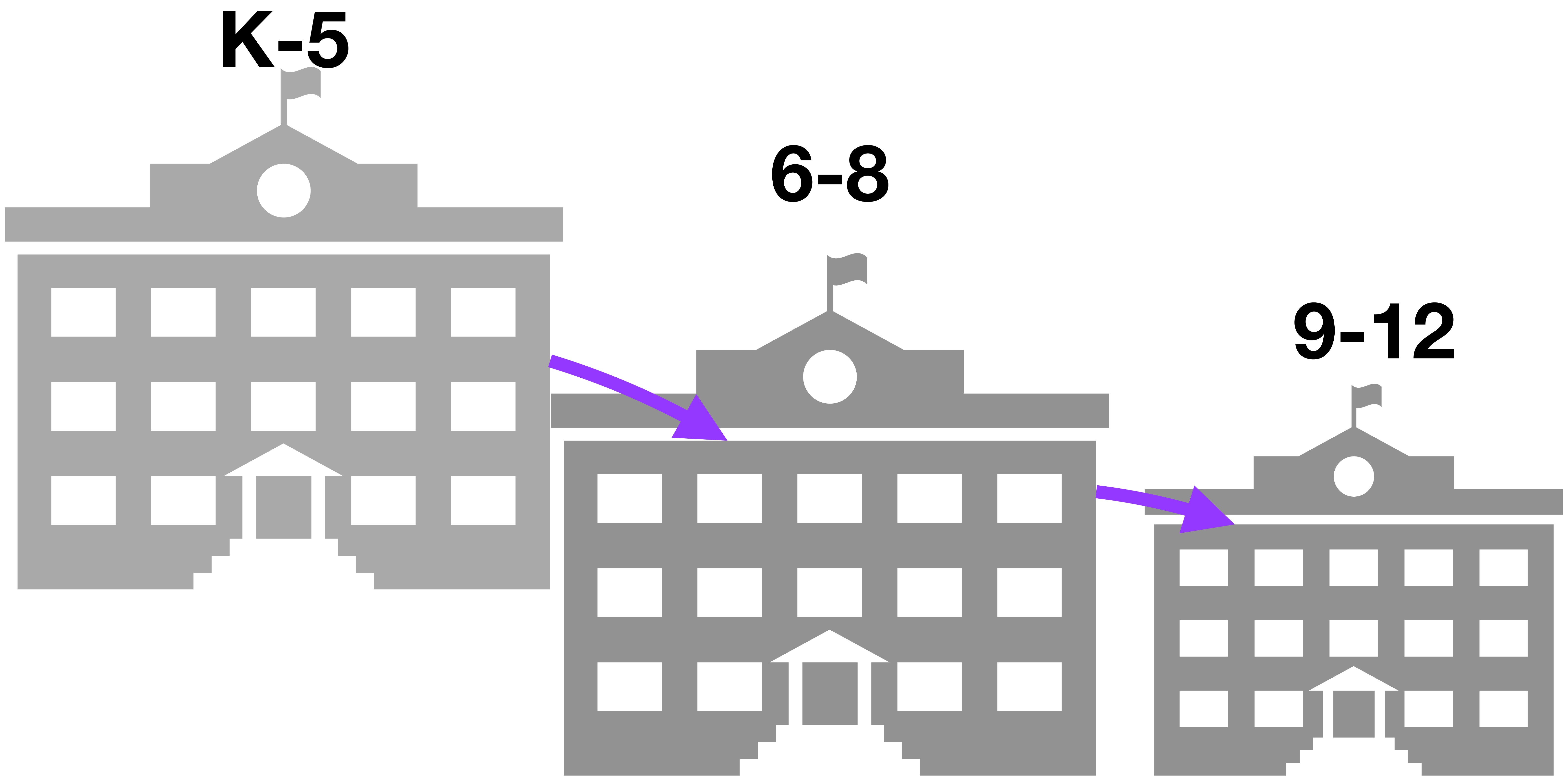

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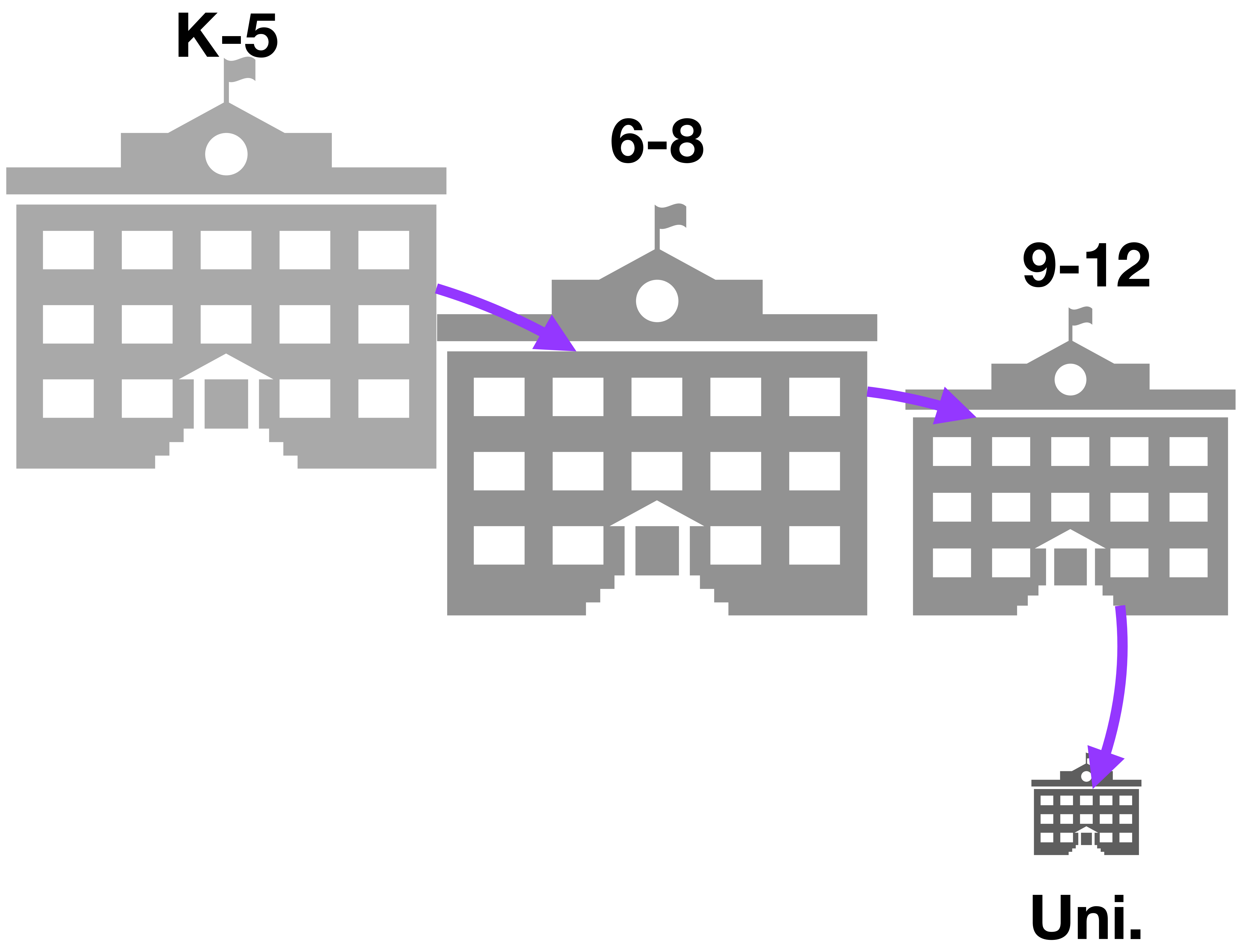

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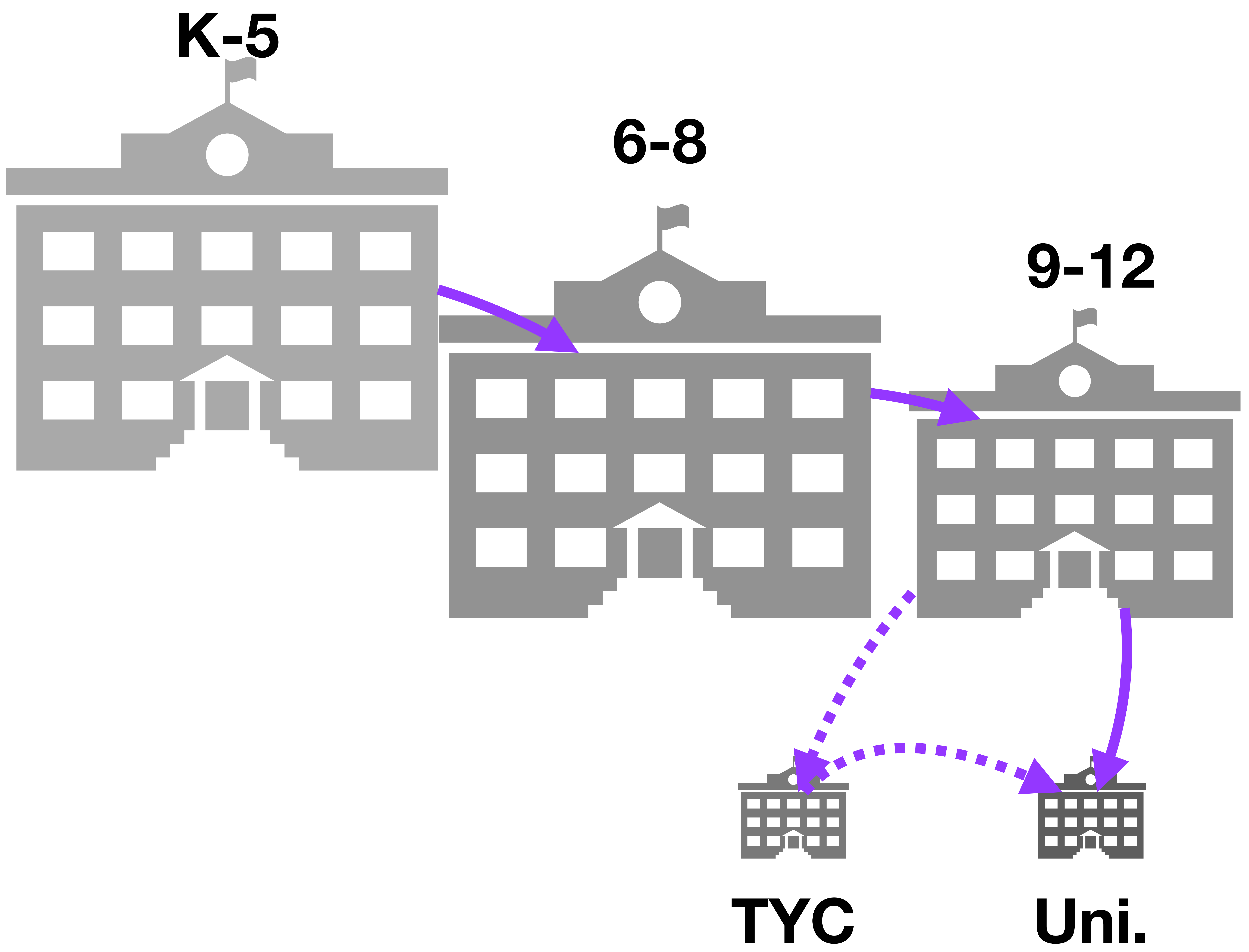

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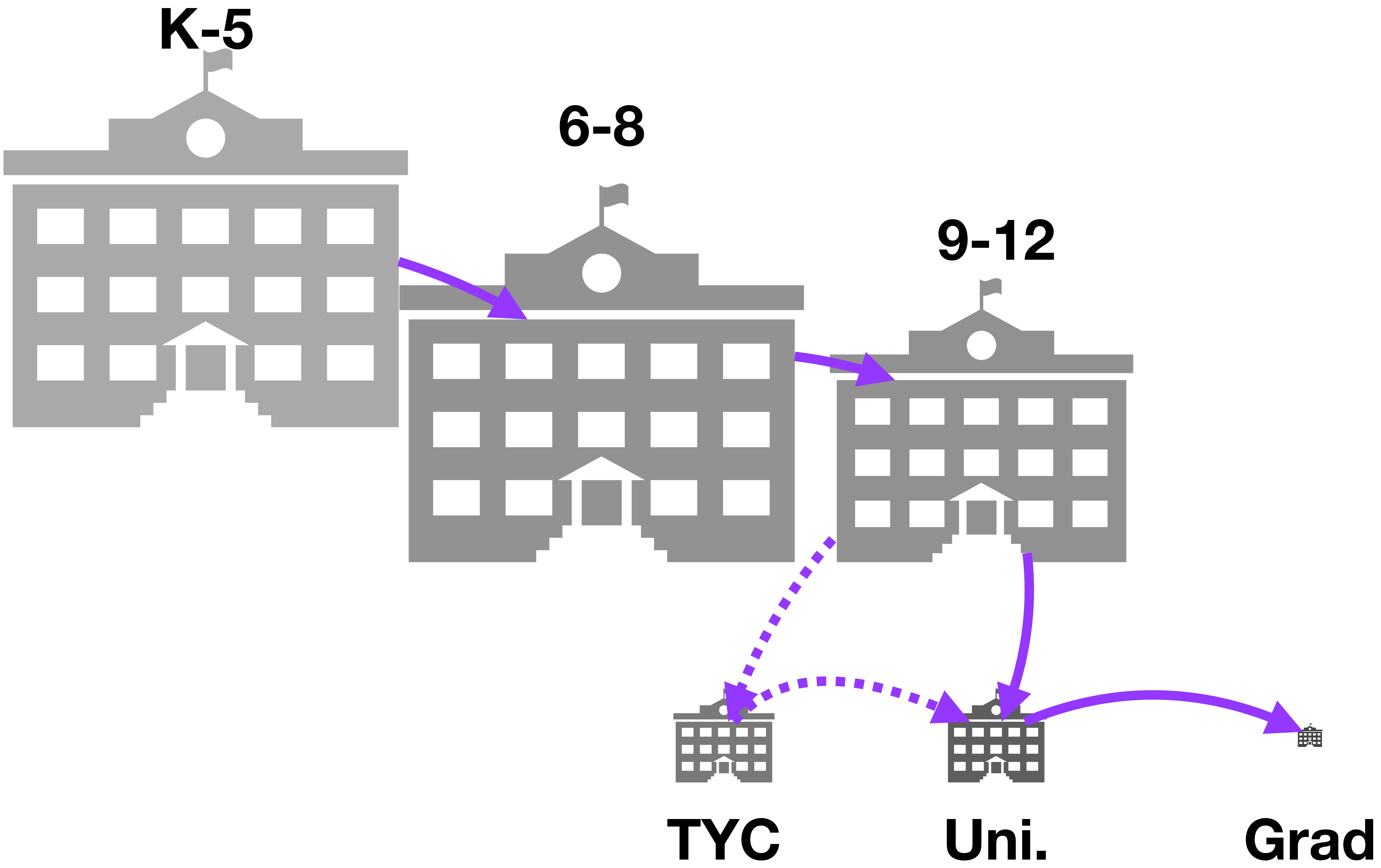

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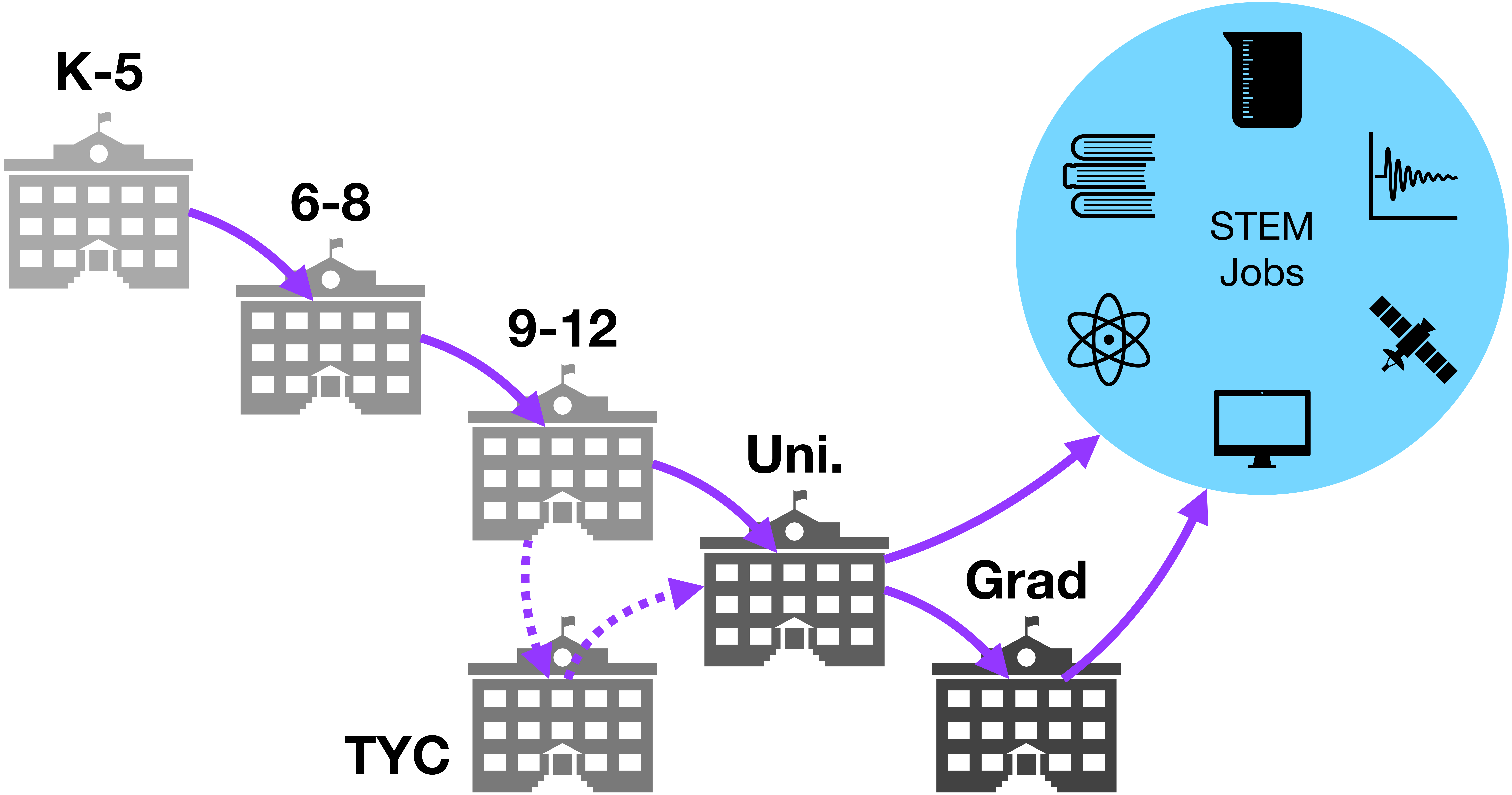
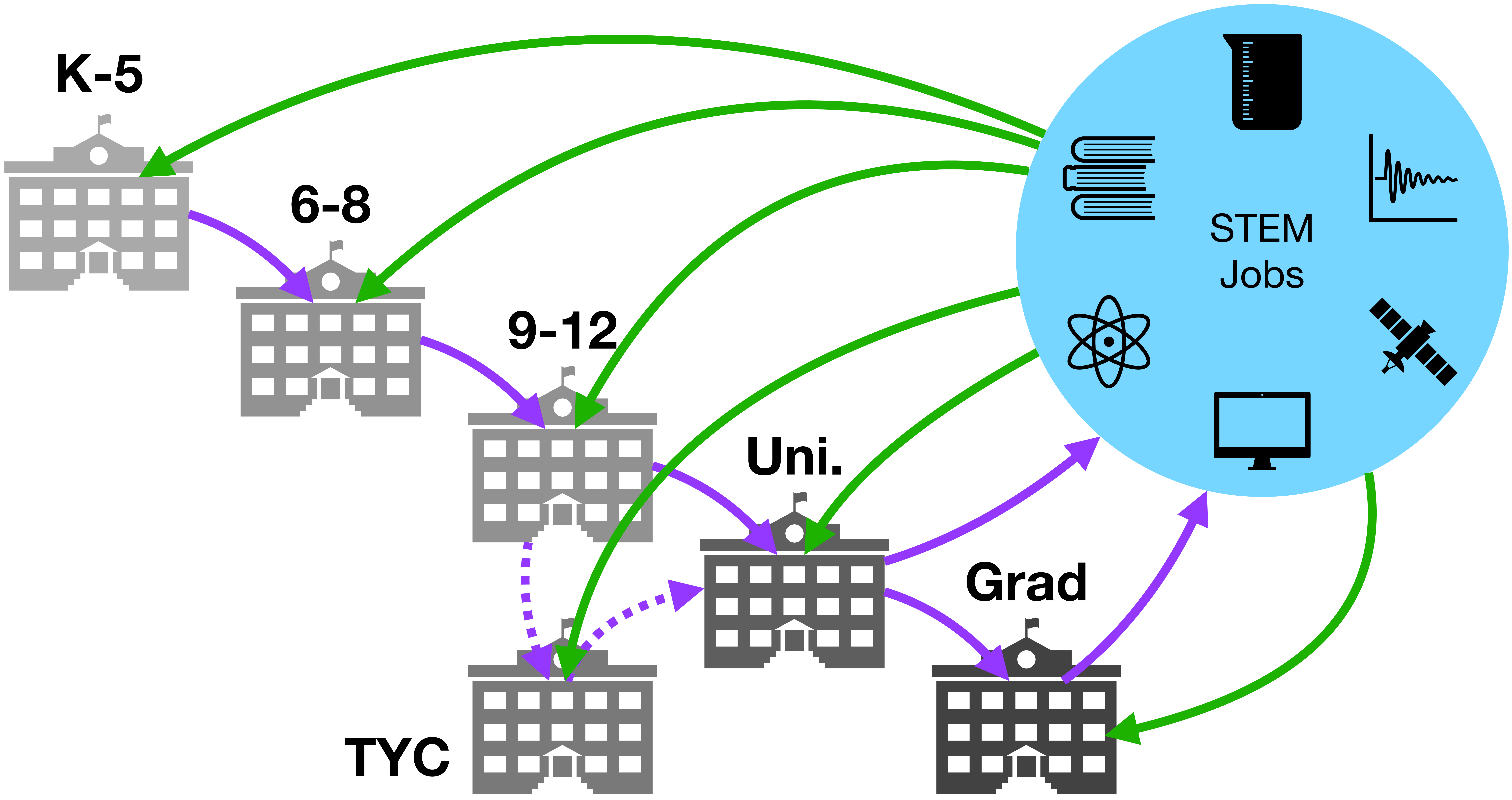
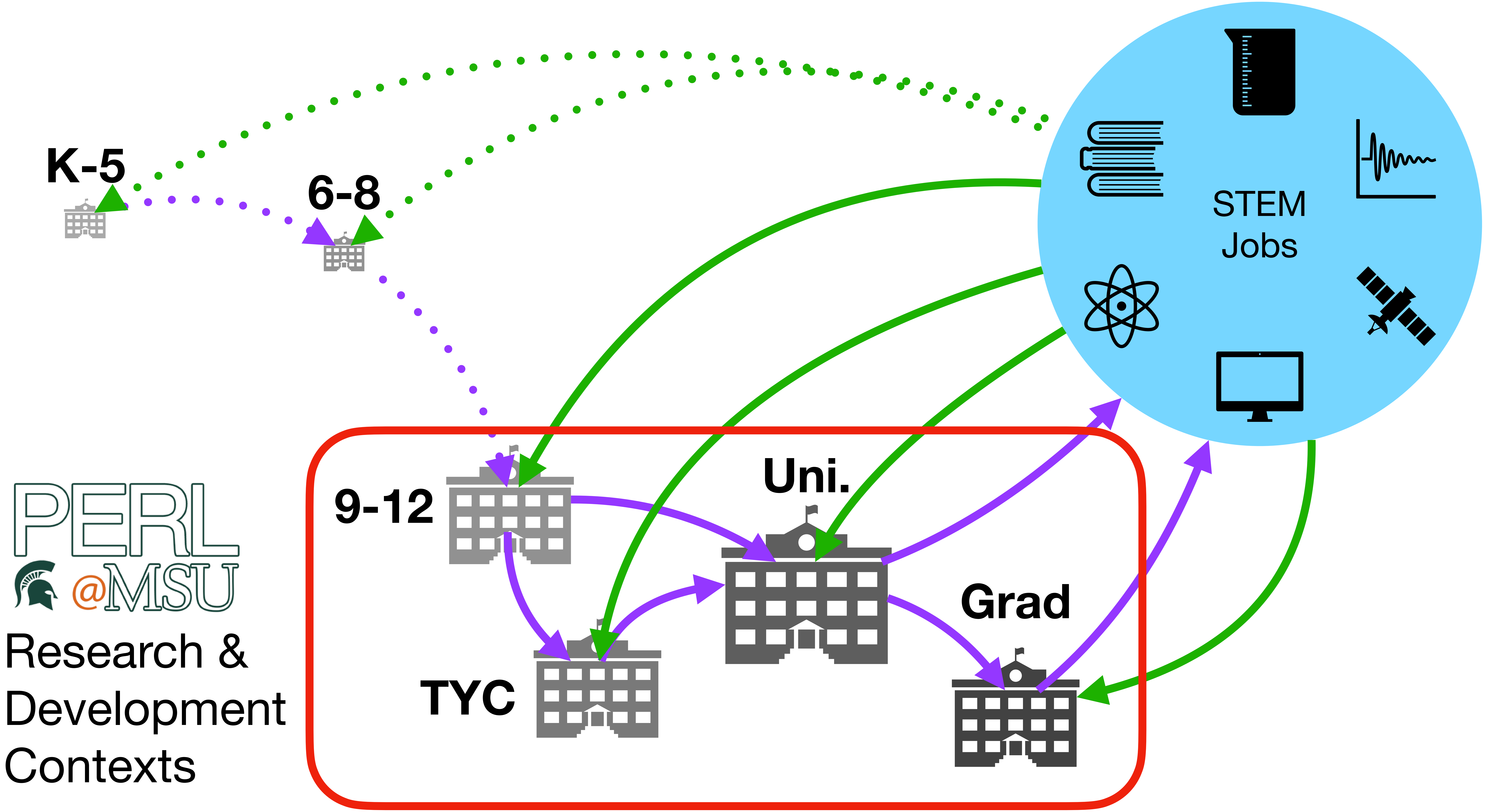


There’s feedback in the system



There’s feedback in the system


K-5
6-8
9-12
TYC
Uni.
Grad
STEM
Jobs
PERL
@MSU
Research &
Development
Contexts

Challenges and Opportunities for PER

Challenges and Opportunities for PER

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)

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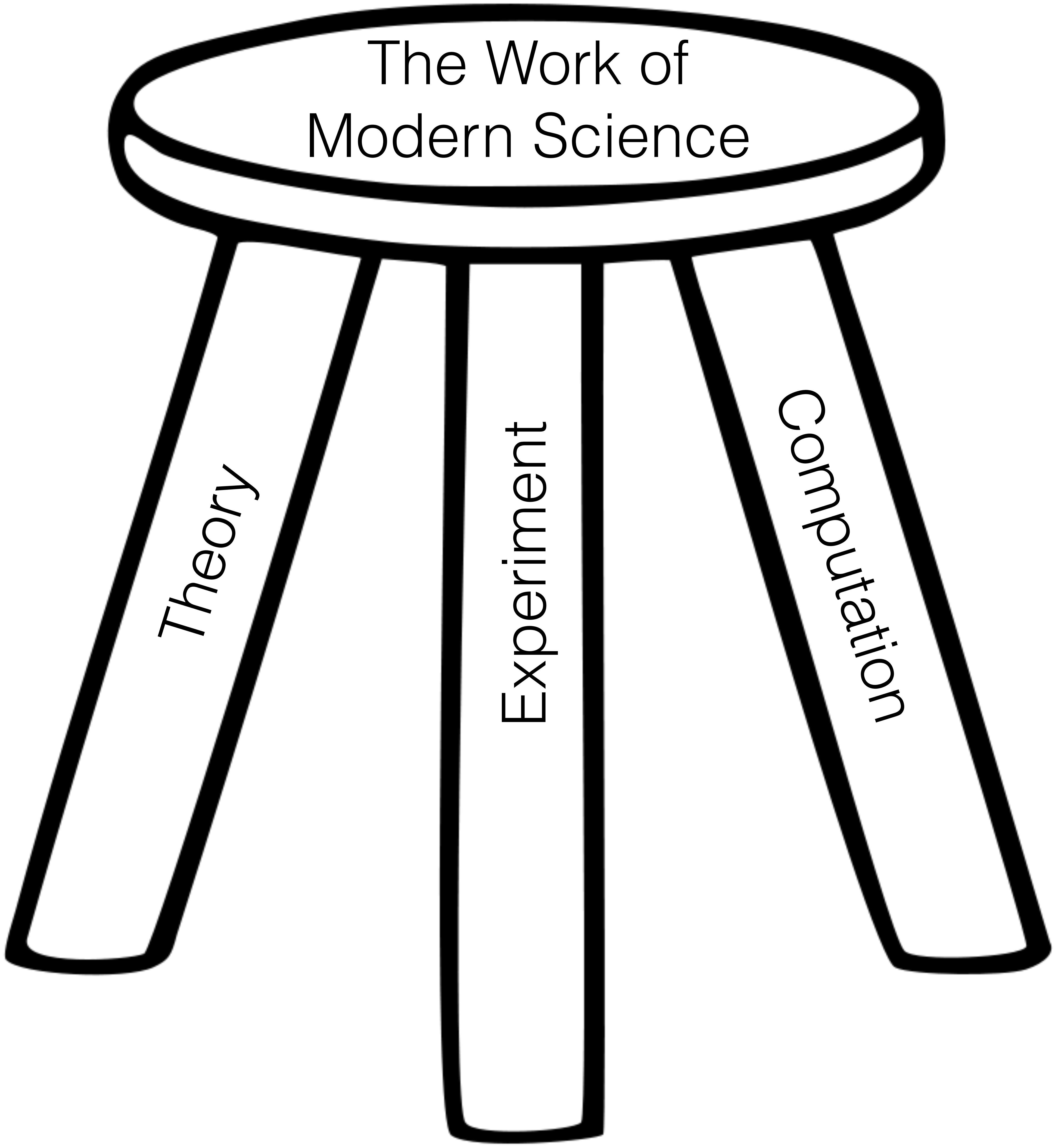
Physics is changing; new tools, new techniques

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

Computation
is how
modern science
is done.



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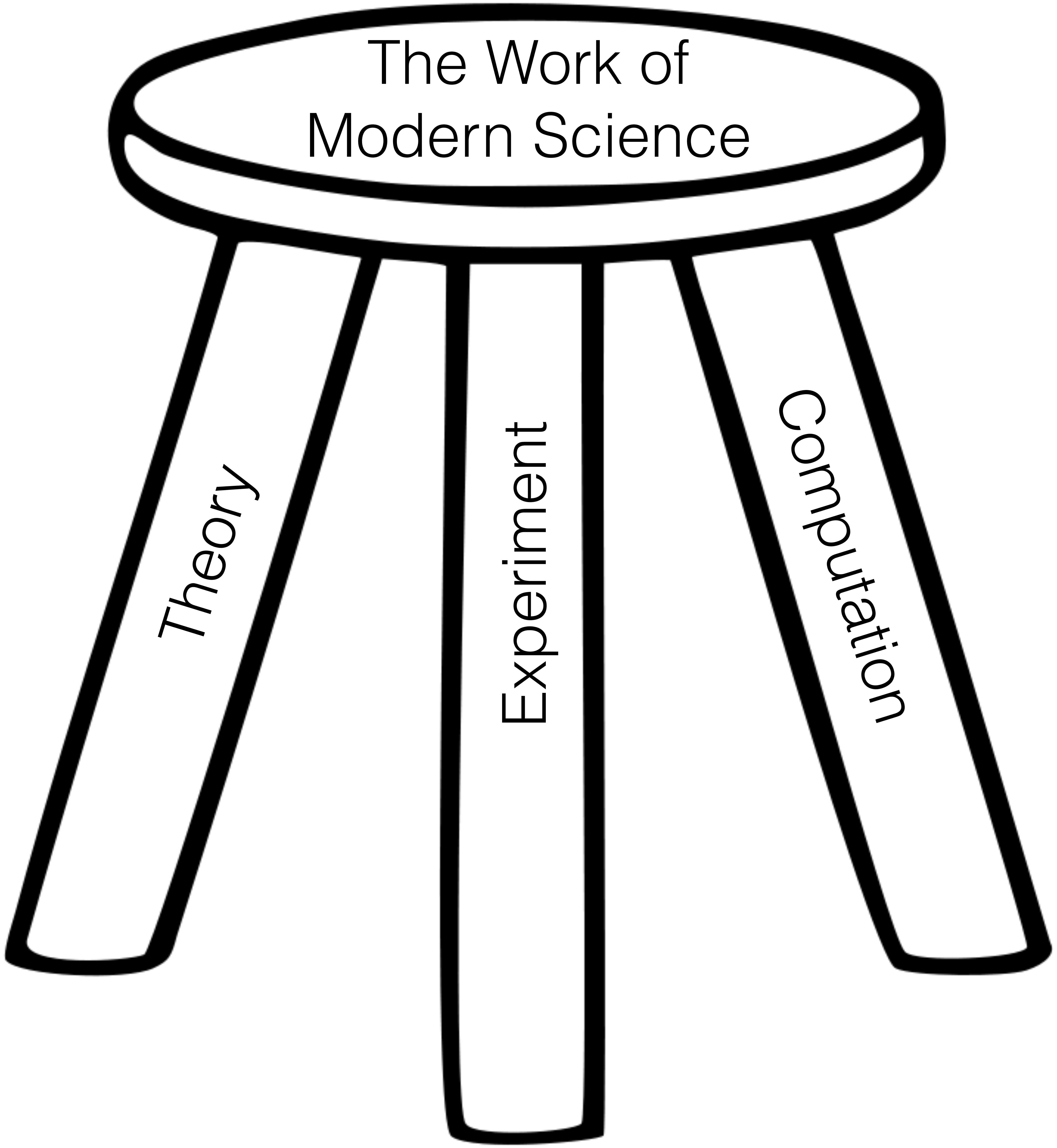

But, what has changed in
physics education?

1860s-1880s

$$\nabla \cdot \mathbf{D} = \rho$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

1860s-1880s

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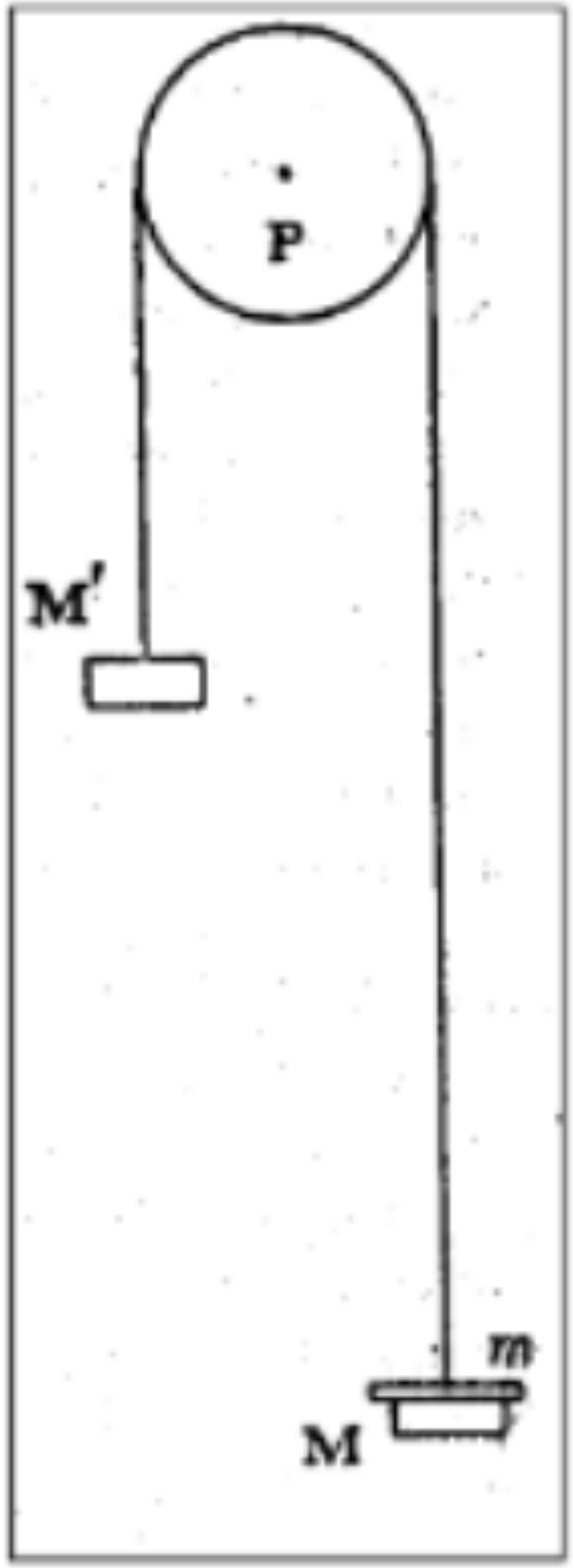
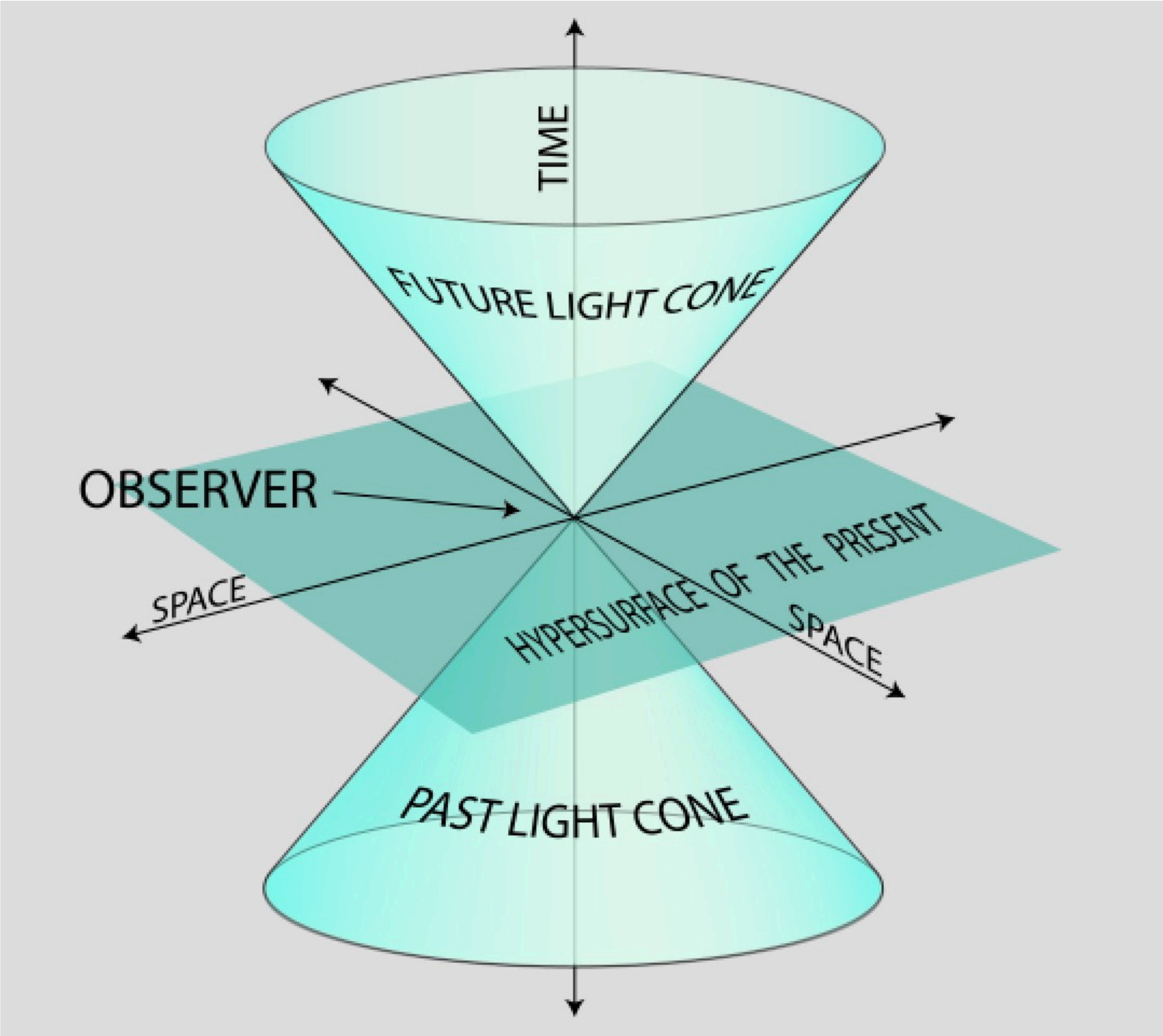
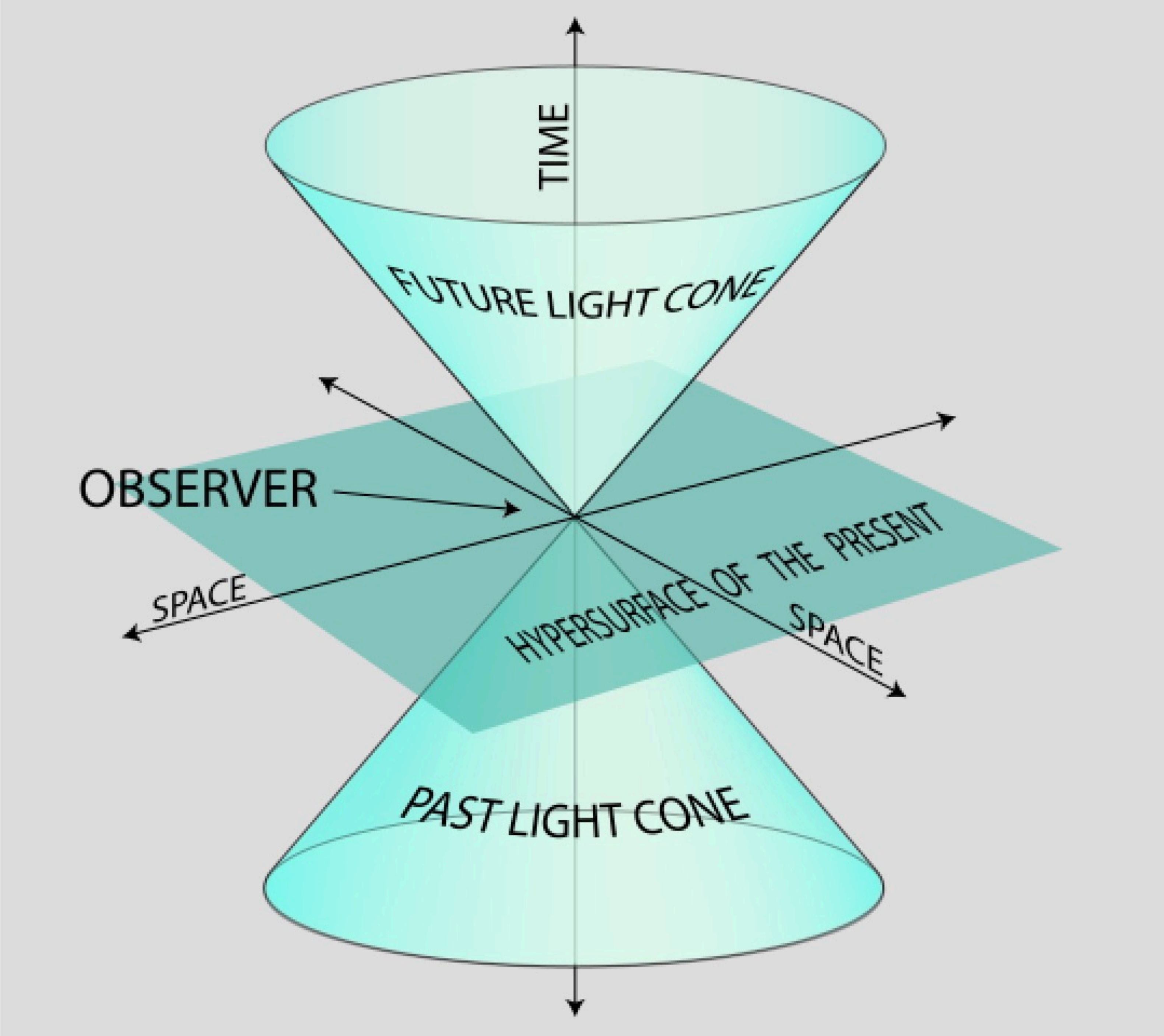


1900s-1910s


TIME
FUTURE LIGHT CONE
OBSERVER
SPACE
HYPERSURFACE OF THE PRESENT
SPACE
PAST LIGHT CONE

1900s-1910s


TIME
FUTURE LIGHT CONE
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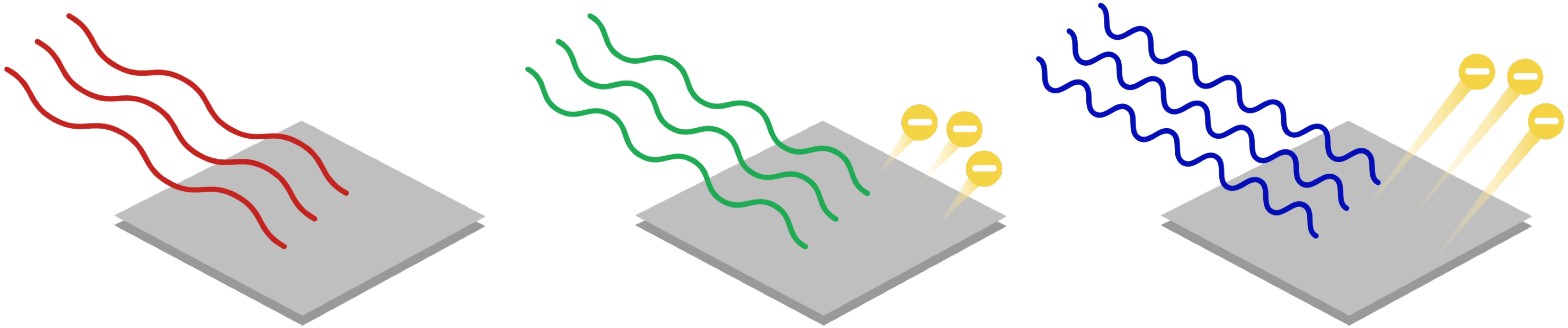
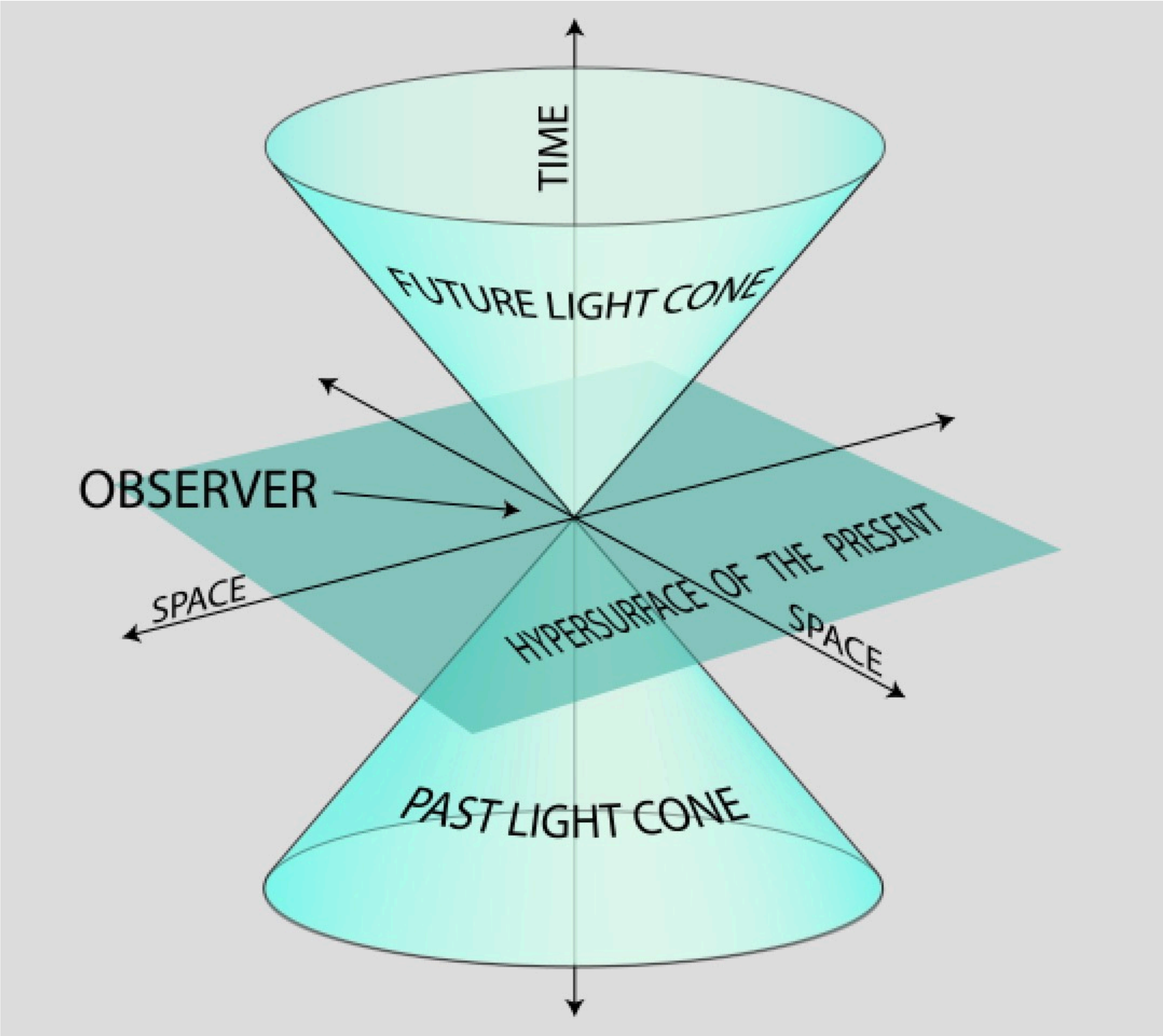
SPACE
PAST LIGHT CONE



1900s-1910s



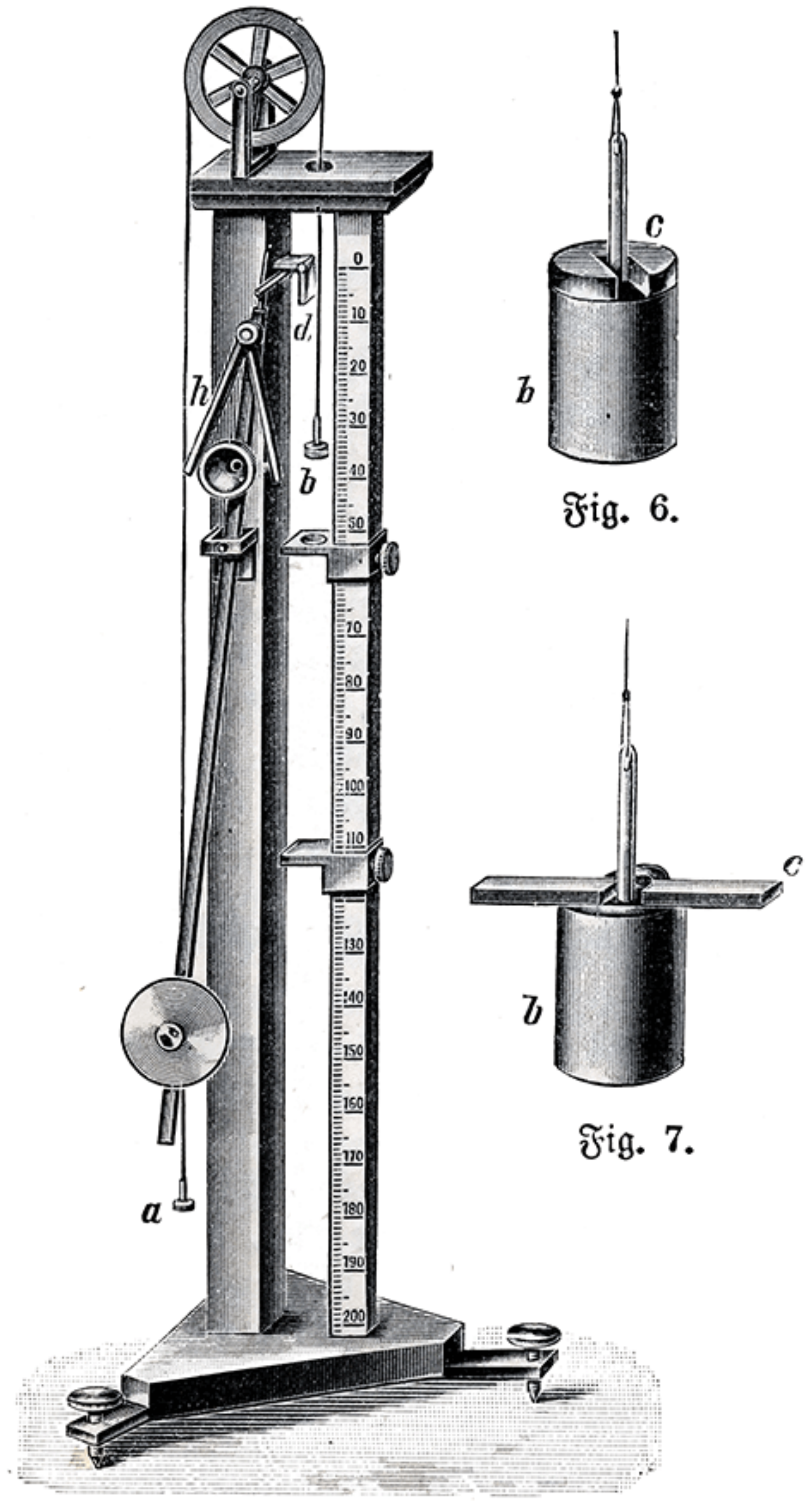
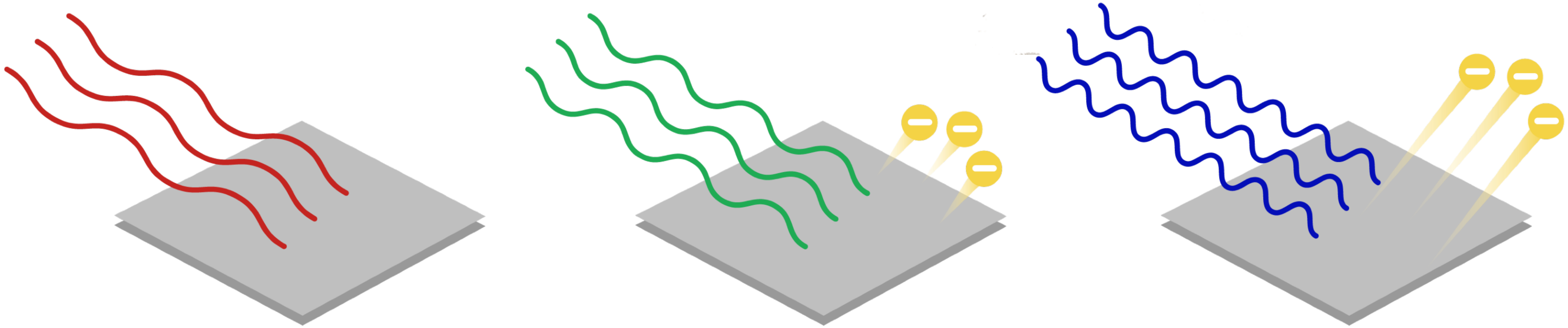
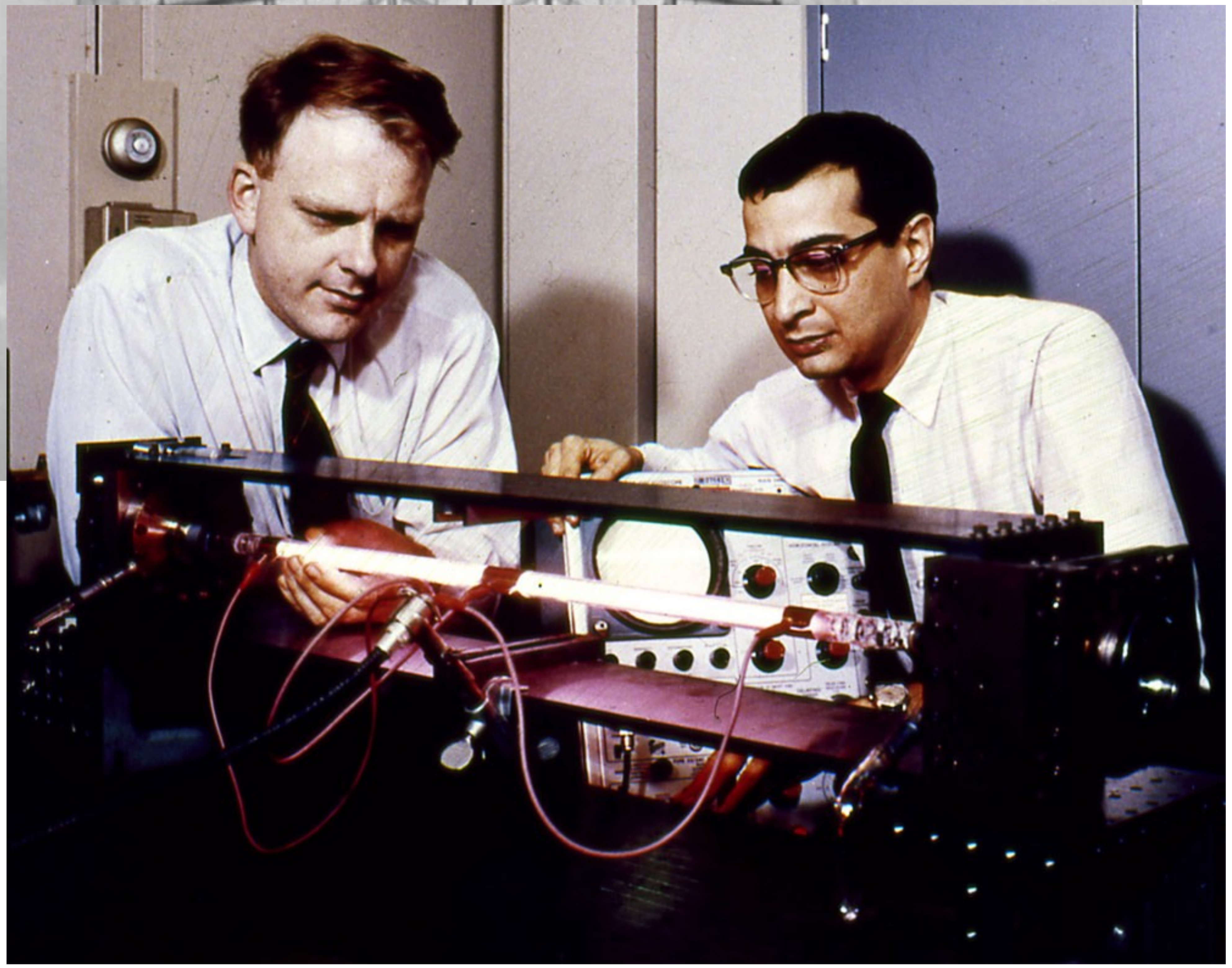


Fig. 5.
Atwoodsche Fallmaschine

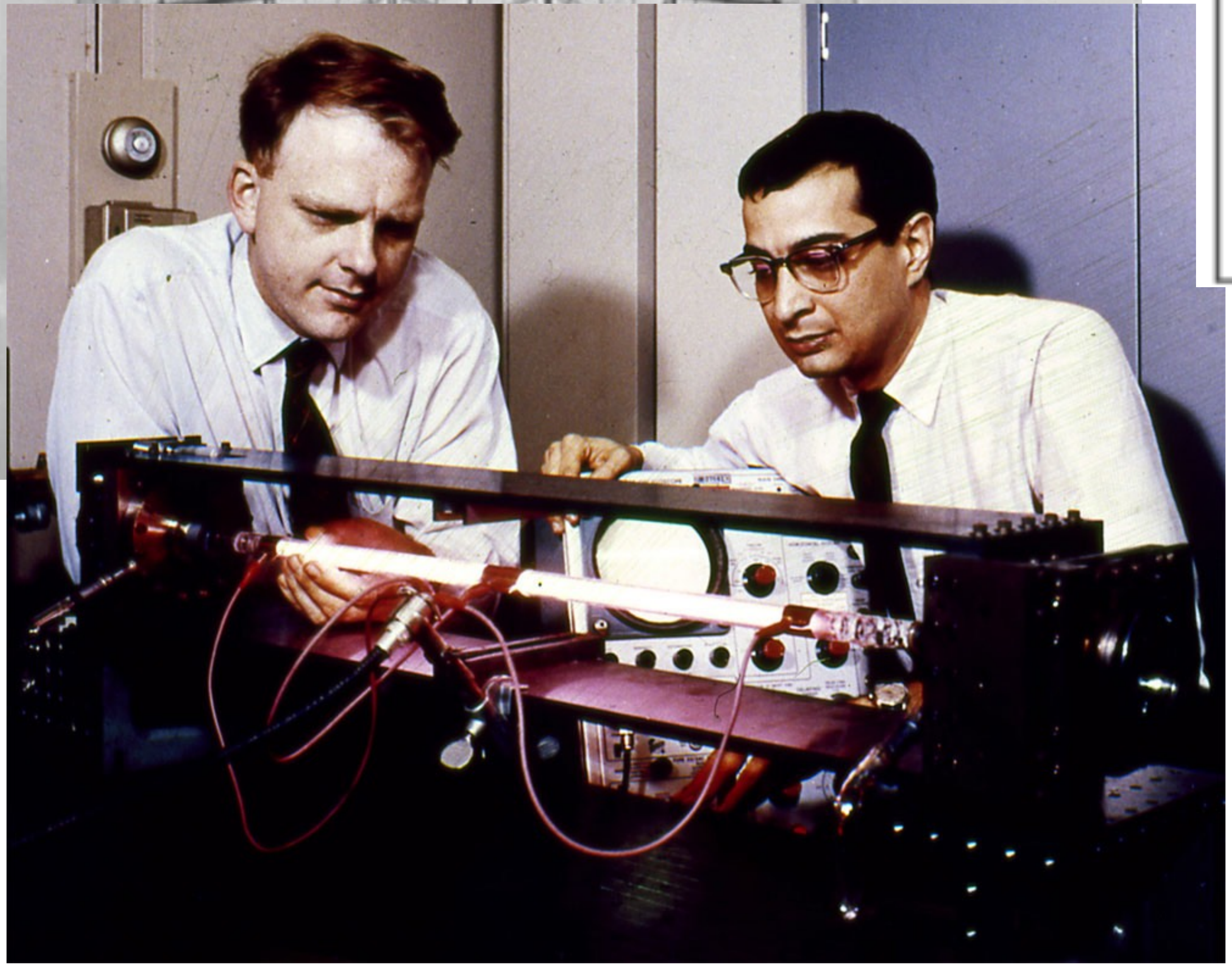


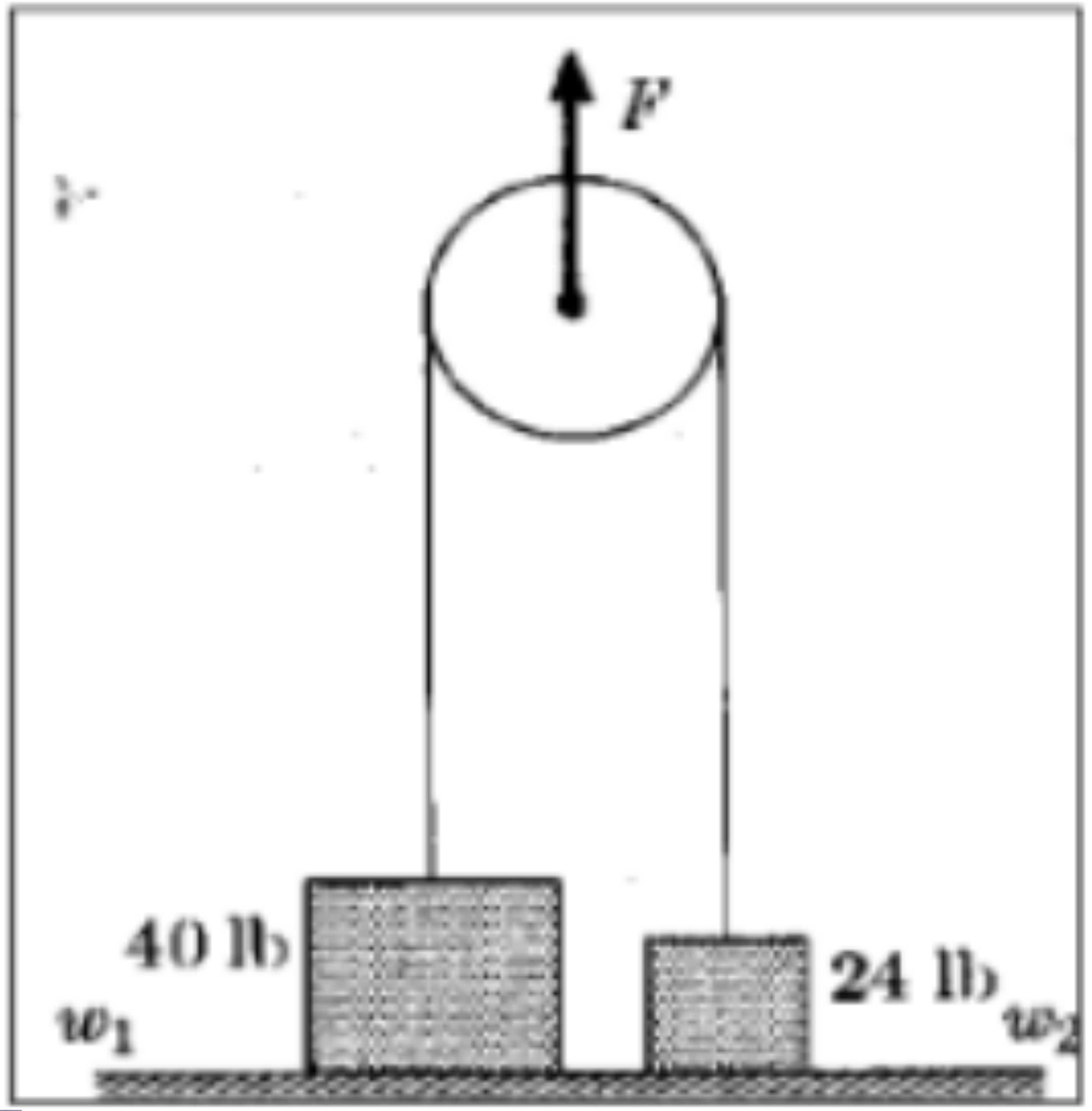
1950s-1960s

1950s-1960s



1950s-1960s

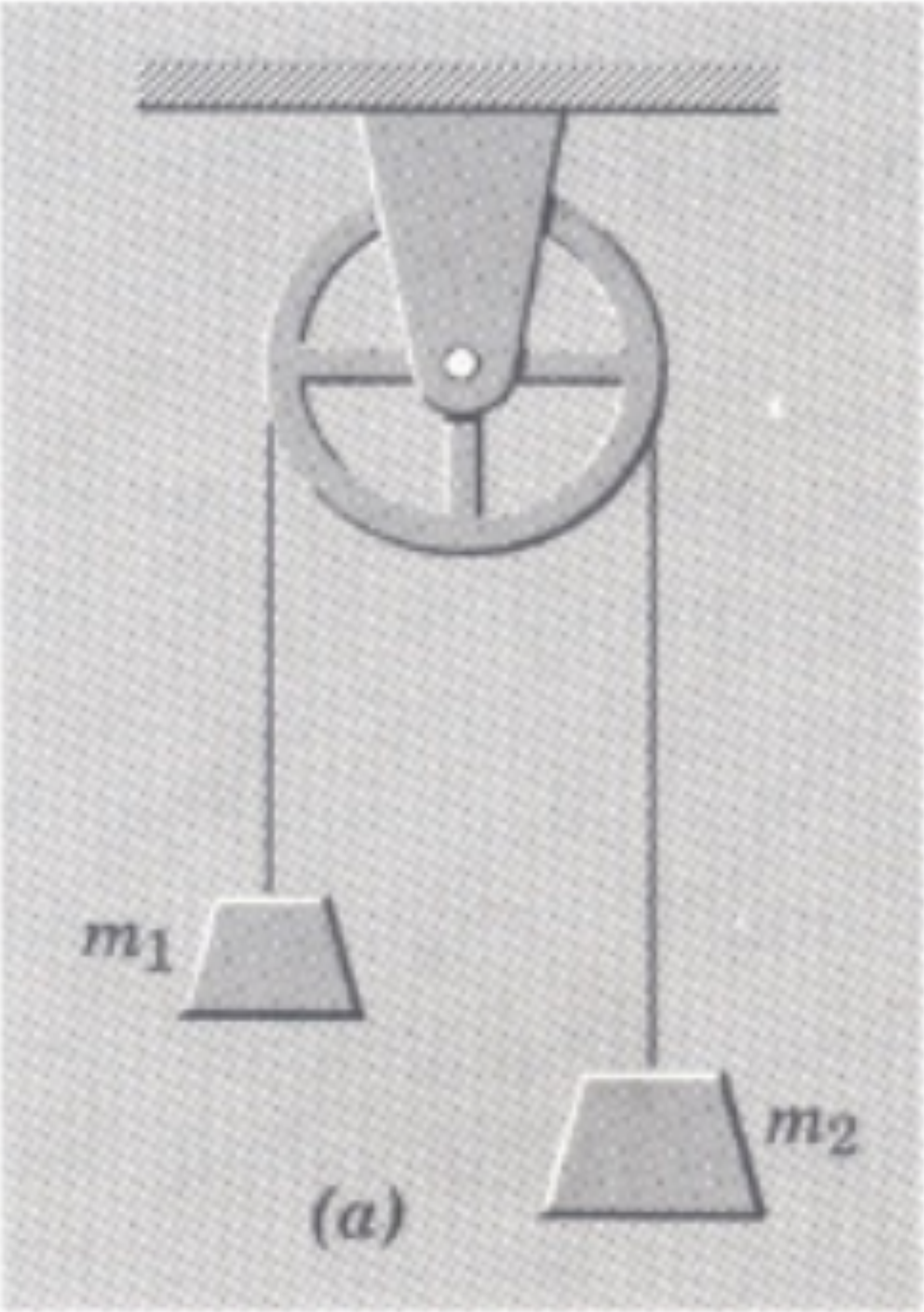




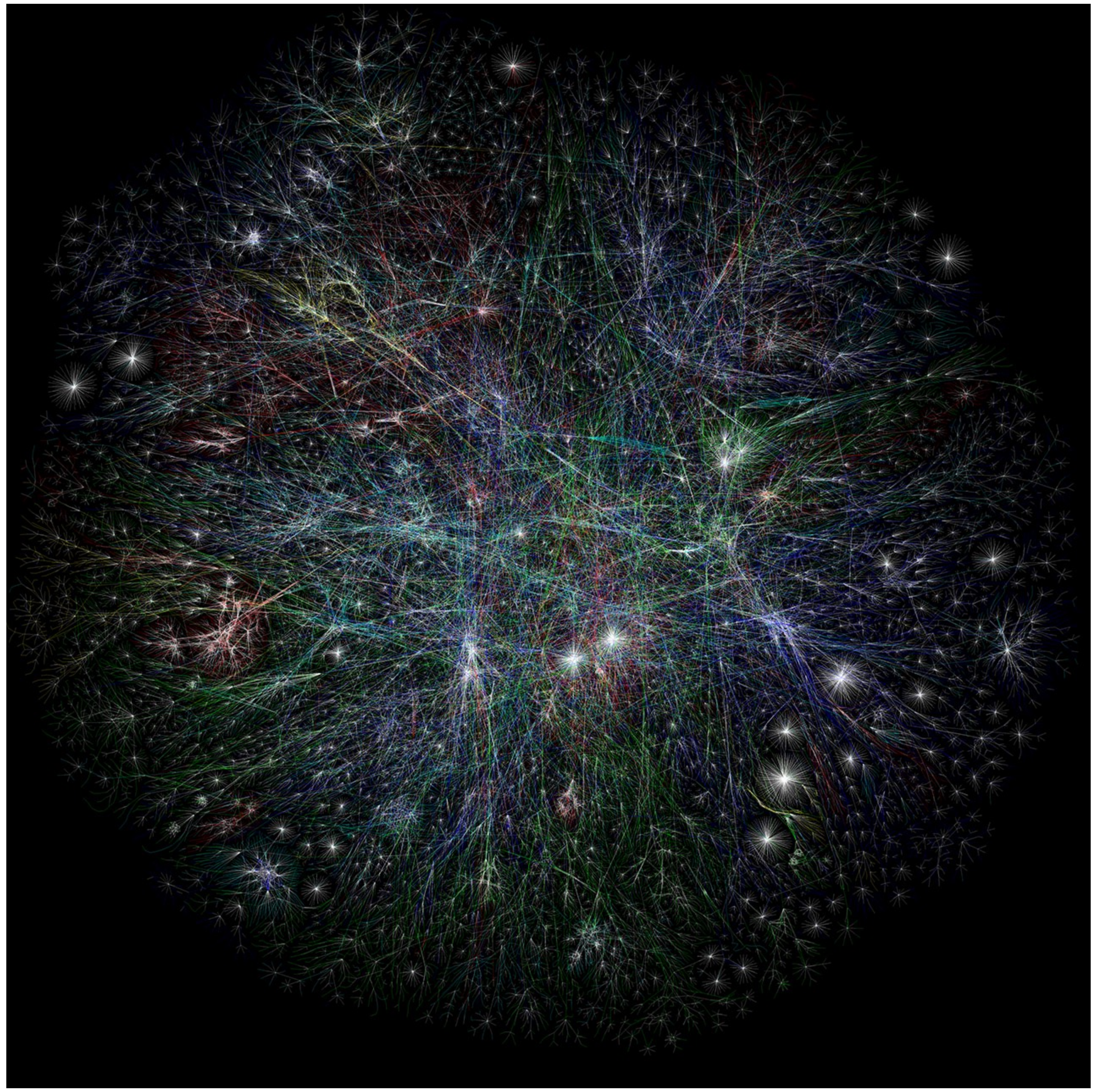
1970s-1980s

1970s-1980s

1970s-1980s



2000s-2010s



2000s-2010s


cingular
9:41 AM
SMS
Text
Tuesday
9
Calendar
Photos
Camera
Calculator
Stocks
280
Maps
73°
Weather
Notes
Clock
Settings
Phone
Mail
Web
iPod

2000s-2010s


cingular
9:41 AM
SMS
Text
Tuesday
9
Calendar
Photos
Camera
Calculator
Stocks
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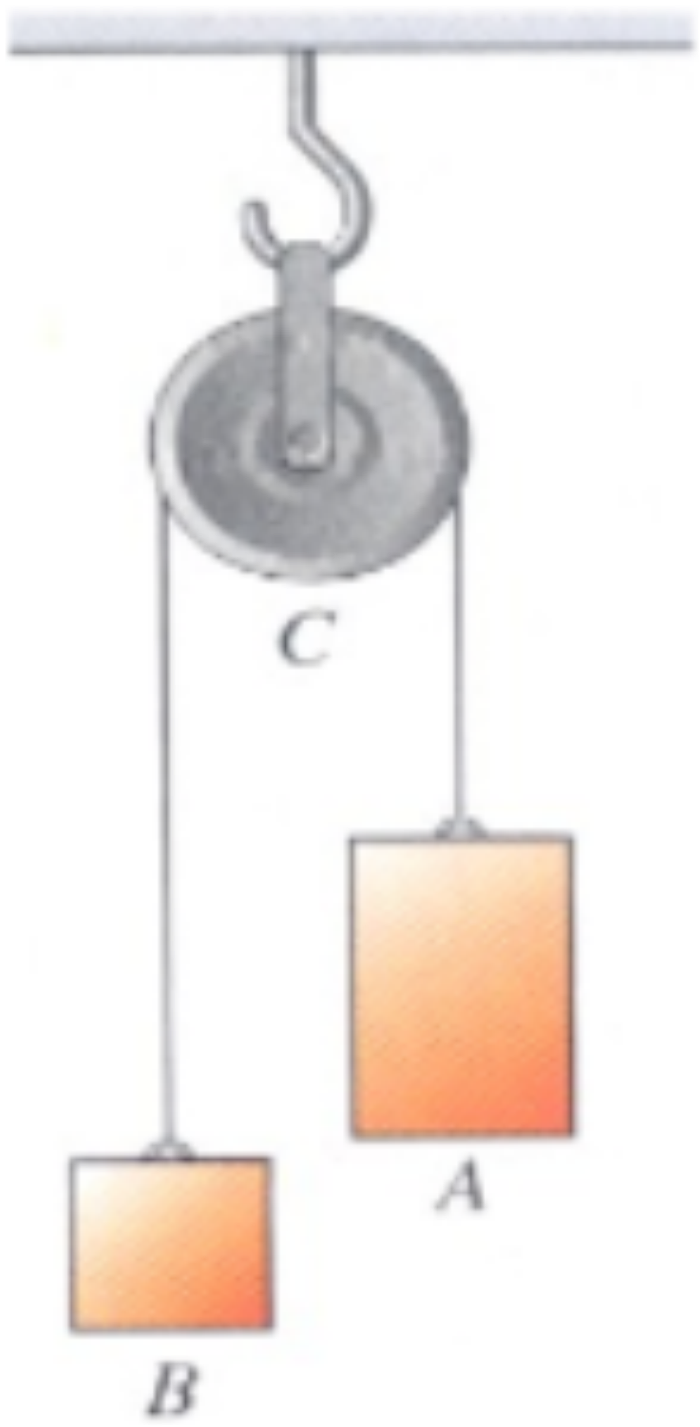
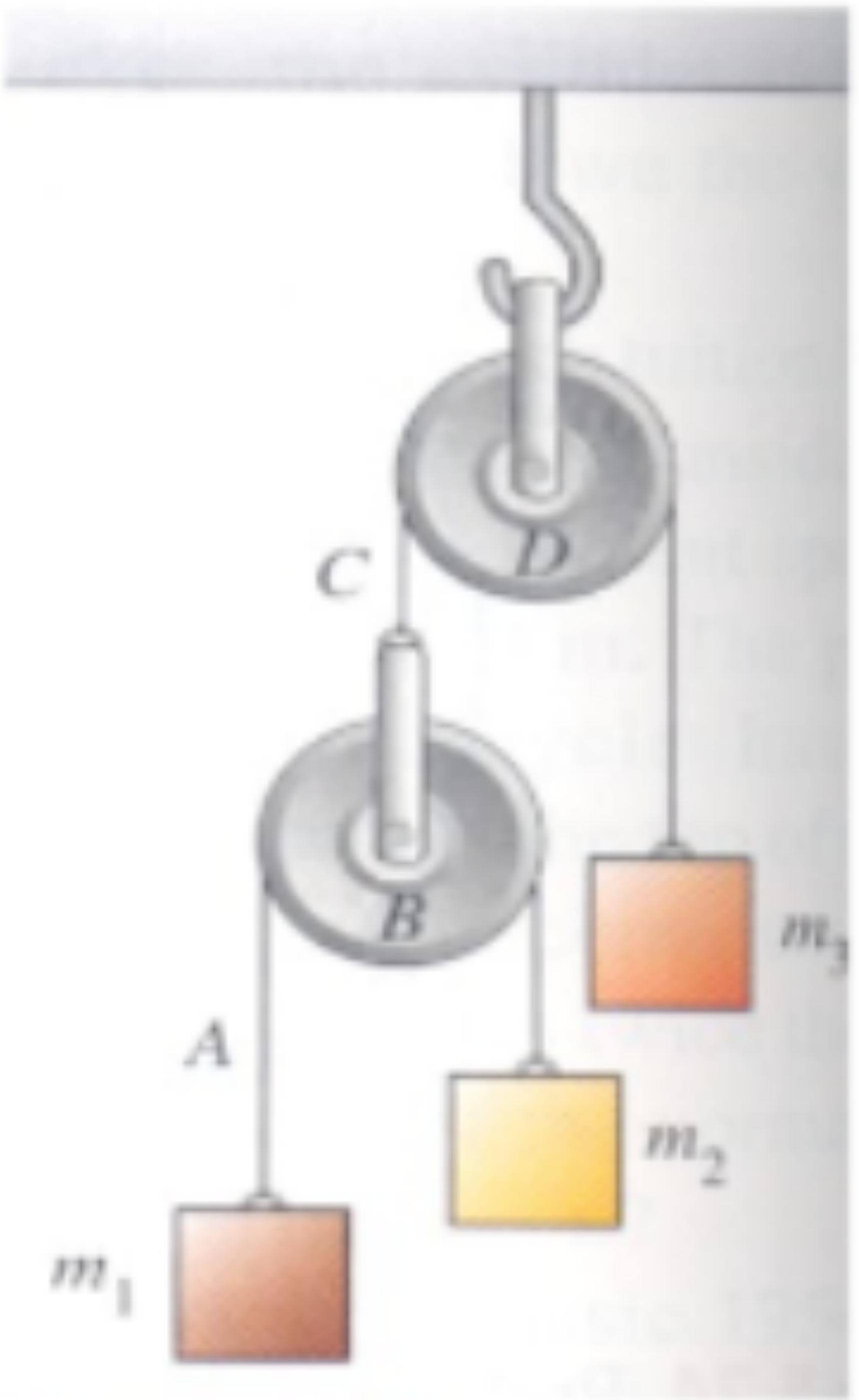
Maps
73°
Weather
Notes
Clock
Settings
Phone
Mail
Web
iPod


C
A
B


C
D
B
A
m_3
m_2
m_1

Physics education requires a computational education

$\left.\frac{\partial Q}{\partial t}\right)$

$|1\,0\rangle=\frac{1}{\sqrt2}(\uparrow\downarrow+\downarrow\uparrow)$

$|1\,{-1}\rangle=\downarrow\downarrow$

triplet, symmetric, lower energy

singlet

$|s\,m\rangle=\sum_{m_1+m_2=m} C^{s_1 s_2 s}_{m_1 m_2 m}|s_1\,m_1\rangle|s_2\,m_2\rangle$

$i\hbar\frac{\partial\chi}{\partial t}=\hat H\chi$, $\chi(t)=a\chi_+e^{i\gamma B_0 t/2}+b\chi_-e^{-i\gamma B_0 t/2}$, $H=-\vec\mu\cdot\vec B=-\gamma\vec S\cdot\vec B$

$\det(A-\mathbb{I}\lambda)=0$, $H\psi=E\psi$, $\chi=a\chi_++b\chi_-$

$n=0,$ $l=0,$ $m_l=$ $m_j=$ $m_s=$

$\psi_n^1=\sum_{m\neq n}\frac{\langle\psi_m^0|H'|\psi_n^0\rangle}{(E_n^0-E_m^0)}\psi_m^0$, $E_n^2=\sum_{m\neq n}\frac{|\langle\psi_m^0|H'|\psi_n^0\rangle|^2}{E_n^0-E_m^0}$, $E_\pm^1=\frac12\left[W_{aa}+W_{bb}\pm\sqrt{(W_{aa}-W_{bb})^2+4|W_{ab}|^2}\right]$

$j=(l+s),($

fine structu

$\begin{pmatrix}\alpha\\ \beta\end{pmatrix}=E_1\begin{pmatrix}\alpha\\ \beta\end{pmatrix}$, $W_{ij}=\langle\psi_i^0|H'|\psi_j^0\rangle$

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

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

$m_j)$: $E_{nj}=\frac{-13.6\,eV}{n^2}\left[1+\frac{\alpha^2}{n^2}\left(\frac{n}{j+1/2}-\frac34\right)\right]$ ← (i), $\alpha=\frac{e^2}{4\pi\epsilon_0\hbar c}$

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

$\int_a^b f\frac{dg}{dx}dx=fg|_a$

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

$\int_{-\infty}^{\infty}e^{-abx^2}dx=$

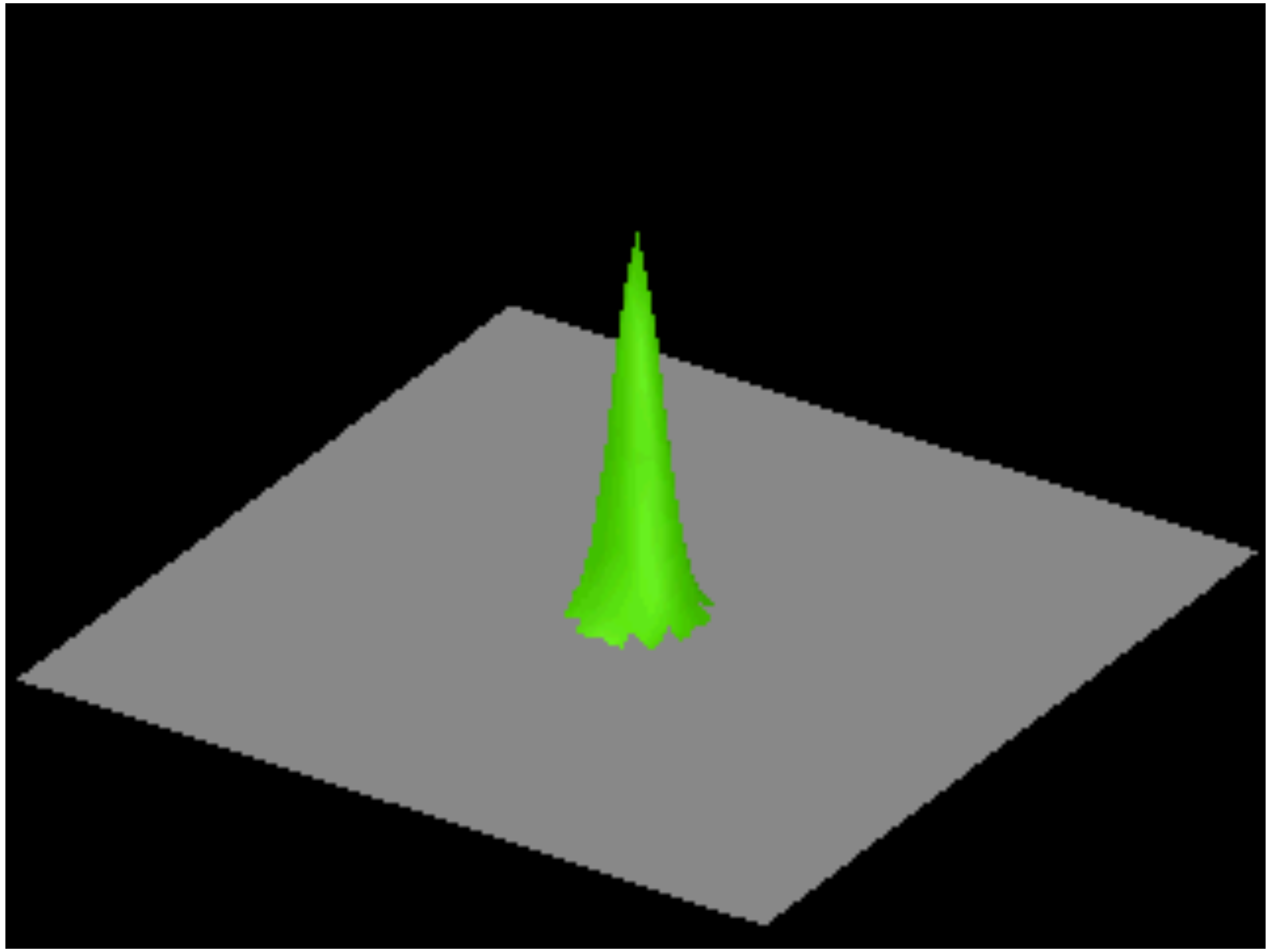
$)$, $E_{n,m_l,m_s}=\frac{-13.6\,eV}{n^2}+\mu_B B_{ext}(m_l+2m_s)$ ← (iii), $E_{fs}^1=\frac{13.6\,eV\alpha^2}{n^3}\left\{\frac{3}{4n}-\left[\frac{l(l+1)-m_lm_s}{l(l+1/2)(l+1)}\right]\right\}$ ← (iv), $E_{tot}(strong)=$ (iii) + (iv)

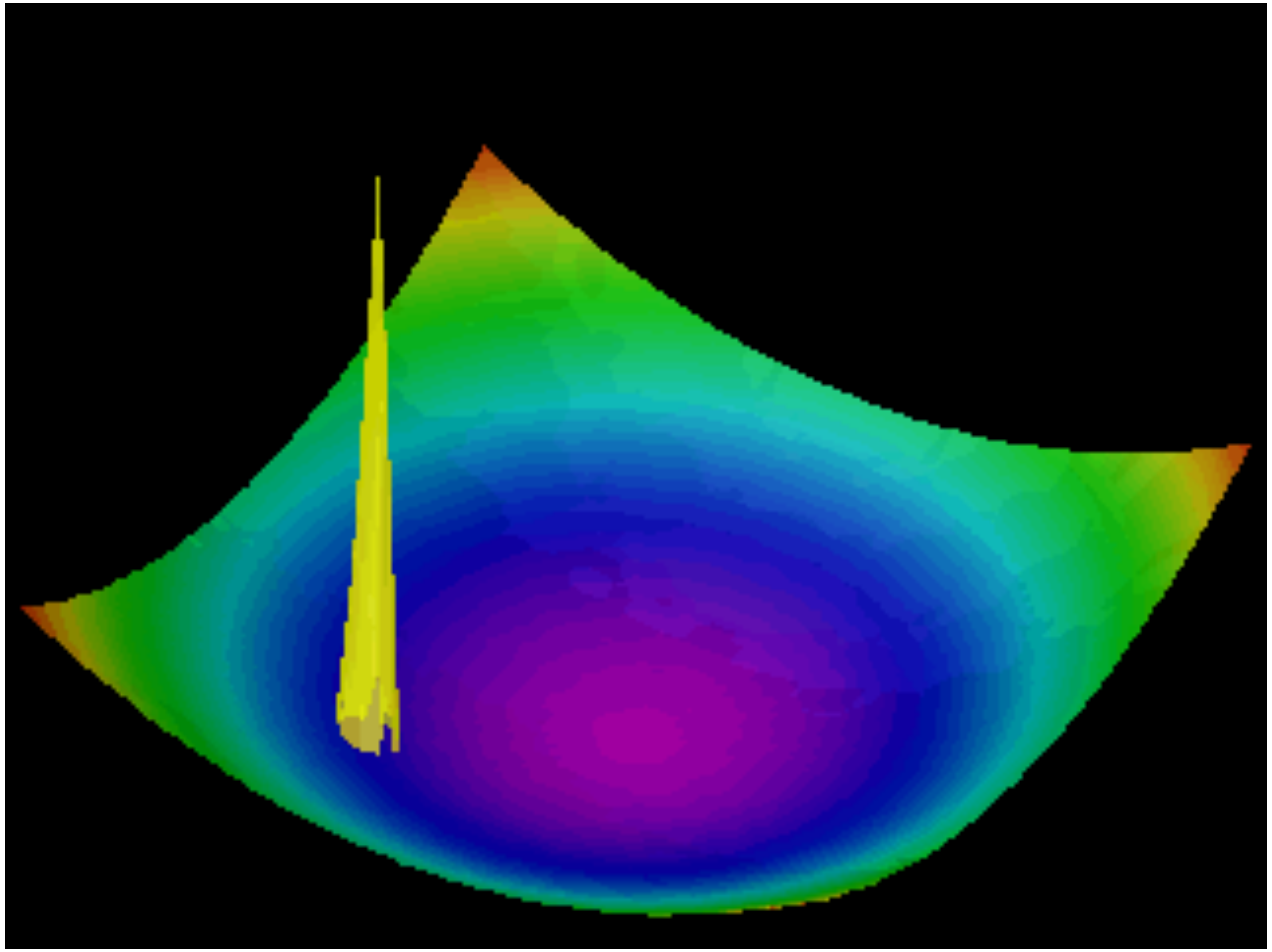
$e^{\pm i\theta}=\cos\theta\pm$

$m_j)$, $H'=H_Z'+H_{FS}'=\frac{e\hbar}{2m}B_{ext}(m_l+2m_s)+\frac{13.6\,eV}{64}\alpha^2\left(3-\frac{8}{j+1/2}\right)$

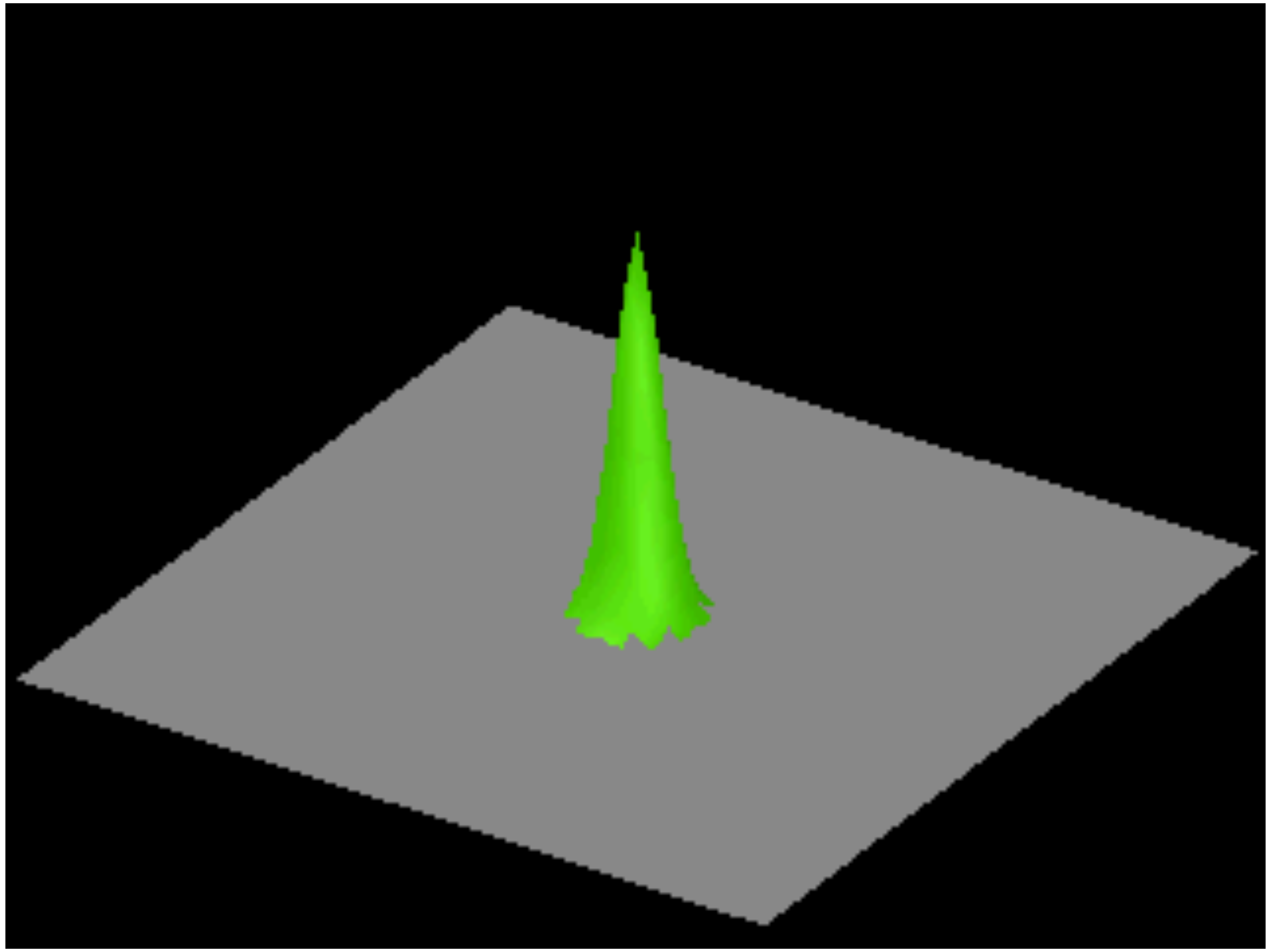
$\cos\theta=\frac12(e^{i\theta}$

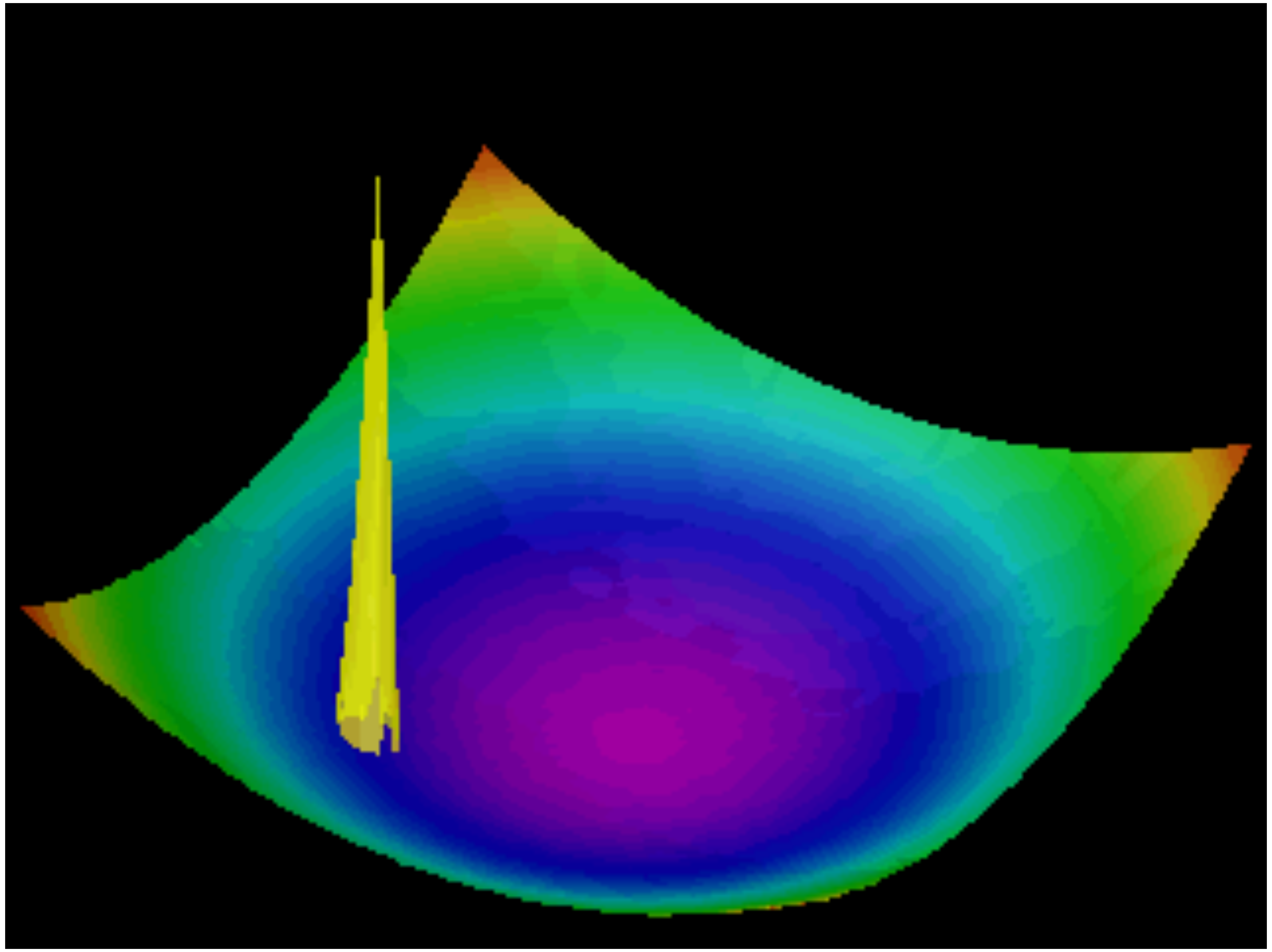
$\sin\theta=\frac{1}{2i}(e^{i\theta}$





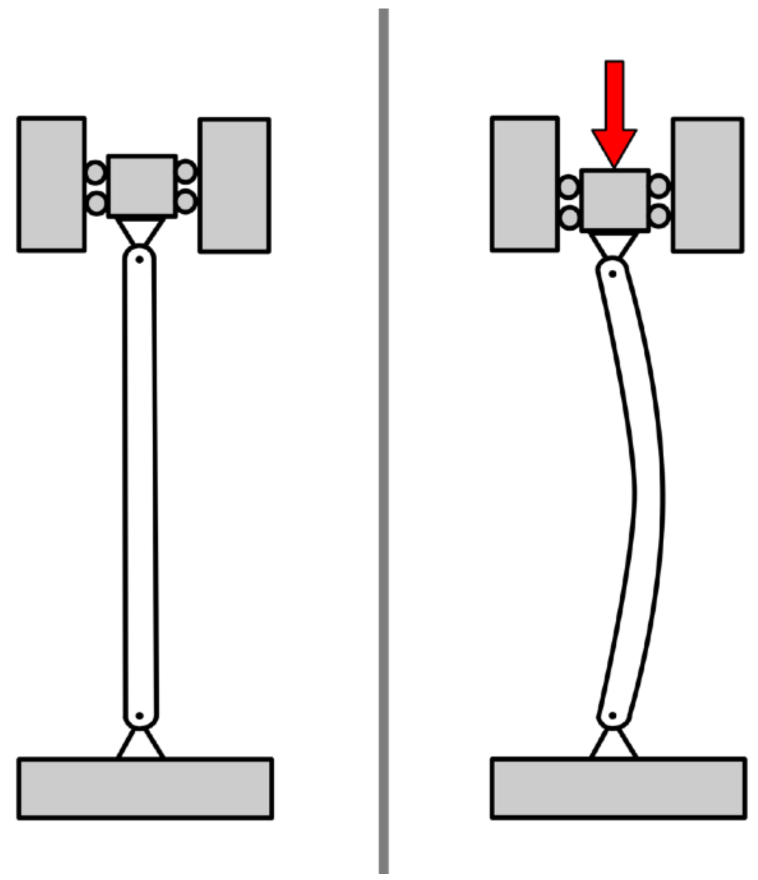
Michielson and De Raedt, 2012





Michielson and De Raedt, 2012

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



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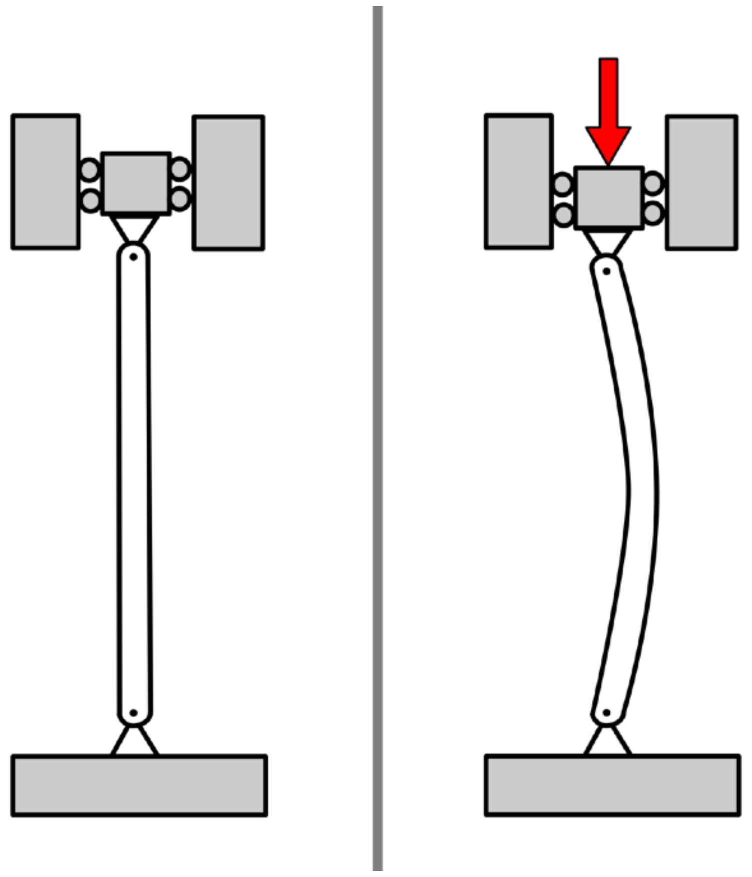

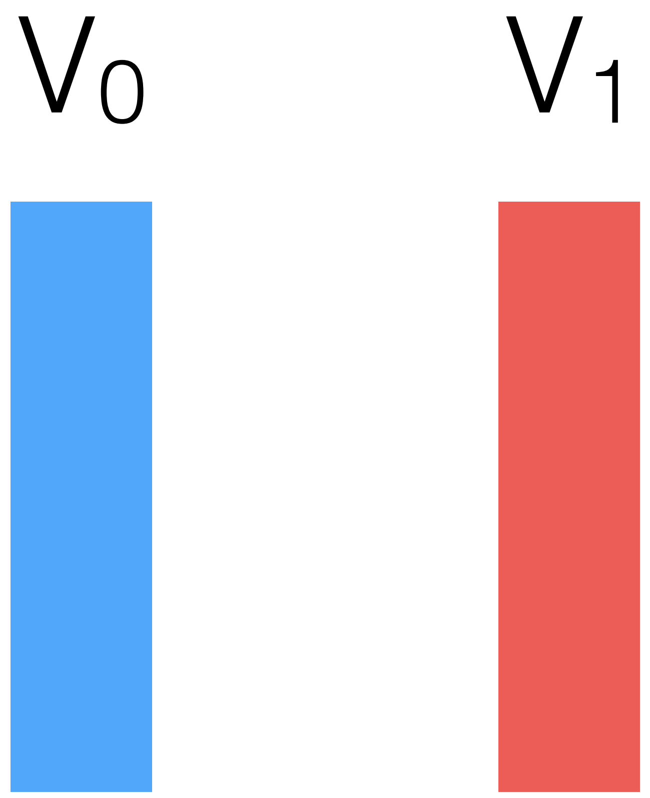

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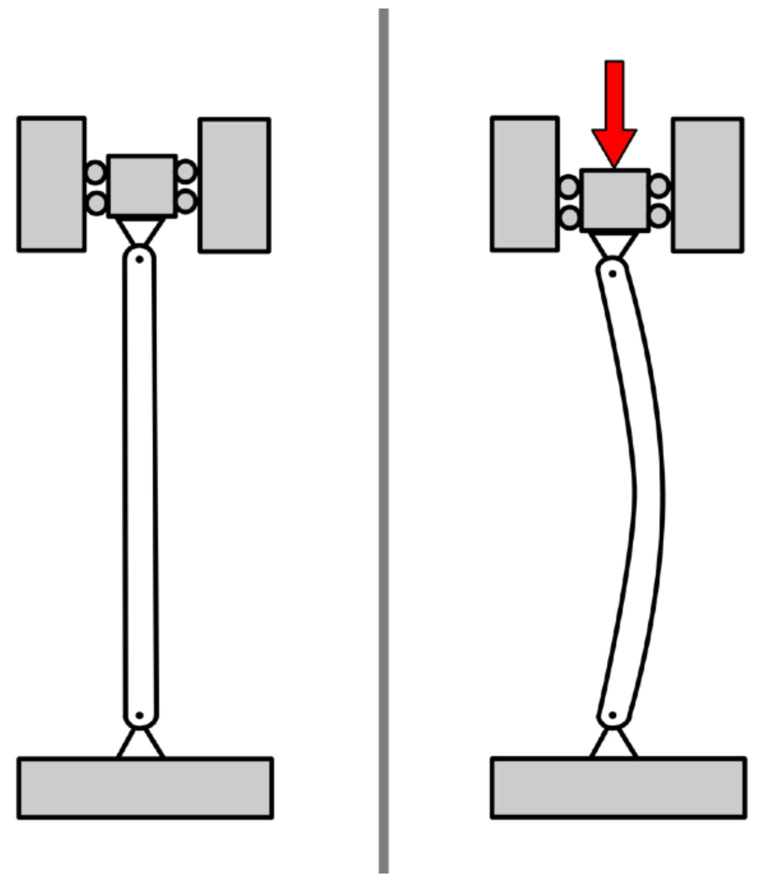

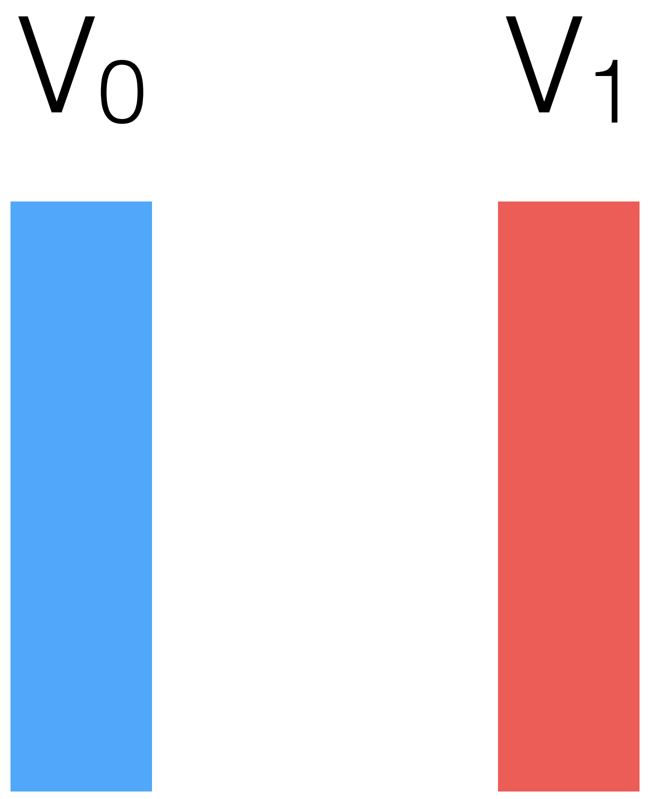

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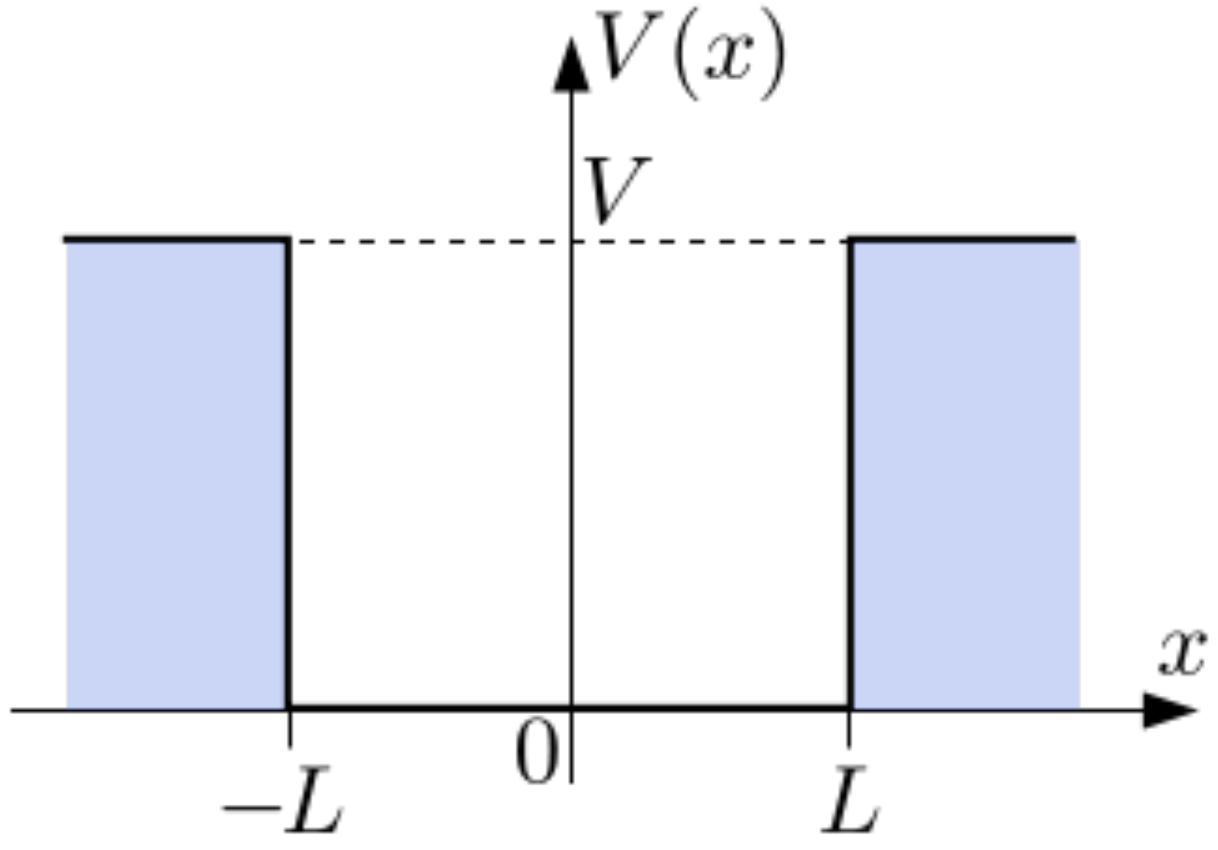

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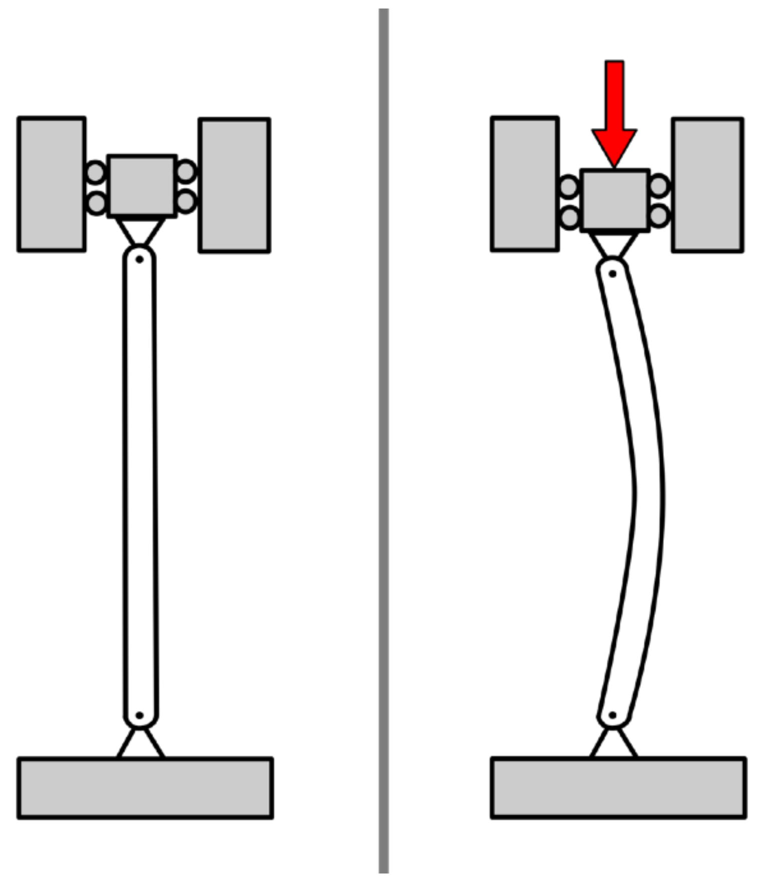
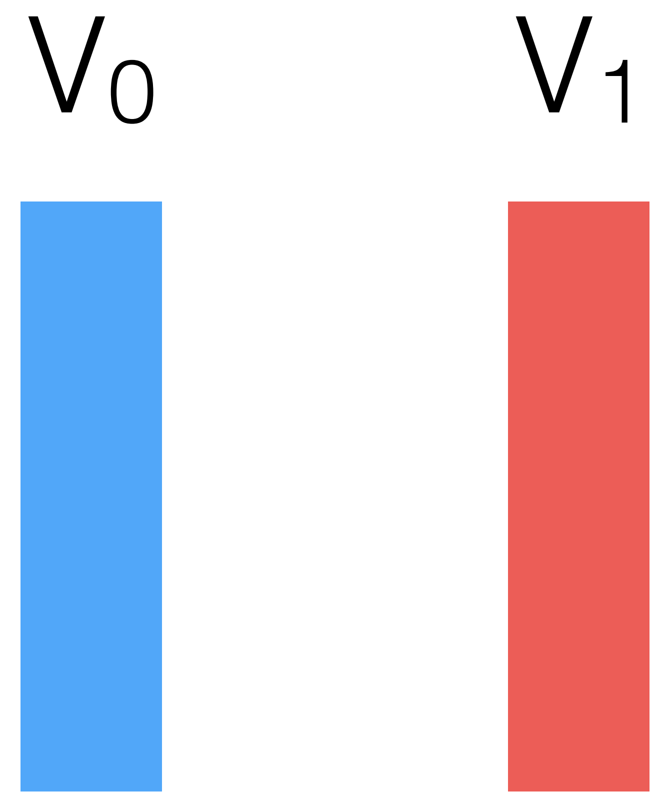
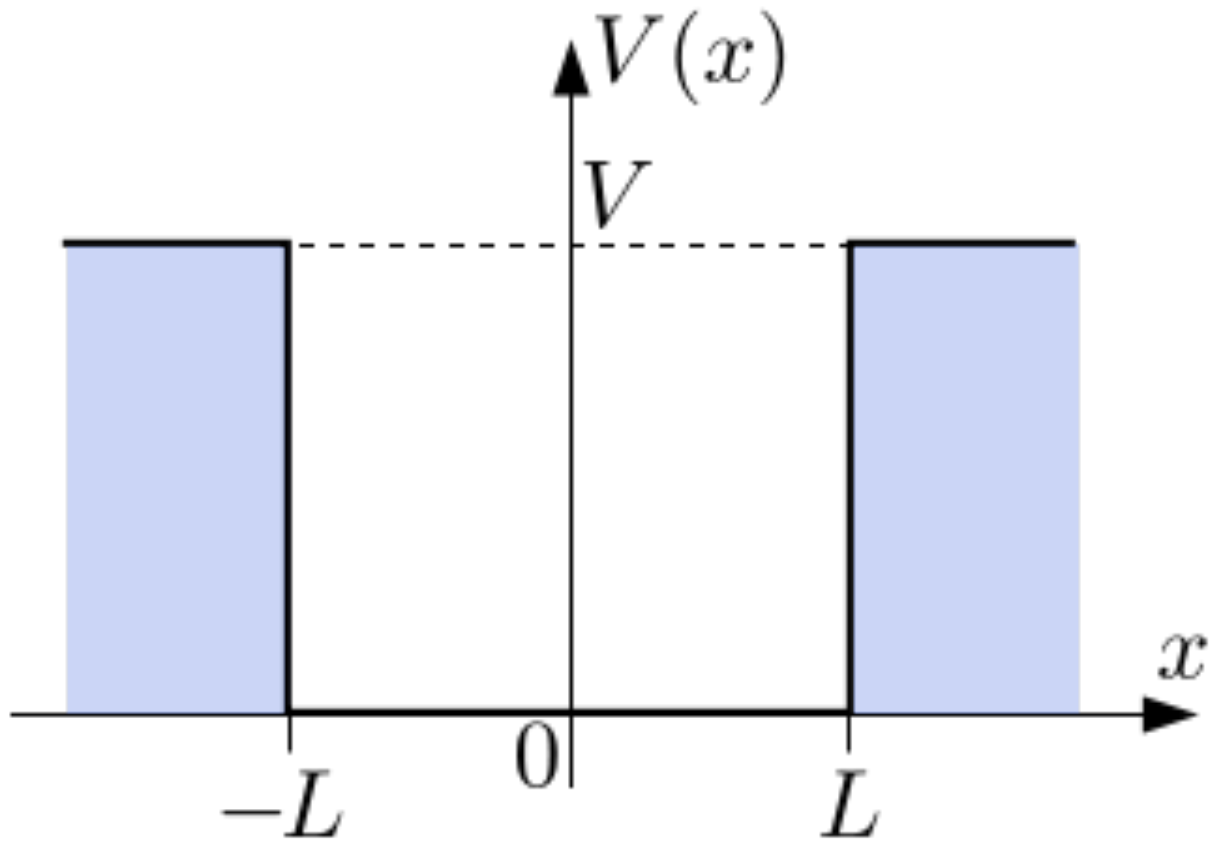
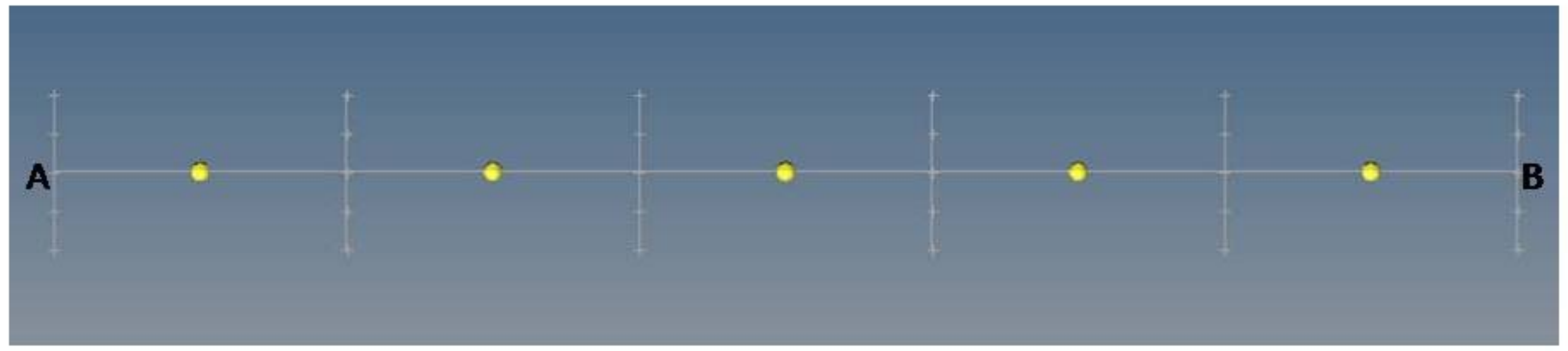
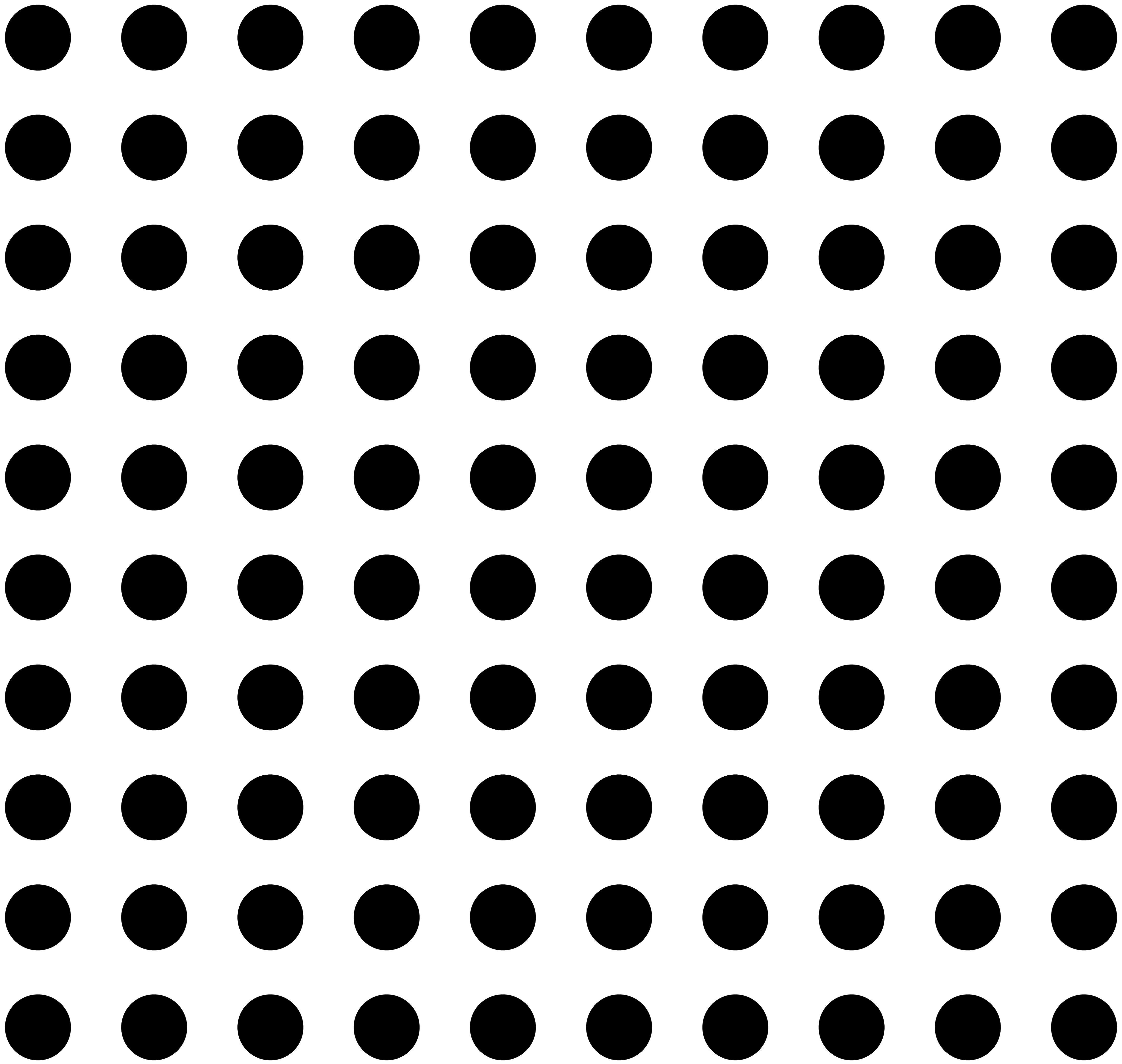






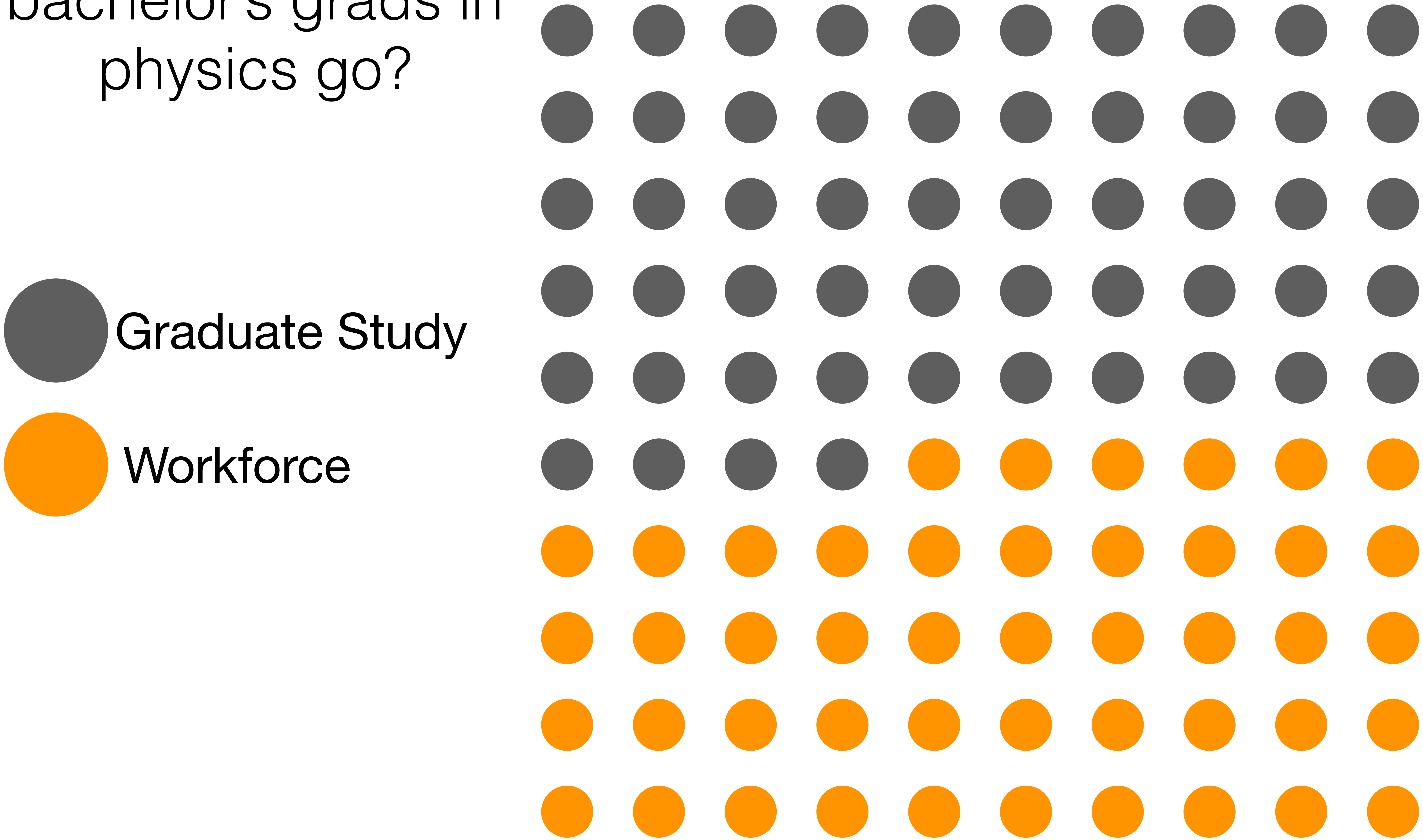


Consider 100 US Physics Bachelor's graduates



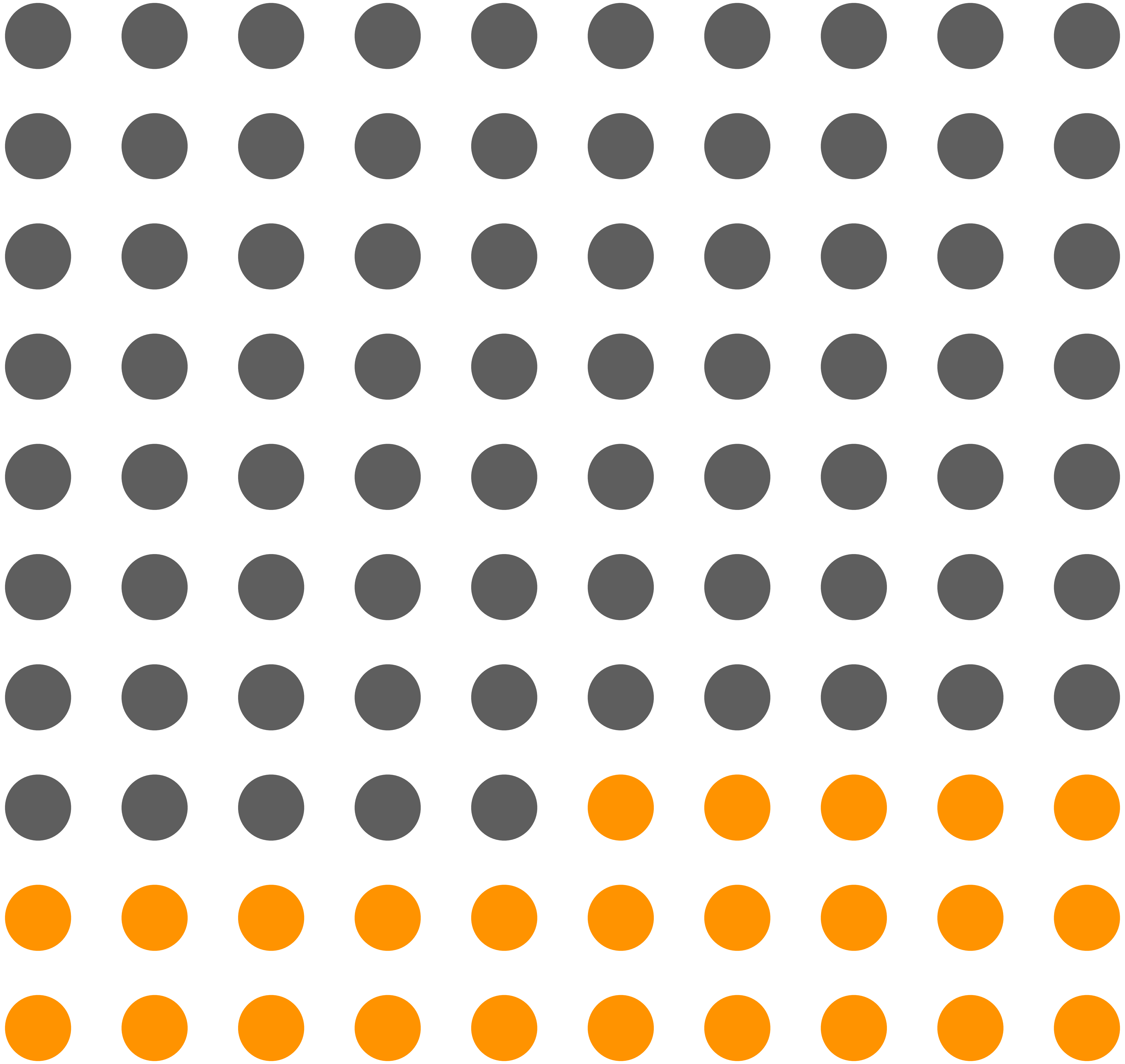
2013 & 2014 Graduates, AIP

In the US, where do bachelor's grads in physics go?



2013 & 2014 Graduates, AIP

In the US, what are bachelor's graduates doing?

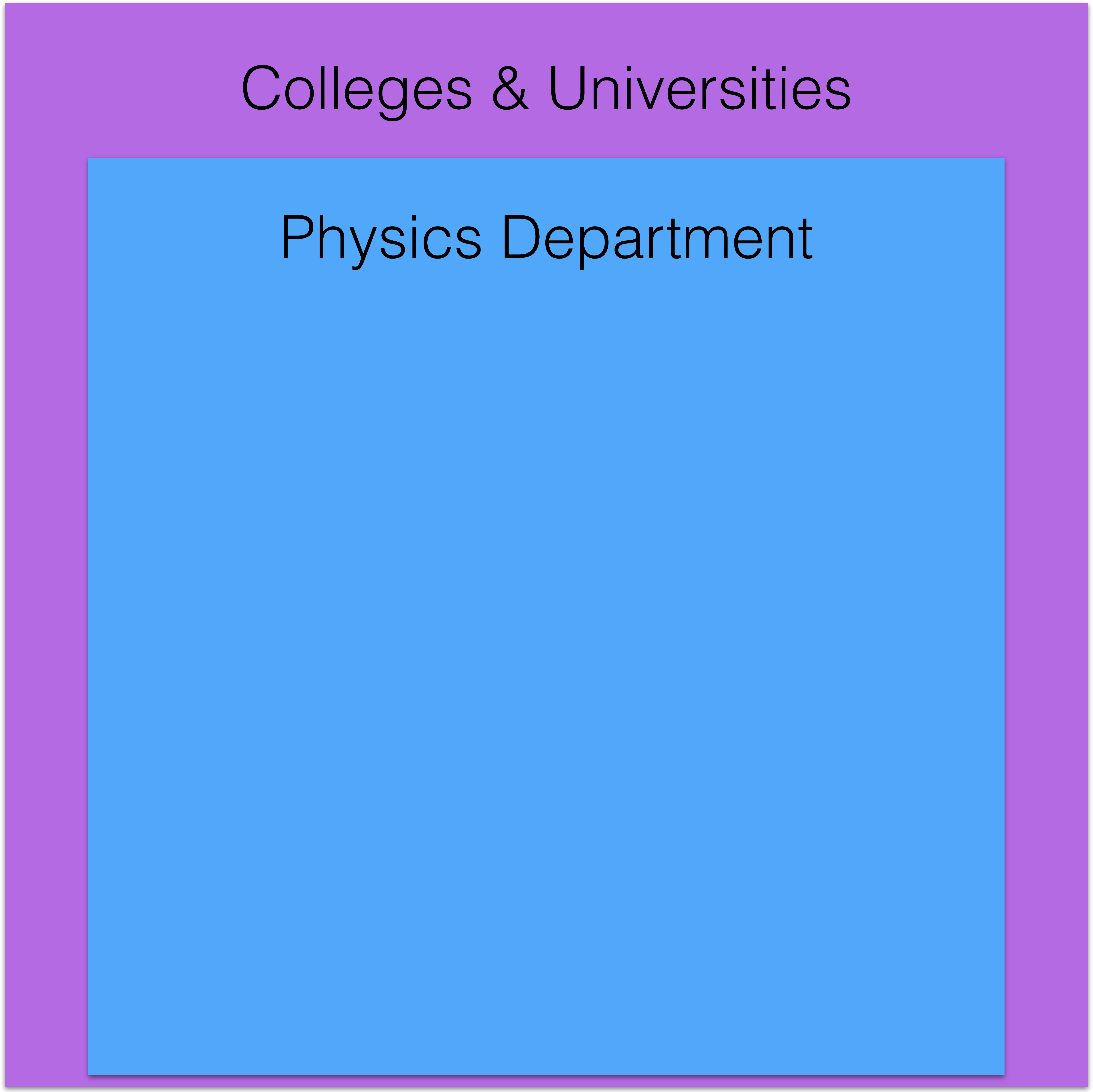


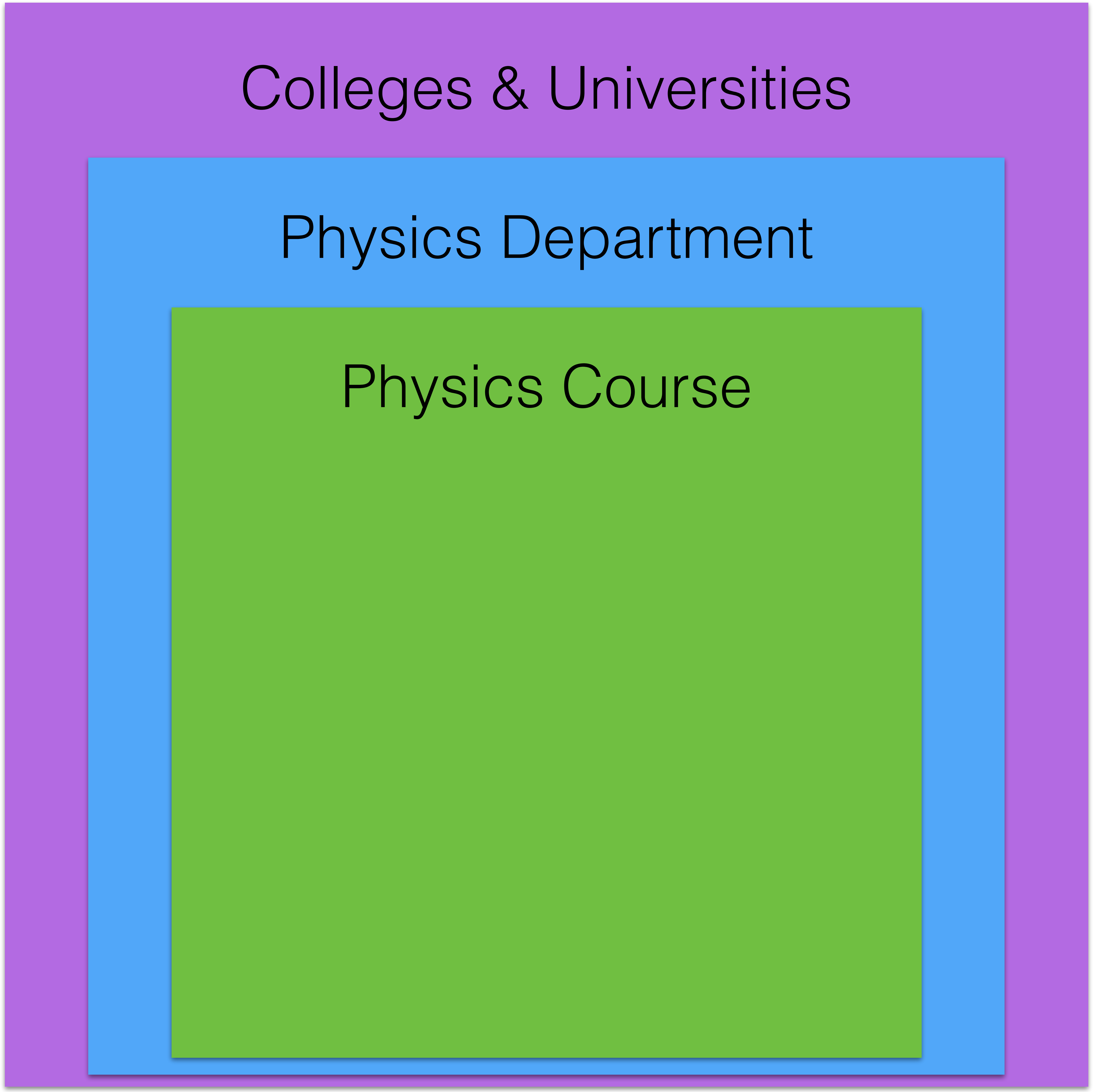
2013 & 2014 Graduates, AIP

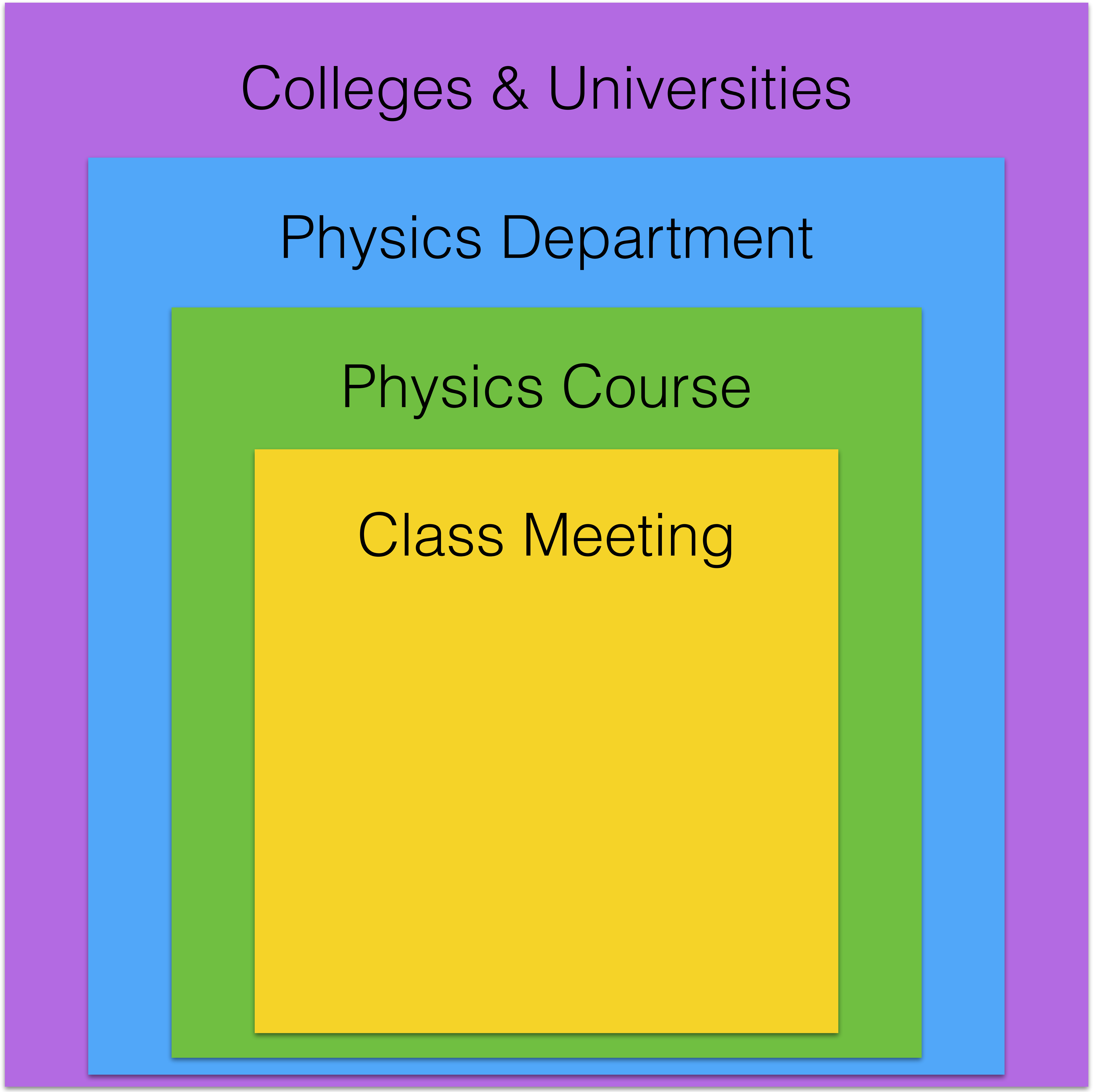
Ok, so how do we integrate computation into physics courses?

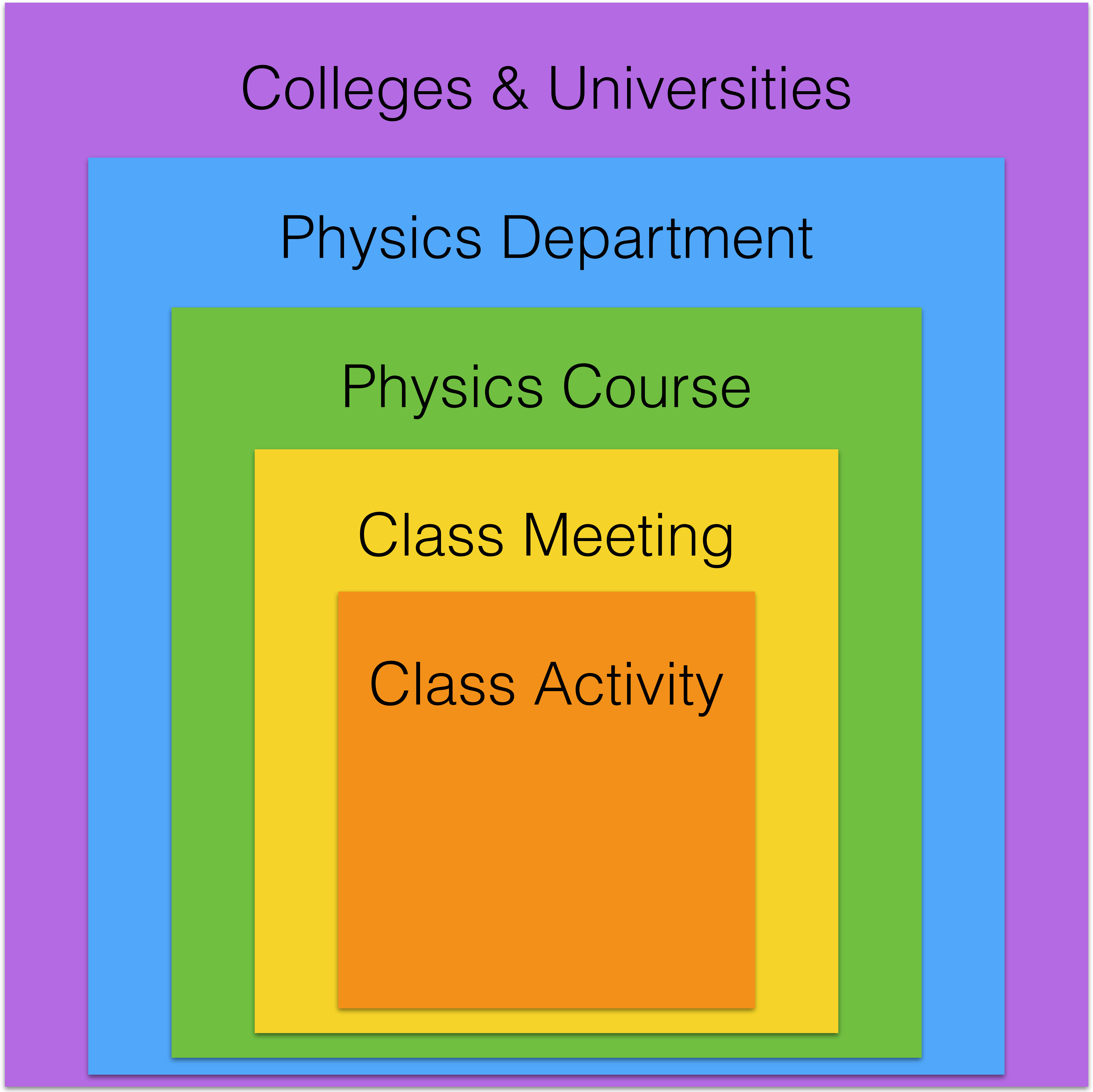
Answer: It's complicated

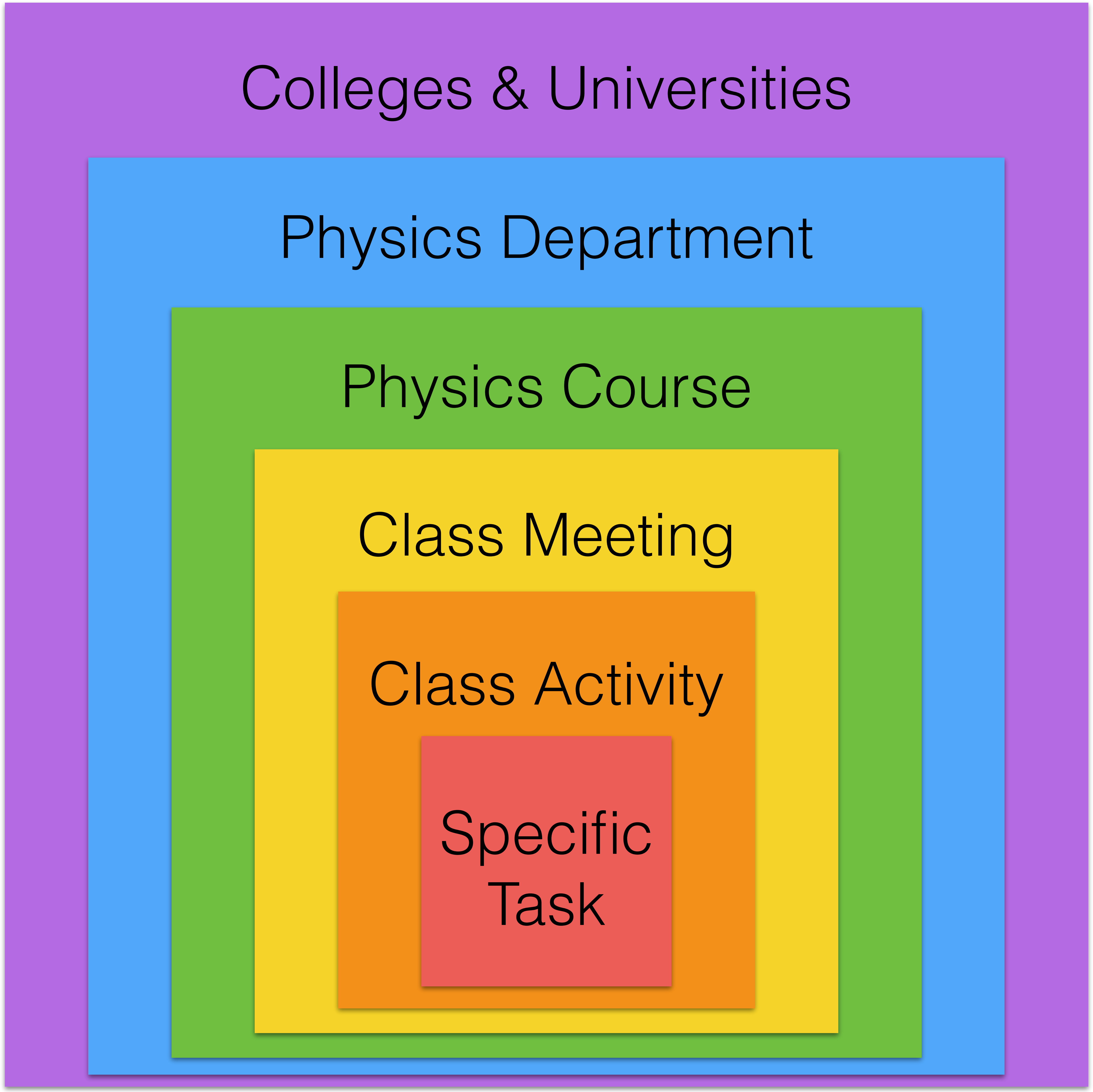
Colleges & Universities

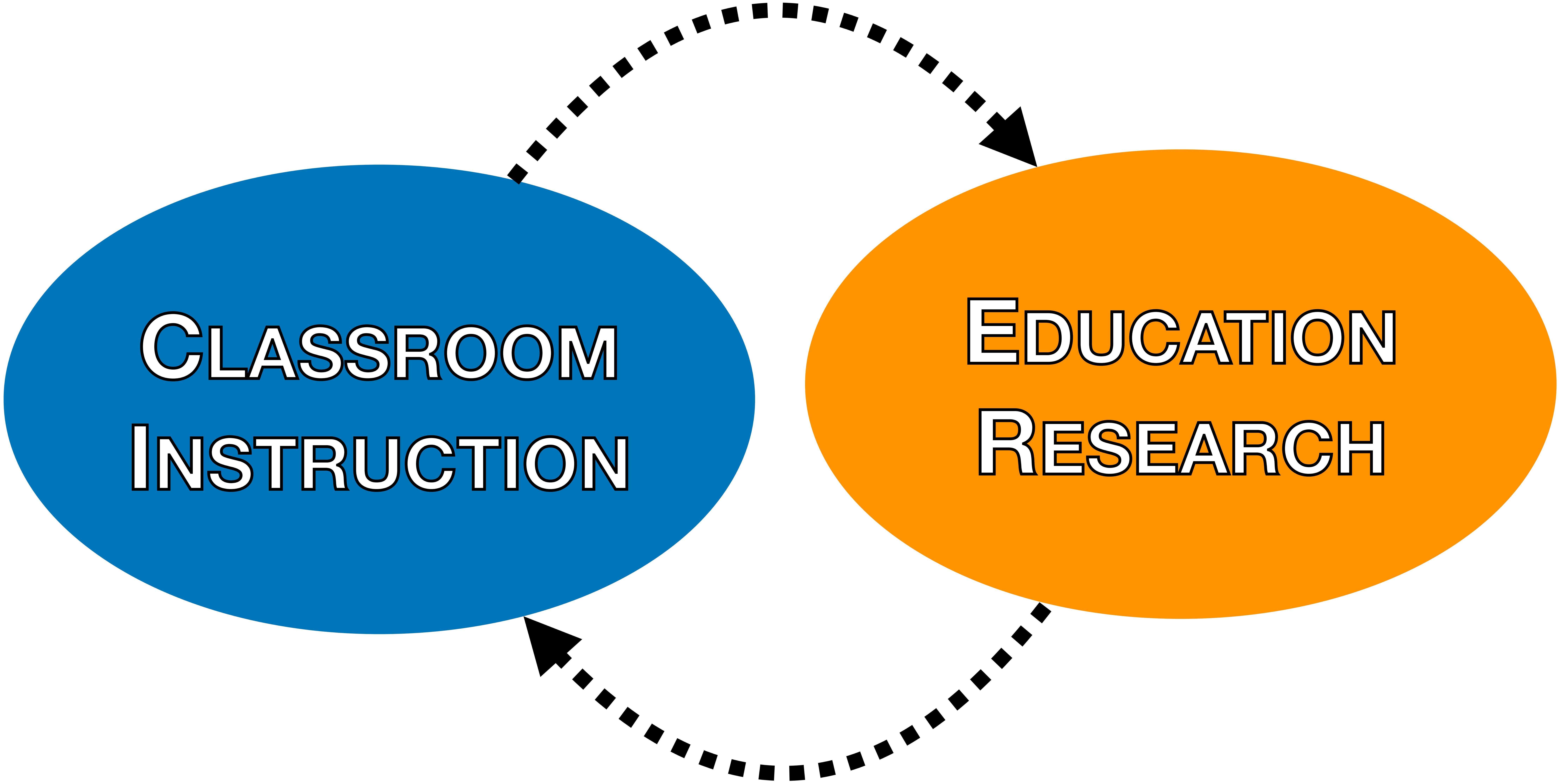

Colleges & Universities
Physics Department

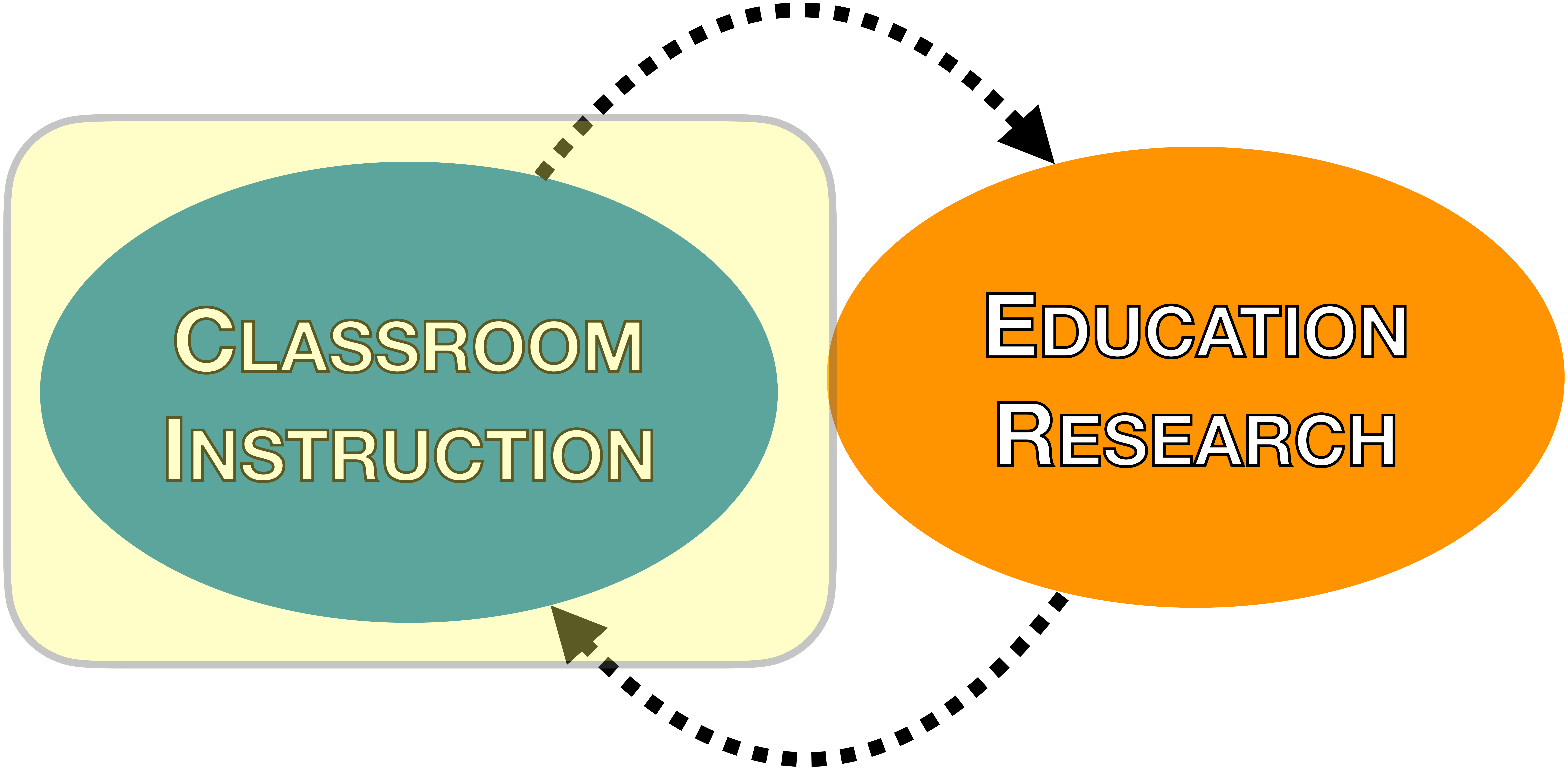

Colleges & Universities
Physics Department
Physics Course


Colleges & Universities
Physics Department
Physics Course
Class Meeting


Colleges & Universities
Physics Department
Physics Course
Class Meeting
Class Activity


Colleges & Universities
Physics Department
Physics Course
Class Meeting
Class Activity
Specific Task


Classroom Instruction
Education Research


Classroom Instruction
Education Research

Numerical Computation is…

Numerical Computation is…

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

Numerical Computation is…

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

High-level computing languages +
Powerful computers

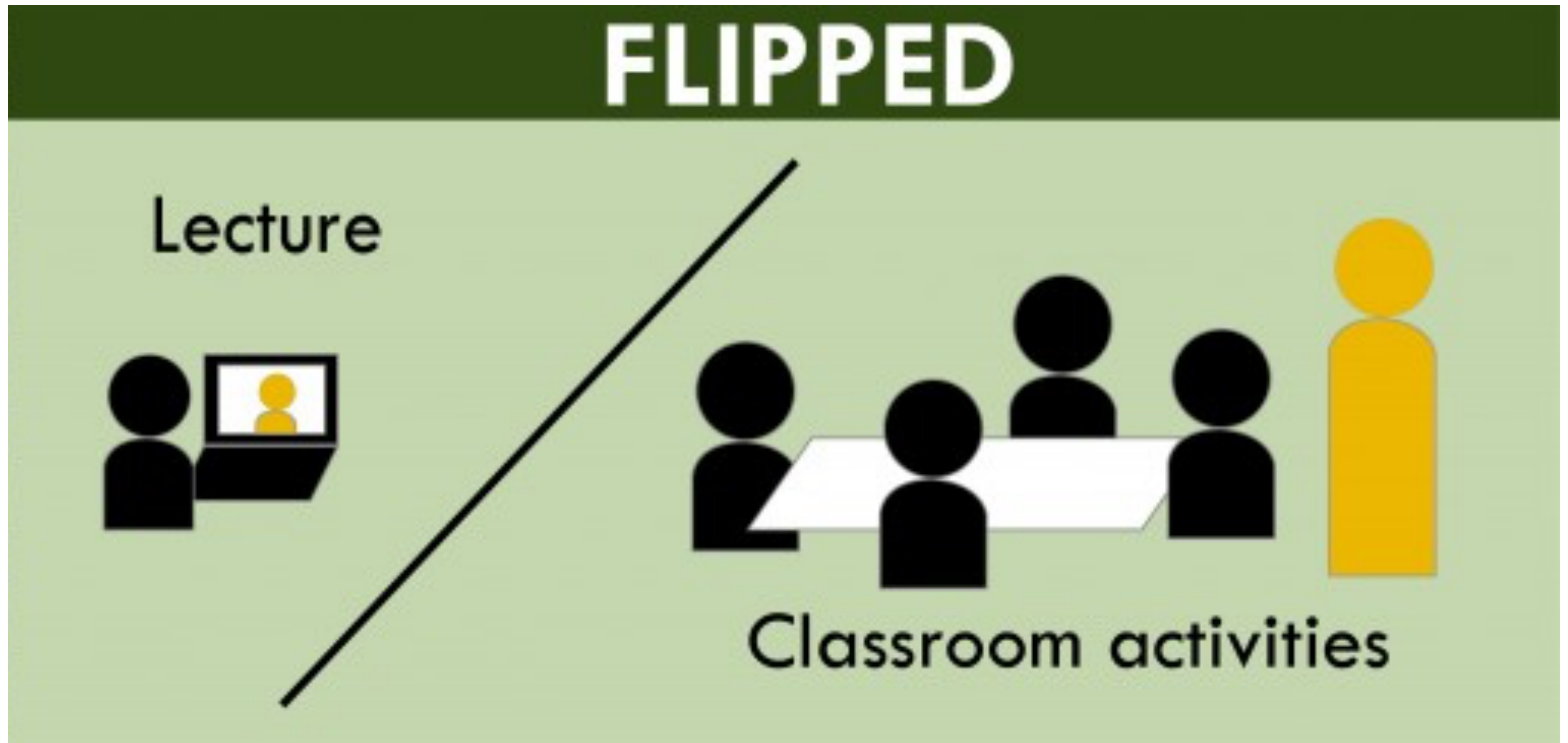
Numerical Computation is…

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

High-level computing languages +
Powerful computers

Some programming is necessary.

Interactive Computational Instruction in Physics



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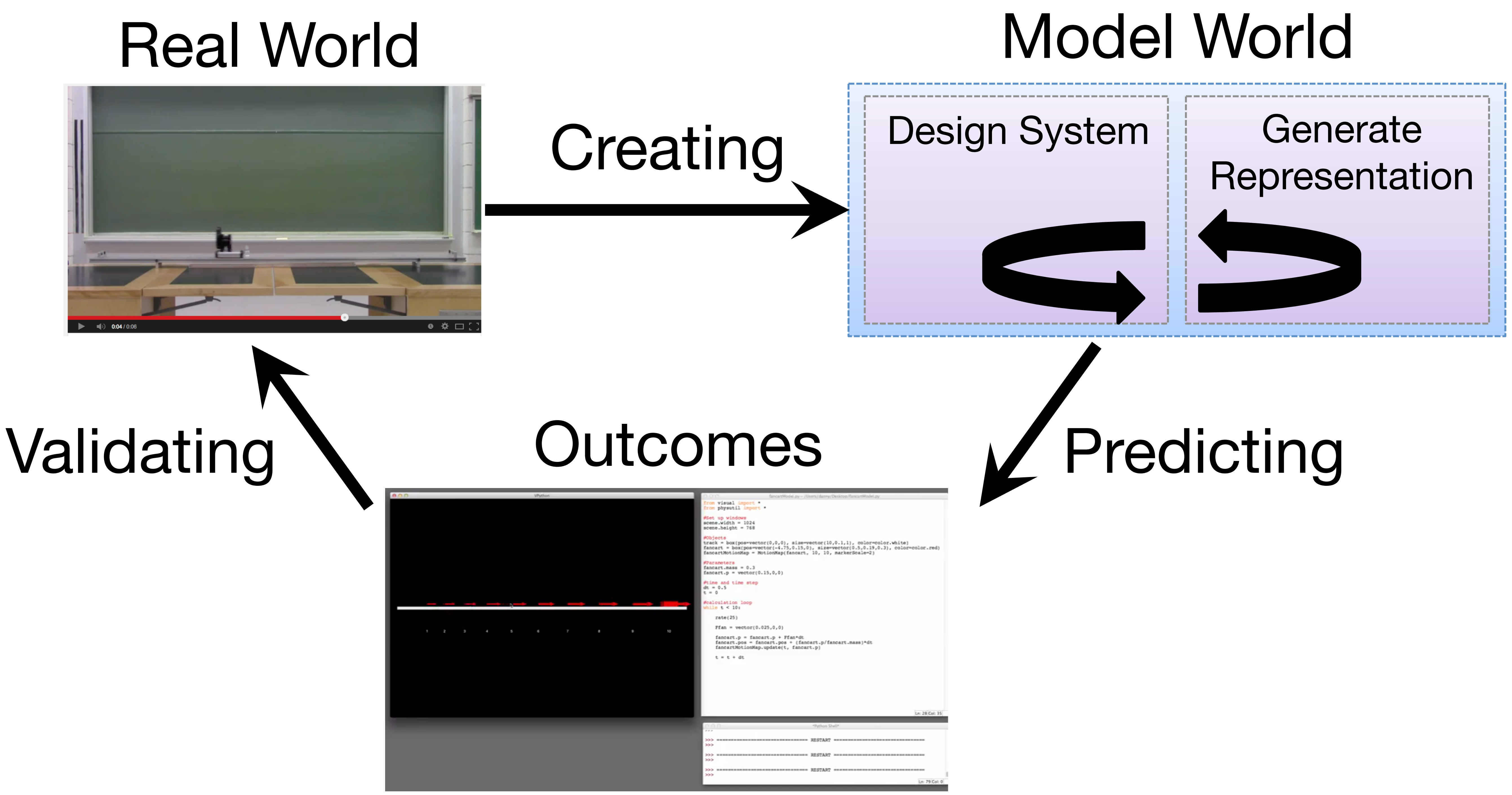
msuperl.org/wikis/pcubed/

MICHIGAN STATE UNIVERSITY

Irving, Obsniuk, & Caballero, EJP (2017)

Projects and Practices in Physics (P^3)

Course design: Modeling cycles



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Projects & Practices in Physics

a community-based learning environment

Table of Contents

Non-constant Force: Newtonian Gravitation

Earlier, you read about the gravitational force near the surface of the Earth. This force was constant and was always directed "downward" (or rather toward the center of the Earth). In these notes, you will read about Newton's formulation of the gravitational force that (in his day) helped explain the motion of the solar system including why the Sun was at the center of the solar system.

Lecture Video

The Gravitational Force

Using a number of empirical observations (by Tycho Brahe and Johannes Kepler) of the motion of various astronomical objects, Isaac Newton was able to develop an empirical formula for the interactions of the those objects that could predict the future (and explain the past) motion

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

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

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

Previous Tries

Project 3: Geosynchronus Orbit: Part A

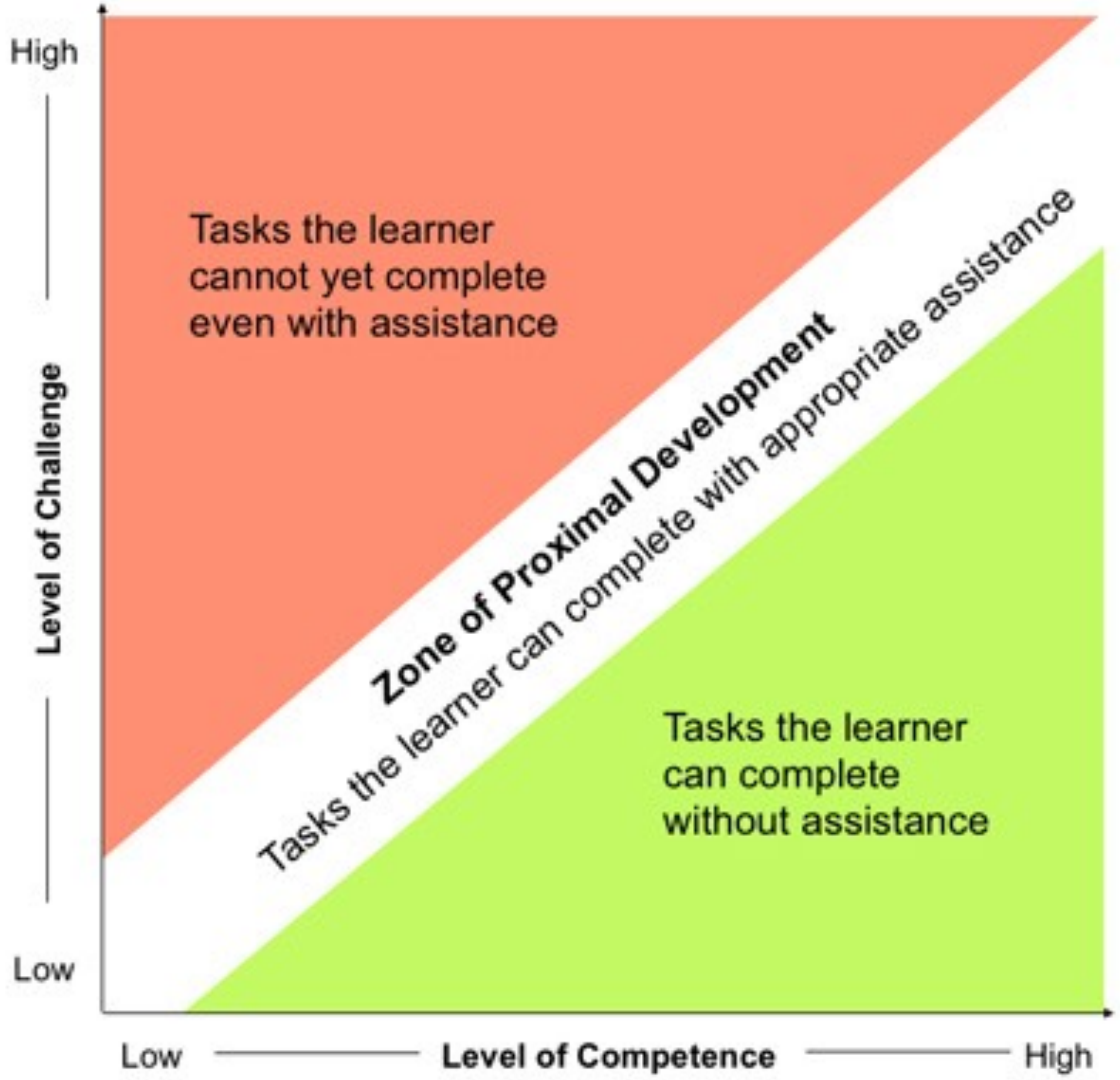
The Carver Media Group is planning the launch of a new communications satellite. Elliot Carver (head of Carver Media Group) is concerned about the launch. This is a $200,000,000 endeavor. In particular, he is worried about the orbital speed necessary to maintain the satellite's geosynchronus orbit (and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

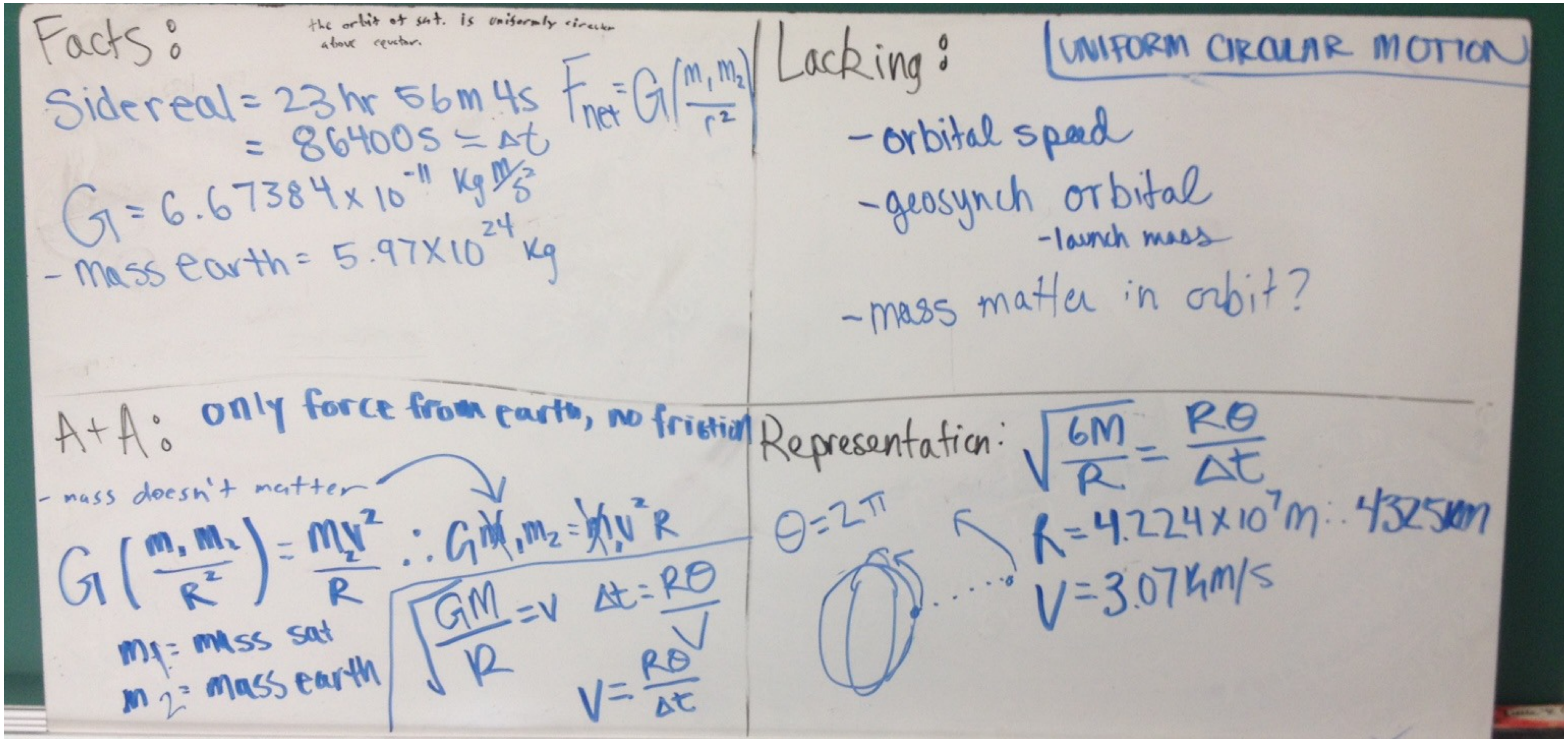
Code for Project 3:
geosync.py
PhysUtil Module

Learning Scaffolds



L. Vygotsky, *Mind in society* (1978)

Conceptual Scaffold: 4 Quadrants

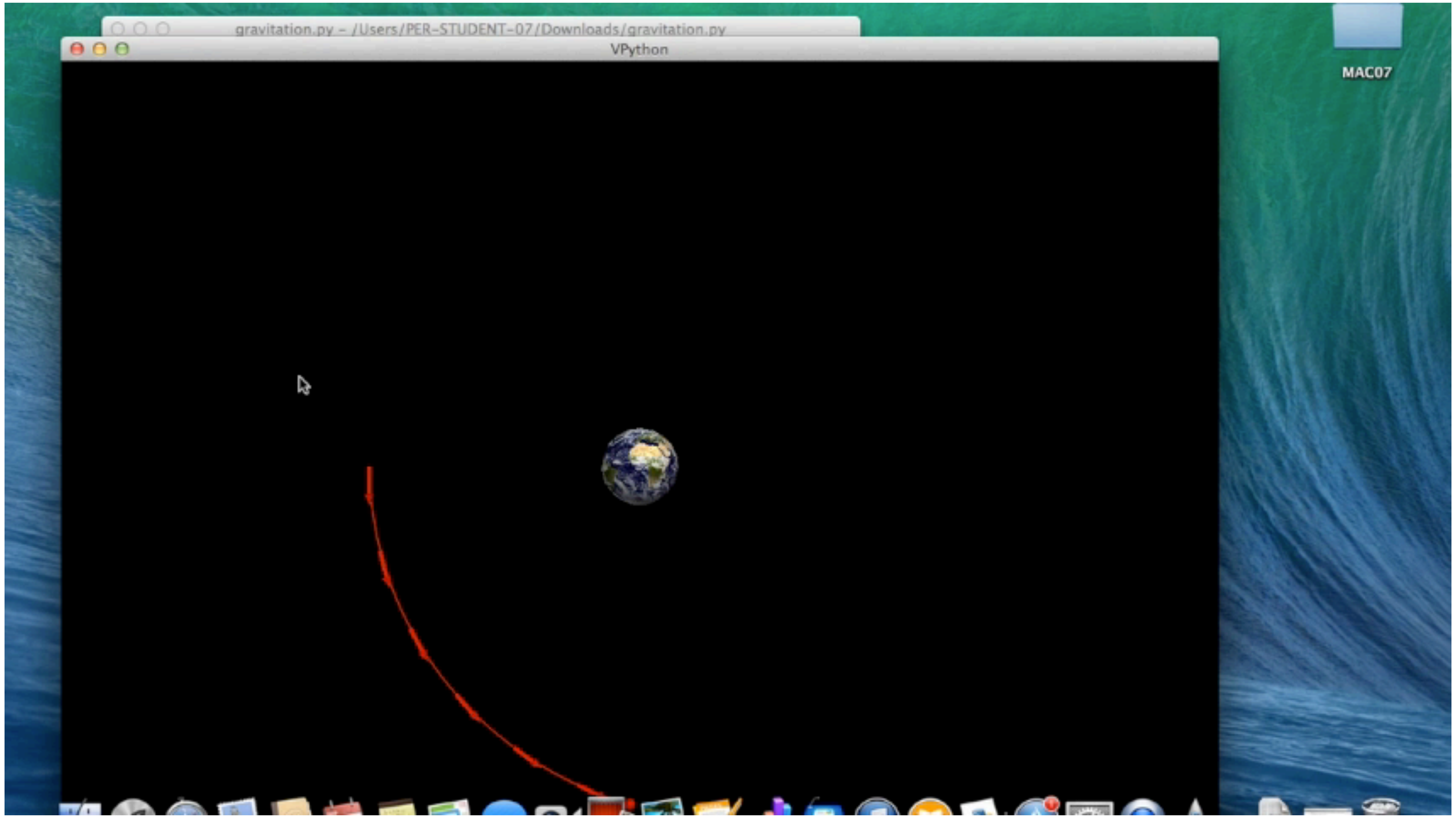


MINIMALLY WORKING PROGRAM

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

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

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

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

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

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

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

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

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

        SatelliteMotionMap.update(t, pSatellite/mSatellite)

        t = t + deltat
```

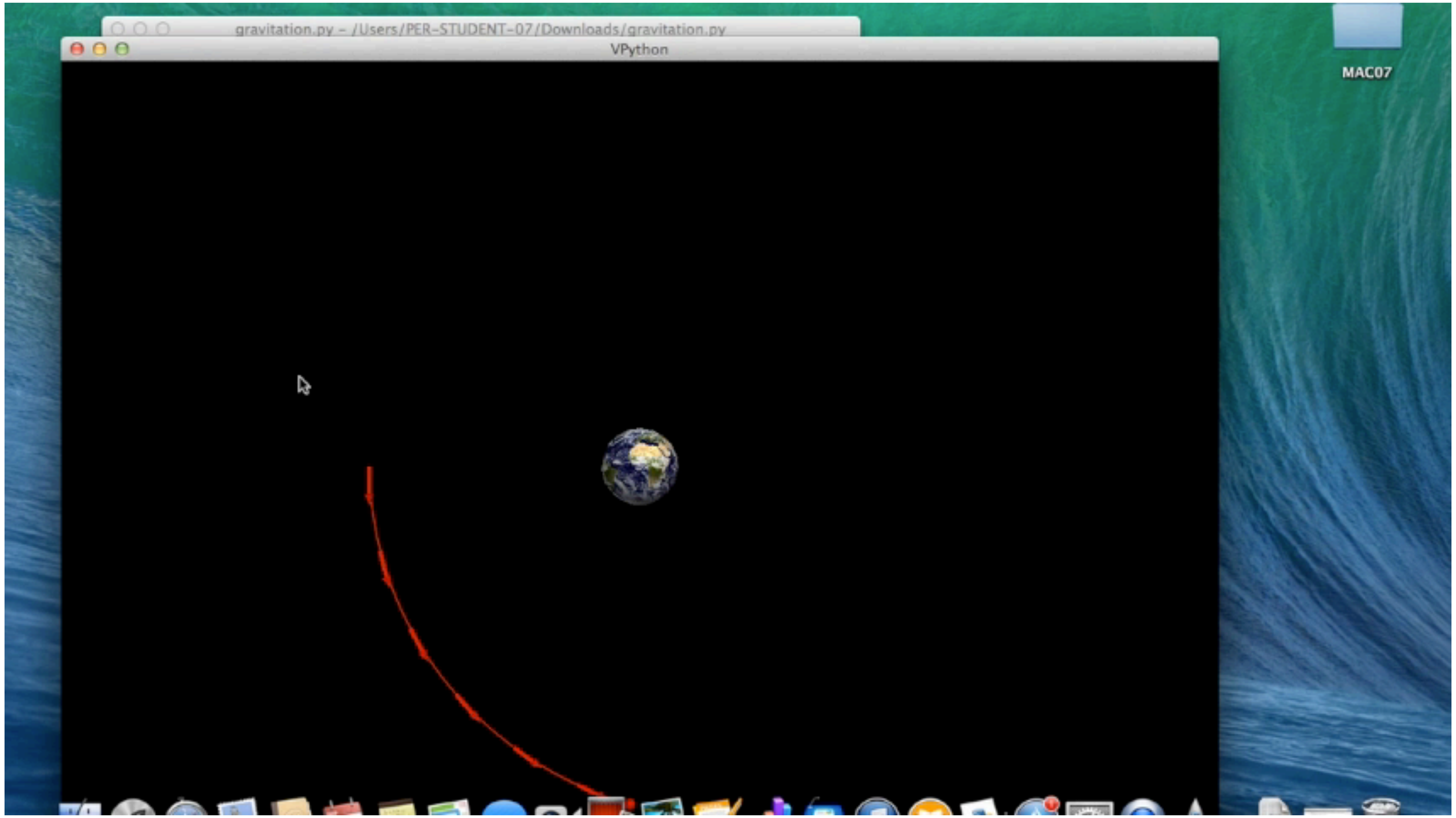
Weatherford, PhD Thesis (2011)

Students solving the Geosynchronous Orbit



Note: video is sped up a bit.

Students solving the Geosynchronous Orbit



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AFTER

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from visual.graph import *
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# Window setup
scene.width = 1024
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# Objects
Earth = sphere(pos=vector(0,0,0), radius=6.4e6, material=materials.BlueMarble)
Satellite = sphere(pos=vector(42164e3, 0,0), radius=1e6, color=color.red, make_trail=True)

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

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

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

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

sepgraph = gcurve(color=color.red)

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

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

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

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

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

        t = t +deltat
```

Tutor questions

- How does “weightlessness” work and how can it be simulated on Earth? Draw a free body diagram of the forces acting on a body experiencing “weightlessness” and explain.

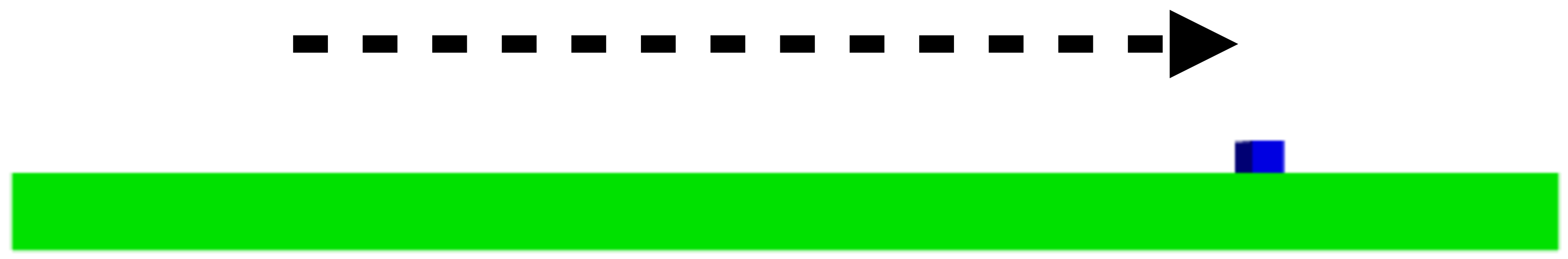
- Two friends are having a conversation. Justin says a satellite in orbit is in free-fall because the satellite keeps falling toward Earth. Amy says a satellite in orbit is not in free-fall because the acceleration due to gravity is not 9.80 m/s^2. Who do you agree with and why?

Hands-on Activity

Please open your phone or computer

shorturl.at/eIQ78

A box slides across a frictionless floor



Hands-on Activity

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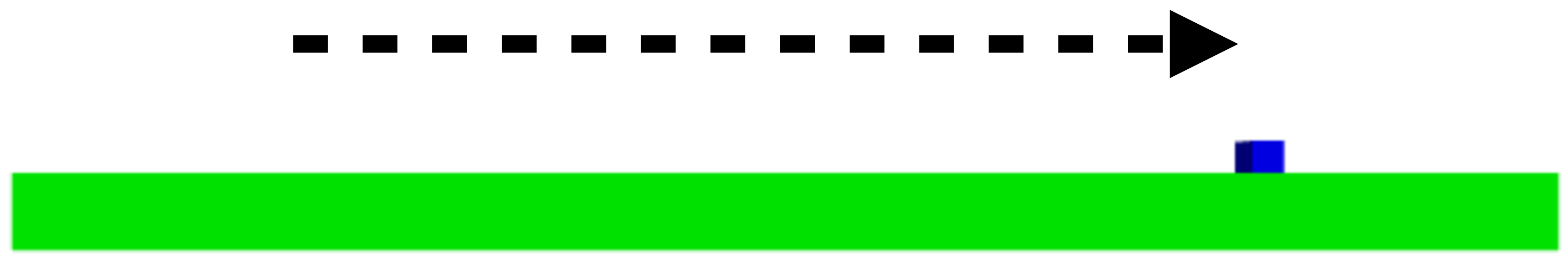

Click "View this Program"

```
Web VPython 3.2

scene.background = color.white

ground = box(pos = vector(0,-1,0), size = vector(40,2,10), color = color.green)

block = box(pos = vector(-15,0.5,0), size = vector(1,1,1), color = color.blue)

block.velocity = vector(1,0,0)

t = 0
timestep = 0.01

while block.pos.x < 15:

    rate(200) ## Slows down animation (no more than 200 updates per second)

    block.pos = block.pos + block.velocity*timestep
```

Hands-on Activity

Please open your phone or computer

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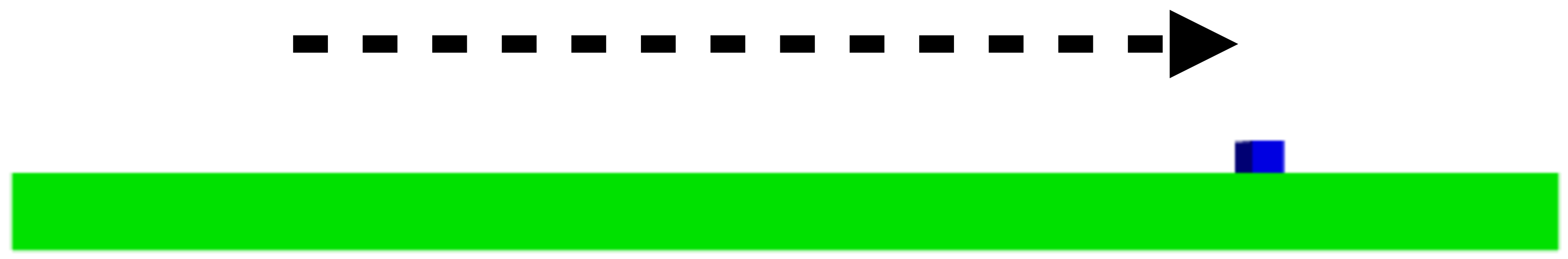

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    block.pos = block.pos + block.velocity*timestep
```

Work in a small group.

1. What is the program doing? How can you tell?
2. Can you change the color of the objects?
3. Can you make the block move faster or slower?
4. Can you make the block stop at a different location?
5. Can you make the block come to rest (add friction?)
6. What other things can you change?

HOW MIGHT YOU INTEGRATE COMPUTATION ACROSS THE DEPARTMENT?

Disclaimer

Your mileage may vary.

Challenges for an R1 school

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

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

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Research Demand/Expectations
Investment varies widely
Instruction by TAs/LAs

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Large, Diverse Faculty
Interest varies widely
Big Changes -> Big Discussion

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Large, Diverse Faculty
Progressive Junior/Mid-Career Faculty
More Computational Physics Hires

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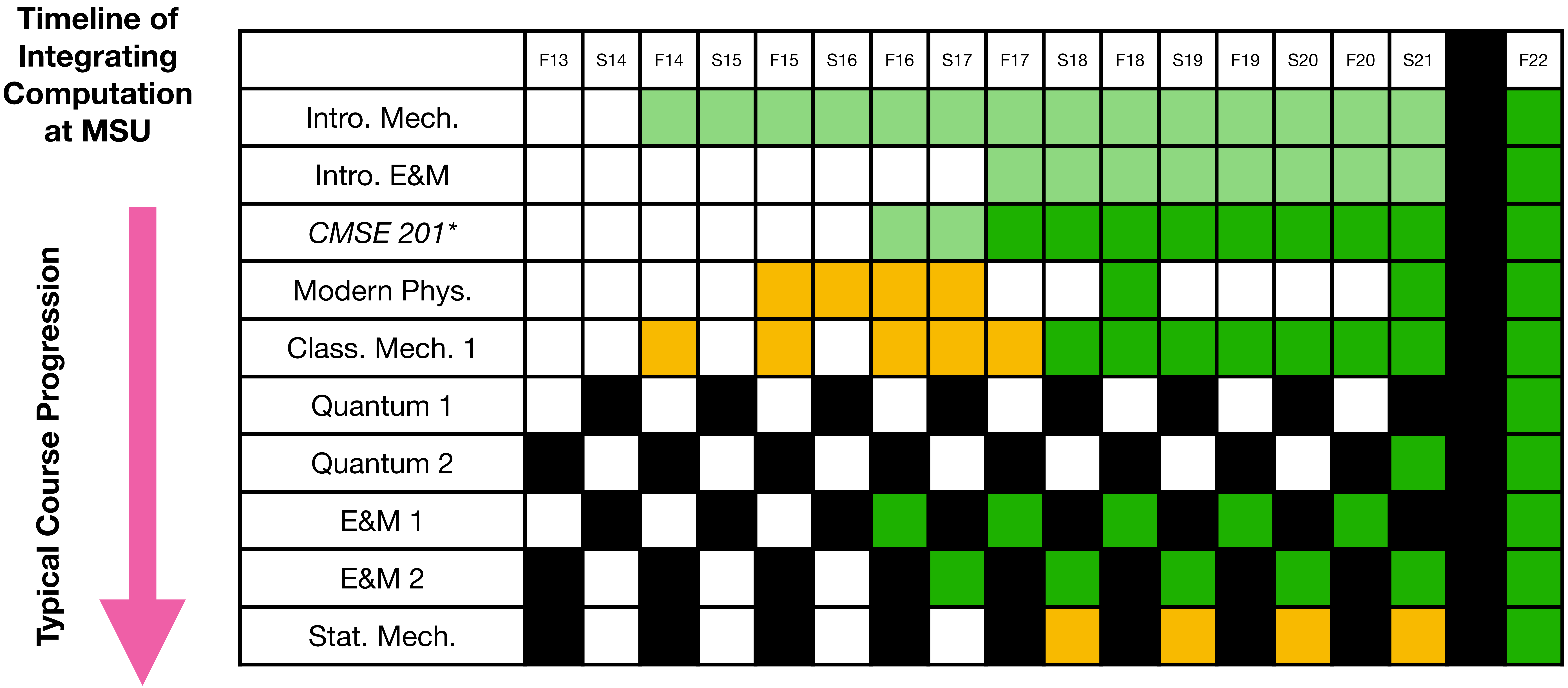
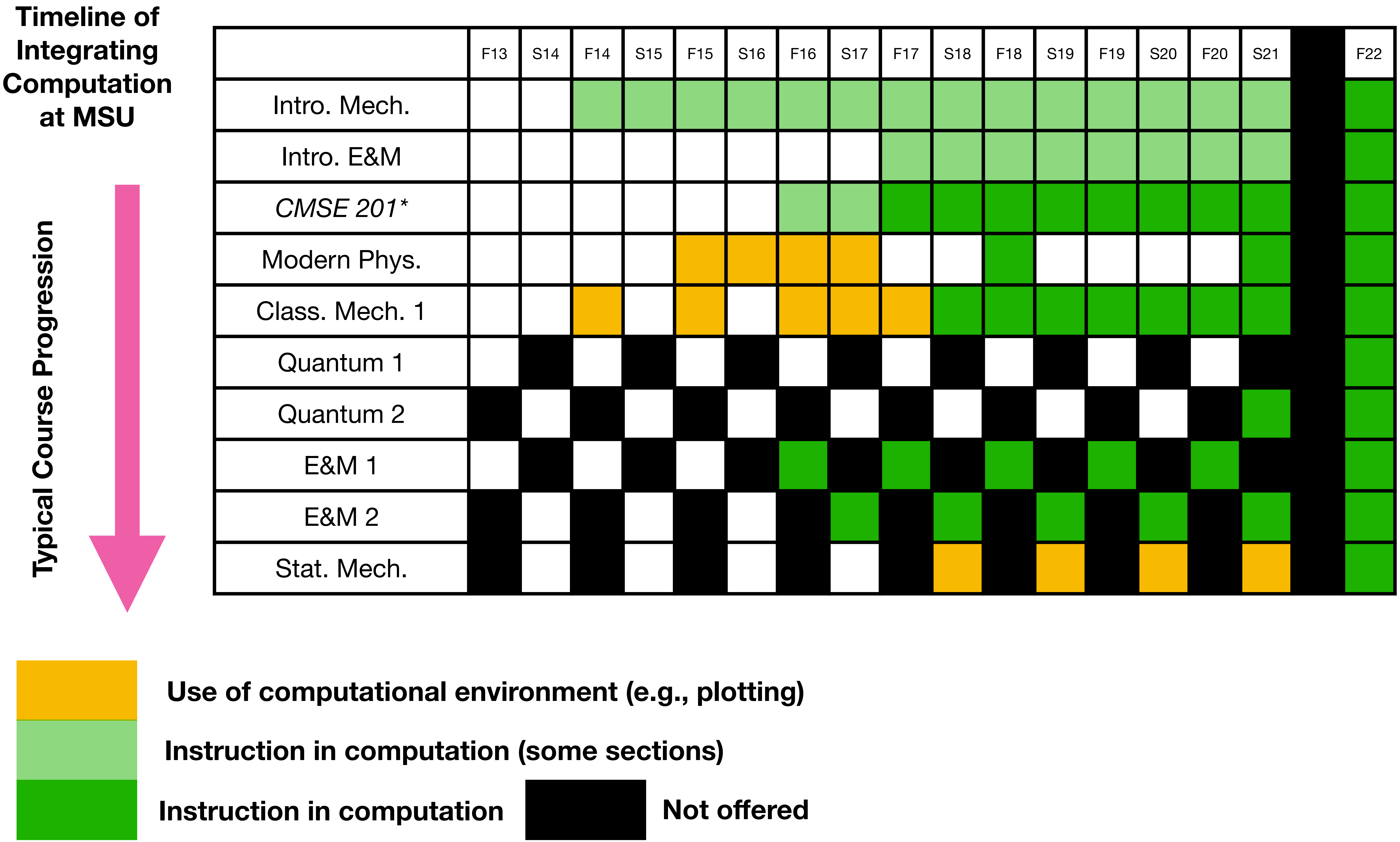
More Computational Physics Hires

State-level Investment
New STEM Teaching Building



Timeline of Integrating Computation at MSU
Typical Course Progression
F13
S14
F14
S15
F15
S16
F16
S17
F17
S18
F18
S19
F19
S20
F20
S21
F22
Intro. Mech.
Intro. E&M
CMSE 201*
Modern Phys.
Class. Mech. 1
Quantum 1
Quantum 2
E&M 1
E&M 2
Stat. Mech.



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S14
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S15
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S16
F16
S17
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S18
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S19
F19
S20
F20
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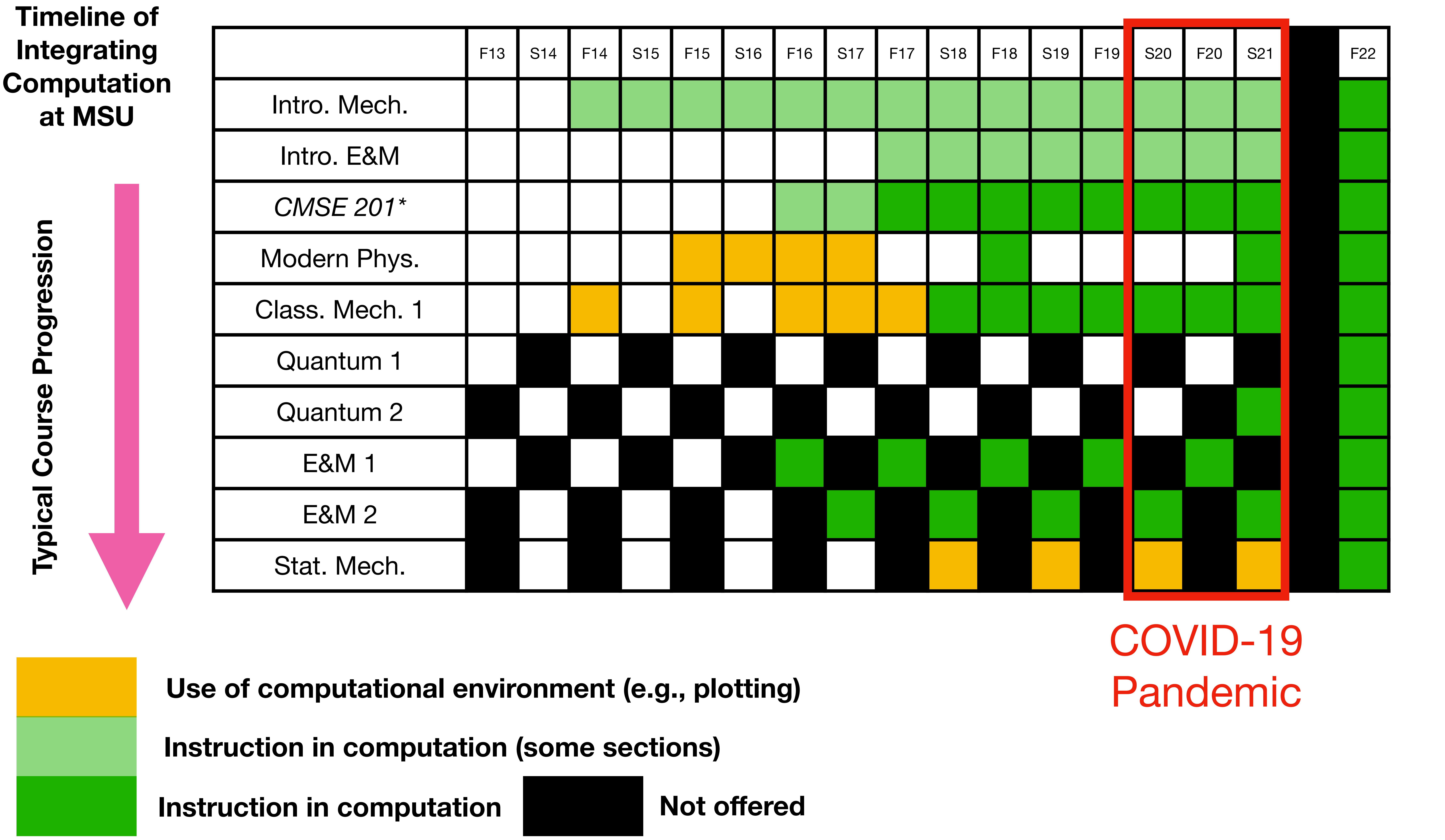
E&M 2
Stat. Mech.
Use of computational environment (e.g., plotting)
Instruction in computation (some sections)
Instruction in computation
Not offered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Quantum 2
E&M 1
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COVID-19 Pandemic
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Instruction in computation (some sections)
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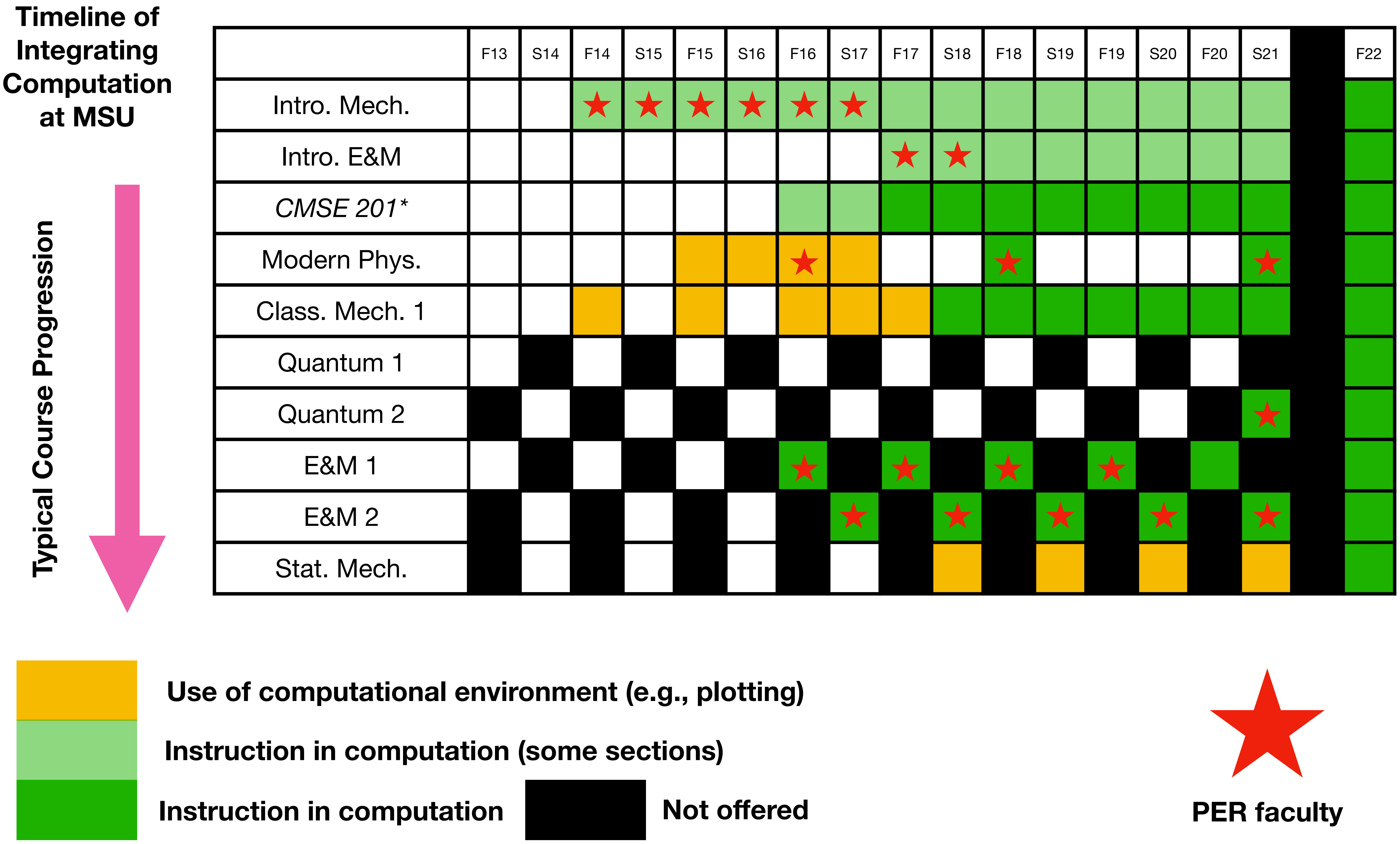
Not offered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E&M 1
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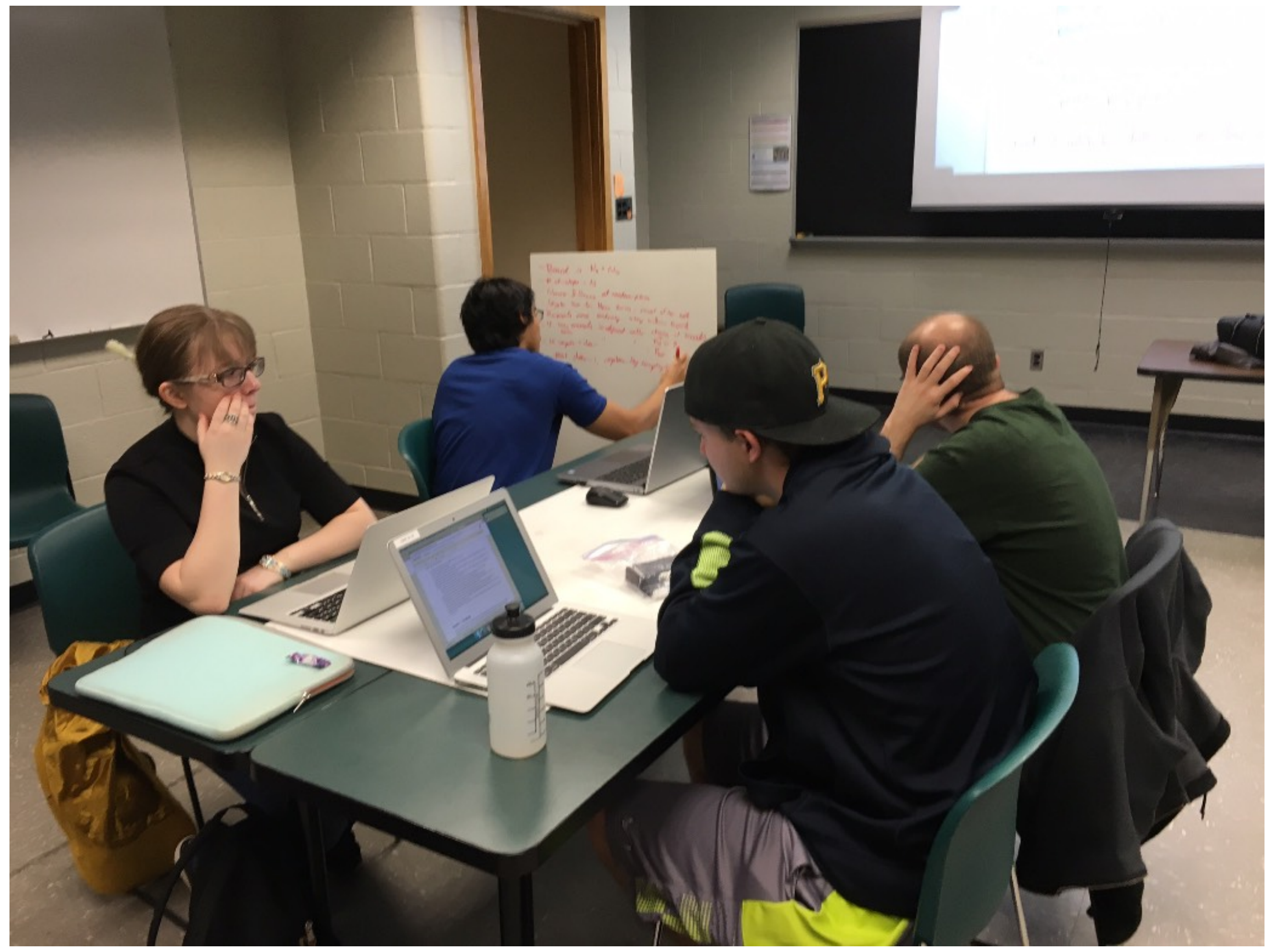
Instruction in computation
Not offered
PER faculty

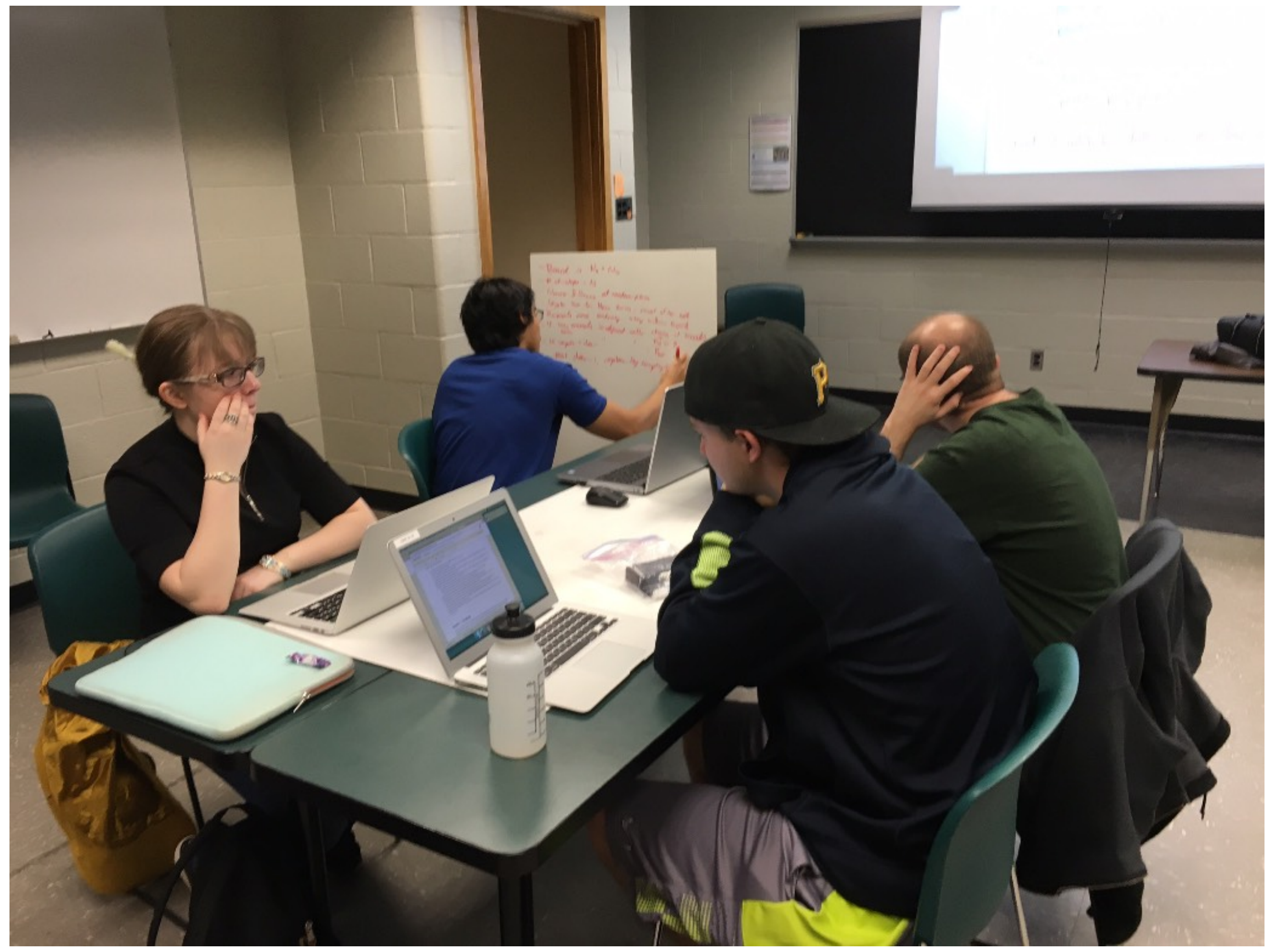
External support can help accelerate the process of integration.

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

Intro. Comp. Modeling (CMSE 201)



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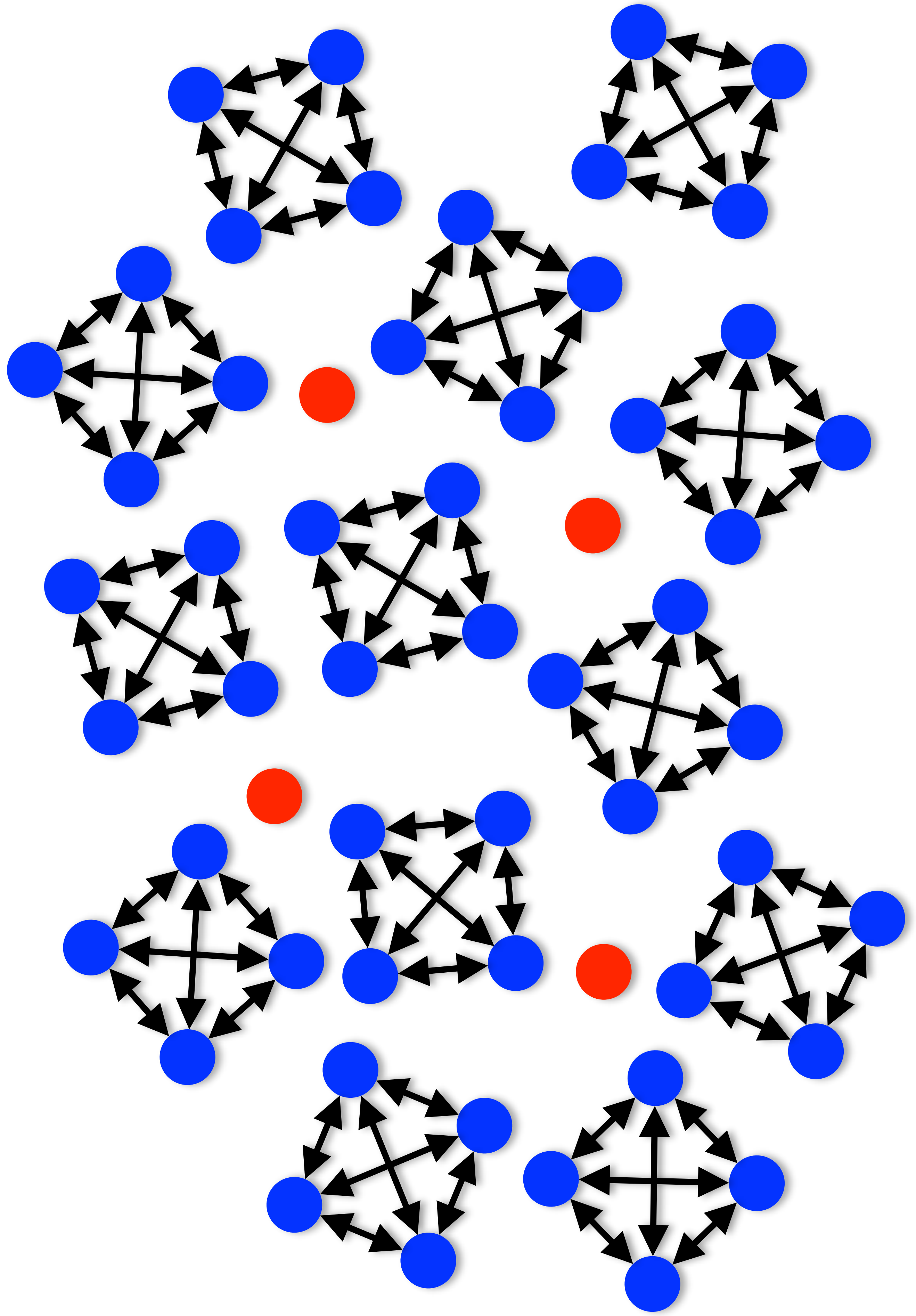

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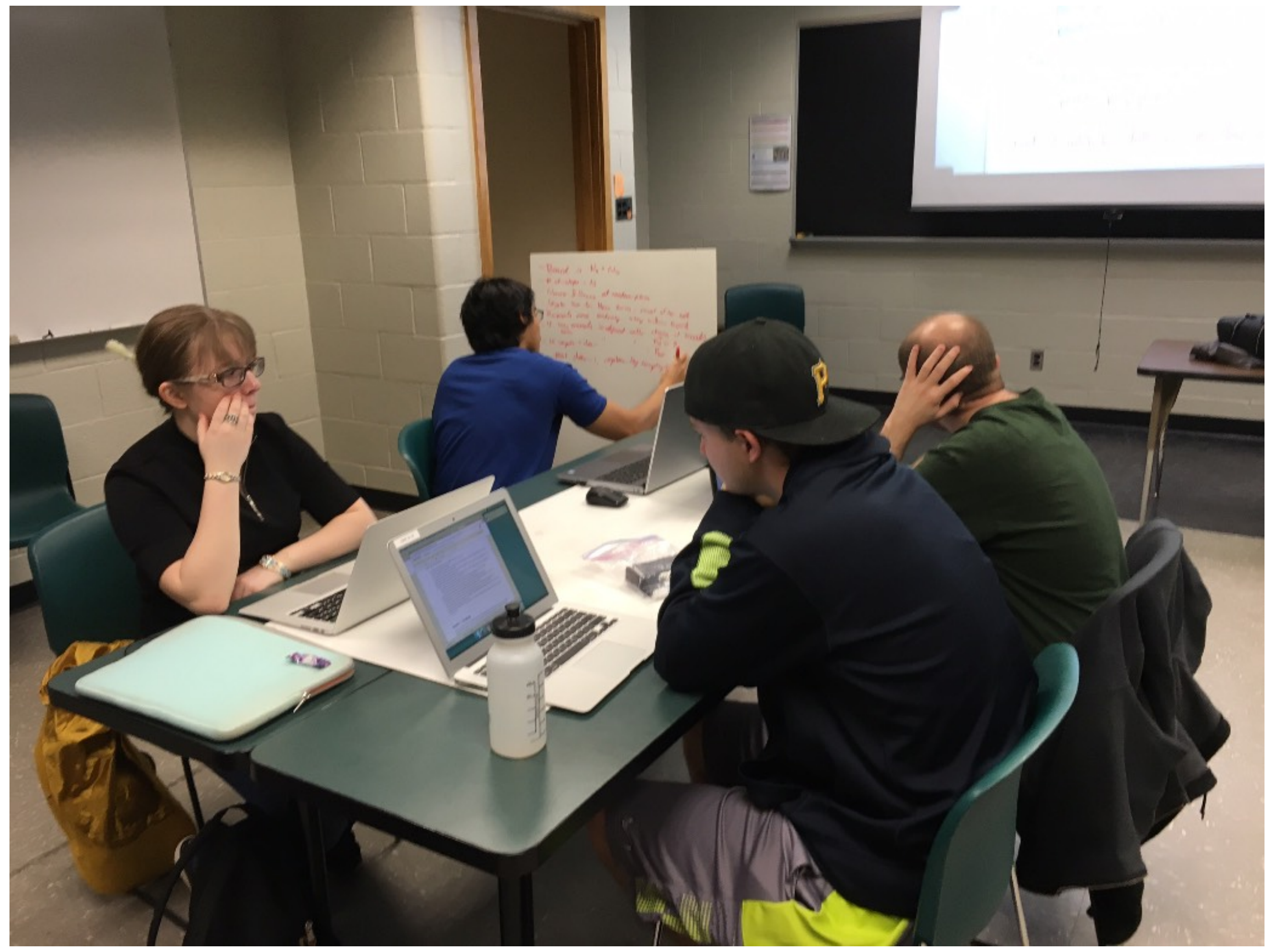

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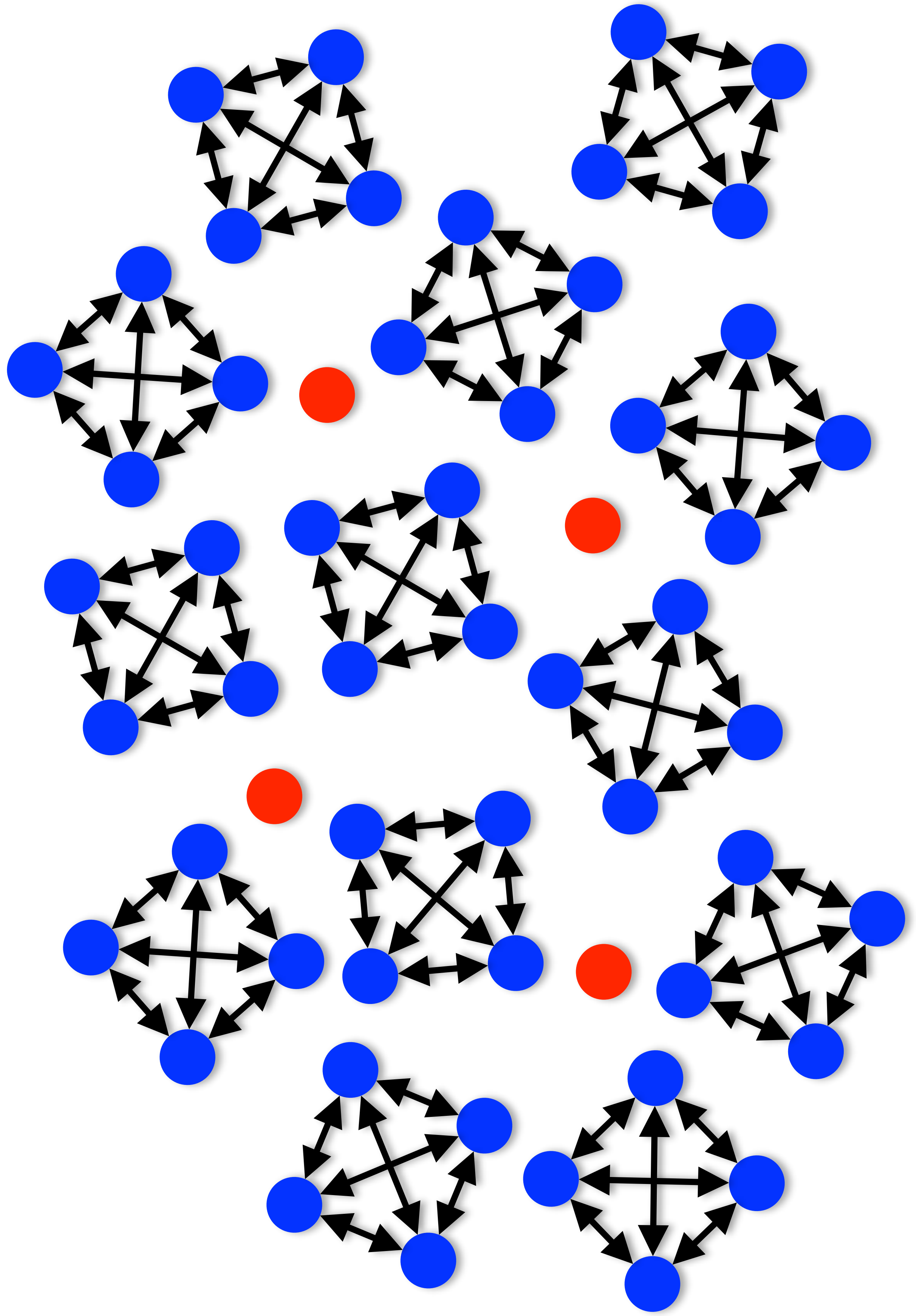

Pre-class assignments: videos, reading, **small programming assignments**

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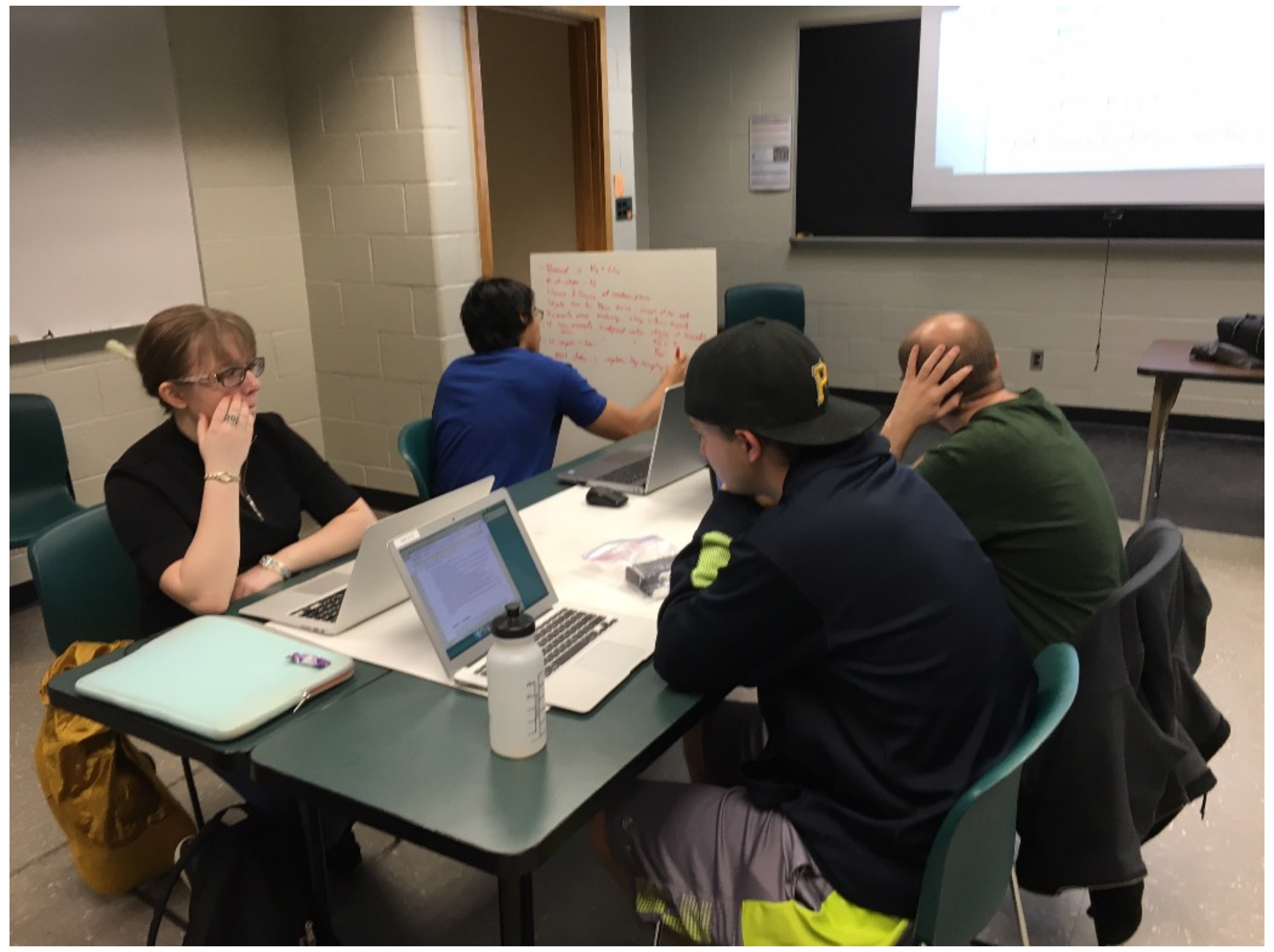

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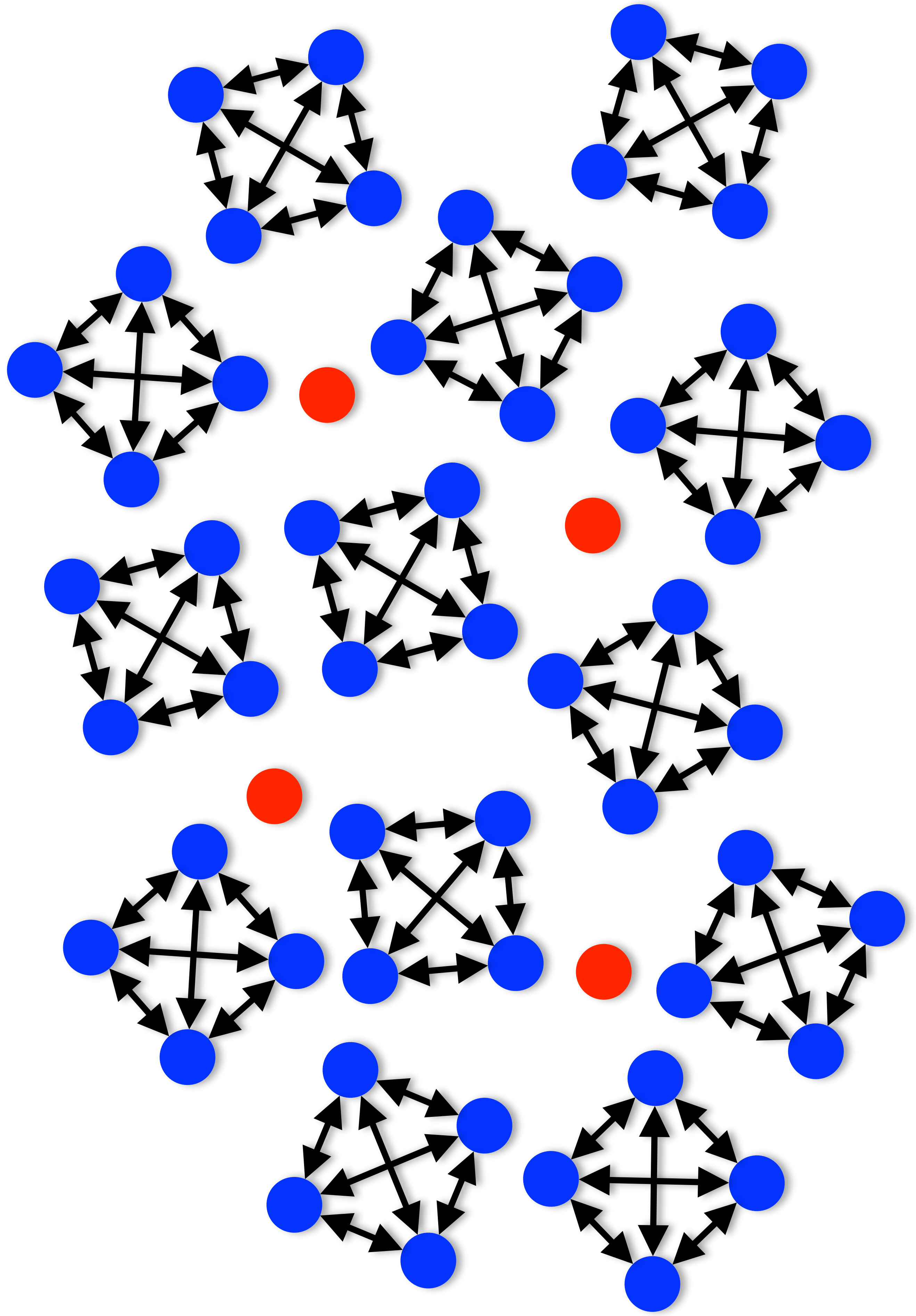

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Paper with detailed course description:
Silvia, O'Shea, and Danielak 2019, ICCS 2019


MICHIGAN STATE

Day 8: In-class Assignment: Modeling extreme sports

Goals for Today's In-Class Assignment

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

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

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Modeling the motion of a skydiver

Part 1: Modeling a falling skydiver without air resistance

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

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

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

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

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Part 2: The falling skydiver meets air resistance

Part 3: Opening the parachute

Part 4: Modeling a bungee jumper

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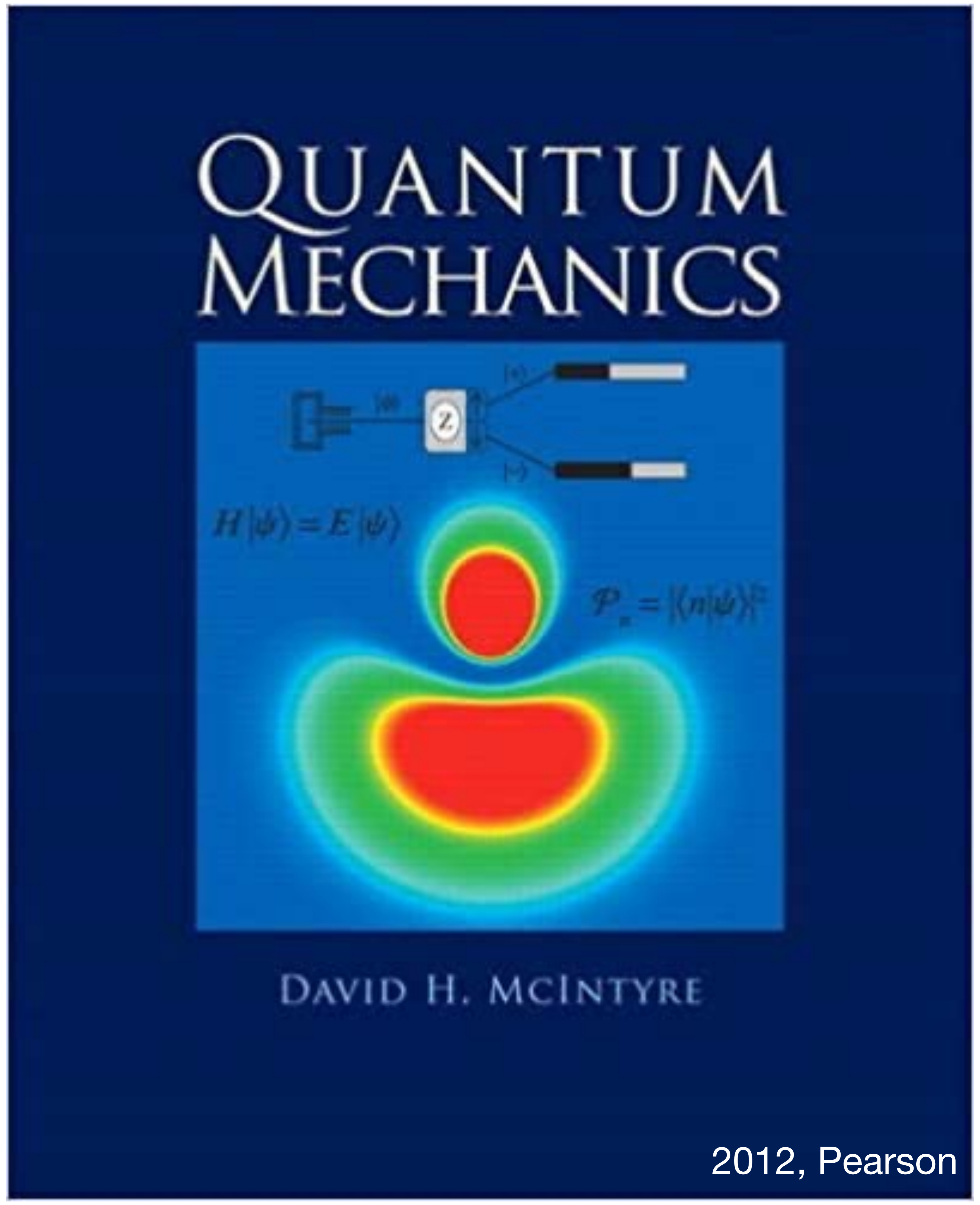
Now required for PA students Before Classical Mechanics 1

But you still need to do the work

PHY 472 - Quantum Mechanics 2

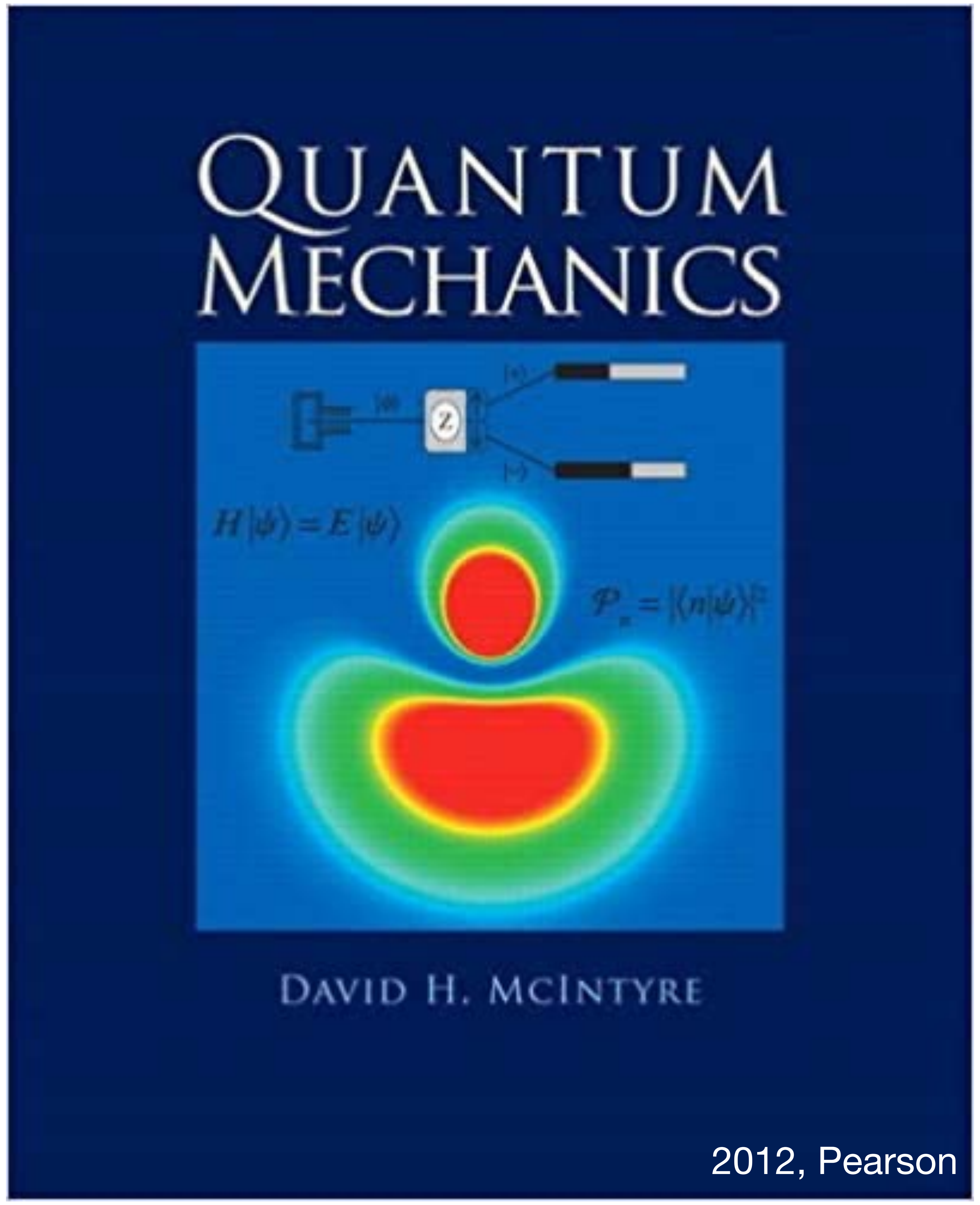


Second-semester Spins First Course

Elective (not required)

3rd and 4th year Physics/Astronomy students

PHY 472 - Quantum Mechanics 2



Second-semester Spins First Course
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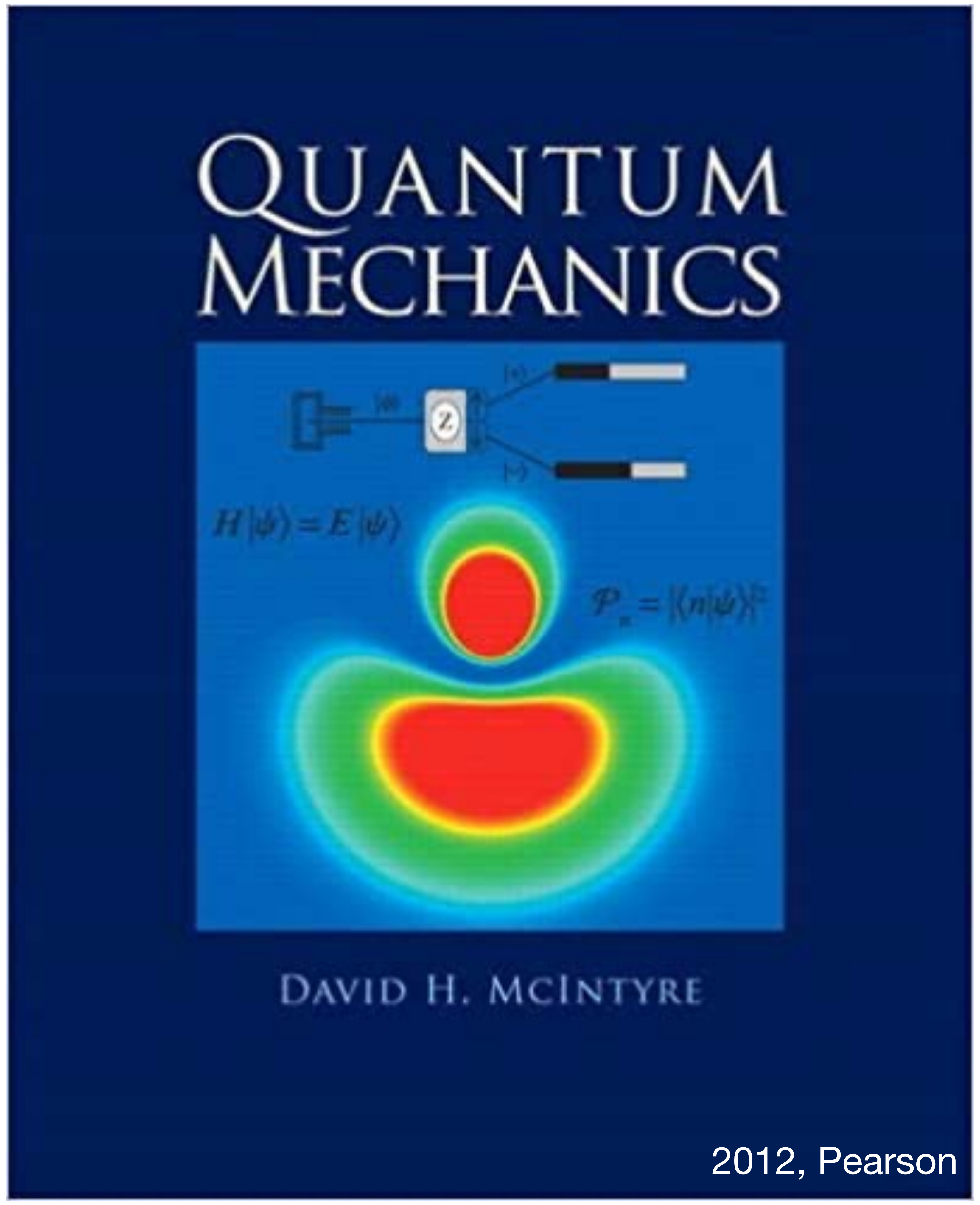
Spin/Measurement
↓
Operators/Kets
↓
Representations
↓
Examples/Approximations

PHY 472 - Quantum Mechanics 2



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PHY 471 QM1	Spin/Measurement ↓ Operators/Kets

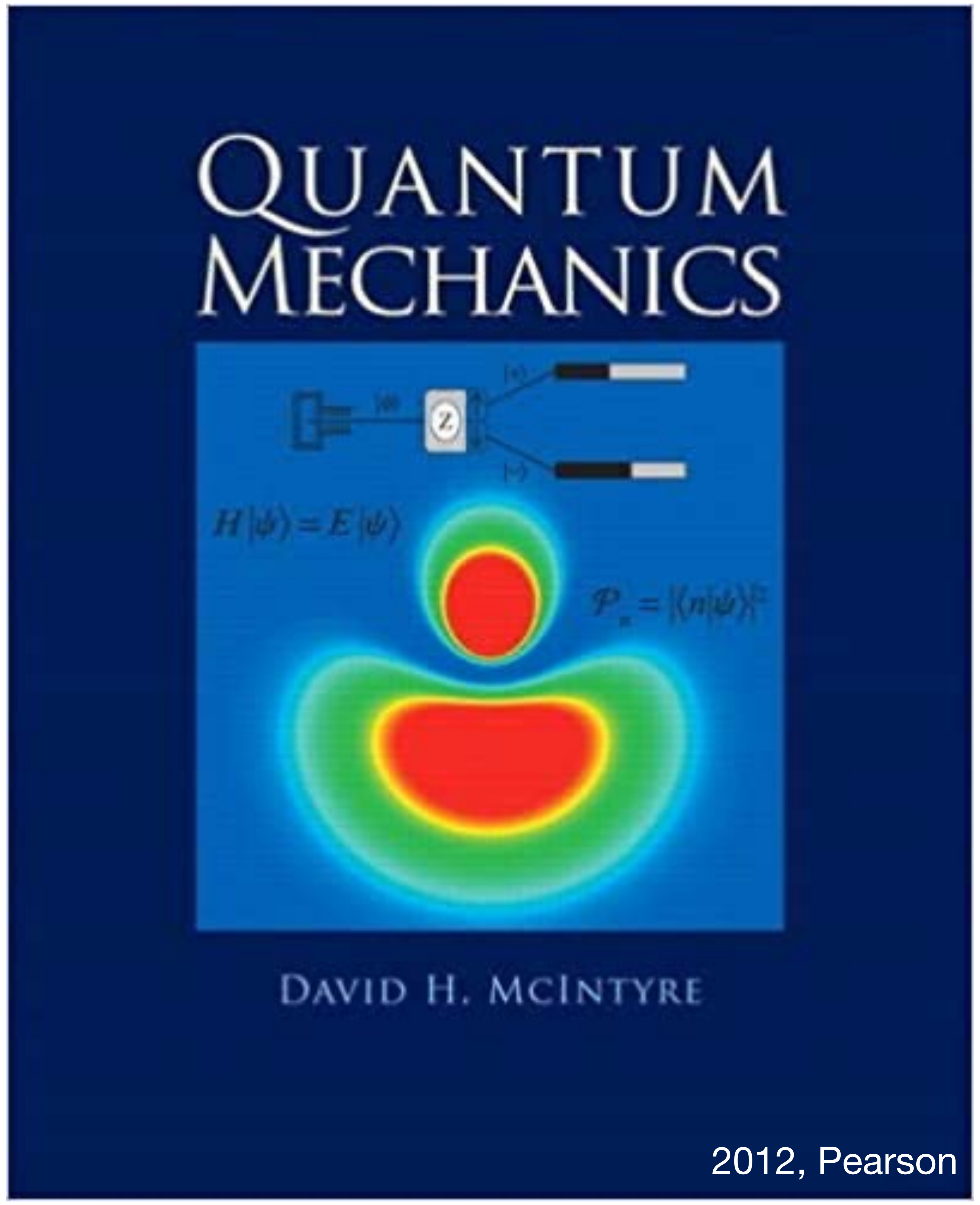
↓

Representations

↓

Examples/Approximations

PHY 472 - Quantum Mechanics 2



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PHY 471
QM1

Spin/Measurement
↓
Operators/Kets
↓
Representations
↓
Examples/Approximations

PHY 472
QM2

Review of student difficulties in upper-level quantum mechanics

Chandralekha Singh and Emily Marshman
Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA
(Received 29 September 2014; published 23 September 2015)

[This paper is part of the Focused Collection on Upper Division Physics Courses.] Learning advanced physics, in general, is challenging not only due to the increased mathematical sophistication but also because one must continue to build on all of the prior knowledge acquired at the introductory and intermediate levels. In addition, learning quantum mechanics can be especially challenging because the paradigms of classical mechanics and quantum mechanics are very different. Here, we review research on student reasoning difficulties in learning upper-level quantum mechanics and research on students' problem-solving and metacognitive skills in these courses. Some of these studies were multiuniversity investigations. The investigations suggest that there is large diversity in student performance in upper-level quantum mechanics regardless of the university, textbook, or instructor, and many students in these courses have not acquired a functional understanding of the fundamental concepts. The nature of reasoning difficulties in learning quantum mechanics is analogous to reasoning difficulties found via research in introductory physics courses. The reasoning difficulties were often due to overgeneralizations of concepts learned in one context to another context where they are not directly applicable. Reasoning difficulties in distinguishing between closely related concepts and in making sense of the formalism of quantum mechanics were common. We conclude with a brief summary of the research-based approaches that take advantage of research on student difficulties in order to improve teaching and learning of quantum mechanics.

DOI: 10.1103/PhysRevSTPER.11.020117 PACS numbers: 01.40.G-, 01.40.Fk

PHYSICAL REVIEW SPECIAL TOPICS—PHYSICS EDUCATION RESEARCH 11, 020117 (2015)

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PHYSICAL REVIEW SPECIAL TOPICS - PHYSICS EDUCATION RESEARCH 11, 020112 (2015)

Student understanding of time dependence in quantum mechanics

Paul J. Emigh, Gina Passante, and Peter S. Shaffer*
Department of Physics, University of Washington, Seattle, Washington 98195-1560, USA
(Received 29 September 2014; published 23 September 2015)

[This paper is part of the Focused Collection on Upper Division Physics Courses.] The time evolution of quantum states is arguably one of the more difficult ideas in quantum mechanics. In this article, we report on results from an investigation of student understanding of this topic after lecture instruction. We demonstrate specific problems that students have in applying time dependence to quantum systems and in recognizing the key role of the energy eigenbasis in determining the time dependence of wave functions. Through analysis of student responses to a set of four interrelated tasks, we categorize some of the difficulties that underlie common errors. The conceptual and reasoning difficulties that have been identified are illustrated through student responses to four sets of questions administered at different points in a junior-level course on quantum mechanics. Evidence is also given that the problems persist throughout undergraduate instruction and into the graduate level.

DOI: 10.1103/PhysRevSTPER.11.020112 PACS numbers: 01.40.Fk, 03.65.-w

PHYSICAL REVIEW SPECIAL TOPICS—PHYSICS EDUCATION RESEARCH **11,** 020117 (2015)

Review of student difficulties in upper-level quantum mechanics

Chandralekha Singh and Emily Marshman

Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA

(Received 29 September 2014; published 23 September 2015)

[This paper is part of the Focused Collection on Upper Division Physics Courses.] Learning advanced physics, in general, is challenging not only due to the increased mathematical sophistication but also because one must continue to build on all of the prior knowledge acquired at the introductory and intermediate levels. In addition, learning quantum mechanics can be especially challenging because the paradigms of classical mechanics and quantum mechanics are very different. Here, we review research on student reasoning difficulties in learning upper-level quantum mechanics and research on students' problem-solving and metacognitive skills in these courses. Some of these studies were multiuniversity investigations. The investigations suggest that there is large diversity in student performance in upper-level quantum mechanics regardless of the university, textbook, or instructor, and many students in these courses have not acquired a functional understanding of the fundamental concepts. The nature of reasoning difficulties in learning quantum mechanics is analogous to reasoning difficulties found via research in introductory physics

PHYSICAL REVIEW SPECIAL TOPICS - PHYSICS EDUCATION RESEARCH **11,** 020112 (2015)

Student understanding of time dependence in quantum mechanics

Paul J. Emigh, Gina Passante, and Peter S. Shaffer*

Department of Physics, University of Washington, Seattle, Washington 98195-1560, USA

(Received 29 September 2014; published 23 September 2015)

PHYSICAL REVIEW SPECIAL TOPICS—PHYSICS EDUCATION RESEARCH **11,** 020135 (2015)

Student ability to distinguish between superposition states and mixed states in quantum mechanics

Gina Passante, Paul J. Emigh, and Peter S. Shaffer

Department of Physics, University of Washington, Seattle, Washington 98195, USA

(Received 1 June 2015; published 25 November 2015)

Superposition gives rise to the probabilistic nature of quantum mechanics and is therefore one of the concepts at the heart of quantum mechanics. Although we have found that many students can successfully use the idea of superposition to calculate the probabilities of different measurement outcomes, they are often unable to identify the experimental implications of a superposition state. In particular, they fail to recognize how a superposition state and a mixed state (sometimes called a "lack of knowledge" state) can produce different experimental results. We present data that suggest that superposition in quantum mechanics is a difficult concept for students enrolled in sophomore-, junior-, and graduate-level quantum mechanics courses. We illustrate how an interactive lecture tutorial can improve student understanding of quantum mechanical superposition. A longitudinal study suggests that the impact persists after an additional quarter of quantum mechanics instruction that does not specifically address these ideas.

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PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **15,** 020146 (2019)

Framing difficulties in quantum mechanics

Bahar Modir,[1] John D. Thompson,[2] and Eleanor C. Sayre[2,*]

[1]*Department of Physics and Astronomy, Texas A&M University – Commerce, Commerce, Texas 75428, USA*
[2]*Department of Physics, Kansas State University, Manhattan, Kansas 66506, USA*

(Received 17 December 2018; published 2 December 2019; corrected 24 March 2020)

Students' difficulties in quantum mechanics may be the result of unproductive framing rather than a fundamental inability to solve the problems or misconceptions about physics content. Using the theoretical lens of epistemological framing, we applied previously developed frames to seek an underlying structure to the long lists of published difficulties that span many topics in quantum mechanics. Mapping descriptions of published difficulties into errors in epistemological framing and resource use, we analyzed descriptions of students' problem solving to find their frames, and compared students' framing to the framing (and frame shifting) required by problem statements. We found three categories of error: mismatches between students' framing and problem statement framing inappropriate or absent shifting between frames and insufficient resource activation within an appropriate frame.

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PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH 15, 020139 (2019)

Editors' Suggestion

Probing student reasoning in relating relative phase and quantum phenomena

Tong Wan,[1,*] Paul J. Emigh,[2] and Peter S. Shaffer[3]

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(Received 17 May 2019; published 31 October 2019; corrected 24 February 2021)

In quantum mechanics, probability amplitudes are complex numbers and the relative phases between the terms in superposition states have measurable effects. This article describes an investigation into sophomore- and junior-level students' reasoning patterns in relating relative phases and real-world quantum phenomena. The investigation involved one observational experiment and three testing experiments, during which we formulated and tested three hypotheses that allow us to gain insights into why students have difficulty recognizing the measurable effects of relative phases. We found that, in both spin-1/2 and infinite square well contexts, many students do not recognize that quantum states differing only by a relative phase are experimentally distinguishable. Moreover, student ability to recognize the measurable effects of relative phase does not improve when given (i) a task that specifically prompts students to compare the probabilities for a particular observable and (ii) a task that does not require taking inner products or changing basis. We also examined the extent to which lacking proficiency with complex numbers may have hindered student understanding of relative phase. The data indicate that most students are proficient with complex numbers. These findings suggest that many students do not, in fact, recognize the purpose of using complex numbers in superposition states. We discuss possible explanations for why students do not seem to recognize this purpose, and we also provide suggestions for future avenues of research.

DOI: 10.1103/PhysRevPhysEducRes.15.020139

Framing difficulties in quantum mechanics

Bahar Modir,[1] John D. Thompson,[2] and Eleanor C. Sayre[2,*]

[1]*Department of Physics and Astronomy, Texas A&M University – Commerce, Commerce, Texas 75428, USA*
[2]*Department of Physics, Kansas State University, Manhattan, Kansas 66506, USA*

(Received 17 December 2018; published 2 December 2019; corrected 24 March 2020)

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DOI: 10.1103/PhysRevPhysEducRes.15.020146

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PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **16**, 020156 (2020)

Research-based quantum instruction: Paradigms and Tutorials

Paul J. Emigh,[1,*] Elizabeth Gire,[1] Corinne A. Manogue,[1]
Gina Passante,[2] and Peter S. Shaffer[3]

[1]*Department of Physics, Oregon State University, Corvallis, Oregon 97331-6507, USA*
[2]*Department of Physics, California State University, Fullerton, Fullerton, California 92831, USA*
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(Received 9 July 2019; accepted 13 December 2019; published 4 December 2020)

A growing body of research-based instructional materials for quantum mechanics has been developed in recent years. Despite a common grounding in the research literature on student ideas about quantum mechanics, there are some major differences between the various sets of instructional materials. In this article, we examine the major instructional considerations that influenced the development of two comprehensive quantum mechanics curricula: *Paradigms in Physics* (the junior-level physics courses at Oregon State University) and *Tutorials in Physics: Quantum Mechanics* (a set of supplementary worksheets designed at the University of Washington). The instructional considerations that we consider vary in nature: some are philosophical or theoretical commitments about teaching and learning, while some are practical structures determined in part by the local instructional environments. We then use these instructional considerations as a lens to explore example activities from each curriculum and to highlight prominent differences between them, along with some underlying reasons for those differences. The *Paradigms* reflect a case where the theoretical commitments drove changes to the practical structures while the *Tutorials* reflect how theoretical commitments were incorporated into a course with a relatively fixed practical structure. Partially as a result of this large-scale difference, we find that each curriculum prioritizes different theoretical commitments about how to promote student understanding of quantum mechanics. We discuss instances of both alignment and tension between the theoretical commitments of the two curricula and their impact on the instructional materials.

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PHYSICAL REVIEW SPECIAL TOPIC

Student understanding

Paul J. Emigh

Department of Physics, Univers

(Received 29 Sept

PHYSICAL REVIEW SPECIAL TOPI

Student ability to distinguis in

Gina Passant

Department of Physics, Univ

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DOI: 10.1103/PhysRevPhysEducRes.15.020146

Adaptable Curricular Exercises for Quantum Mechanics

developed by Steven Pollock, Gina Passante, and Homeyra Sadaghiani

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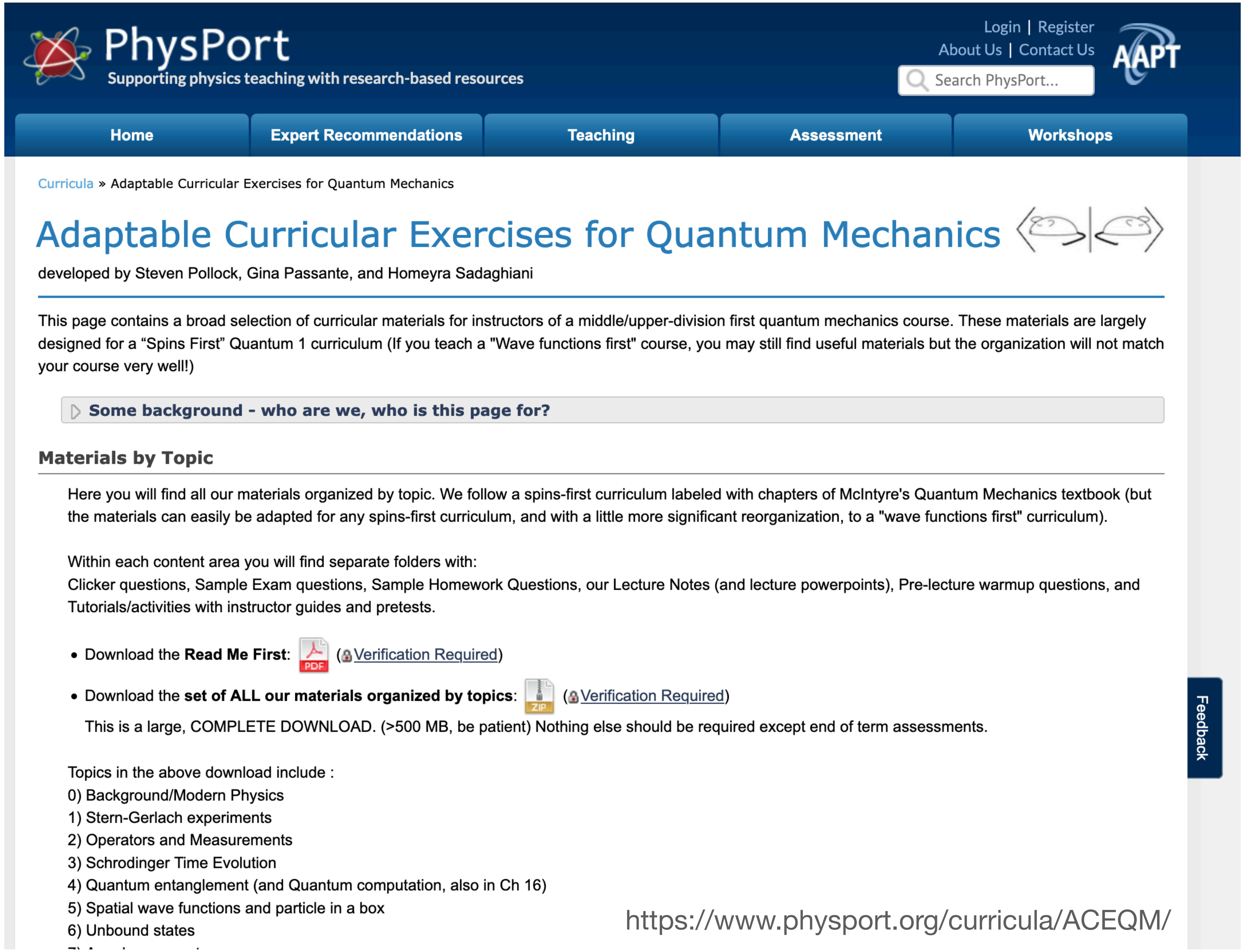

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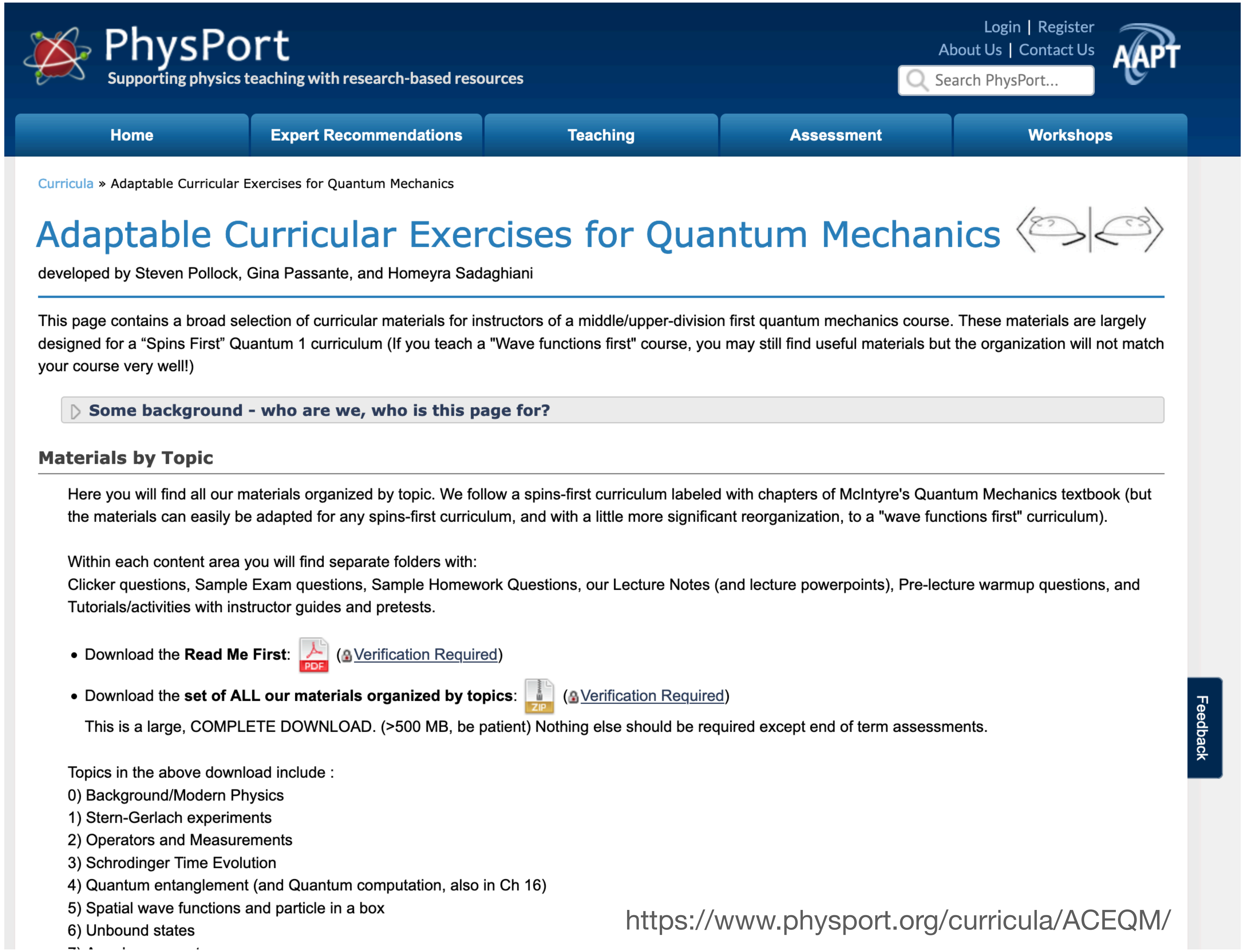
Sample Learning Goals

Students should be able to…

- recognize the difference between an overall phase and a relative phase and the effect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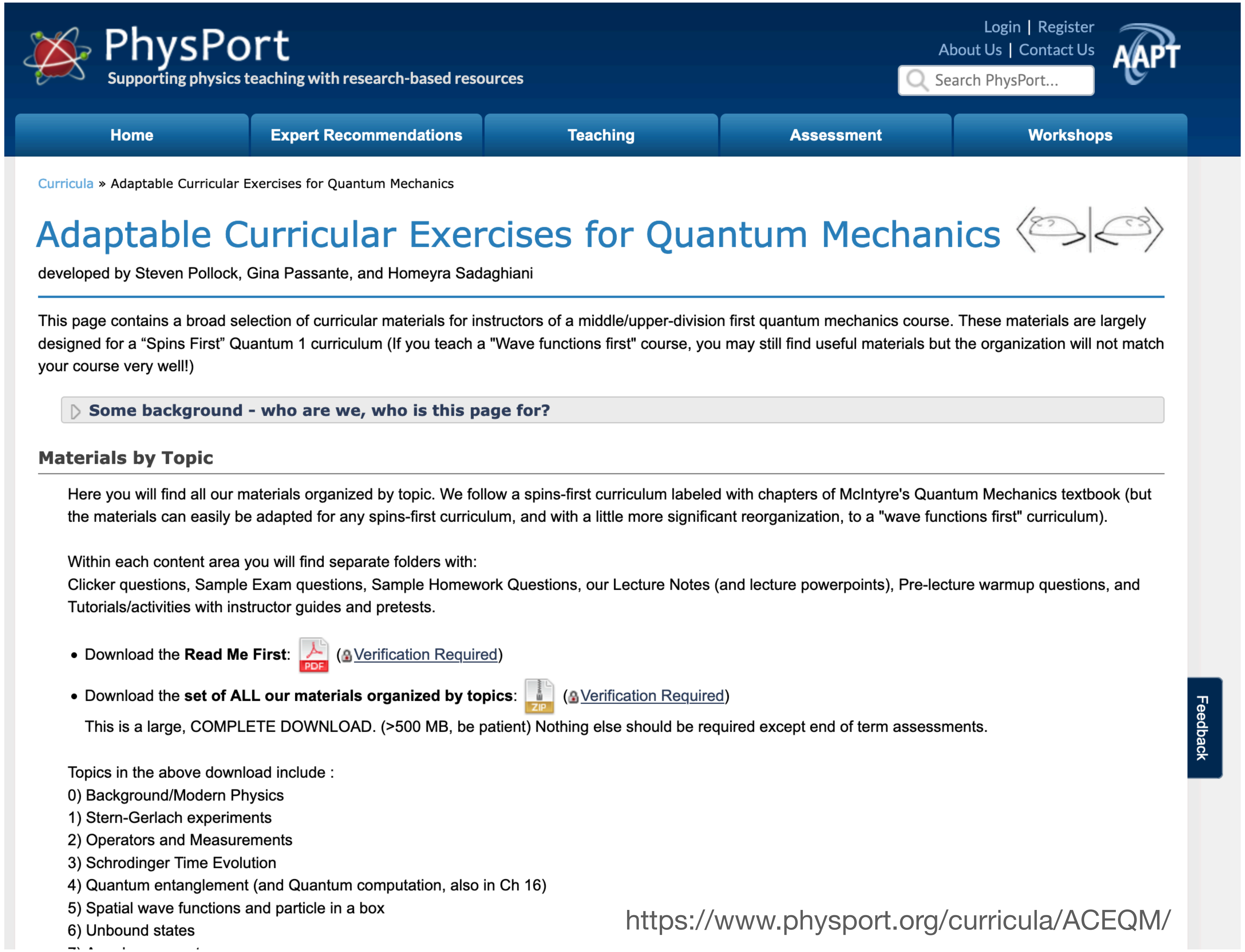
- recognize the difference between an overall phase and a relative phase and the effect
- that has on measurement outcomes.



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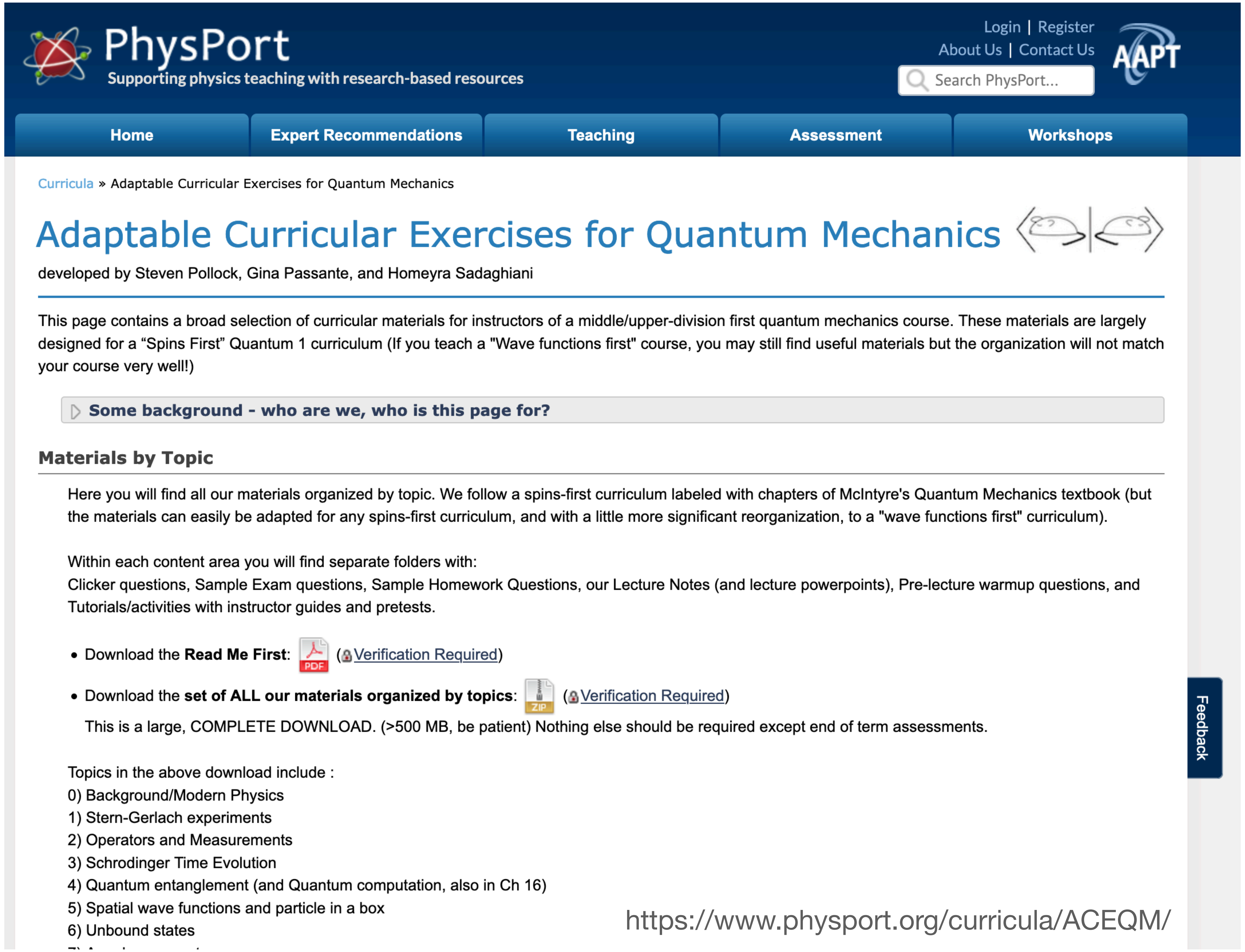
Sample Learning Goals

Students should be able to…

- recognize the difference between an overall phase and a relative phase and the effect
- that has on measurement outcomes.
- determine the possible set of values that could result from a measurement of a given observable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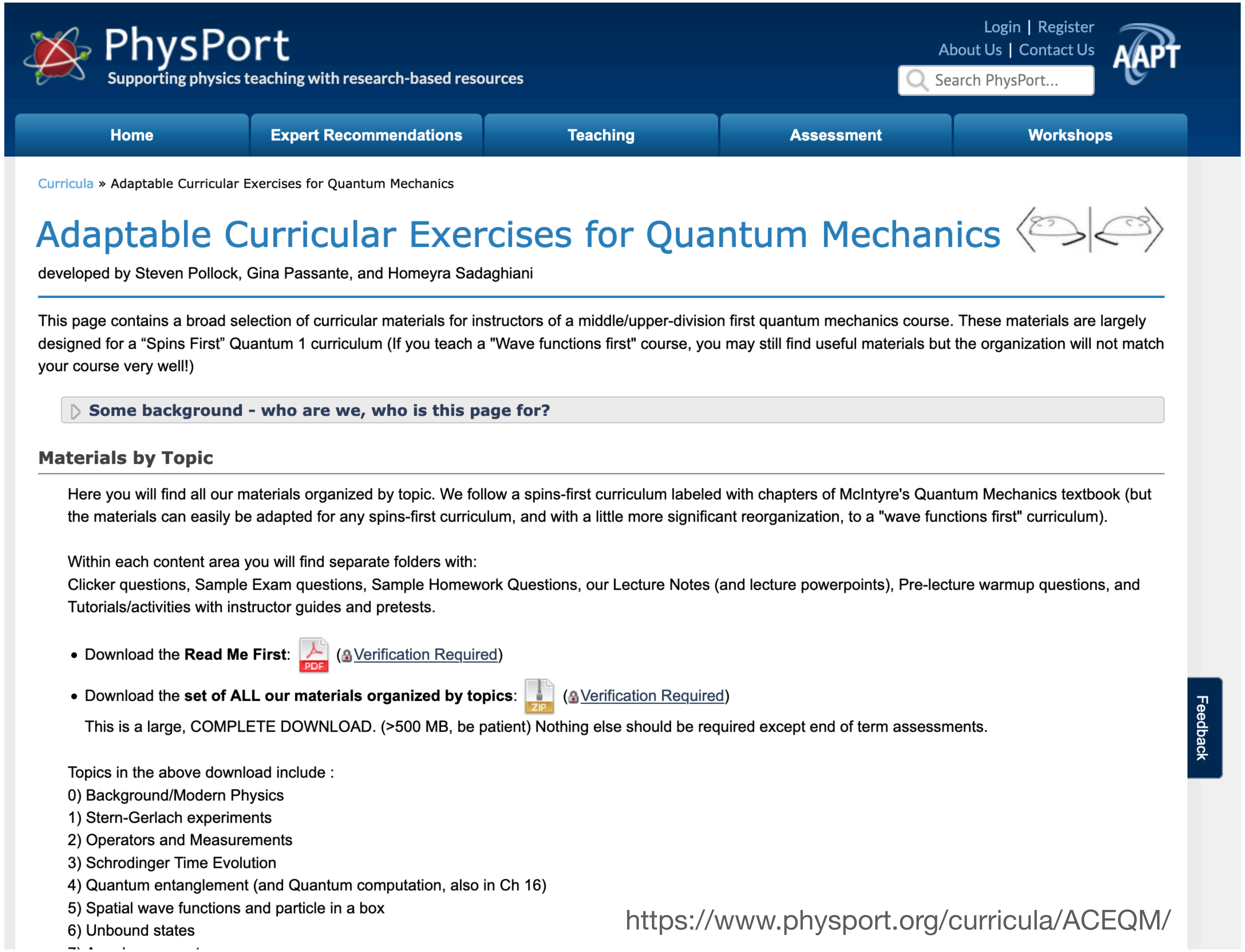
Sample Learning Goals

Students should be able to…

- recognize the difference between an overall phase and a relative phase and the effect
- that has on measurement outcomes.
- determine the possible set of values that could result from a measurement of a given observable
- distinguish between expectation values, allowed values, most probable value.



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  This is a large, COMPLETE DOWNLOAD. (>500 MB, be patient) Nothing else should be required except end of term assessments.

Topics in the above download include :
0) Background/Modern Physics
1) Stern-Gerlach experiments
2) Operators and Measurements
3) Schrodinger Time Evolution
4) Quantum entanglement (and Quantum computation, also in Ch 16)
5) Spatial wave functions and particle in a box
6) Unbound states

Feedback

https://www.physport.org/curricula/ACEQM/

Sample Learning Goals

Students should be able to…

- recognize the difference between an overall phase and a relative phase and the effect
- that has on measurement outcomes.
- determine the possible set of values that could result from a measurement of a given observable
- distinguish between expectation values, allowed values, most probable value.
- sketch a qualitatively correct wave function given a 1D potential (attending to features
  like the number of nodes, the sign of the curvature, the relative wavelengths and amplitudes).

We have a Hamiltonian H with eigenstates $|E_n>$

Consider the state $|\psi(0)> = \frac{1}{\sqrt{5}}|E_1> + \frac{2i}{\sqrt{5}}|E_3>$

True (A) or False (B):

This state is an eigenstate of **H**

Courtesy of Gina Passante (CSUF), Homeyra Sadaghiani (CPP), and Steve Pollock (CU-Boulder)

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True (A) or False (B):

This state is a solution of the time-independent Schrödinger equation, $\hat{H}|\psi> = E\,|\psi>$

What is the probability of measuring E_3 at t=0?

A) $\frac{2}{\sqrt{5}}$ B) 50% C) 4/5 D) Impossible!

E) Something else….

Courtesy of Gina Passante (CSUF), Homeyra Sadaghiani (CPP), and Steve Pollock (CU-Boulder)

Time Dependence Activity

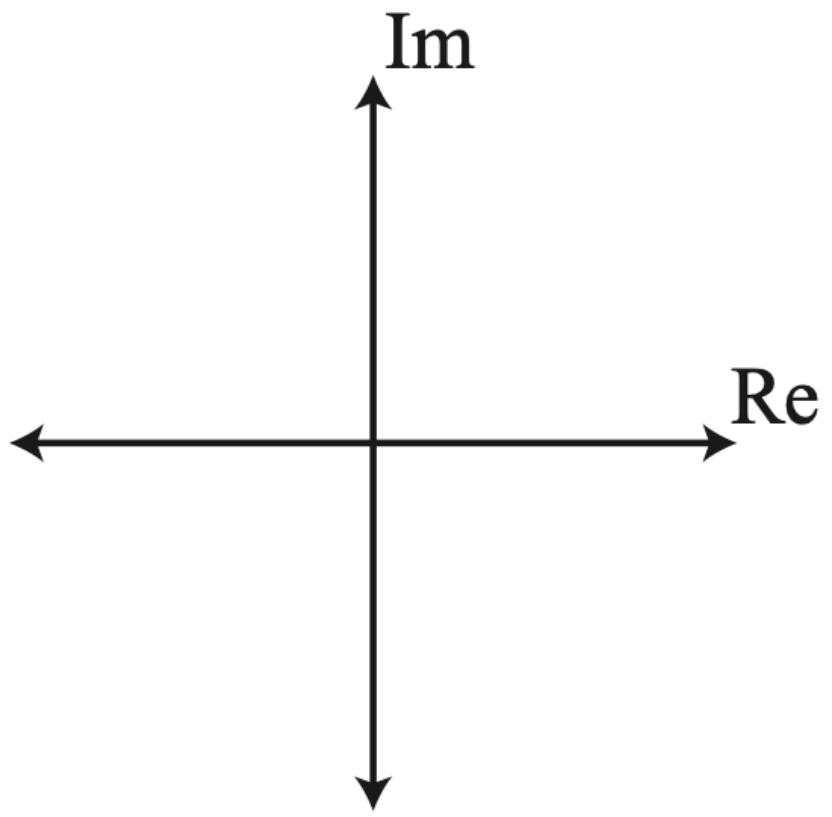
Part I. A particle is in an ∞ square well with potential energy $V(x) = 0$ for $0<x<L$ (and is ∞ elsewhere.) The $\psi_n(x)$ are the spatial parts of the energy eigenfunctions with energy values E_n, such that $E_n = n^2 E_1$. Consider a particle in the **ground state** at time $t = 0$ given by $\psi_1(x)$.

1. Sketch the **ground state** energy eigenfunction $\psi_1(x)$ at time $t = 0$. Label your axes.

2. Draw a vertical line on your graph to indicate the value of $\psi_1(x)$ at the point $x = L/2$.

3. Write an expression for the time evolution of the energy eigenfunction $\psi_1(x,t)$ in terms of $\psi_1(x)$.

4. Consider ψ_1 at the point $x = L/2$. Plot the time evolution of $\psi_1(x = L/2, t)$ on the graph of the complex plane. *(Hint: Try plotting the values of* $e^{-iE_1 t/\hbar}$ *for* $E_1 t/\hbar = 0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}$ *on the graph and interpolate between them.)*
   Describe this time evolution in words.



b) Now consider the probability density $|\psi_1|^2$ at the point $x = L/2$. Plot the value of the probability density on the same set of axes above for the same times. How is this value related to the value of ψ_1?

Courtesy of Gina Passante (CSUF), and Antje Kohnle (St. Andrews)

Two things I learned about teaching science during a pandemic…

1. If at all possible, avoid.
2. Else, don't simply put your in-person course online.

Online Quantum 2

Online Quantum 2

Multiple modes of learning material:

- Passive - semi-flipped (lecture videos; Just in Time questions)
- Active - interactive lecture (clicker style questions; wait time)
- Practice - small group work (concepts and application)

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- Course material posted 1 week in advance
- Homework due Friday, accepted until Sunday
  - Accepted for 70% credit thereafter
- Take-home quizzes open for 27 hours, no time limit
- Schedule final project based on class input

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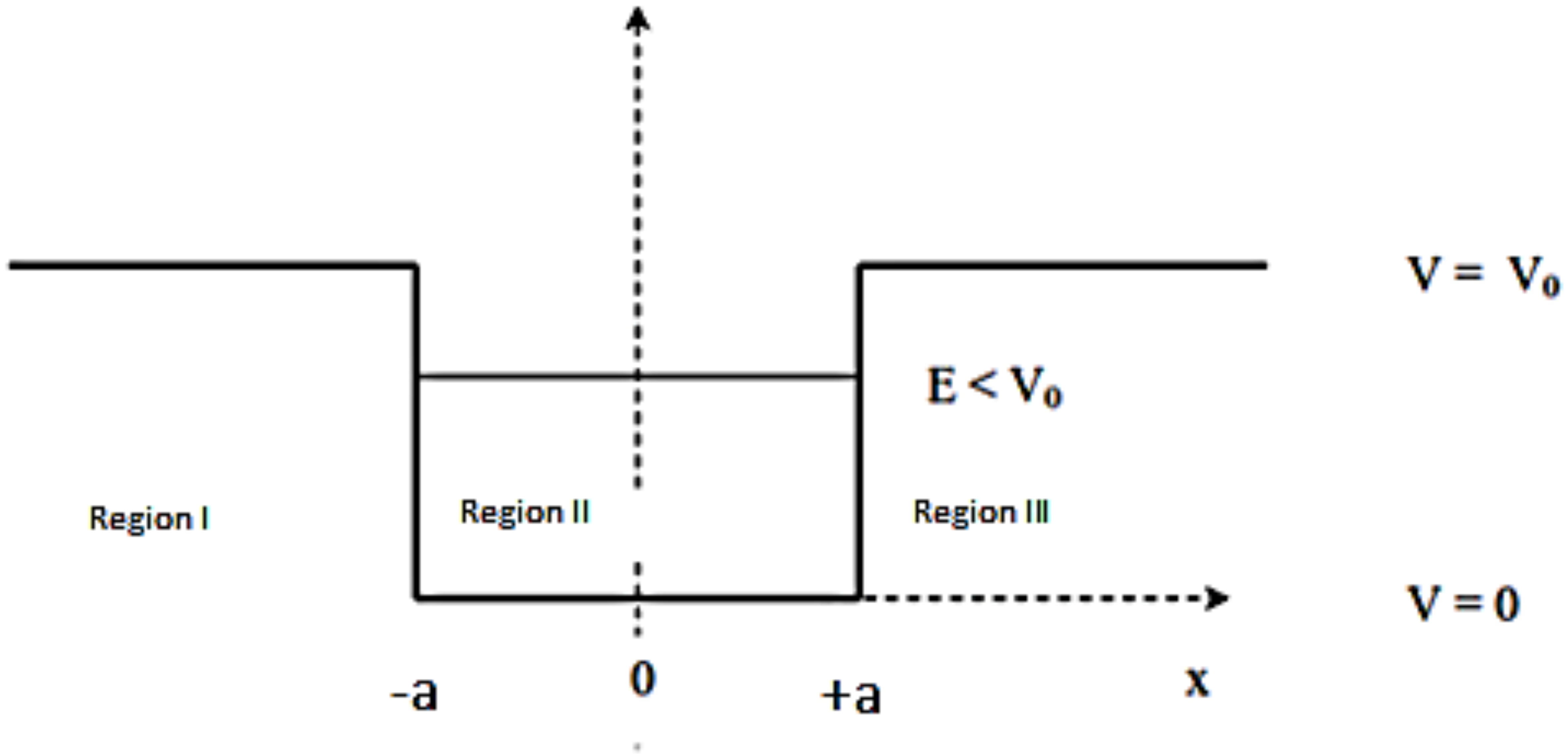
Low-Stakes Assessment

- Pre-class and Homework - 50%
- Take-home quizzes (5 total) - 30%
- Final Group Project - 20%

dannycab.githib.io/phy472msu_s2021/

Bound States of the Finite Potential Well



$$H|E_n\rangle = E_n|E_n\rangle$$

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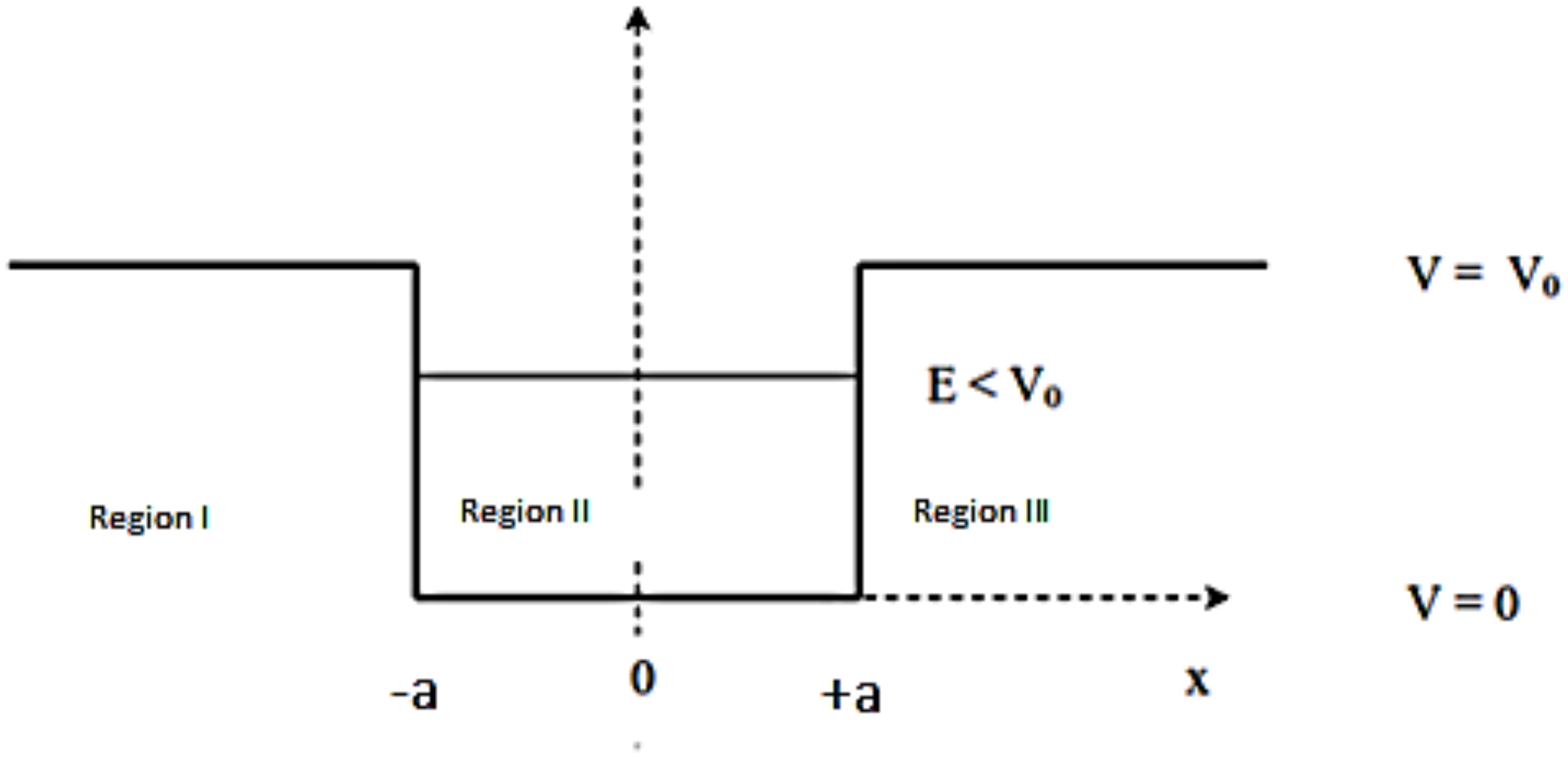

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$$\frac{\sqrt{2m(V_0 - E)}}{\hbar} = \frac{\sqrt{2mE}}{\hbar}\tan(\frac{\sqrt{2mE}a}{\hbar})$$

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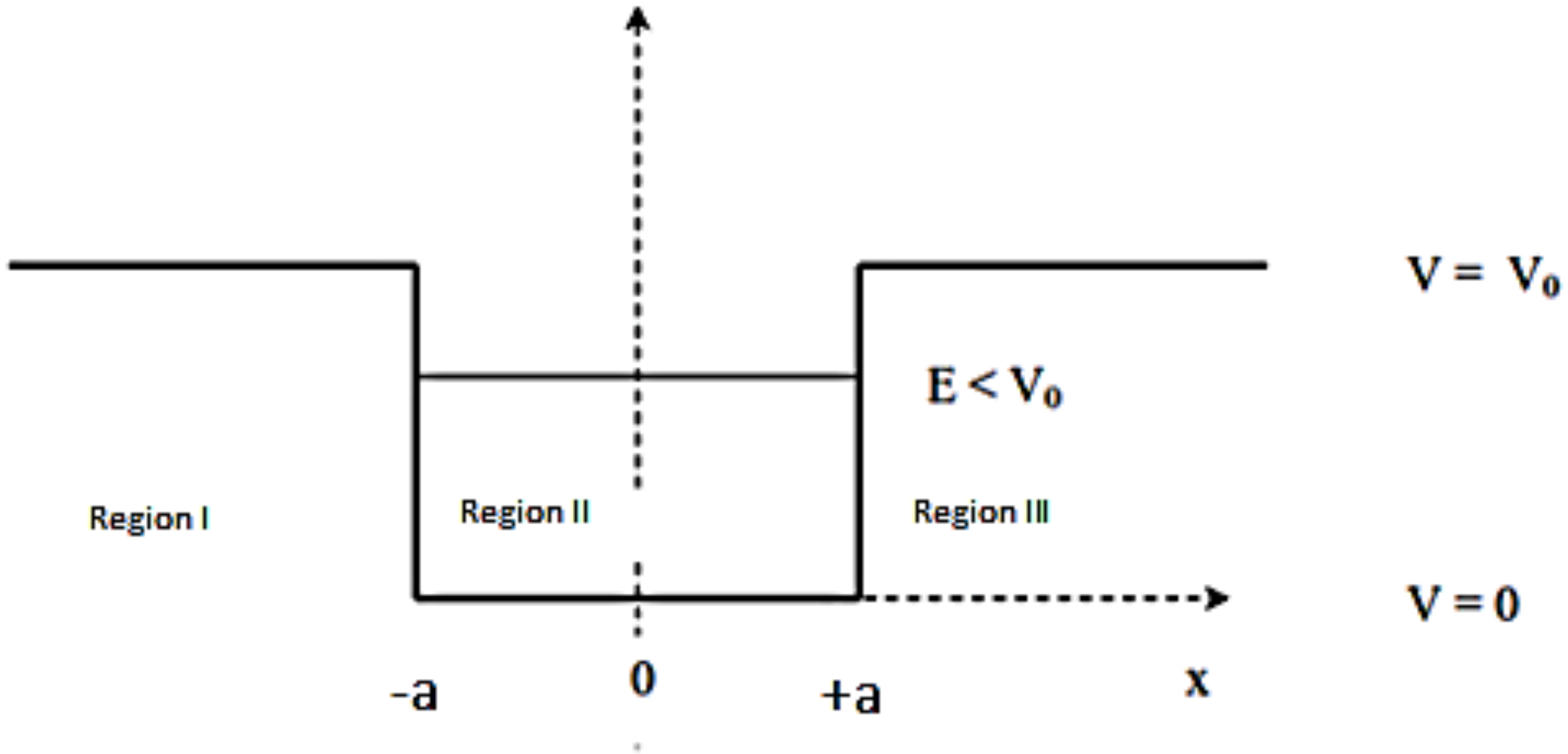

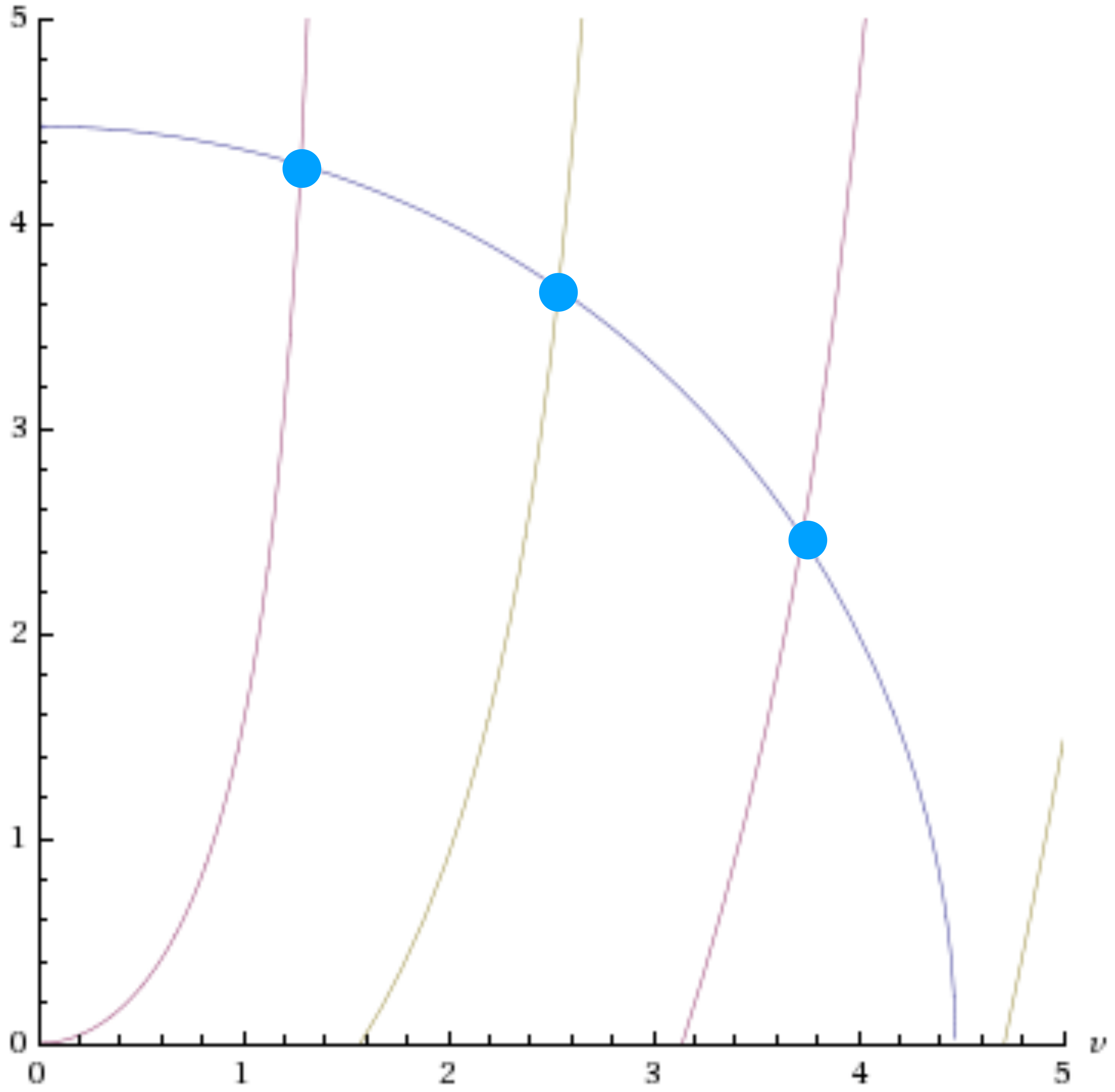

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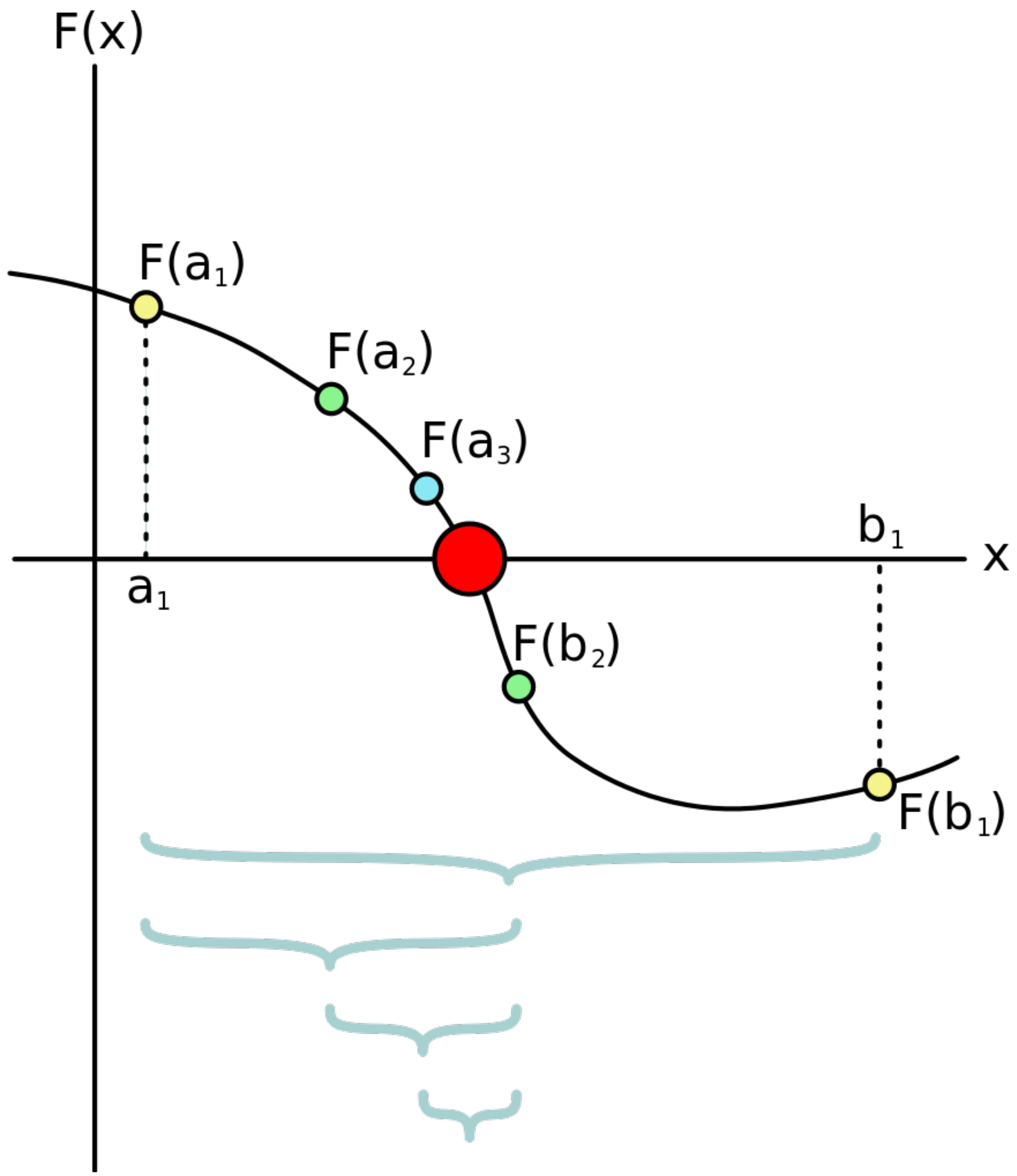
Bisection Method



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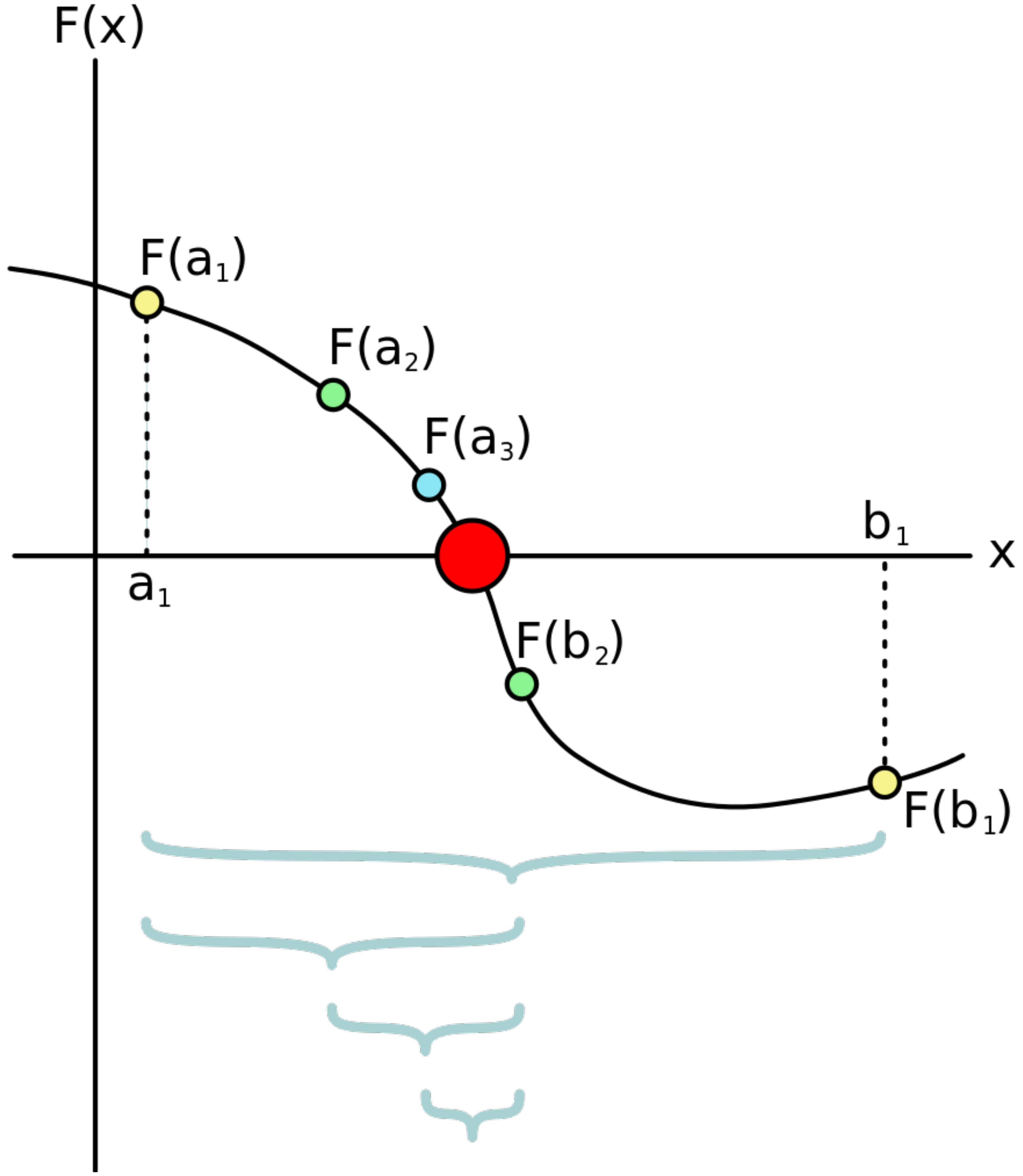
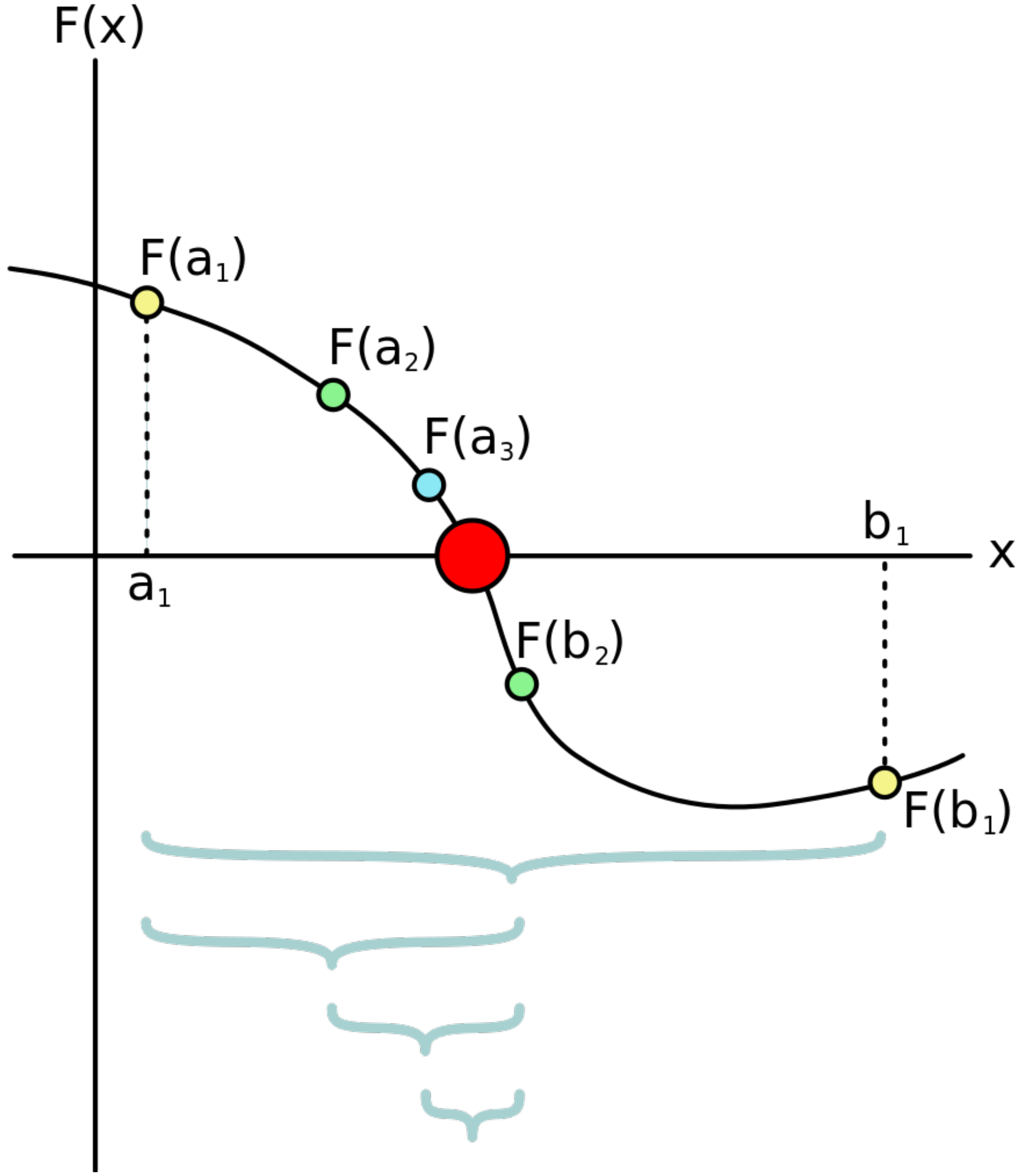


For f(x) with real roots with a selected tolerance, TOL

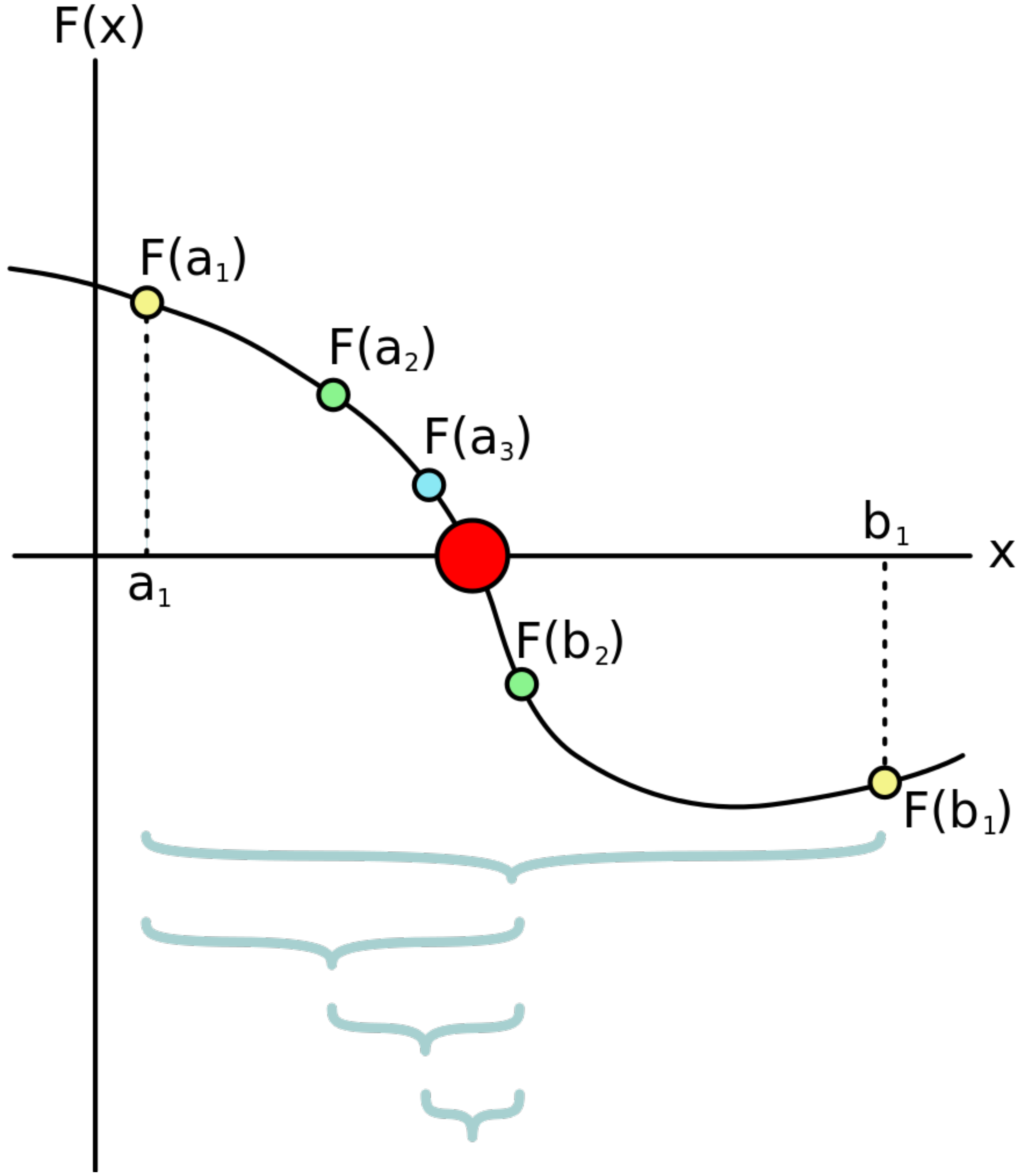
Bisection Method



For f(x) with real roots with a selected tolerance, TOL

1. Pick a_1 and b_1 such that $f(a_1)$ and $f(b_1)$ have different signs

Bisection Method



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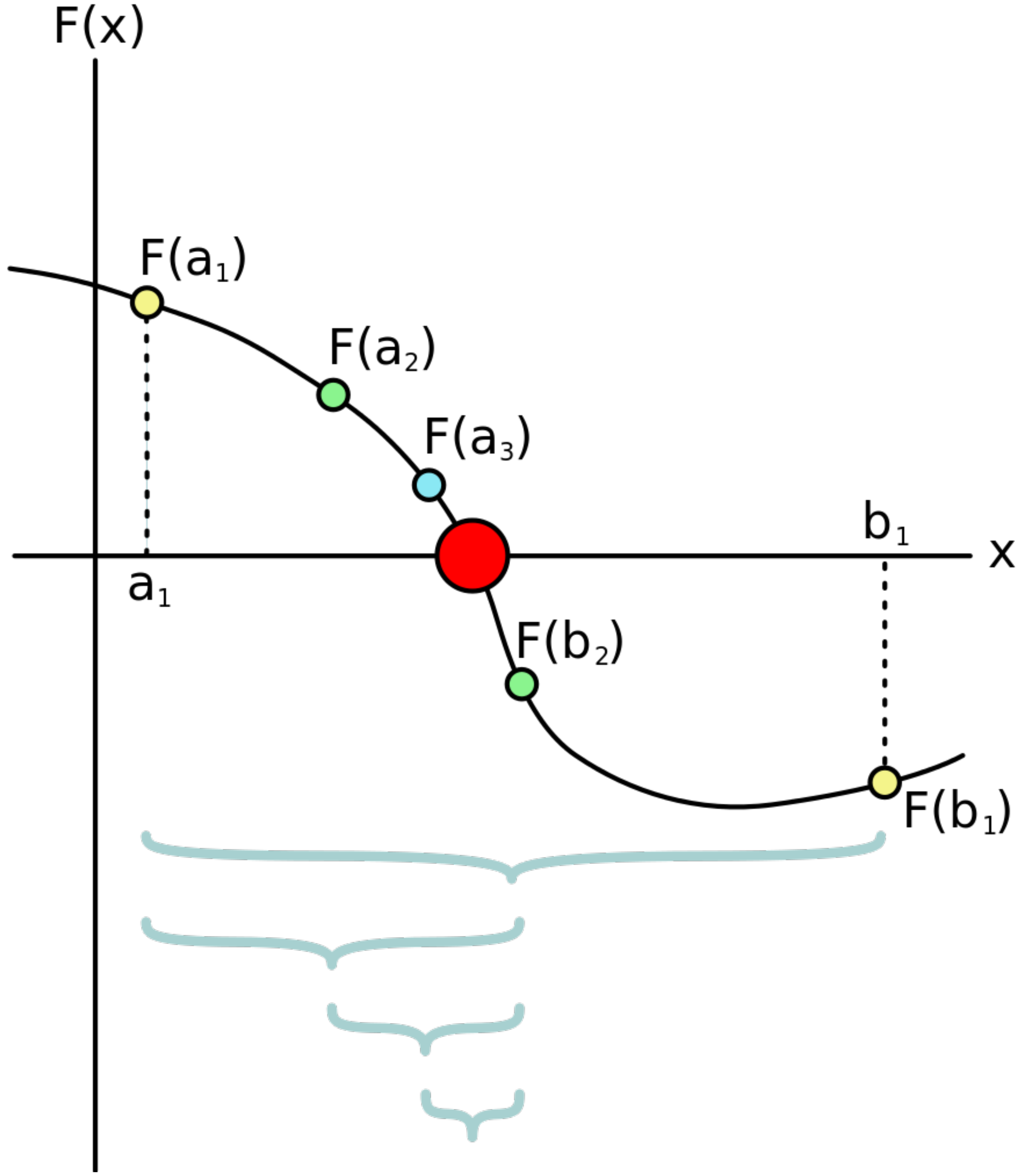
1. Pick a_1 and b_1 such that $f(a_1)$ and $f(b_1)$ have different signs
2. Calculate the midpoint, $c_1 = (a_1+b_1)/2$

Bisection Method



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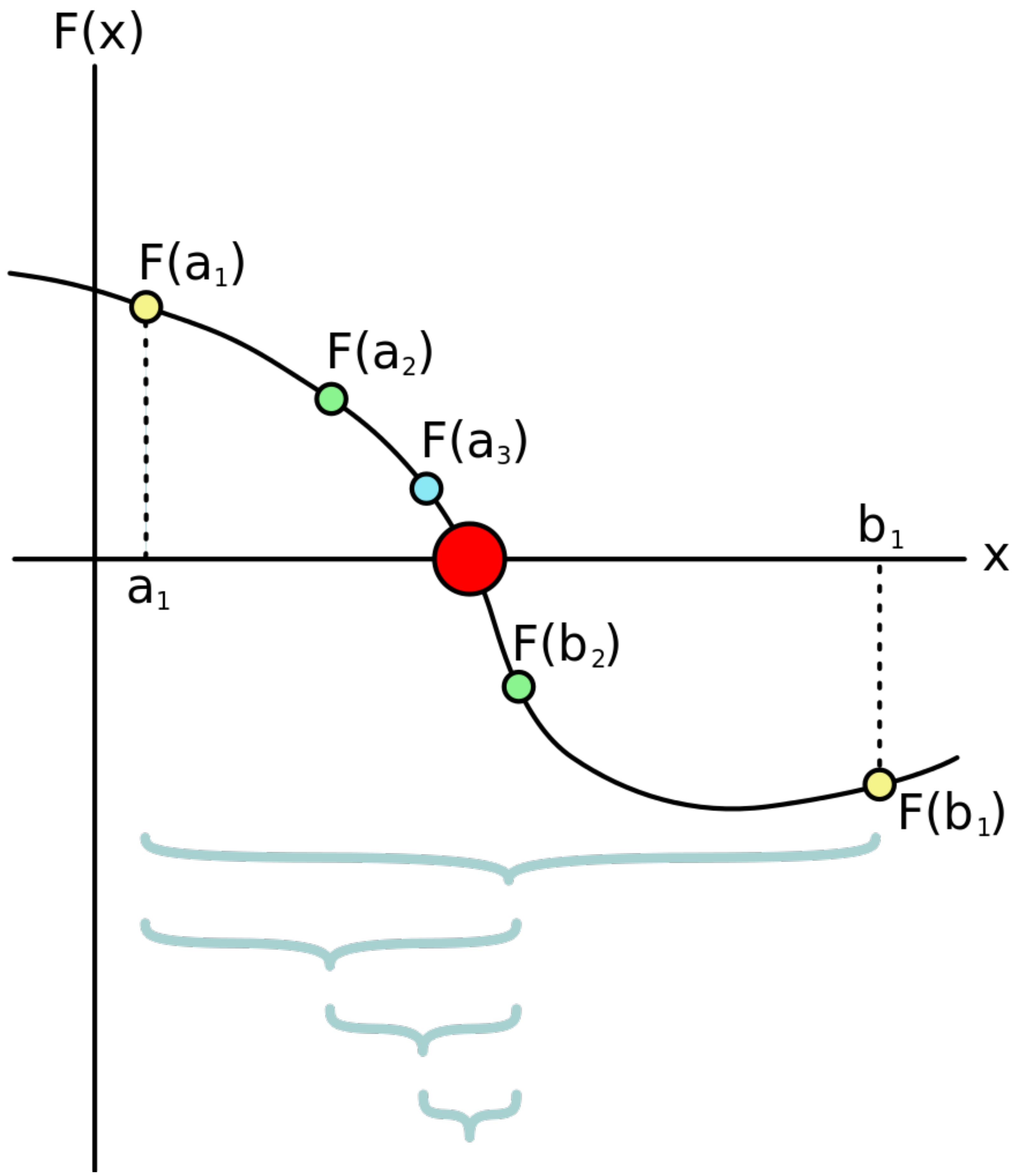
Bisection Method



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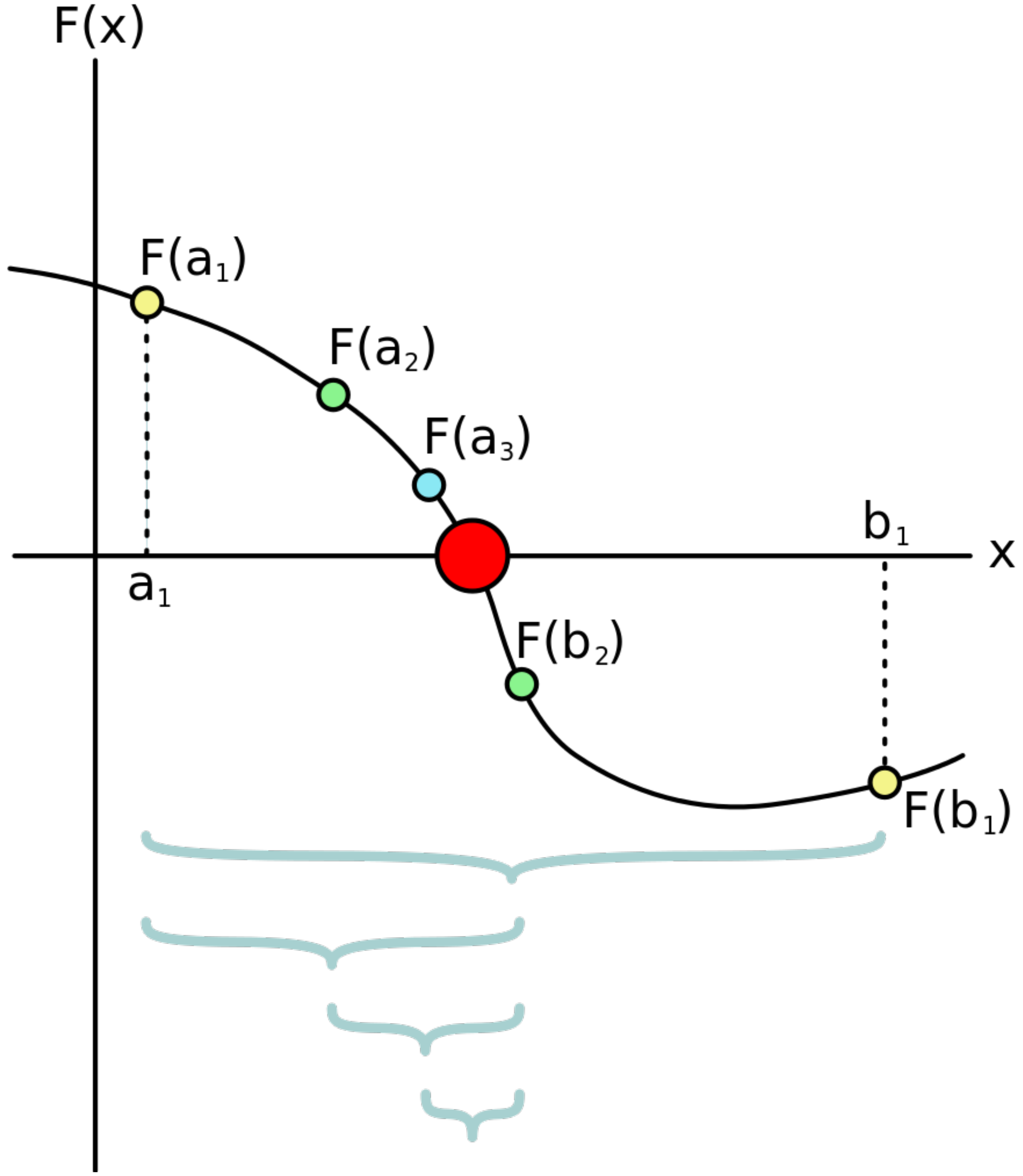
3. Calculate $f(c_1)$
4. If $f(c_1)$ less than TOL
    - Stop!

Bisection Method



For f(x) with real roots with a selected tolerance, TOL

1. Pick a_1 and b_1 such that $f(a_1)$ and $f(b_1)$ have different signs
2. Calculate the midpoint, $c_1 = (a_1+b_1)/2$
3. Calculate $f(c_1)$
4. If $f(c_1)$ less than TOL
   - Stop!
5. Else
   i. Check sign of $f(c_1)$
   ii. Sign of $f(c_1)$ same as $f(a_1)$?
      - Replace a_1 with c_1 and $f(a_1)$ with $f(c_1)$
   iii. Else
      - Replace b_1 with c_1 and $f(b_1)$ with $f(c_1)$
   iv. Repeat step 2

Steps for Bisection Method.

(1) Pick two points near the root, a & b.

⇒ Make sure $f(a)$ & $f(b)$ have opposite signs!

(2) Calculate the midpoint between a & b ⇒ $c = \frac{a+b}{2}$

(3) Calculate $f(c)$.

⇒ check if $f(c)$ is smaller than tolerance

eg. if Tolerance is 0.005 check if

$-0.005 < f(c) < 0.005$

if it is, stop!

if not, continue

(4) Assuming $|f(c)| > \text{tolerance}$, check sign of $f(c)$.

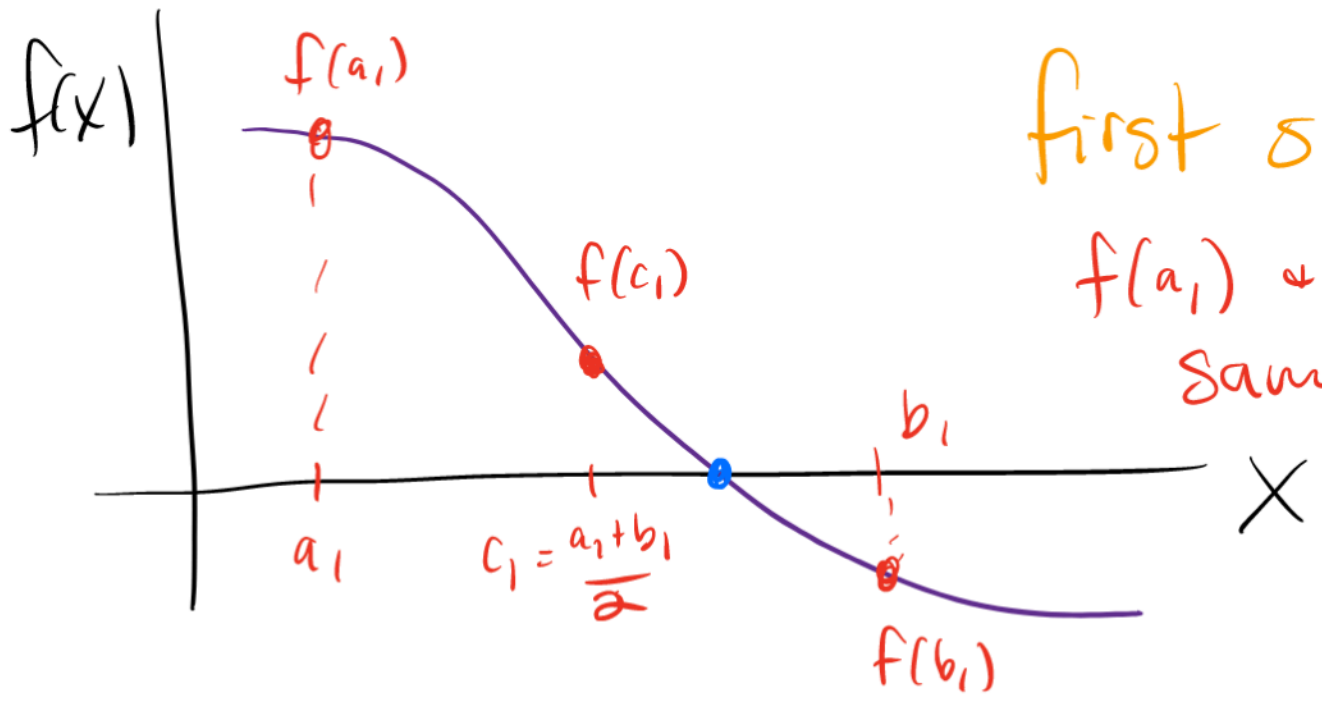
(5) if $f(c)$ same sign as $f(a)$?

replace a with c & $f(a)$ with $f(c)$

if $f(c)$ same sign as $f(b)$?

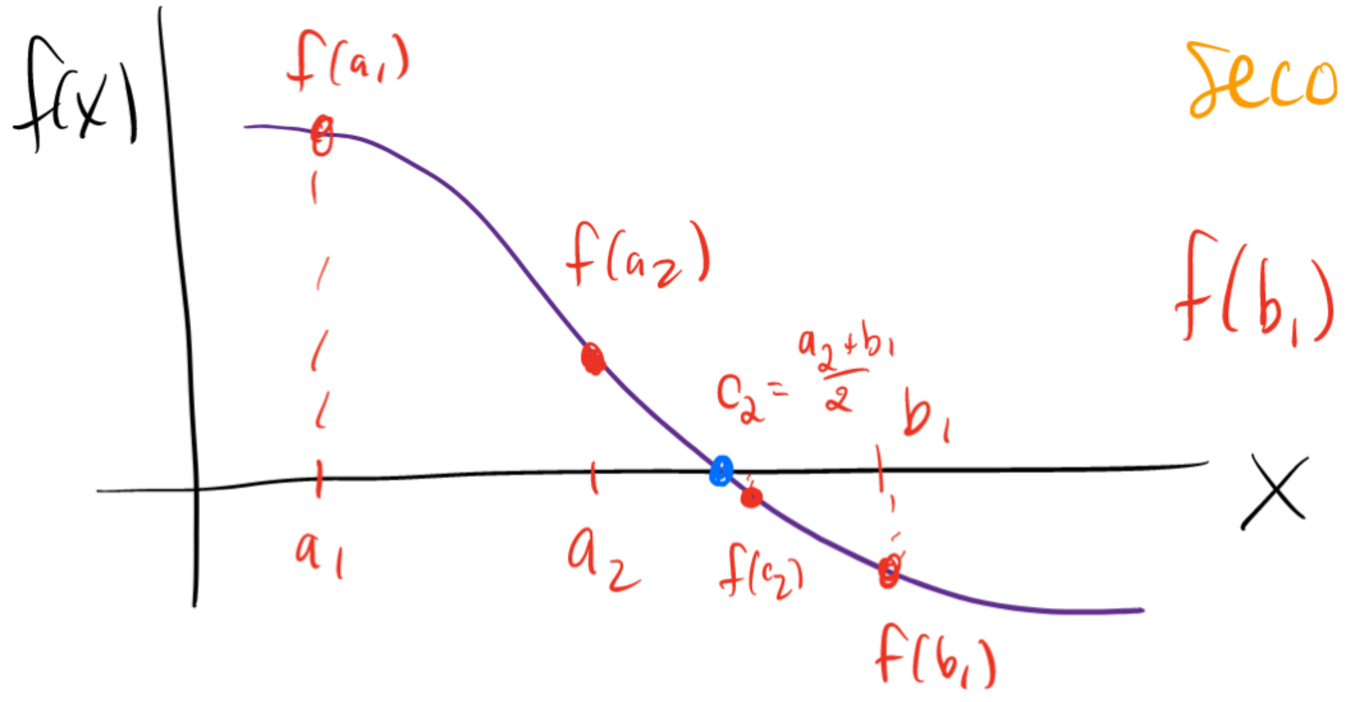
replace b with c & $f(b)$ with $f(c)$

(6) Continue 2–5 until $|f(c)| < \text{tolerance}$.



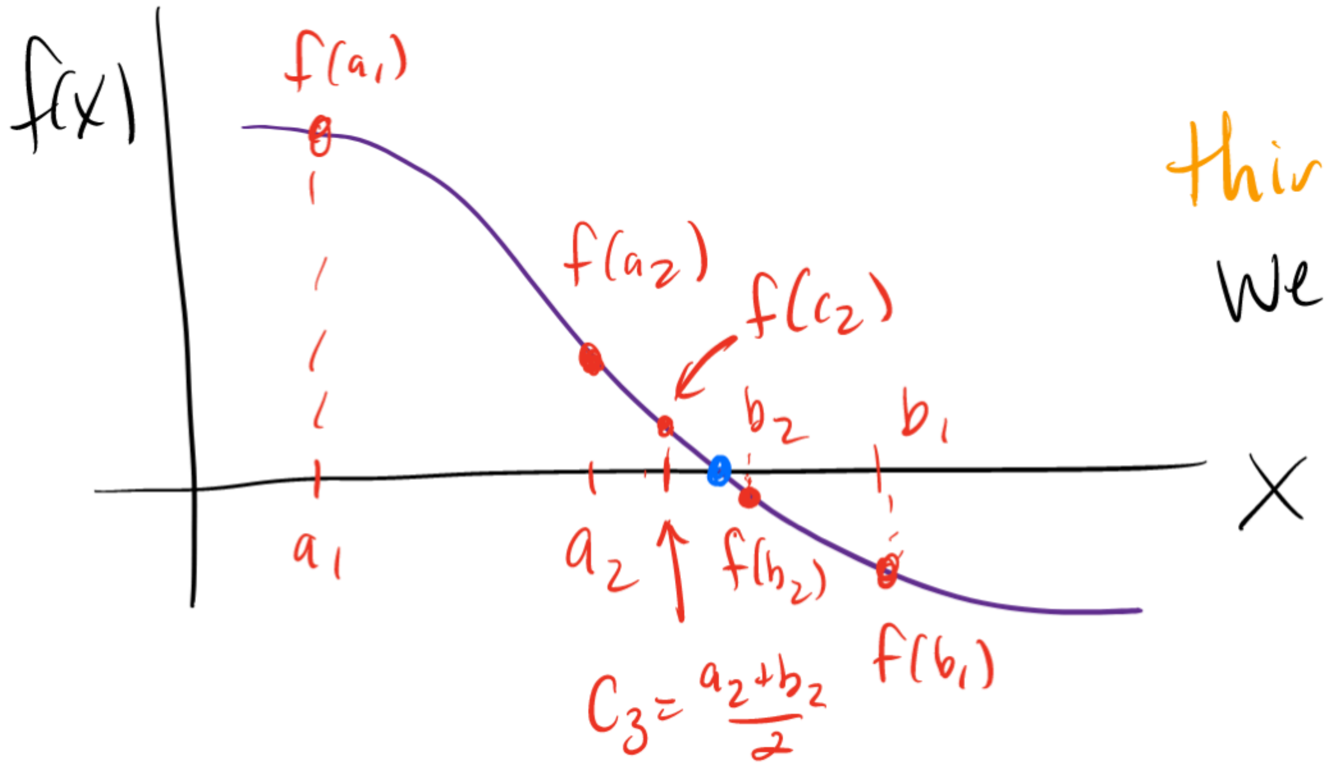
first step

$f(a_1)$ & $f(c_1)$ same sign



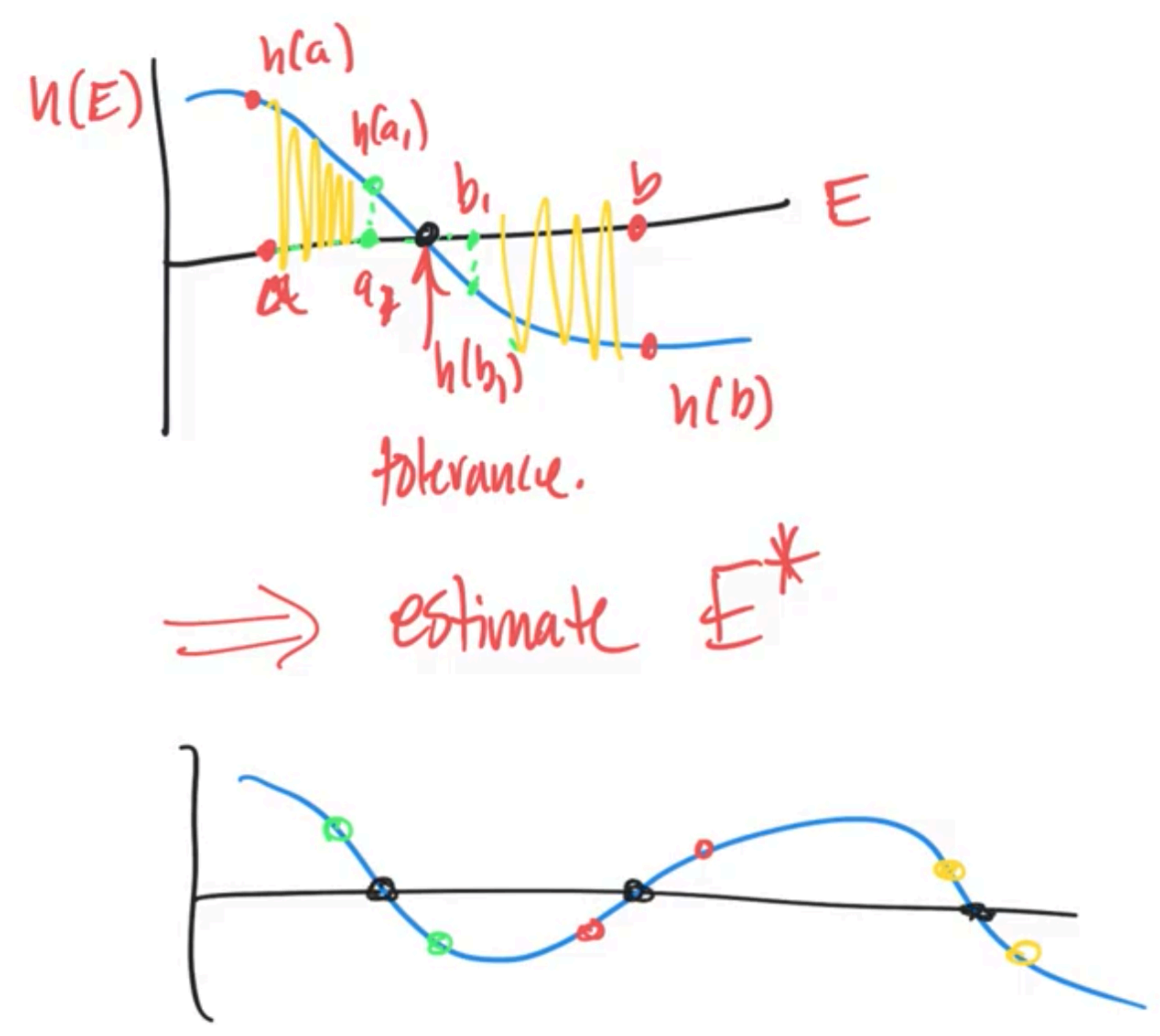
Second step

$f(b_1)$ & $f(c_2)$ same sign



third step

We could continue but that's the idea.



The Bisection Method for Root Finding

Danny Caballero
22 subscribers

Pre-Class Questions

- What were the main ideas of the videos/notes you watched for this week?
- What concepts or ideas were the easiest for you to understand from the videos/notes?
- What concepts or ideas did you find most difficult to understand from the videos/notes?
- What questions do you have about the concepts or ideas presented in the videos/notes?
- Do you have any other thoughts, questions, or concerns?

Day 6 In-Class Activity

The Finite Square Well

The next most complicated potential is where we drop the walls of the infinite square well down to $V_0 > 0$. In this case, we will observe bound states ($E < V_0$) and unbound states ($E > V_0$). For now, we focus on bound states, which lead to quantized energy eigenstates. The potential we are given is:

$$V(x) = \begin{cases} V_0 & \text{if } x < -a \\ 0 & \text{if } -a < x < a \\ V_0 & \text{if } x > a \end{cases}$$

We can show that the general solutions for energy eigenstates are:

$$\phi_E(x) = \begin{cases} Ae^{qx} + Be^{-qx} & \text{if } x < -a \\ C\sin kx + D\cos kx & \text{if } -a < x < a \\ Fe^{qx} + Ge^{-qx} & \text{if } x > a \end{cases}$$

where $k = \sqrt{\dfrac{2mE}{\hbar^2}} > 0$ and $q = \sqrt{\dfrac{2m(V_0 - E)}{\hbar^2}} > 0.$

1. **Question:** There are 3 “boundary” conditions on $\phi_E(x)$. What are they?
    - **Discussion:** What is the physical or practical origin of each of these boundary conditions? Why are there not additional conditions on the derivatives of $\phi_E(x)$?
2. **Question:** We can apply these boundary conditions (as in McIntyre or my notes), and show that the energy equations we must satisfy are: $ka\tan(ka) = qa$ and $-ka\cot(ka) = qa$. How do we know these equations are transcendental? That is, how do we recognize that we won’t be able to find an analytical solution?
    - **Discussion:** What are some ways we can find approximate solutions to these equations? What are the benefits and tradeoffs to each method you come up with?
3. **Question:** Using McIntyre’s definitions for $z = \sqrt{\dfrac{2MEa^2}{\hbar^2}}$ and $z_0 = \sqrt{\dfrac{2MV_0a^2}{\hbar^2}}$, derive the transcendental relationships: $z\tan(z) = \sqrt{z_0^2 - z^2}$ and $-z\cot(z) = \sqrt{z_0^2 - z^2}$.
    - **Discussion:** For a strongly bound particle, what would your expect for the values of z_0 and z? What about for a weakly bound particle?

Contact: caballero@pa.msu.edu

File Edit View Run Kernel Tabs Settings Help

Launcher | Finite_Square_Well_Demo.i

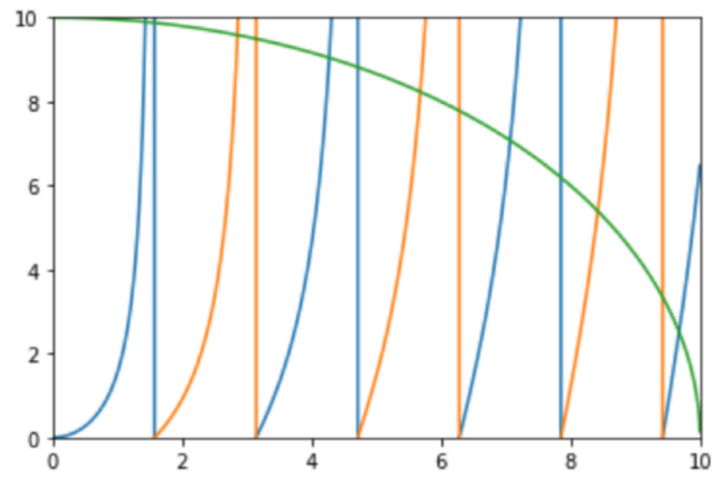
Finite Square Well Demo

[1]:
```python
import numpy as np
import matplotlib.pyplot as plt
```

[2]:
```python
def f1(z):

    return z*np.tan(z)

def f2(z):

    return -z/np.tan(z)

def g(z,z0):

    return np.sqrt(z0**2-z**2)

def h1(z,z0):

    return g(z,z0)-f1(z)

def h2(z,z0):

    return g(z,z0)-f2(z)
```

[3]:
```python
z0 = 10
zarr = np.arange(0.01,z0,0.001)

plt.plot(zarr, f1(zarr))
plt.plot(zarr, f2(zarr))
plt.plot(zarr, g(zarr,z0))

plt.axis([0,z0,0,z0])
```

[3]: (0.0, 10.0, 0.0, 10.0)

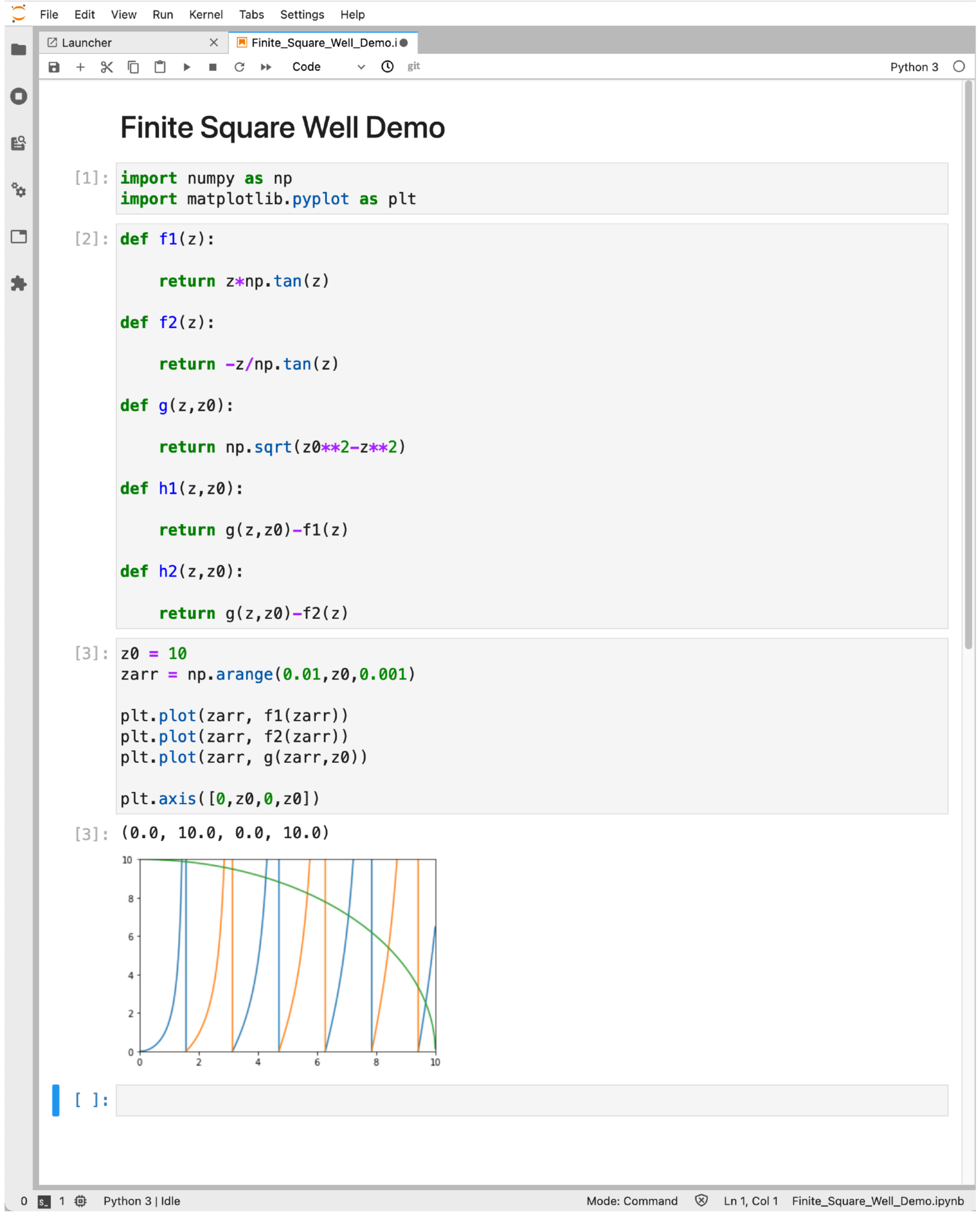


[ ]:

0 1 Python 3 | Idle Mode: Command Ln 1, Col 1 Finite_Square_Well_Demo.ipynb

Live Coded In-Class Demo

But how do we find these roots?



Live Coded In-Class Demo

But how do we find these roots?

5. Finding the Eigenenergies of the Finite Square Well Numerically

You will turn in this question using a Dropbox file request. Turn in the notebook, not a PDF of it.

For this question, download this Jupyter notebook and work through the notebook. All the instructions appear in the notebook. The design is such that you are shown how to do some calculation, and then asked to translate that calculation to the problem at hand.

Finding the Eigenenergies of the Finite Square Well

One of the more useful numerical tools you can learn is root finding. Many problems can be cast as an algebraic problem where you are seeking the scalar value where a function goes to zero. Mathematically, we characterize this problem as seeking the values x^* for a continuous function $f(x)$ where

$$f(x^*) = 0$$

In some cases (e.g., quadratic polynomials), you might be able to find x^* exactly. But in most cases, that is not the case, and you will need to instead find an approximate x^* and characterize the numerical error in the value you determined.

In this notebook, we will work through the Bisection method for finding roots of equations. This method is relatively robust, but does have a few drawbacks for cetain kinds of functions and problems.

We will start with finding the intersections of two functions. Later, we will apply this to the finite square well to determine the approximate eigenenergies. As usual, we go through some of the conceptual elements before having you write your own code.

First, we import the libraries we need for numerics and plotting.

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

1. Conceptual Idea of the Bisection Method

1.1 Define the functions

We are seeking the intersection points of two equations:

$$f_1(x) = 100\cos(x) \text{ and } f_2(x) = x^2 + 2x - 3$$

which we cast as a root finding problem by subtracting them:

$$f(x) = f_1(x) - f_2(x) = 100\cos(x) - x^2 - 2x + 3$$

We define these scalar functions below.

[2]:
```
def f1(x): ## Defining f1

    return 100*np.cos(x)

def f2(x): ## Defining f2

    return x**2 + 2*x - 3

def f(x): ## Defining f

    return f1(x)-f2(x)
```

Computational Homework Assignments:

- Instruct students in the representations and algorithms
- Ask them apply to QM problem
- Use known tools

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Homework3_Problem5_ST

Markdown git Python 3

Finding the Eigenenergies of the Finite Square Well

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Computational Homework Assignments:

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Let's look at what is given to students and what students turn in!

Physics 472 Syllabus Calendar Pre-class Notes and Activties Homework

Final Project (Due April 29th at midnight)

Your final project will consist of a 8-10 minute video presentation of some original work or analysis you have done in a quantum mechanical system. You will be asked to work in groups no larger than 3 (you can choose your groups). Every person must contribute to the preparation and presentation. I will create a form to ask you about the contributions of each member and to make sure that each student in the group should be awarded the same grade.

For the project, I have the following expectations:

1. That you work together drawing on each other's strengths to prepare your video presentation.
2. That you presentation consists of some original analysis (theoretical and computational) of some interesting quantum system.
3. That you discuss the background and set up for this analysis.
4. That you provide a full discussion of the analysis and results you have produced.
5. That you provide an associated Jupyter notebook that illustrates your work.

You may choose any topics that you are interested in. Some potential topics include:

- Anything beyond Chapter 10 of McIntyre
- Simulations of multiple quantum bodies
- Exploring common QM numerical analysis to problems (e.g., the shooting method for the square well)
- Applications of what we have learned to new physical systems (e.g., atomic, nuclear, elementary particles)

For grading the assignment, the structure will be:

- 30% - Video Presentation (graded by the Instructor)
- 30% - Explanatory Notebook (graded by the Instructor)
- 15% - Feedback From Other Student Evaluations (you will be asked to review some small number of other students projects)
- 10% - How Well You Reviewed Other Students Evaluations (your feedback will be reviewed for quality and depth)
- 15% - Feedback From Your Group Mates

Turn-In Procedure

- Your group can turn-in your project anytime before Thursday, April 29th at midnight. To do so, zip up your files (e.g., notebooks, code, slides, video, anything else) and upload it to the Dropbox file request
- I will review the turn-ins on the morning of April 30th and assign reviews. I will send you an individual email by noon on Friday the 30th with your reviewing assignments. Make sure to check your spam filter!
- Your reviews will be due Sunday May 2nd by midnight. I expect this reviewing to take you 60-90 minutes. This gives you over 48 hours to complete the reviews. To conduct a review, you will complete this form for every group you are assigned.

Website for Physics 472 - Quantum Mechanics II at Michigan State University Contact: caballero@pa.msu.edu

- Original analysis or model of something we haven't covered
- Video presentation of your work
- Jupyter notebook describing the work
- Peer and Instructor Review

Rubric for Final Project

4.0 - Exceeds Expectations

3.5 - Meets Expectations

3.0 - Nearing Expectations

2.0 - Does Not Meet

0.0 - Missing Expectations

Rubric for Final Project

4.0 - Exceeds Expectations

3.5 - Meets Expectations

3.0 - Nearing Expectations

2.0 - Does Not Meet

0.0 - Missing Expectations

Stating the Problem (10%)

- Exceeds Expectations (4.0) - States problem with compelling discussion of importance, interest, and background.
- Meets Expectations (3.5) - States problem with adequate discussion of importance, interest, and background.
- Nearing Expectations (3.0) - States problem with minimal discussion of importance, interest.
- Does Not Meet Expectations (2.0) - States problem with no additional discussion.
- Missing (0.0) - Absent, no evidence

Explaining the Relevant Theory/Model/Approach (25%)

- Exceeds Expectations (4.0) - Clearly and concisely explains the theory/model/approach that is being investigated and how it relates to the physics. Describes assumptions and approximations that are being made.
- Meets Expectations (3.5) - Clearly and concisely explains the theory/model/approach that is being investigated. Describes assumptions and approximations that are being made.
- Nearing Expectations (3.0) - Clearly and concisely explains the models that is being investigated in this poster.
- Does Not Meet Expectations (2.0) - Explains what the symbols in the model mean
- Missing (0.0) - Absent, no evidence

Performing the Appropriate Calculations/Derivations/Analysis (25%)

- Exceeds Expectations (4.0) - Clearly explains the analysis being done in a way that can be not only followed but reporoduced easily.
- Meets Expectations (3.5) - Clearly explains the analysis being done in a way that can be followed easily.
- Nearing Expectations (3.0) - Explains the analysis being done, but hard to follow, unclear, or otherwise missing aspects.
- Does Not Meet Expectations (2.0) - Conducts analysis.
- Missing (0.0) - Absent, no evidence

Rubric for Final Project

4.0 - Exceeds Expectations

3.5 - Meets Expectations

3.0 - Nearing Expectations

2.0 - Does Not Meet

0.0 - Missing Expectations

Stating the Problem (10%)

- Exceeds Expectations (4.0) - States problem with compelling di
- Meets Expectations (3.5) - States problem with adequate discus
- Nearing Expectations (3.0) - States problem with minimal discus
- Does Not Meet Expectations (2.0) - States problem with no addi
- Missing (0.0) - Absent, no evidence

Explaining the Relevant Theory/Model/A

- Exceeds Expectations (4.0) - Clearly and concisely explains the physics. Describes assumptions and approximations that are be
- Meets Expectations (3.5) - Clearly and concisely explains the th approximations that are being made.
- Nearing Expectations (3.0) - Clearly and concisely explains the r
- Does Not Meet Expectations (2.0) - Explains what the symbols i
- Missing (0.0) - Absent, no evidence

Performing the Appropriate Calculations

- Exceeds Expectations (4.0) - Clearly explains the analysis being
- Meets Expectations (3.5) - Clearly explains the analysis being do
- Nearing Expectations (3.0) - Explains the analysis being done, b
- Does Not Meet Expectations (2.0) - Conducts analysis.
- Missing (0.0) - Absent, no evidence

Presenting your Results (20%)

- Exceeds Expectations (4.0) - Clearly presents figures that demonstrate the results of the analytical and computational modeling conducted. Describes the figure in a concise way and relates it to the underlying physics.
- Meets Expectations (3.5) - Clearly presents figures that demonstrate the results of the analytical and computational modeling conducted. Describes the figure in a concise way.
- Nearing Expectations (3.0) - Figures are presented that result from the modeling and are described in a concise way.
- Does Not Meet Expectations (2.0) - There are figures resulting from the calculations.
- Missing (0.0) - Absent, no evidence

Discussing your Findings, Conclusions, and Implications (10%)

- Exceeds Expectations (4.0) - The discussion describes the results in the context of the theory/model and the physics. Limitations and signficances of the work are discussed. Future directions are described that follow from the work that has been completed.
- Meets Expectations (3.5) - The discussion describes the results in the context of the theory/model and the physics. Limitations and signficances of the work are discussed.
- Nearing Expectations (3.0) - The discussion describes the results in the context of the theory/model and the physics.
- Does Not Meet Expectations (2.0) - There is a discussion of the results.
- Missing (0.0) - Absent, no evidence

Including Appropriate References/Resources (10%)

- Exceeds Expectations (4.0) - All cited works, both text and visual, are done in the correct format with no errors. Includes more than 5 major references (e.g. science journal articles, books, but no more than two internet sites.)
- Meets Expectations (3.5) - Some cited works, both text and visual, are done in the correct format. Inconsistencies evident. Includes 5 major references (e.g. science journal articles, books, but no more than two internet sites.)
- Nearing Expectations (3.0) - Few cited works, both text and visual, are done in the correct format. Includes 4 major references (e.g. science journal articles, books, but no more than two internet sites.)
- Does Not Meet Expectations (2.0) - Includes 3 major references (e.g. science journal articles, books, but no more than two internet sites.)
- Missing (0.0) - Absent or the only references are internet sites.

Rubric for Final Project

4.0 - Exceeds Expectations
3.5 - Meets Expectations
3.0 - Nearing Expectations
2.0 - Does Not Meet
0.0 - Missing Expectations

Rubric Components

- Stating the Problem (10%)
- Explaining the Relevant Theory/Model/Approach (25%)
- Performing the Appropriate Calculations/Derivations/Analysis (25%)
- Presenting your Results (20%)
- Discussing your Findings, Conclusions, and Implications (10%)
- Including Appropriate References/Resources (10%)

Positives

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- Most students are able to complete computational activities.

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Issues

- More students have dropped than typical
- About half of students regularly attend class
- International students find keeping up with class challenging
- Zoom groups are no substitute of in-class group work
- Less material (and less computation) discussed

Going back to in-person…

Going back to in-person…

Keeping flipped format and multiple modes of engagement

Going back to in-person…

Keeping flipped format and multiple modes of engagement

Keeping flexible deadlines, potentially expanding

Going back to in-person…

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Writing more instructional notebooks for homework

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Change instructor live-coding to in-class coding activities

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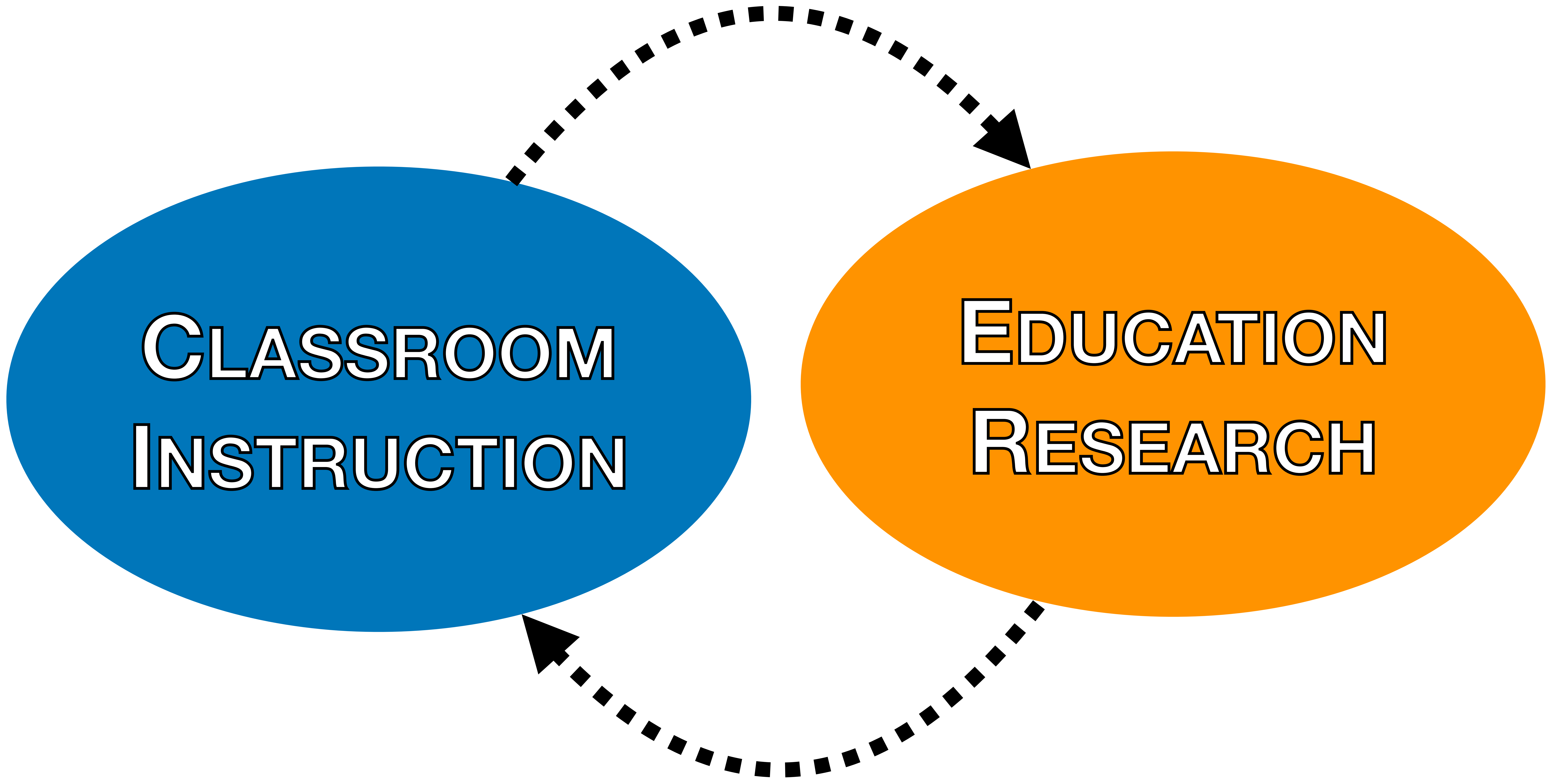
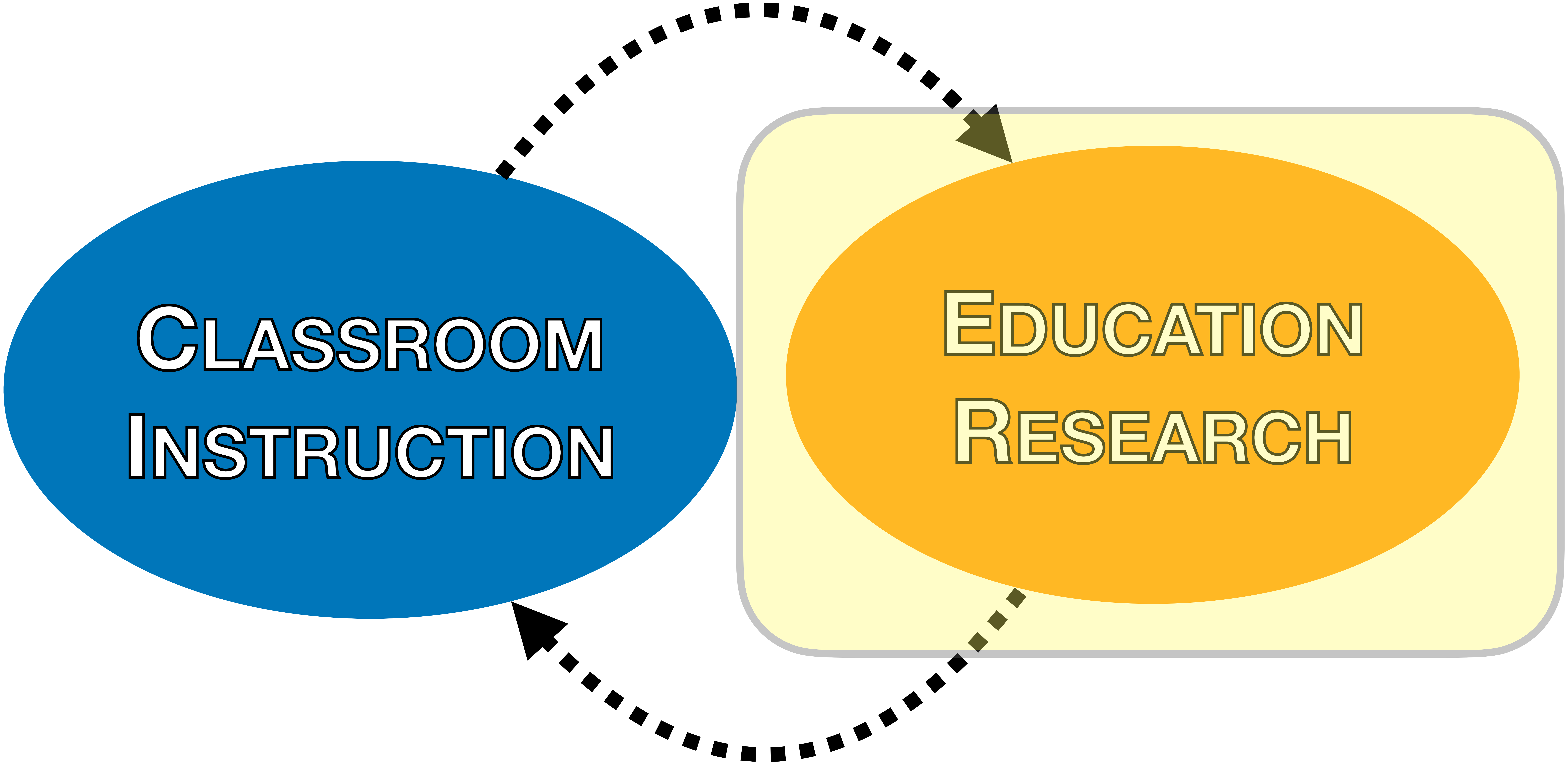
Keeping flexible deadlines, potentially expanding

Writing more instructional notebooks for homework

Change instructor live-coding to in-class coding activities

Better integrate final project into course instruction overall


Classroom Instruction
Education Research


Classroom Instruction
Education Research

WHAT HAVE STUDENTS LEARNED AFTER INSTRUCTION?

MINIMALLY WORKING PROGRAM

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

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

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

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

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

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

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

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

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

        SatelliteMotionMap.update(t, pSatellite/mSatellite)

        t = t + deltat
```

Weatherford, PhD Thesis, 2011

AFTER

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

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

# Objects
Earth = sphere(pos=vector(0,0,0), radius=6.4e6, material=materials.BlueMarble)
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# More window setup
scene.range=12*Earth.radius

# Parameters and Initial conditions
mSatellite = 15e3
pSatellite = mSatellite*vector(0,3073,0)
G = 6.67e-11
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        Earth.rotate(angle=theta, axis=vector(0,0,1), origin=vector(0,0,0))     #       IGNORE THIS LINE
        rate(10000)

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

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

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

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

        t = t +deltat
```

How proficient are they?

New Model: Central Force

- Assign initial conditions
- Compute force
- Update velocity

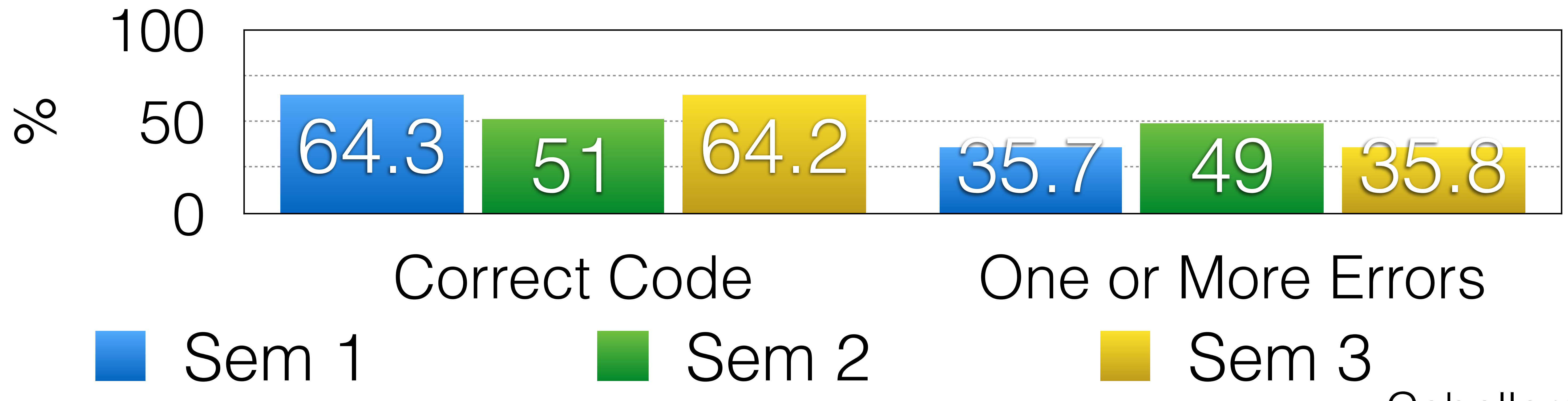
approx. 1300 students

```
blueObject = sphere(pos=vector(5,4,0), radius=0.25, color=color.blue)
redObject = sphere(pos=vector(-3,-2,0), radius=0.25, color=color.red)
trail = curve(color = redObject.color)

k = 0.3
redObject.m = 5e-3

redObject.p = redObject.m*vector(800,800,0)

t = 0
deltat = 5e-6

while t < 1:

    r = redObject.pos - blueObject.pos
    rhat = r/mag(r)
    F = -k/mag(r)**4*rhat

    redObject.p = redObject.p + F*deltat

    redObject.pos = redObject.pos + redObject.p/redObject.m*deltat

    trail.append(pos = redObject.pos)
    t = t + deltat
```

Initial Conditions (identify and assign)

Force Calculation (contextualize)

Newton's Second Law (implement)

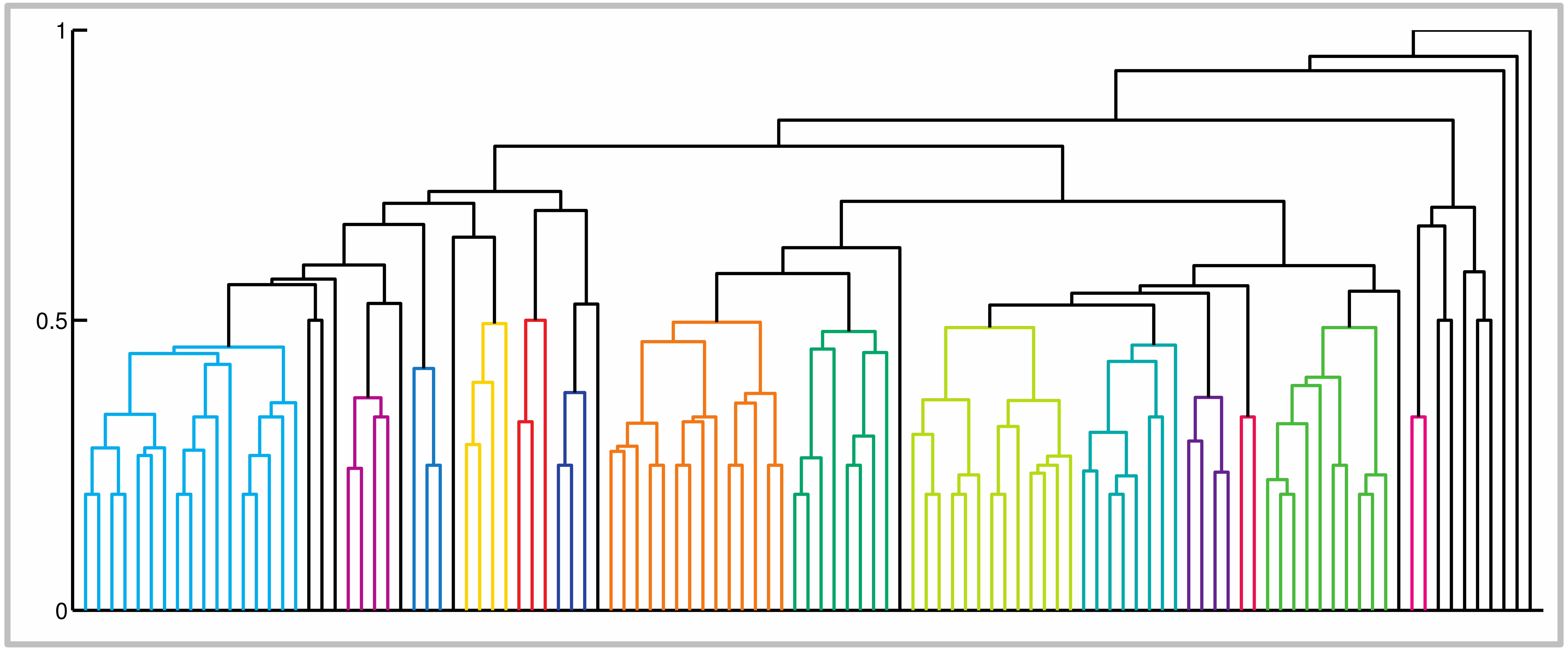


Caballero, Kohlmyer, Schatz, PRST-PER 8, 020106 (2012)

Finding Commonalities in Students' Erroneous Programs

Two raters "grade" codes using rubric
High Inter-rater Reliability 91%

Reduce data complexity
Search for similarity using Cluster Analysis



Caballero, Kohlmyer, Schatz, PRST-PER 8, 020106 (2012)

Dominant Errors are Not Syntactic*

80% of students in 5 clusters

Dominant Error	%
Sign Error in Force Calculation	34.6
Running Code; Error in Initial Conditions	19.8
Net Force as Scalar	13.3
Raised Separation Vector to Power	7.6
Force Calculated Outside Loop	7.1

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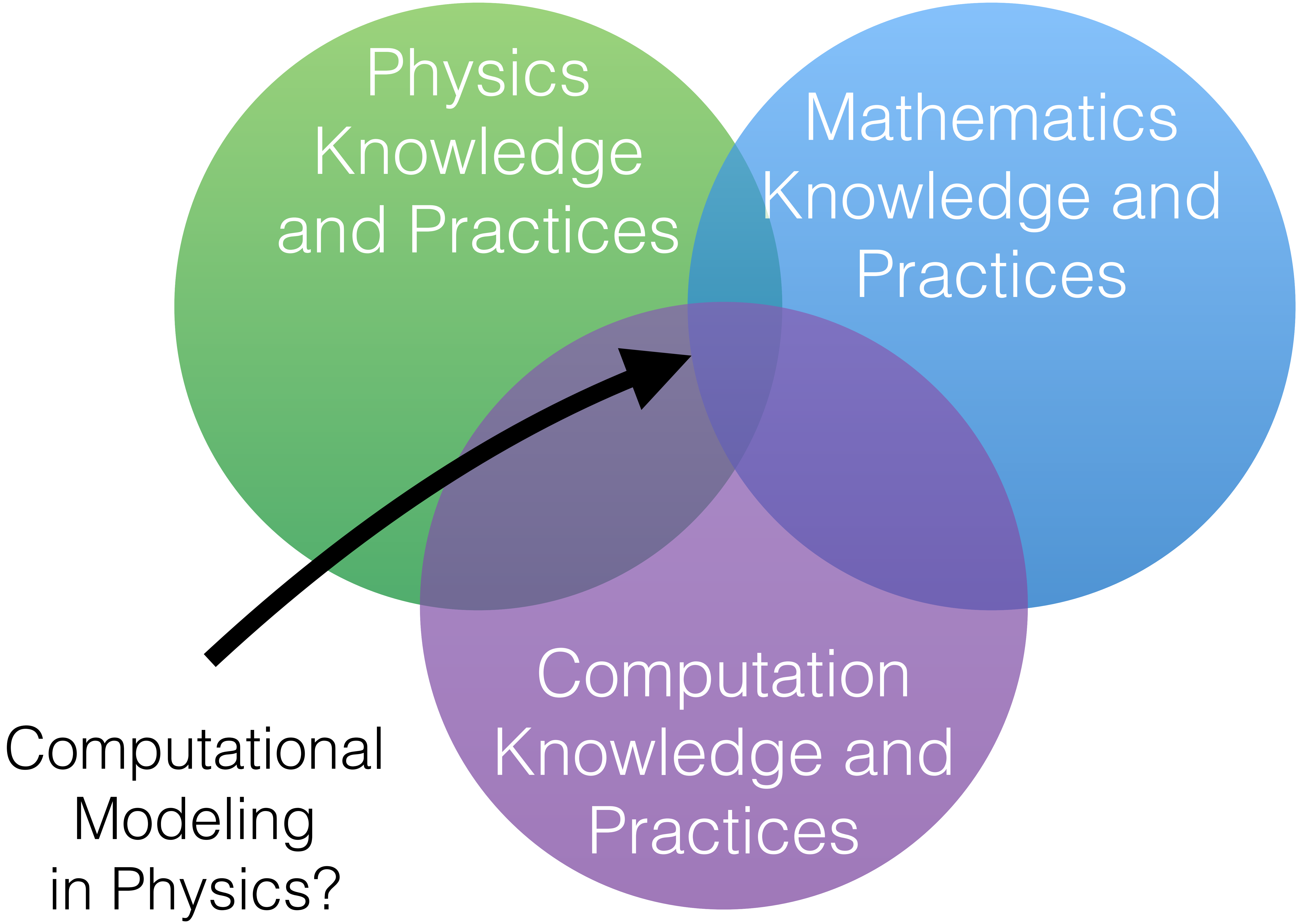
*Can we separate physics errors from syntactic ones?

Caballero, Kohlmyer, Schatz, PRST-PER 8, 020106 (2012)


Physics Knowledge and Practices
Mathematics Knowledge and Practices
Computation Knowledge and Practices
Computational Modeling in Physics?

Open Questions

Open Questions

- How do students go about constructing these physics programs?

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- What knowledge and ideas do students leverage while engaged in numerical computation?

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- What patterns of participation do we see when students are engaged in numerical computation?

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- What knowledge and ideas do students leverage while engaged in numerical computation?
- What patterns of participation do we see when students are engaged in numerical computation?
- What forms of instruction support different computational physics learning outcomes?

WHAT CAN COMPUTATIONAL INSTRUCTION LOOK LIKE?

Projects & Practices in Physics

a community-based learning environment

Project 3: Geosynchronous Orbit: Part A

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

Project 3: Geosynchronous Orbit: Part B

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

Code for Project 3:

geosync.py

PhysUtil Module

Irving, Obsniuk, & Caballero, EJP (2017)

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

msuperl.org/wikis/pcubed/

Investigating Learning Assistants' Instructional Approaches

Learning Assistants

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# Objects
Earth = sphere(pos=vector(0,0,0), radius=6.4e6, material=materials.BlueMarble)
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scene.range=12*Earth.radius

# Parameters and Initial conditions
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        rate(10000)

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

        SatelliteMotionMap.update(t, pSatellite/mSatellite)

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Computational Modeling

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

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Computational Modeling

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)

Final Themes

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

Final Themes

- Utility of computation
  - Perceptions of the usefulness of computation, inside or outside of the classroom

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

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  - Perceptions of the usefulness of computation, inside or outside of the classroom
- Teaching outcome
  - What an LA wants their students to take away from the computational problems

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

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  - What an LA wants their students to take away from the computational problems
- Characteristic to moderate
  - On-going aspect of a group's work that an LA monitors and influences

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

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- Teaching outcome
  - What an LA wants their students to take away from the computational problems
- Characteristic to moderate
  - On-going aspect of a group's work that an LA monitors and influences
- Teaching strategy
  - Methods an LA uses to teach computational problems

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

Results

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

Theme and Variation

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Results

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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.

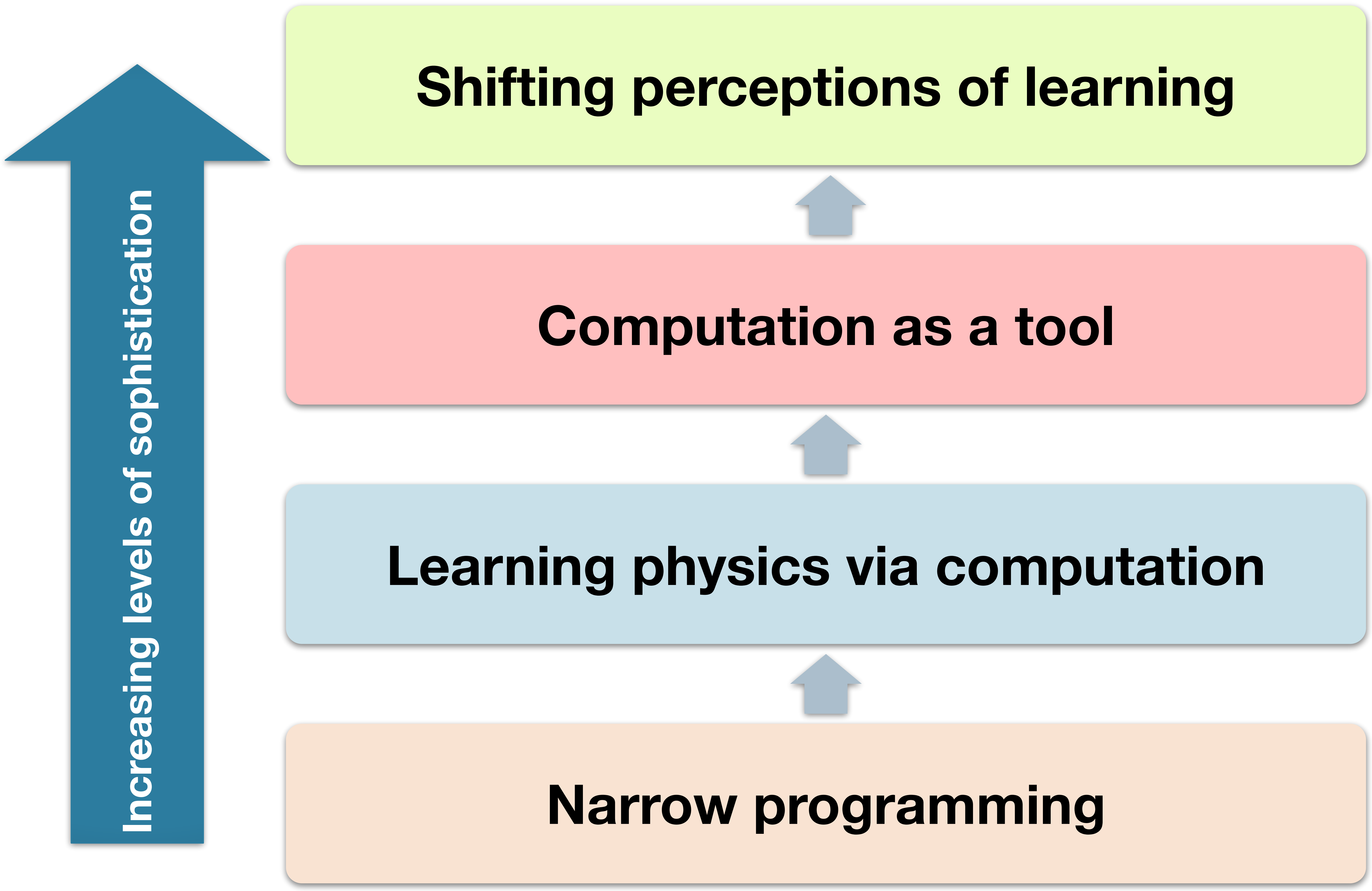
Molly

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

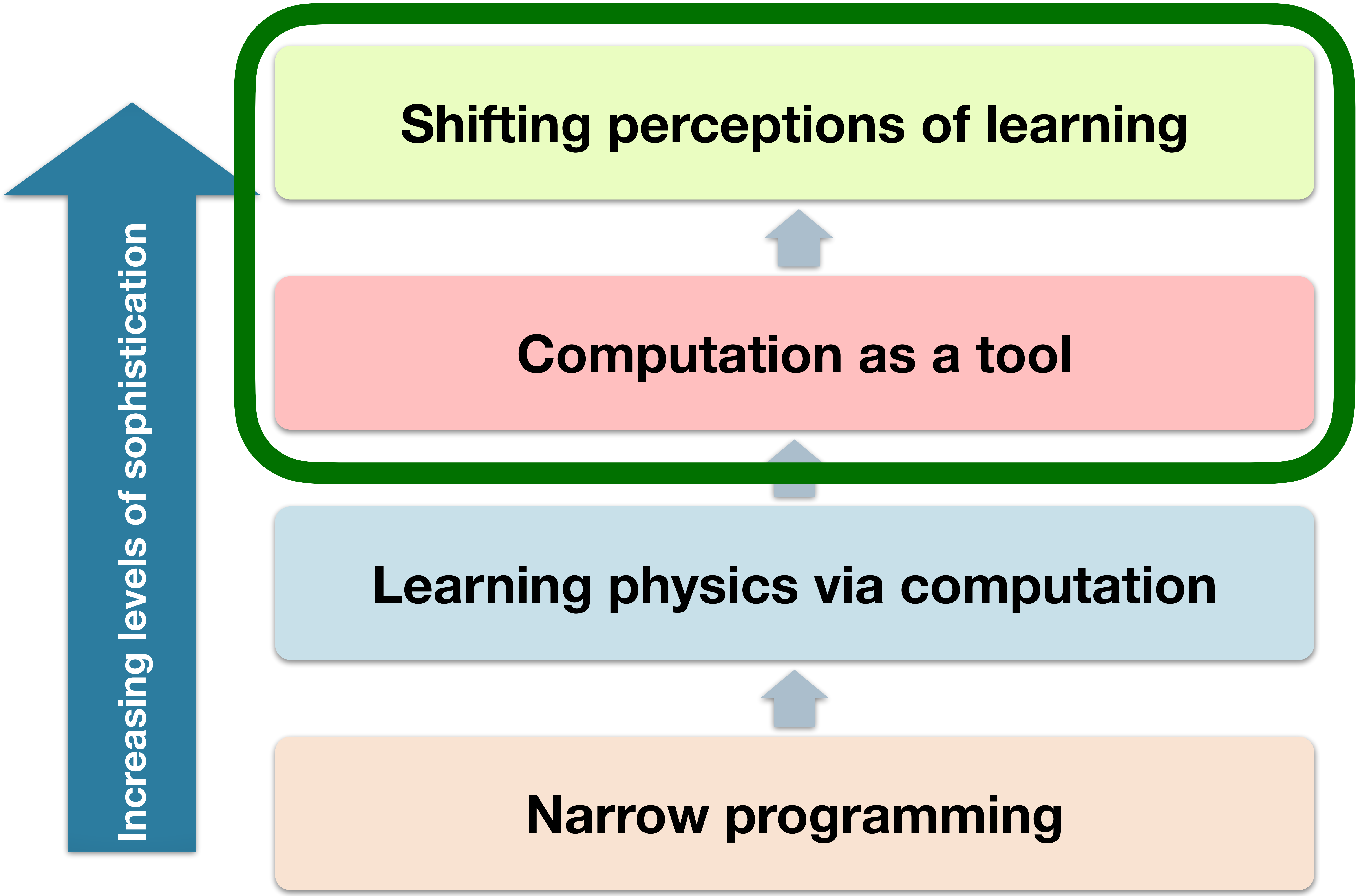
Categories of description

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



Open Questions

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- How do different instructional approaches by LAs lead to different computational learning outcomes for our students?

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- How do instructional approaches by LAs change over time?

Open Questions

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- How do instructional approaches by LAs change over time?

- How do we support instructional approaches that lead to computational learning we want to see?

Open Questions

- How do different instructional approaches by LAs lead to different computational learning outcomes for our students?
- How do instructional approaches by LAs change over time?
- How do we support instructional approaches that lead to computational learning we want to see?
- How does this work apply to faculty and graduate students?

SPECIFIC TASK

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

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

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

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

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

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

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

sepgraph = gcurve(color=color.red)

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

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

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

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

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

        t = t +deltat
```

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

Obsniuk, PhD Thesis (in progress)

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

$$\vec{F}_{grav} = -G\frac{m_{sat}M_{Earth}}{r^2}\hat{r}$$

Obsniuk, PhD Thesis (in progress)

How do students construct the direction vector?

Step (Sub-Task)	Associated Code
Construct separation vector between interacting objects	`sep = obj2.pos - obj1.pos`
Construct the unit vector	`usep = sep/mag(sep)`
Construct the net force vector	`Fnet = -G*m1*m2*usep /mag(sep)**2`
Integrate the net force over time into momentum	`obj.p = obj.p + Fnet*dt`

```
Fgrav = mSatellite*vSatellite**2/mag(Satellite.pos)
```

```
Fgrav = mSatellite*vSatellite**2/mag(Satellite.pos)
```

$$F_{grav} = \frac{m_{sat} v_{sat}^2}{R}$$

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Shelley: *But ummm wait, hold on, remember this? The uniform circular is equal to the gravity is equal to the net? So we could just do what you did, except instead of using the uniform circular motion equation we use that gravity equation [points to equation].*

Joe: *Yeah...*

Chuck: *Okay, yeah, that sounds good.*

```
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Chuck: *Okay, yeah, that sounds good.*

```
Fgrav = G*mEarth*msat/R**2
```

```
Fgrav = mSatellite*vSatellite**2/mag(Satellite.pos)
```

$$F_{grav} = \frac{m_{sat} v_{sat}^2}{R}$$

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Joe: *Yeah...*

Chuck: *Okay, yeah, that sounds good.*

```
Fgrav = G*mEarth*msat/R**2
```

$$F_{grav} = G\frac{M_{Earth} m_{sat}}{R^2}$$

Chuck: *How do we, okay, how do we define a direction?*
Cody: *I don't know...*
Chuck: *Isn't the direction like, okay, so here I'm gonna give like four points on a circle [drawing on whiteboard] so this is the center, and this is a b c and d. Isn't it always just the position vector of a, so ummm what is it, like satellite dot position minus position dot Earth, and then you can divide that by magnitude?*

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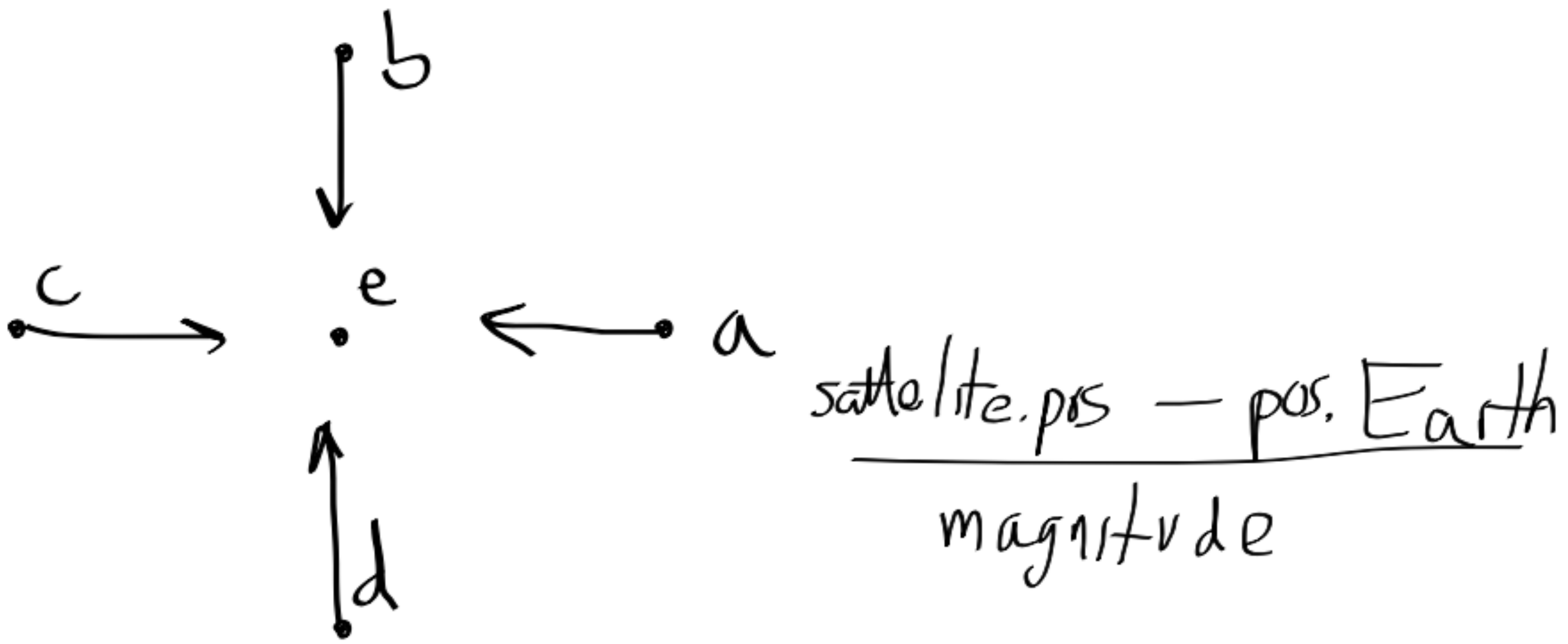

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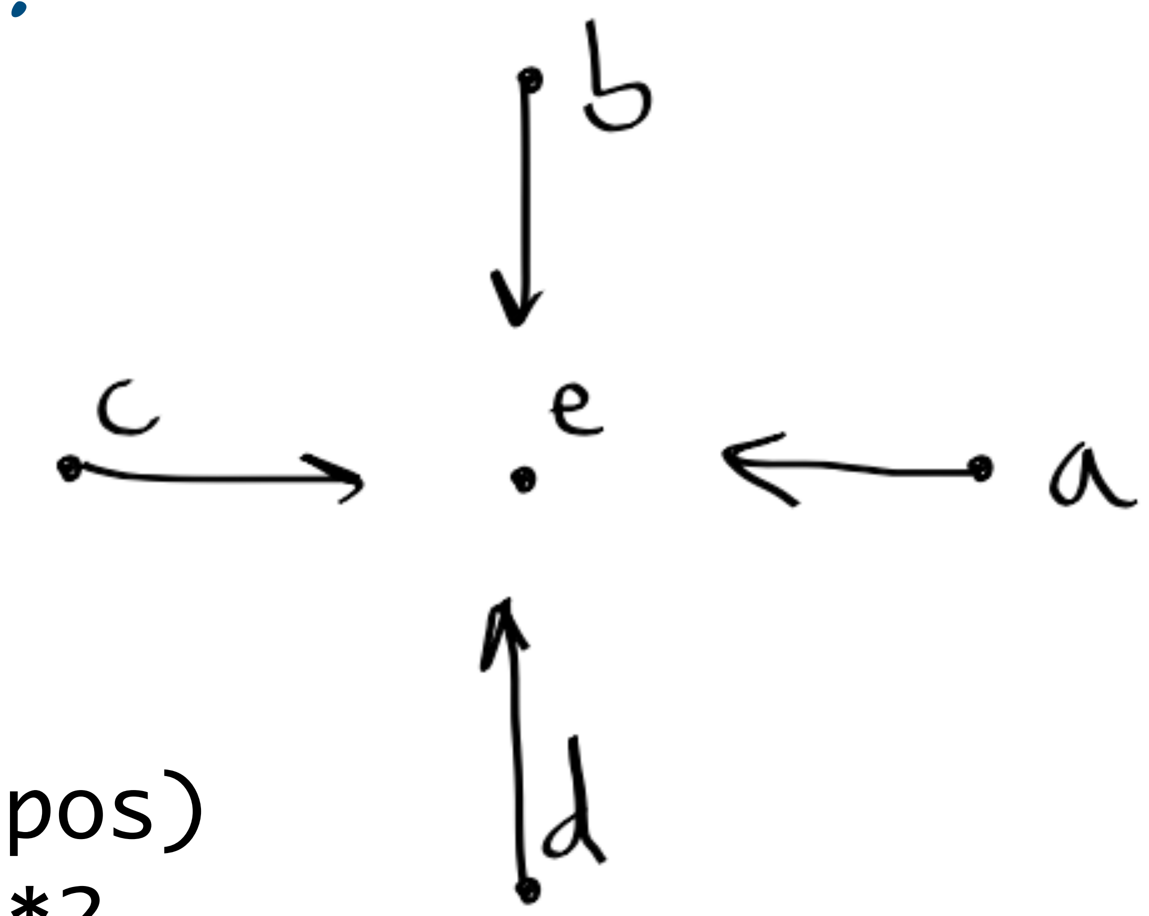

$$\frac{\text{sattelite.pos} - \text{pos. Earth}}{\text{magnitude}}$$

```
dir = sat.pos/mag(sat.pos)
Fnet = -G*m1*m2*dir/R**2
```

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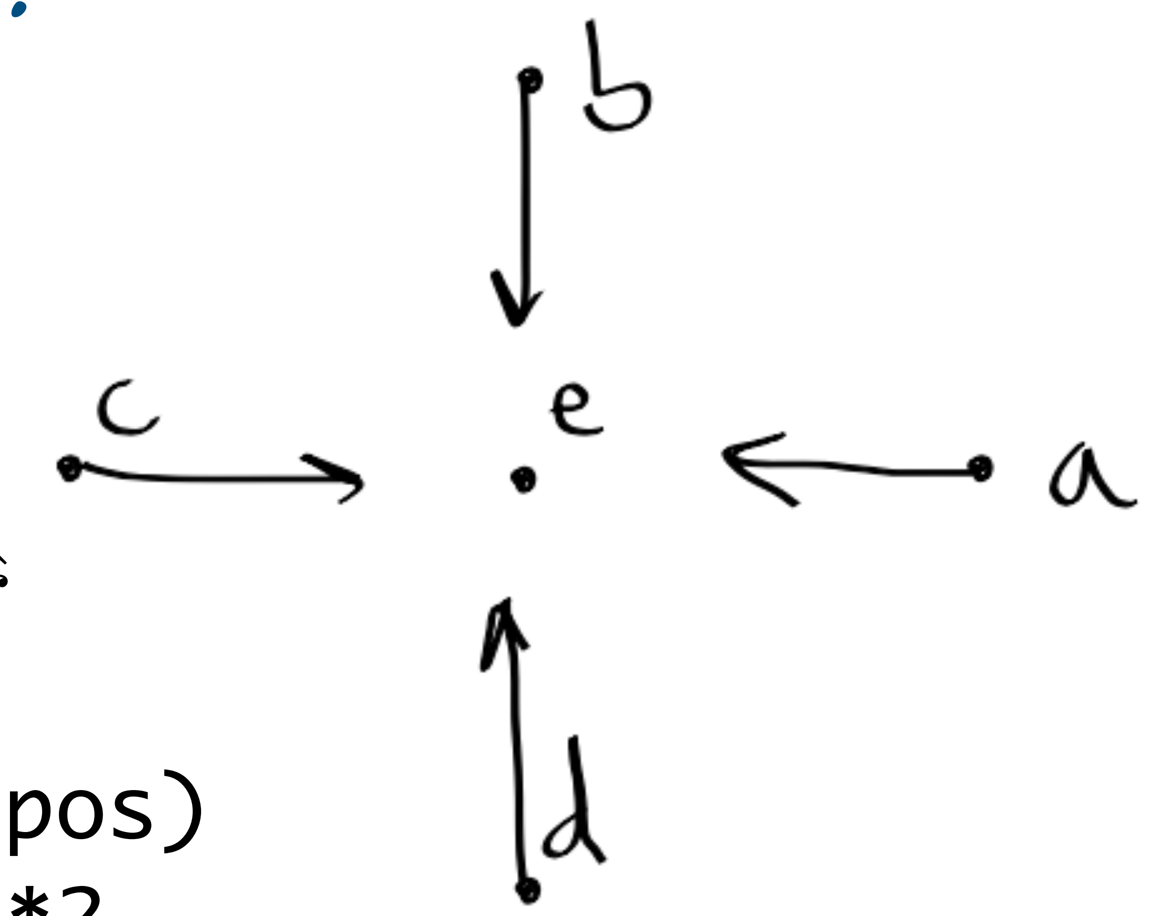


$$\vec{F}_{grav} = -G\frac{m_{sat}M_{Earth}}{r^2}\hat{r}$$

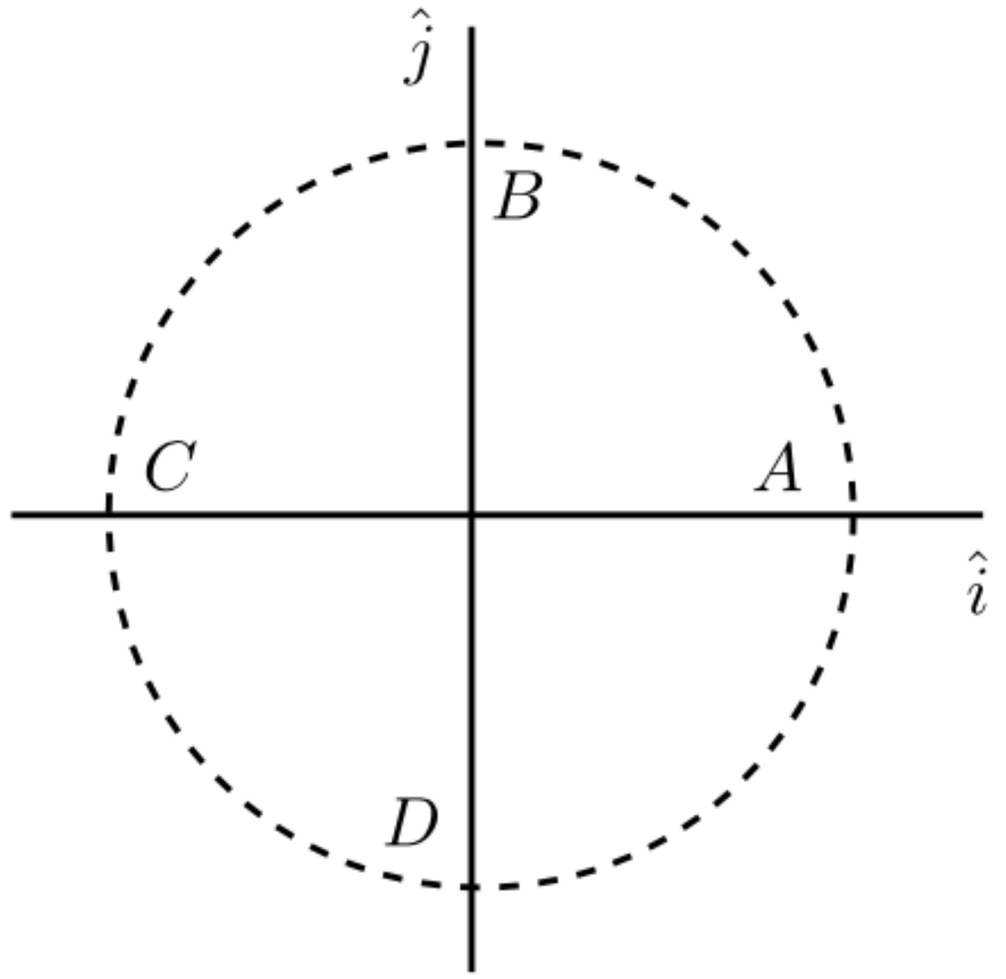
```
dir = sat.pos/mag(sat.pos)
Fnet = -G*m1*m2*dir/R**2
```

$$\frac{\text{satellite.pos} - \text{pos. Earth}}{\text{magnitude}}$$

A stationary star is located at $\langle 1,3,0\rangle \times 10^{14}\,\mathrm{m}$ and a planet moving with a velocity of $\langle 2,-1,0\rangle \times 10^{3}\,\mathrm{m/s}$ is located at a position $\langle -4,1,0\rangle \times 10^{14}\,\mathrm{m}$. What is the vector pointing from the initial location of the star to the planet?

$\vec{r} = \langle \square, \square, \square \rangle$

The Moon orbits the Earth in a roughly circular orbit. To calculate the force the Earth exerts on the Moon, you need to know the direction of the separation unit vector ($\hat{r}$) and the gravitational force unit vector ($\hat{F}$). For locations A-D, find $\hat{r}$ and $\hat{F}$.



At A:

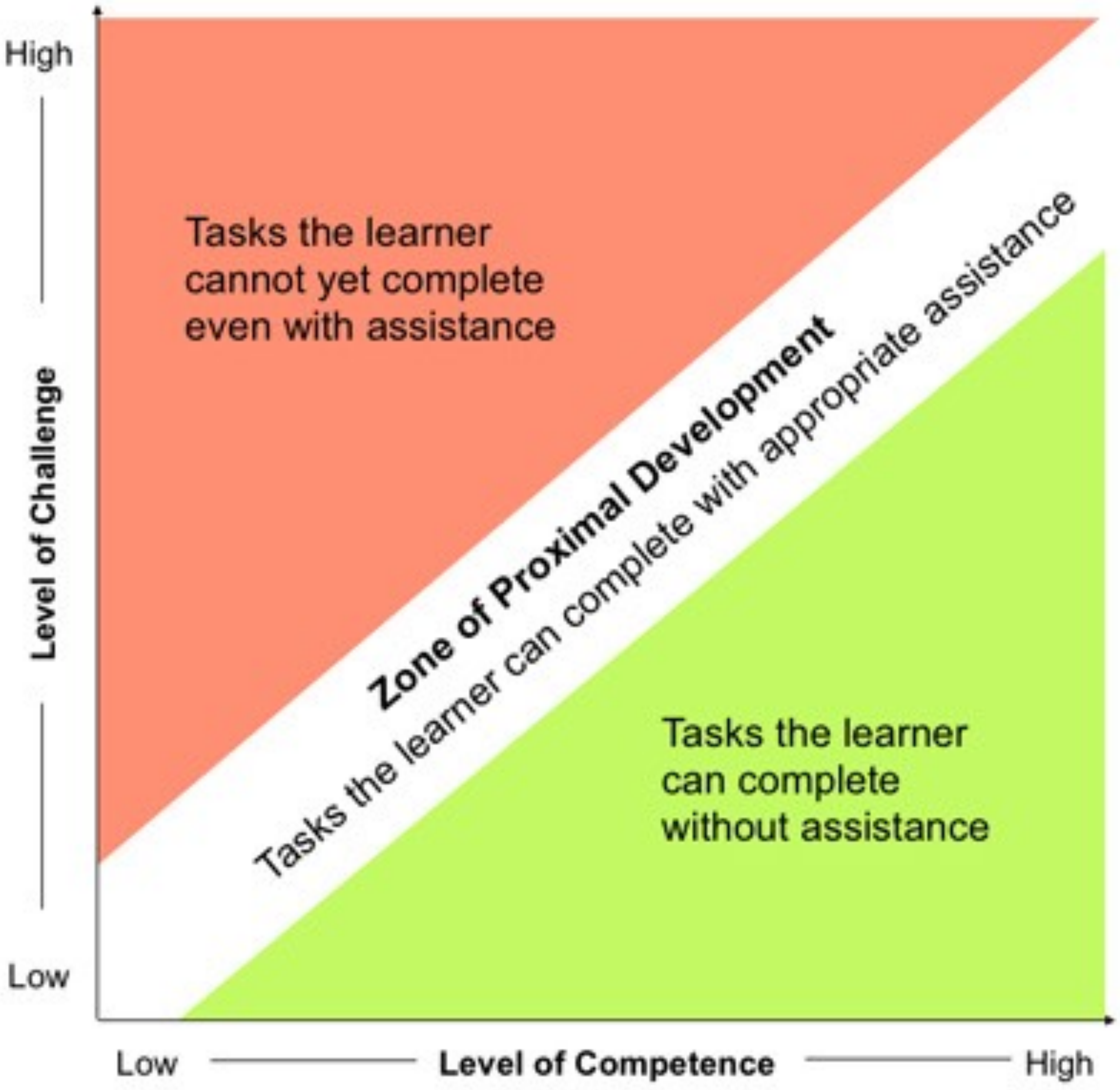
$\hat{r} = \langle \square, \square, \square \rangle$

$\hat{F} = \langle \square, \square, \square \rangle$

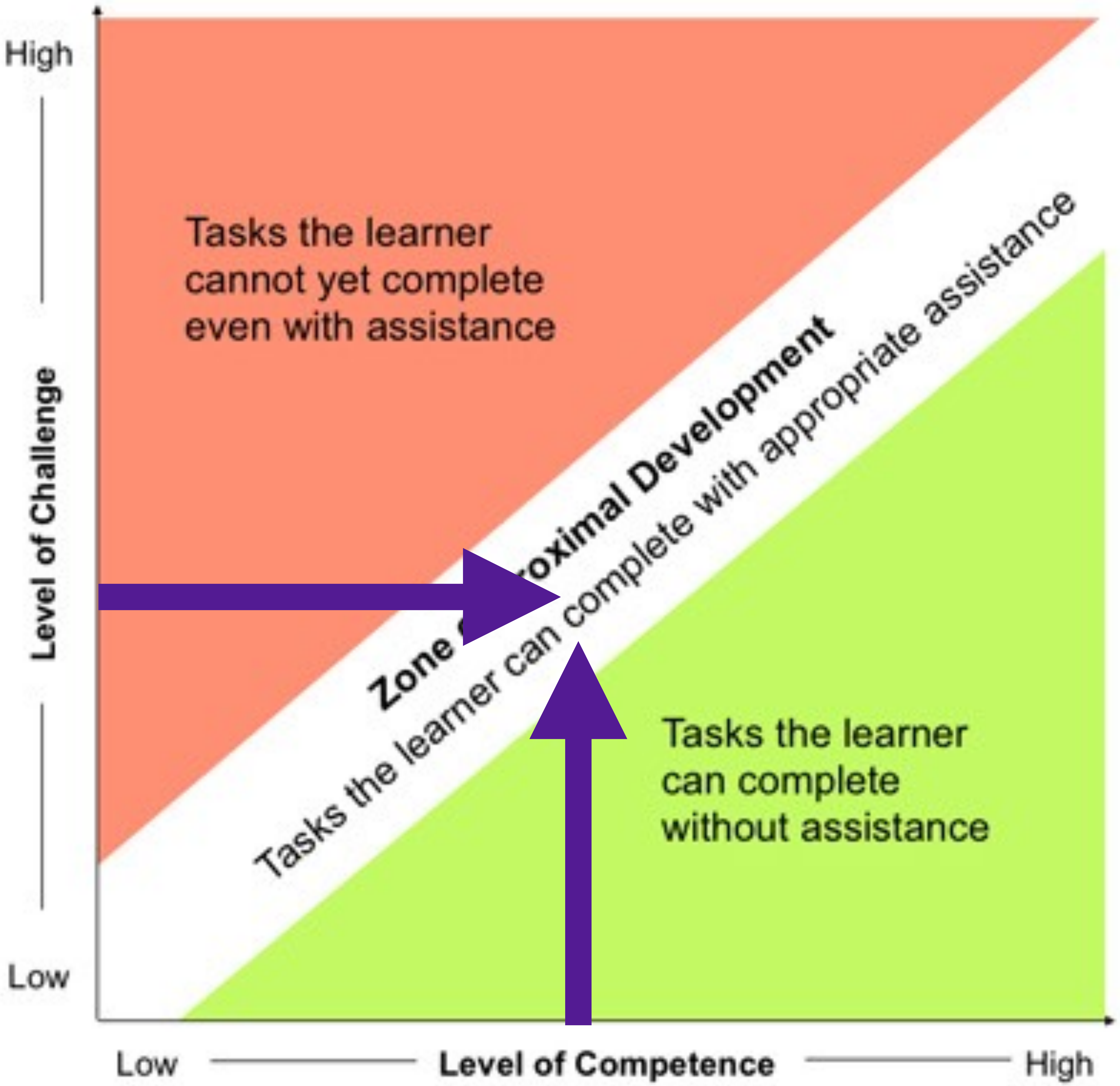
At C:

$\hat{r} = \langle \square, \square, \square \rangle$

$\hat{F} = \langle \square, \square, \square \rangle$



L. Vygotsky, *Mind in society* (1978)



L. Vygotsky, *Mind in society* (1978)

WHO TEACHES COMPUTATION?

Surveying the state computational physics instruction in the US

- Work with AIP to distribute survey
- Draw implications for faculty and departments
- Track changes to the state over time

- Sample: 357 departments; 1296 faculty

Surveying the state computational physics instruction in the US

- Work with AIP to distribute survey
- Draw implications for faculty and departments
- Track changes to the state over time

- Sample: 357 departments; 1296 faculty

PREAMBLE: *For the purposes of this survey, we are taking a broad view of computation, which includes a wide spectrum of examples such as: having students work with simulations and/or algorithms, giving students pieces of code to complete on their own, and/or advising students on undergraduate research projects where they write code from scratch.*

PICUP

>50% of US physics departments have majority of faculty reporting experience teaching computation

Caballero & Merner, Phys. Rev. PER, 2018

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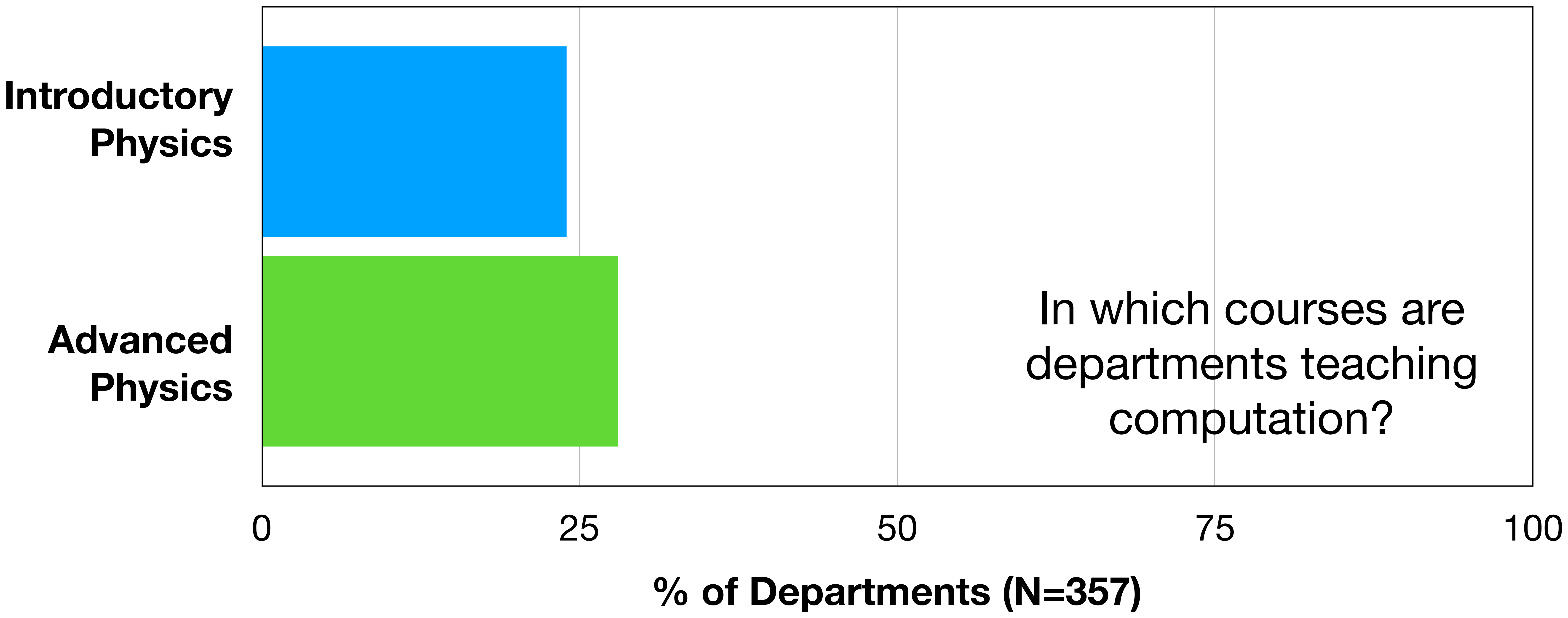
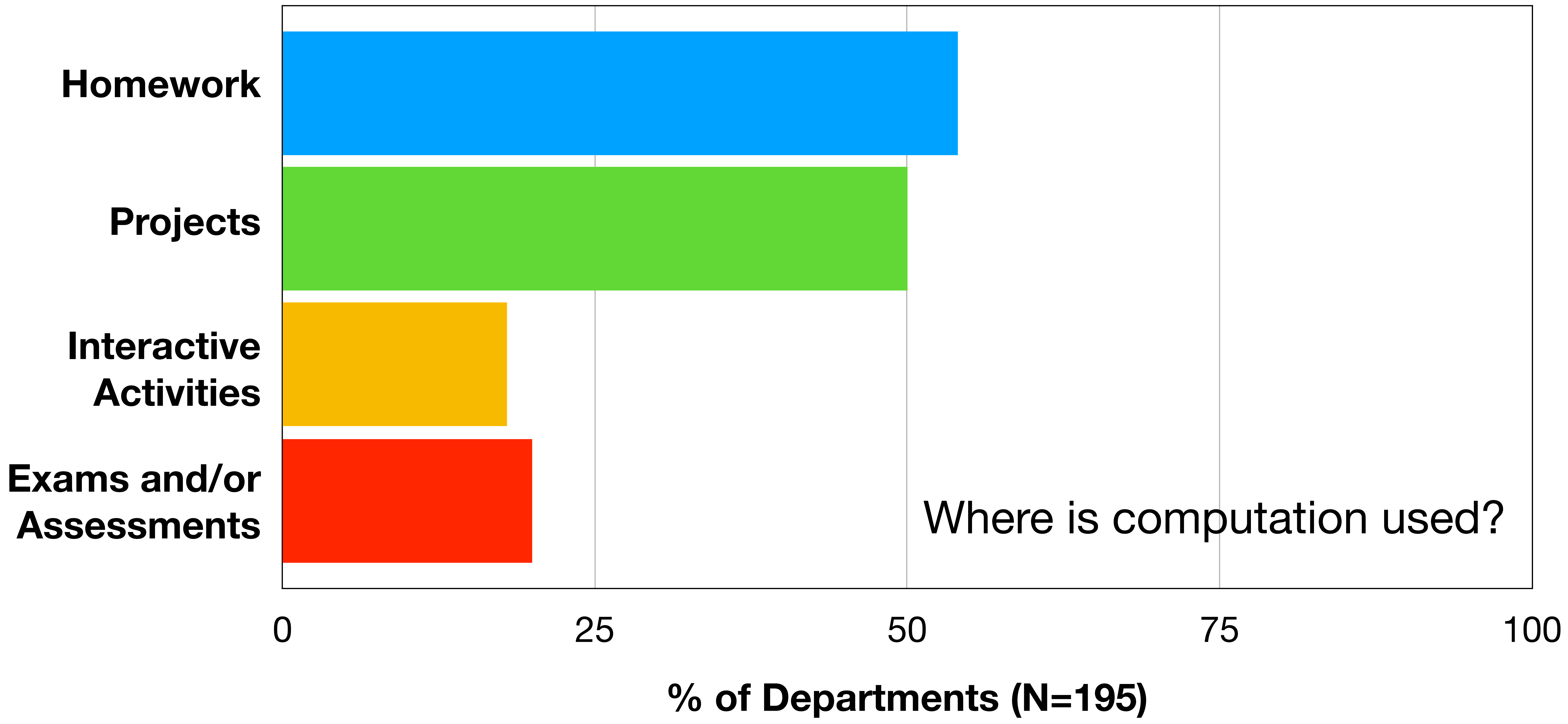
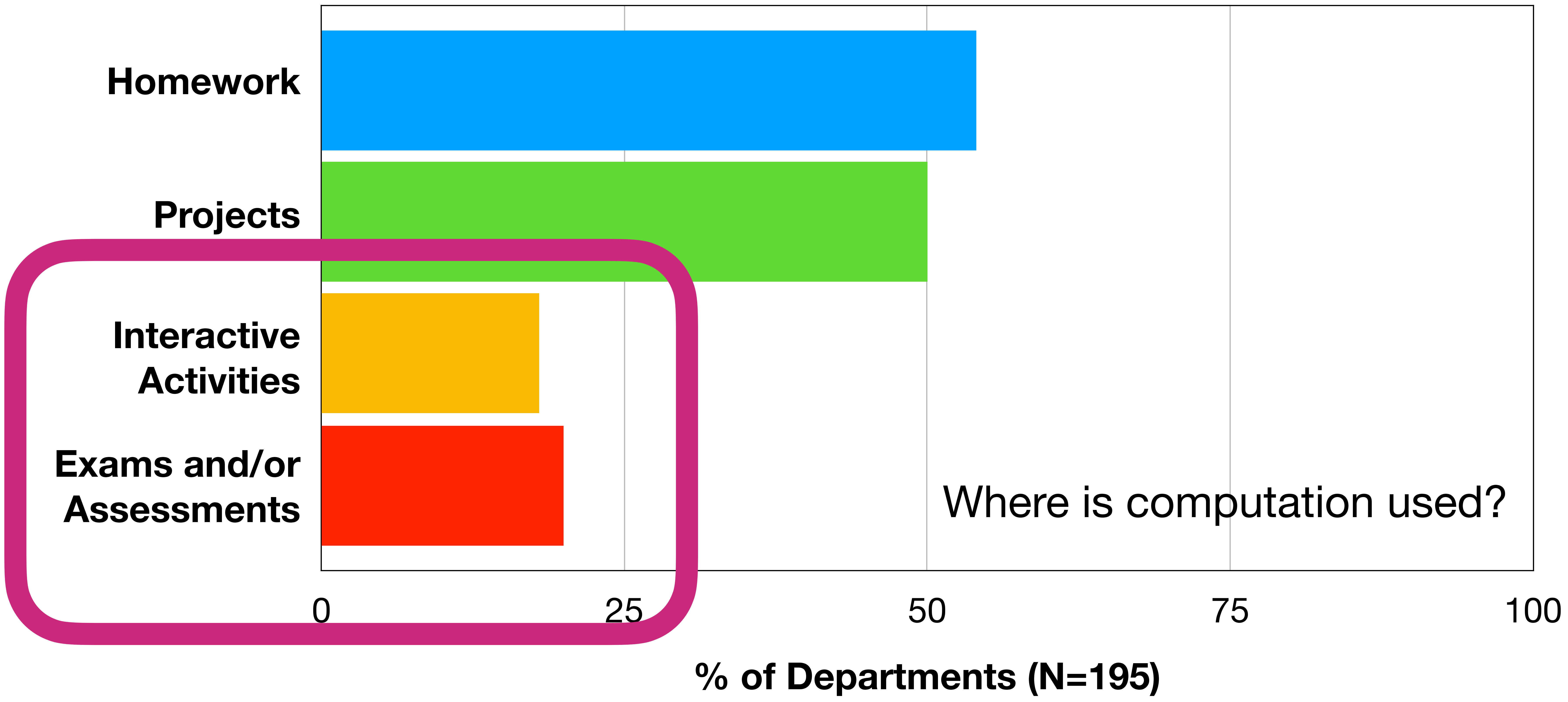


Caballero & Merner, Phys. Rev. PER, 2018



Caballero & Merner, Phys. Rev. PER, 2018



Caballero & Merner, Phys. Rev. PER, 2018

Take-Aways

Take-Aways

- A majority of faculty report having experience teaching undergraduate students computation

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

[1]Chonacky and Winch, Am. J. Phys., 2008

Take-Aways

- A majority of faculty report having experience teaching undergraduate students computation
- Computational instruction is more prevalent than in the past[1]
- We are lacking formal computational physics programs (7% have degree program)

[1]Chonacky and Winch, Am. J. Phys., 2008

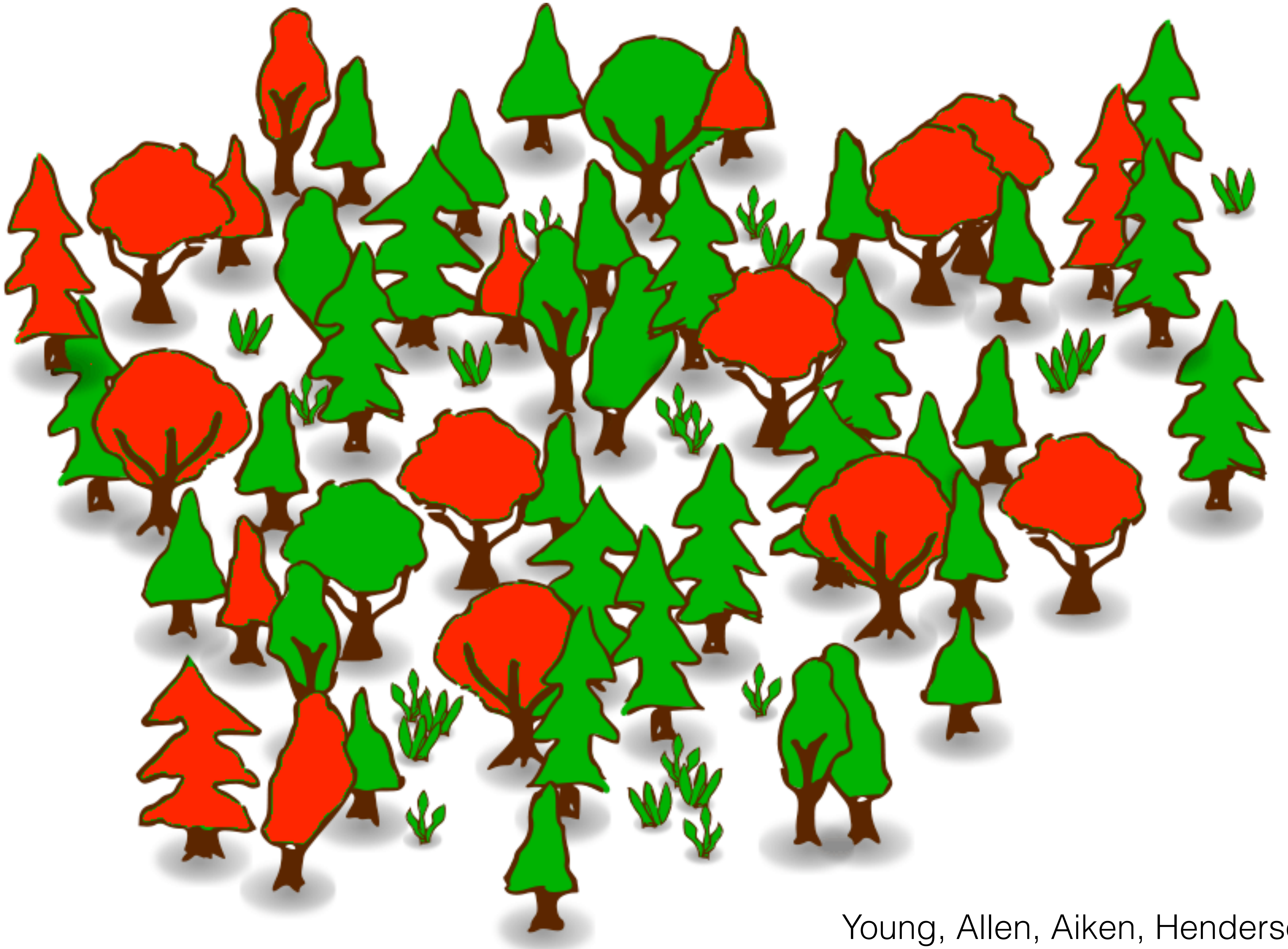
Take-Aways

- A majority of faculty report having experience teaching undergraduate students computation
- Computational instruction is more prevalent than in the past[1]
- We are lacking formal computational physics programs (7% have degree program)
- There is a need to explore interactive methods and assessment techniques for computation

[1]Chonacky and Winch, Am. J. Phys., 2008

But “who” teaches computation?

But “who” teaches computation?



Young, Allen, Aiken, Henderson, & Caballero, Phys Rev. PER, 2019

Sample Questions

Computational physics is hard to teach in the classroom.

Computational physics provides workforce skills for students.

My department rewards me for teaching computation.

There is no institutional support for me to teach computation.

Computation can solve unsolvable (analytical) problems.

Computation is generalizable to many different kinds of problems.

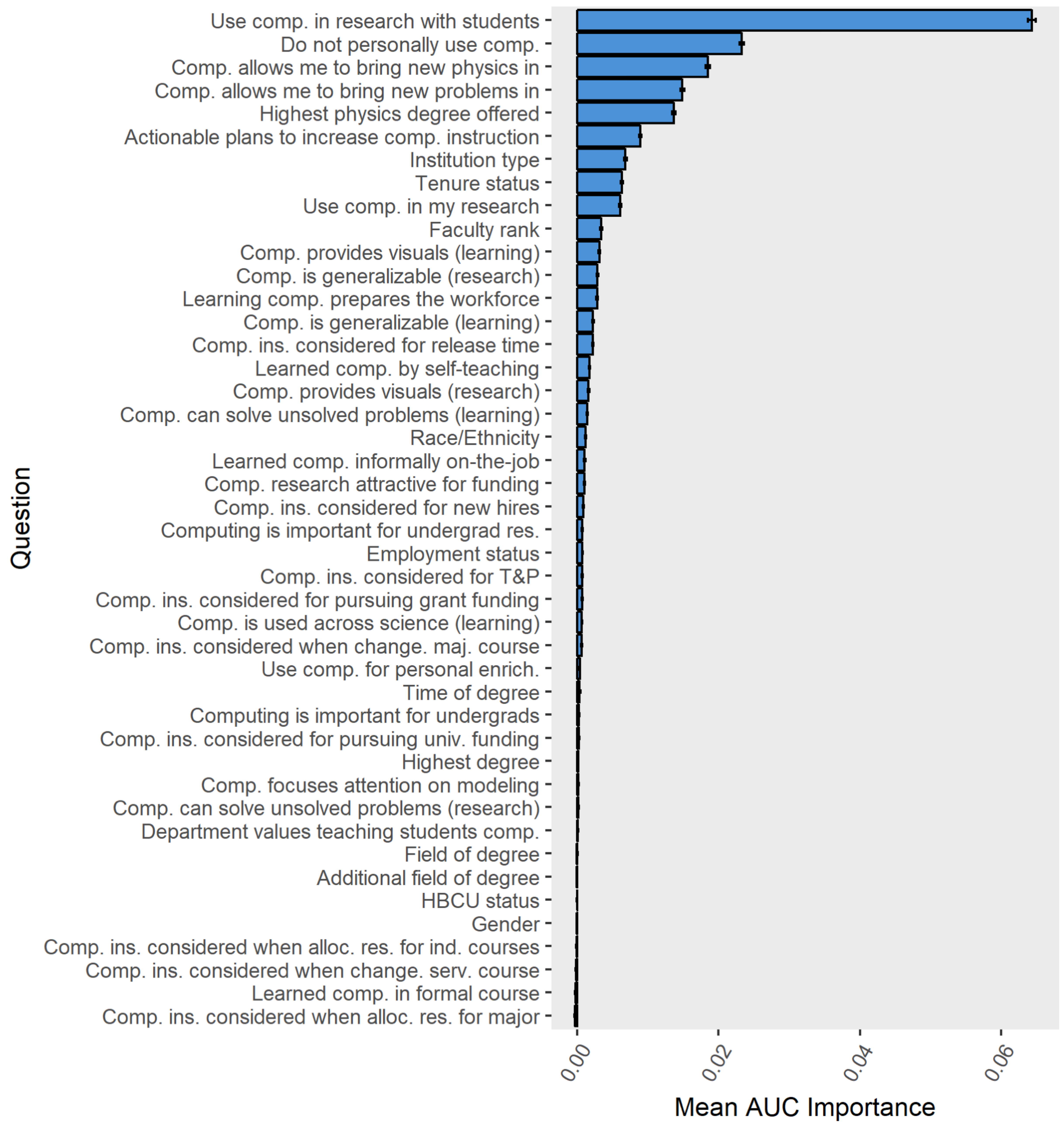
Computation allows me to bring new physics into the classroom that I otherwise couldn't.

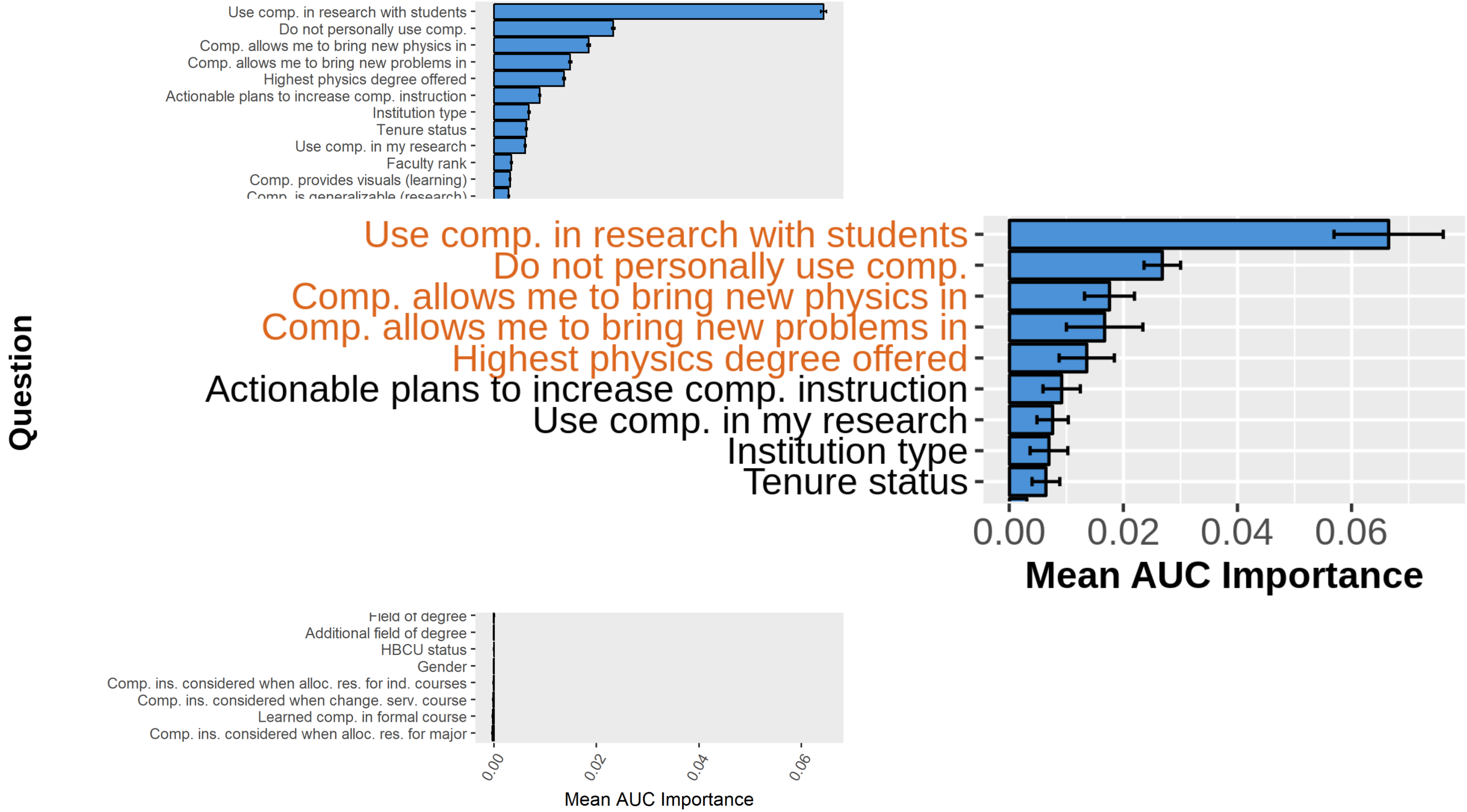
Computation allows me to bring new problems into the classroom that I otherwise couldn't.

My department considers computational instruction when hiring new faculty.

My department considers computational instruction in tenure and promotion decisions.

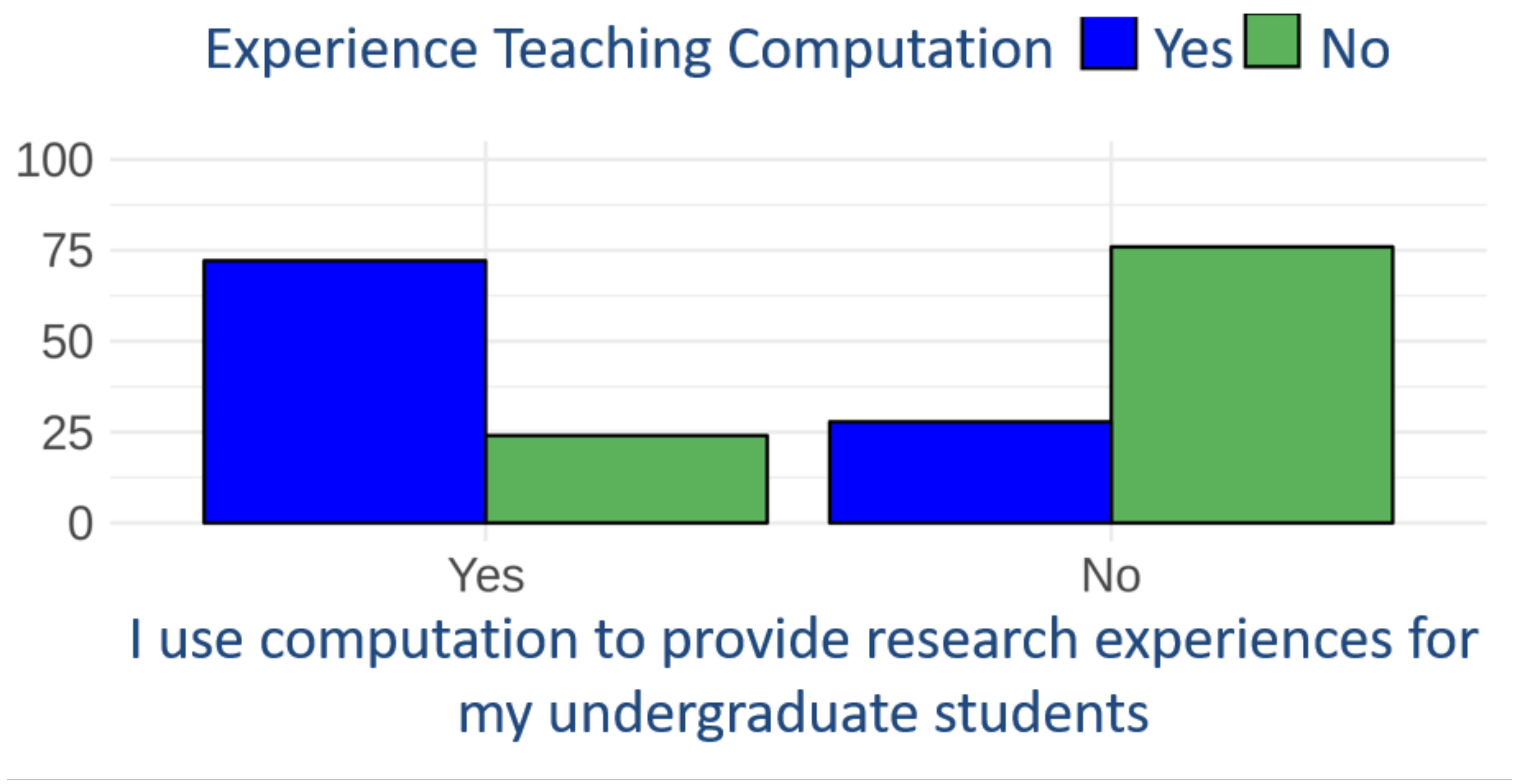
Demographic information and school information


Use comp. in research with students
Do not personally use comp.
Comp. allows me to bring new physics in
Comp. allows me to bring new problems in
Highest physics degree offered
Actionable plans to increase comp. instruction
Institution type
Tenure status
Use comp. in my research
Faculty rank
Comp. provides visuals (learning)
Comp. is generalizable (research)
Learning comp. prepares the workforce
Comp. is generalizable (learning)
Comp. ins. considered for release time
Learned comp. by self-teaching
Comp. provides visuals (research)
Comp. can solve unsolved problems (learning)
Race/Ethnicity
Learned comp. informally on-the-job
Comp. research attractive for funding
Comp. ins. considered for new hires
Computing is important for undergrad res.
Employment status
Comp. ins. considered for T&P
Comp. ins. considered for pursuing grant funding
Comp. is used across science (learning)
Comp. ins. considered when change. maj. course
Use comp. for personal enrich.
Time of degree
Computing is important for undergrads
Comp. ins. considered for pursuing univ. funding
Highest degree
Comp. focuses attention on modeling
Comp. can solve unsolved problems (research)
Department values teaching students comp.
Field of degree
Additional field of degree
HBCU status
Gender
Comp. ins. considered when alloc. res. for ind. courses
Comp. ins. considered when change. serv. course
Learned comp. in formal course
Comp. ins. considered when alloc. res. for major
Question
0.00
0.02
0.04
0.06
Mean AUC Importance



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

Do these factors make sense?



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

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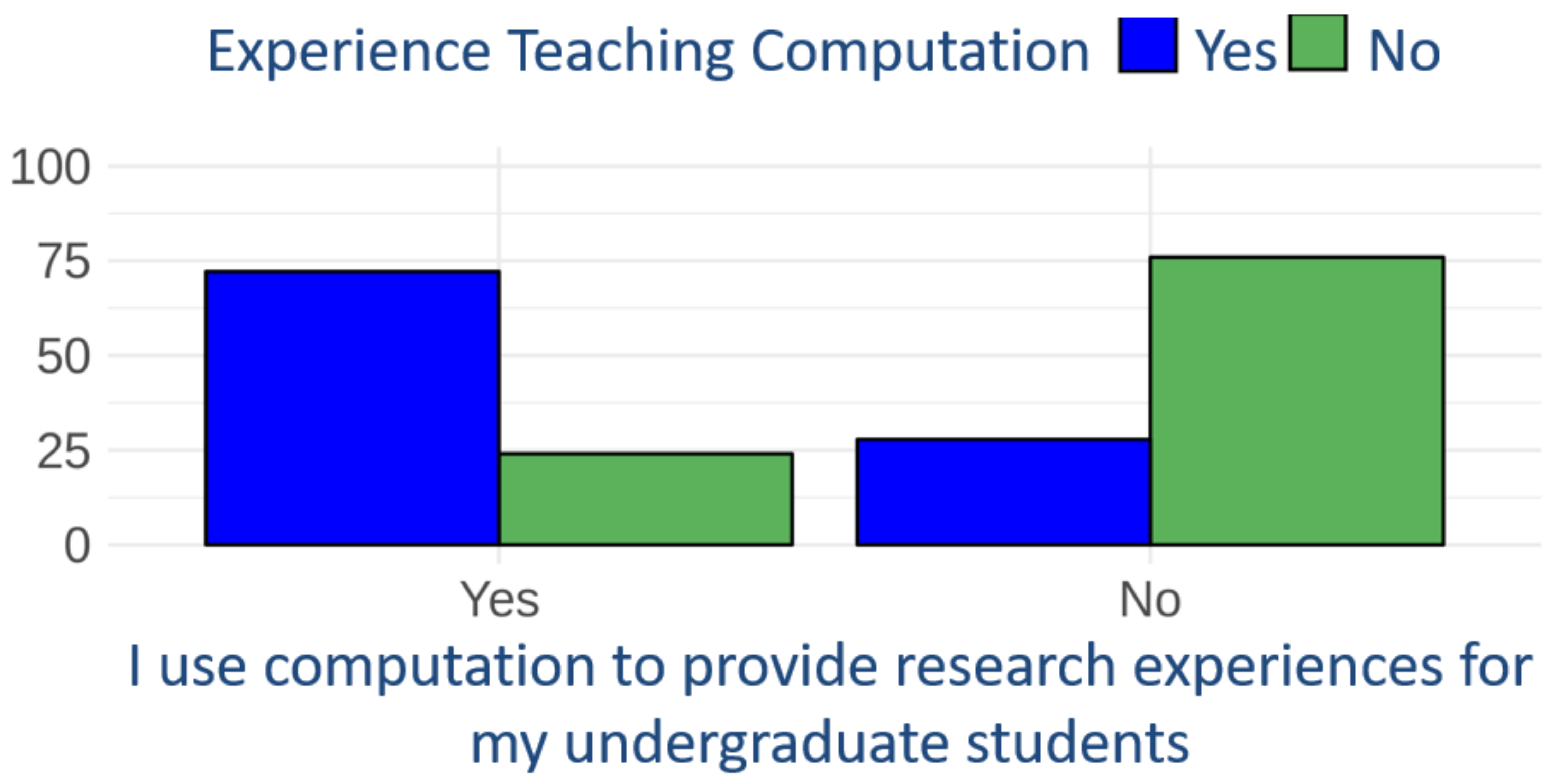

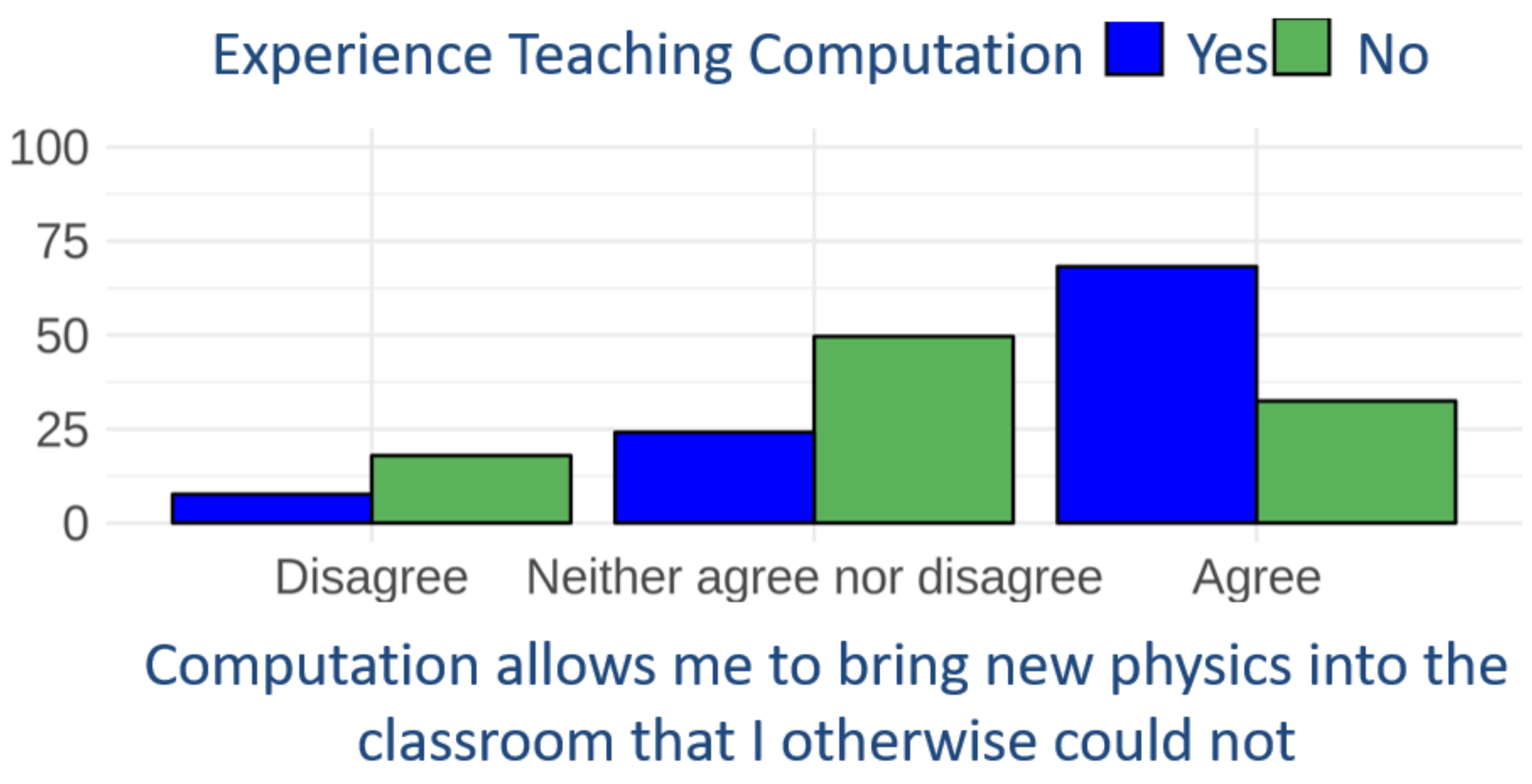

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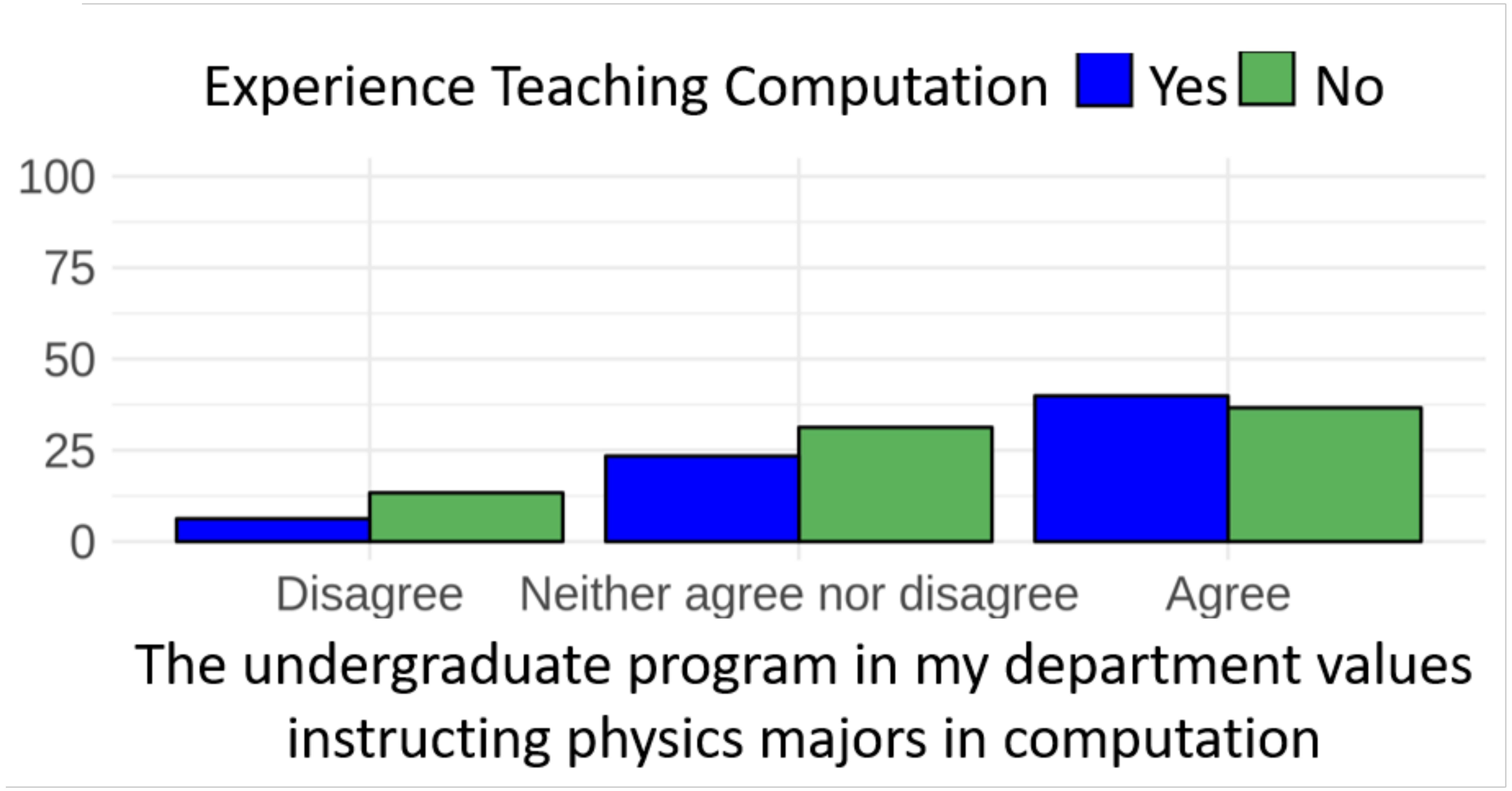

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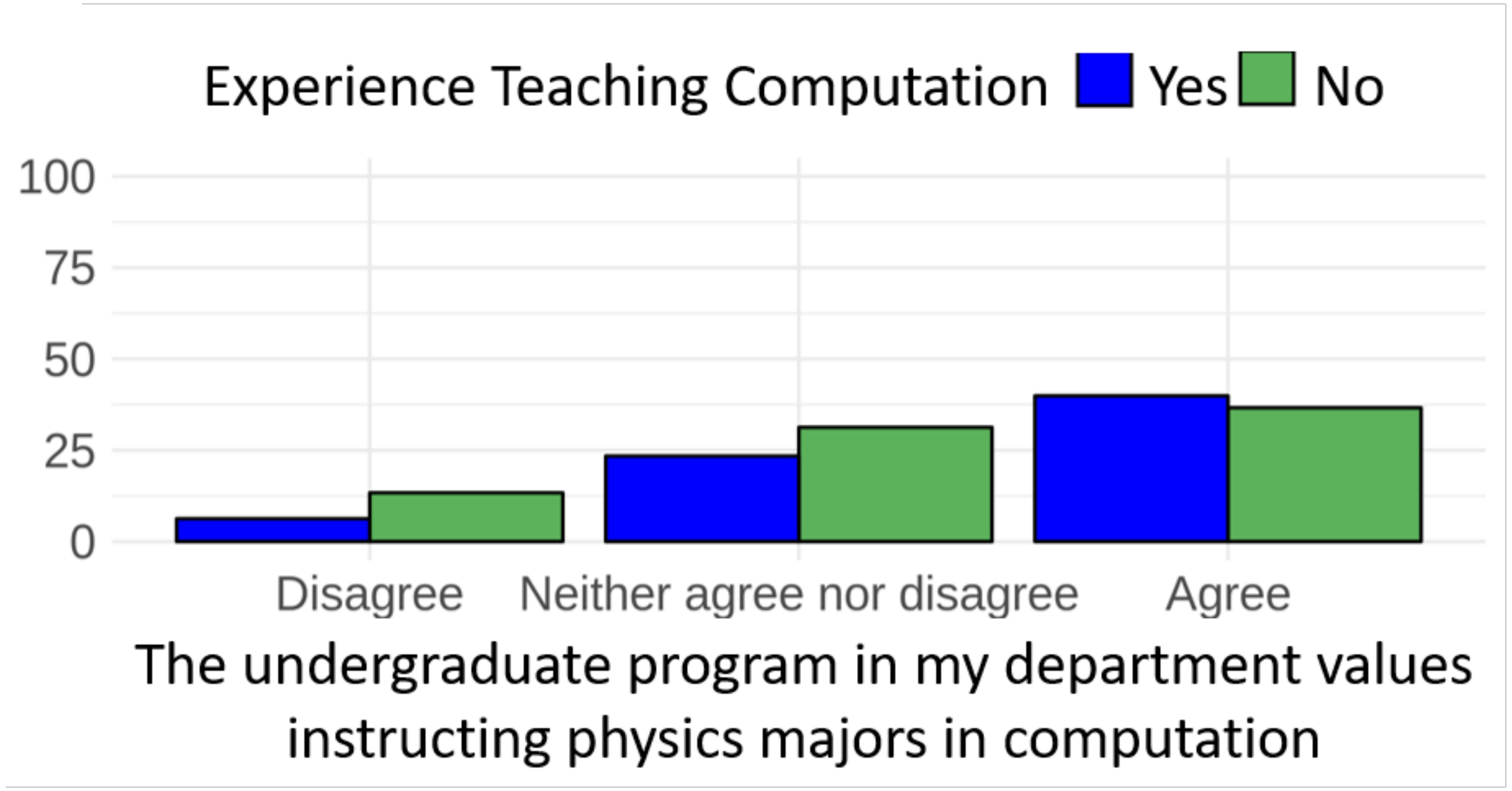
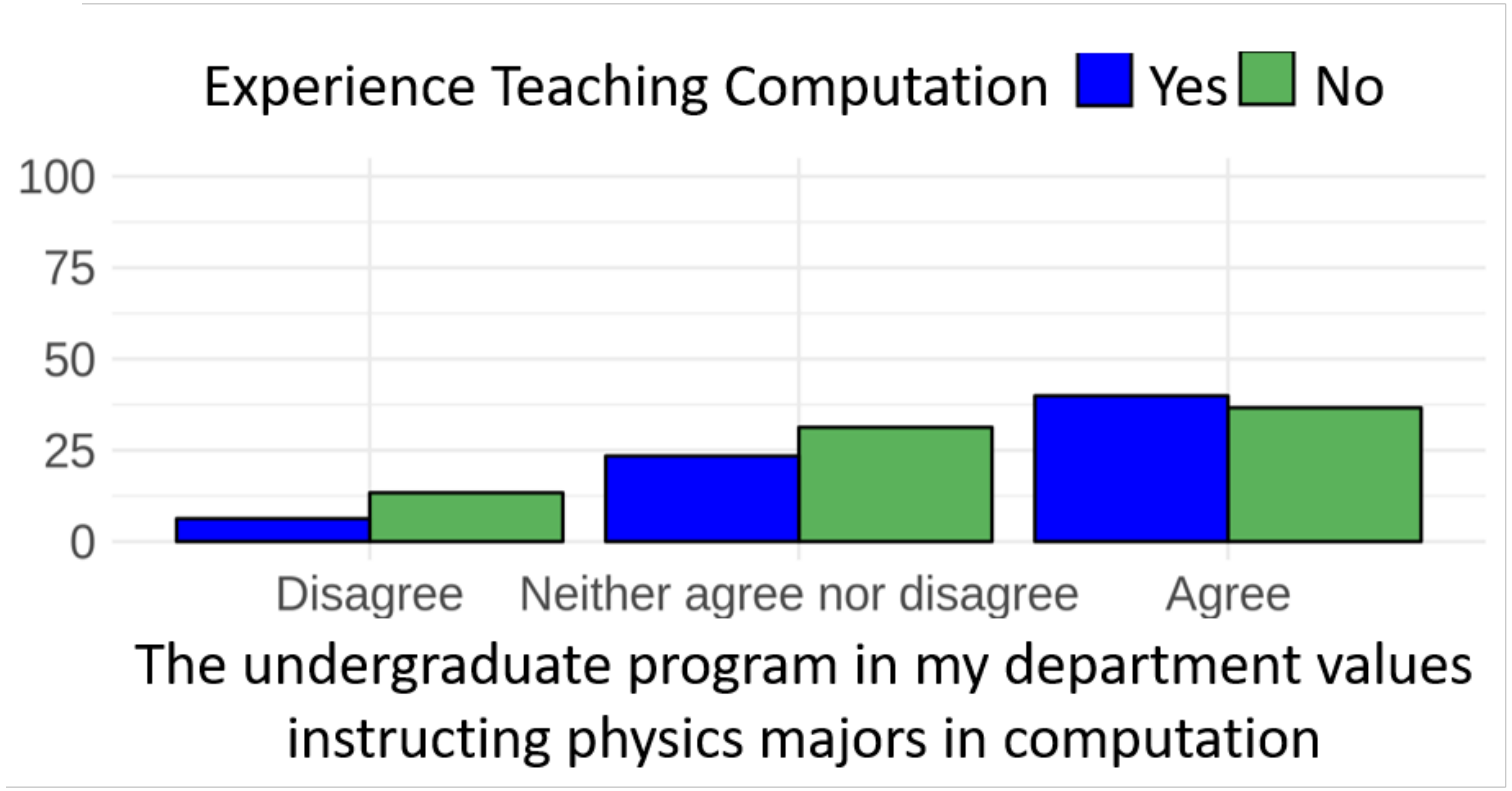


(At the moment)

Faculty that teach computation tend to:

- Use computation in their research with students or some other way outside of the classroom

Do these factors make sense?



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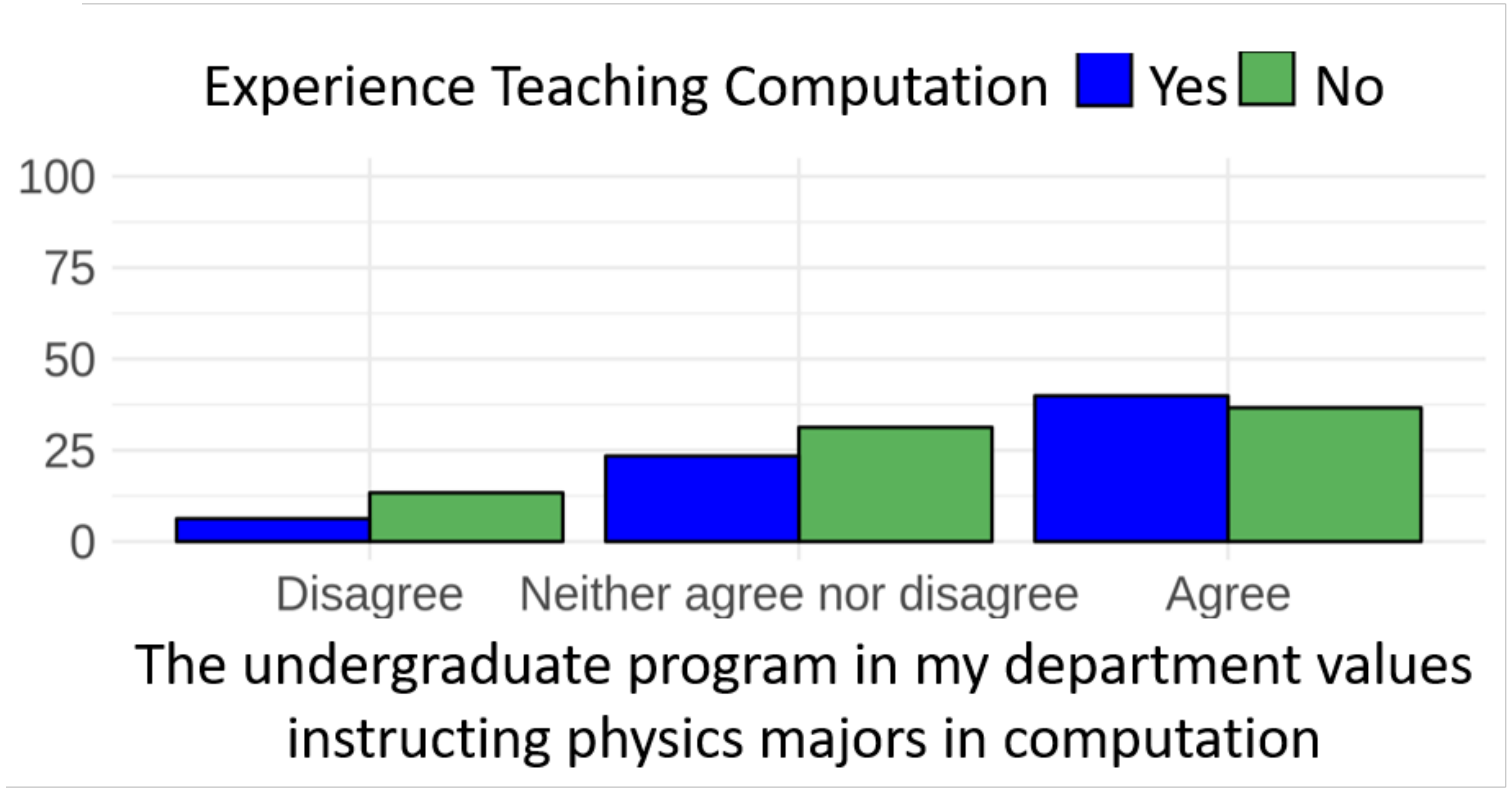
Faculty that teach computation tend to:

- Use computation in their research with students or some other way outside of the classroom
- Believe computation brings new physics and problems into the curriculum

Do these factors make sense?

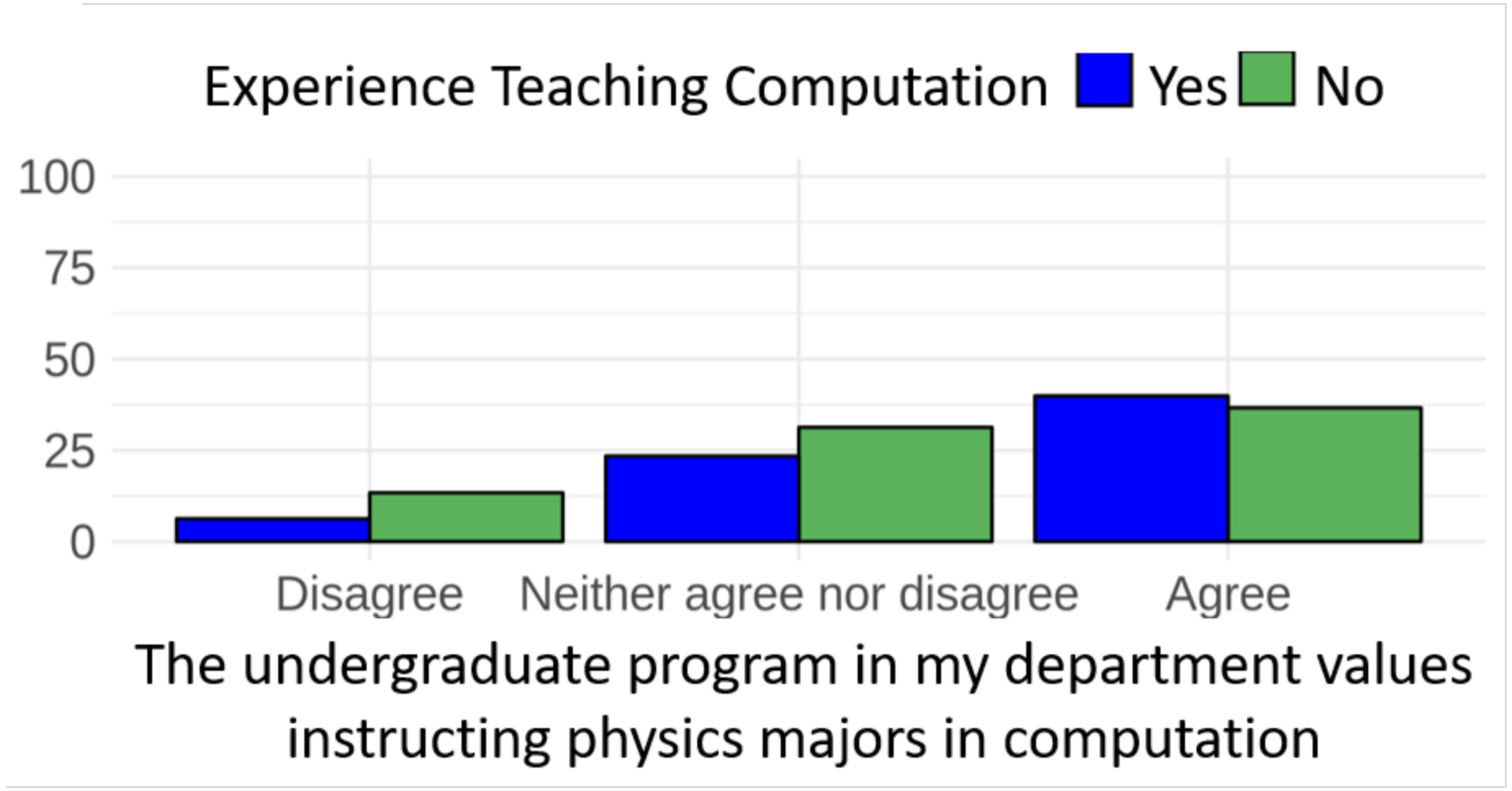


(At the moment)

Faculty that teach computation tend to:

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

Do these factors make sense?



(At the moment)

Faculty that teach computation tend to:

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

Faculty treat teaching computation as an individual choice

Open Questions

Open Questions

- How do we support a broader cross-section of faculty to integrate numerical computation?

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- What can departments do to support moves to integrate numerical computation?

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- How do we support a broader cross-section of faculty to integrate numerical computation?
- What can departments do to support moves to integrate numerical computation?
- How do we help faculty design courses, curricula, pedagogy, and activities to teach numerical computation effectively?

PICUP

PARTNERSHIP FOR INTEGRATION OF COMPUTATION INTO UNDERGRADUATE PHYSICS

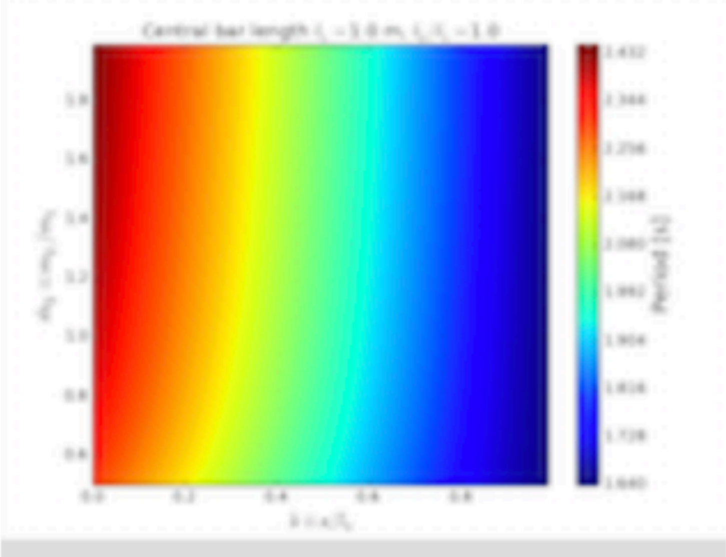
2016
2017
2018
2019

Map of Workshop Participants

Map of Workshop Participants

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**);

Download Options

Download Exercises - Word

Share a Variation

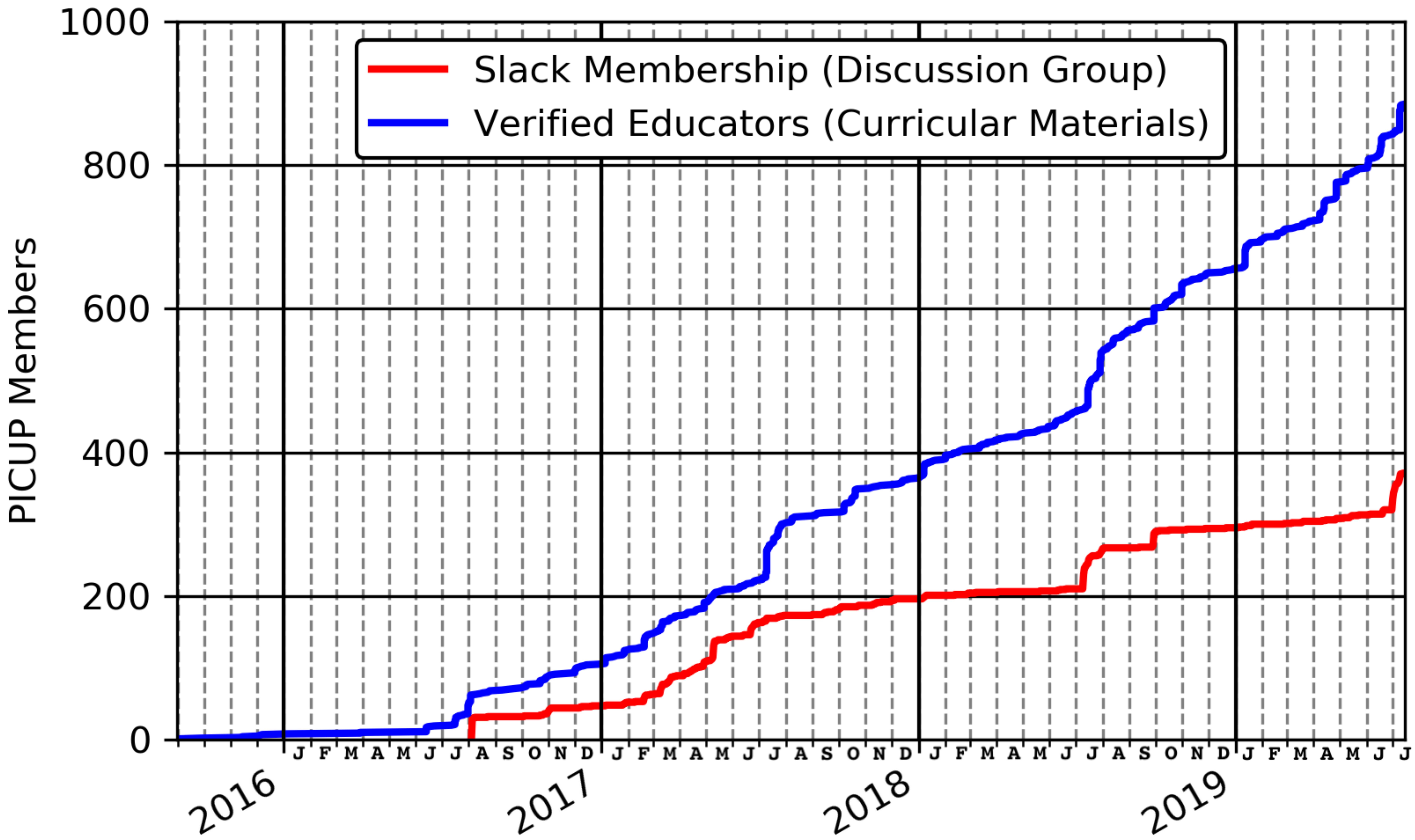
Did you have to edit this material to fit your needs? Share your changes by

Creating a Variation

Credits and Licensing

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

gopicup.org



Slack Membership (Discussion Group)
Verified Educators (Curricular Materials)
PICUP Members
1000
800
600
400
200
0
J F M A M J J A S O N D
J F M A M J J A S O N D
J F M A M J J A S O N D
J F M A M J J
2016
2017
2018
2019

Map of PICUP Verified Educators in the US

Map of PICUP Verified Educators Worldwide

Big Questions from PICUPers (& other folks)

How do we integrate computation across my department?

What do I have to give up to do this?

How do I know what my students are learning?

What is the best format to teach computation to my students?

How do I teach TAs to teach computation?

How do I help my colleagues, department, college get on board with this?

And many, many, many more…

PER CAN HELP SUPPORT AND FACILITATE WORK TO INTEGRATE NUMERICAL COMPUTATION

PER CAN HELP SUPPORT AND FACILITATE WORK TO INTEGRATE NUMERICAL COMPUTATION

- Research with students

PER CAN HELP SUPPORT AND FACILITATE WORK TO INTEGRATE NUMERICAL COMPUTATION

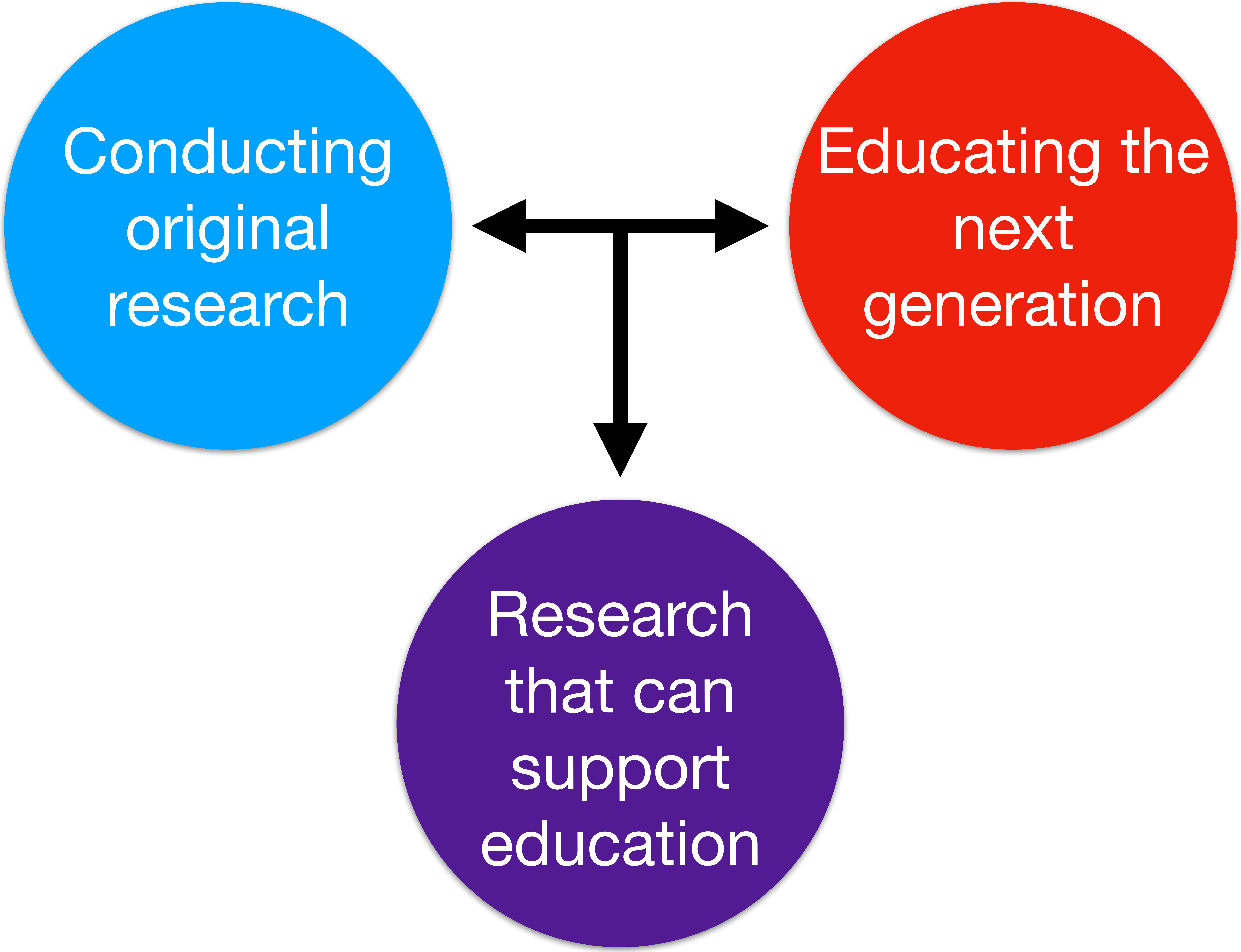
- Research with students
- Research on activities, pedagogy, curricula

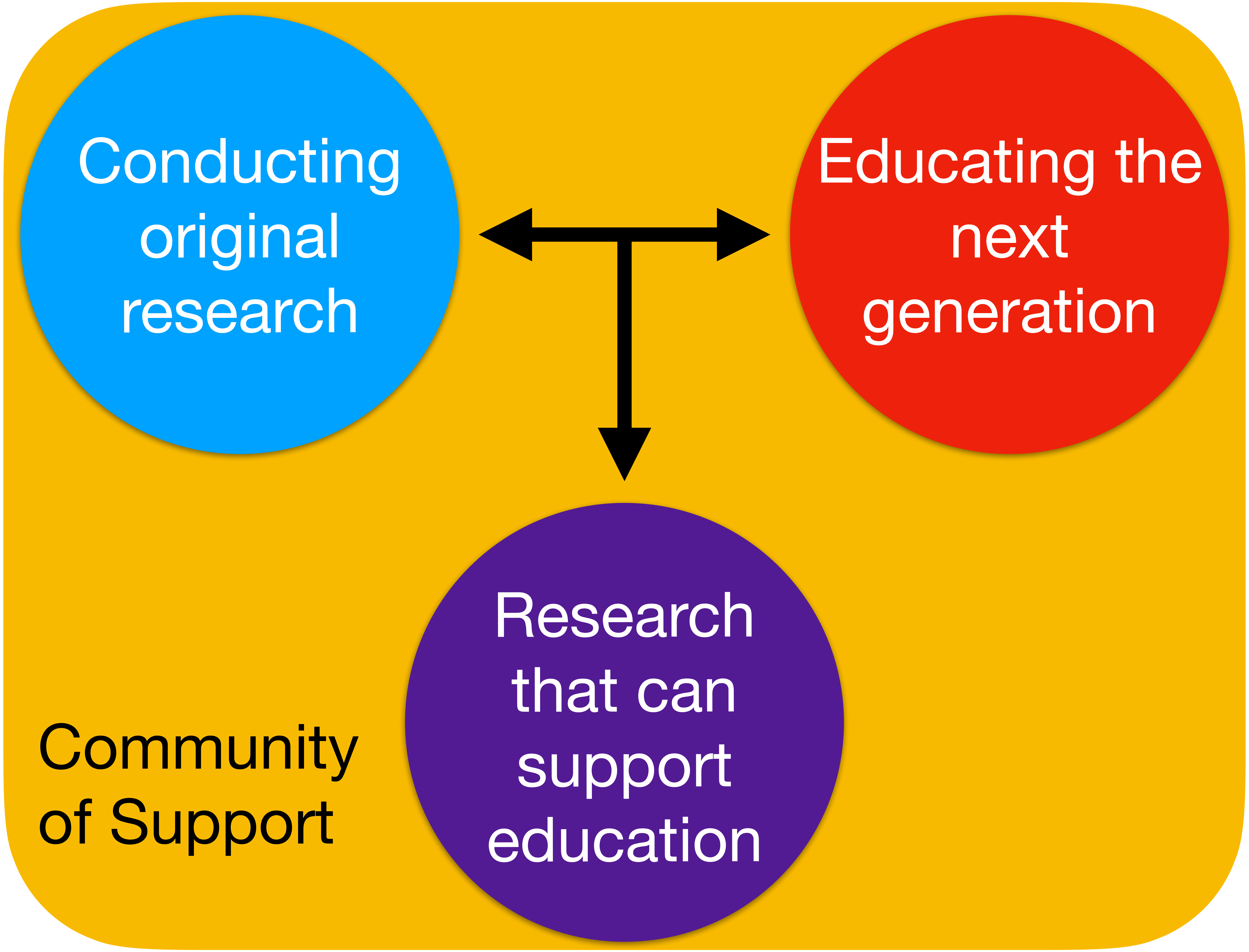
PER CAN HELP SUPPORT AND FACILITATE WORK TO INTEGRATE NUMERICAL COMPUTATION

- Research with students
- Research on activities, pedagogy, curricula
- Research with faculty

PER CAN HELP SUPPORT AND FACILITATE WORK TO INTEGRATE NUMERICAL COMPUTATION

- Research with students
- Research on activities, pedagogy, curricula
- Research with faculty
- Research with departments & larger systems


Conducting original research
Educating the next generation
Research that can support education


Conducting original research
Educating the next generation
Research that can support education
Community of Support


I MISS YOU ALL
CHILI
SINCE 1936

Thank you!
Questions?

caballero@pa.msu.edu

perl.natsci.msu.edu

And thanks to our sponsors

More slides

What happens when
the code doesn’t work?!

AFTER

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

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

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

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

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

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

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

sepgraph = gcurve(color=color.red)

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

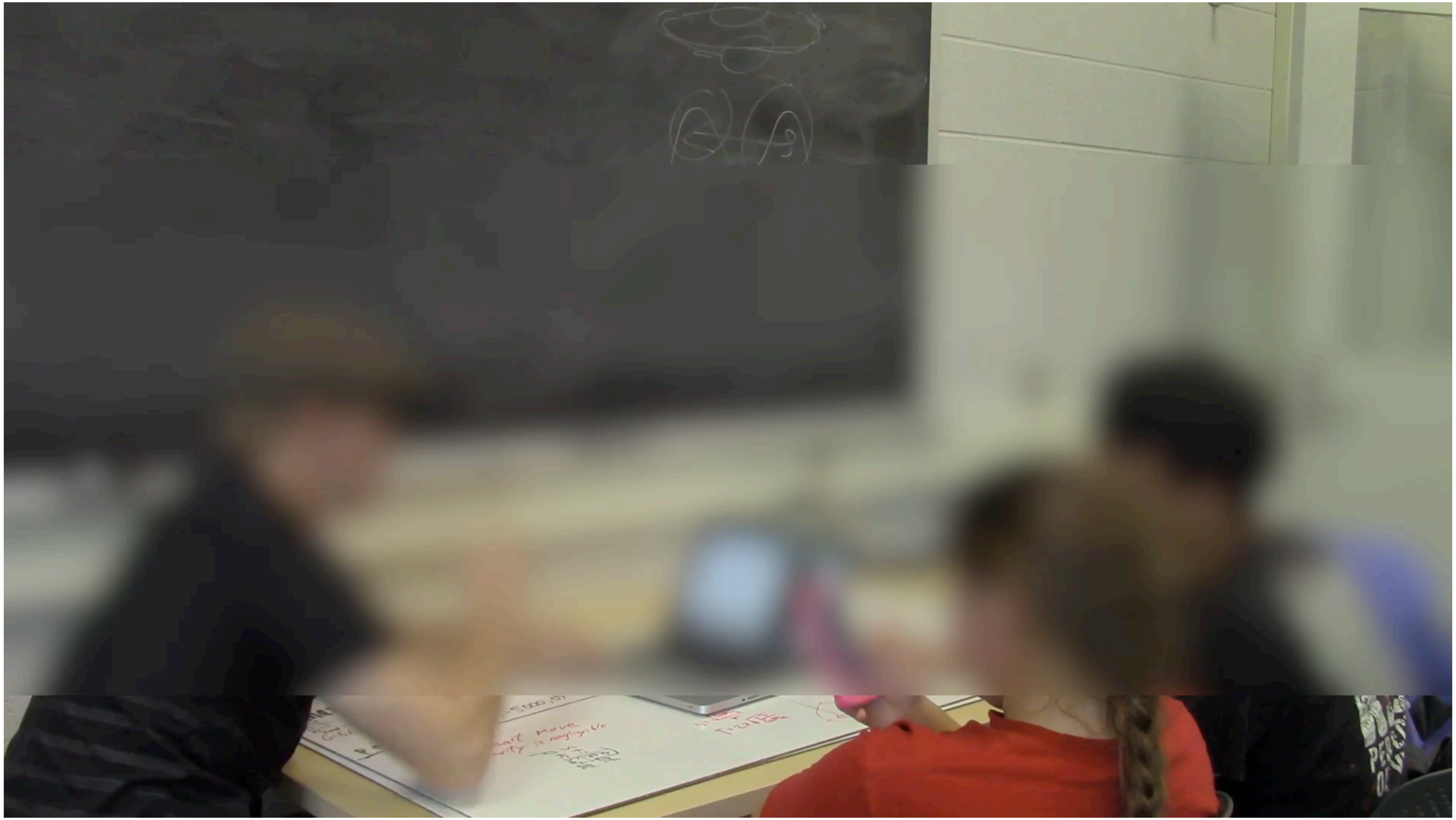
        Fgrav = -G*mSatellite*mEarth*Satellite.pos/(mag(Satellite.pos)**3)
        Fnet = Fgrav

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

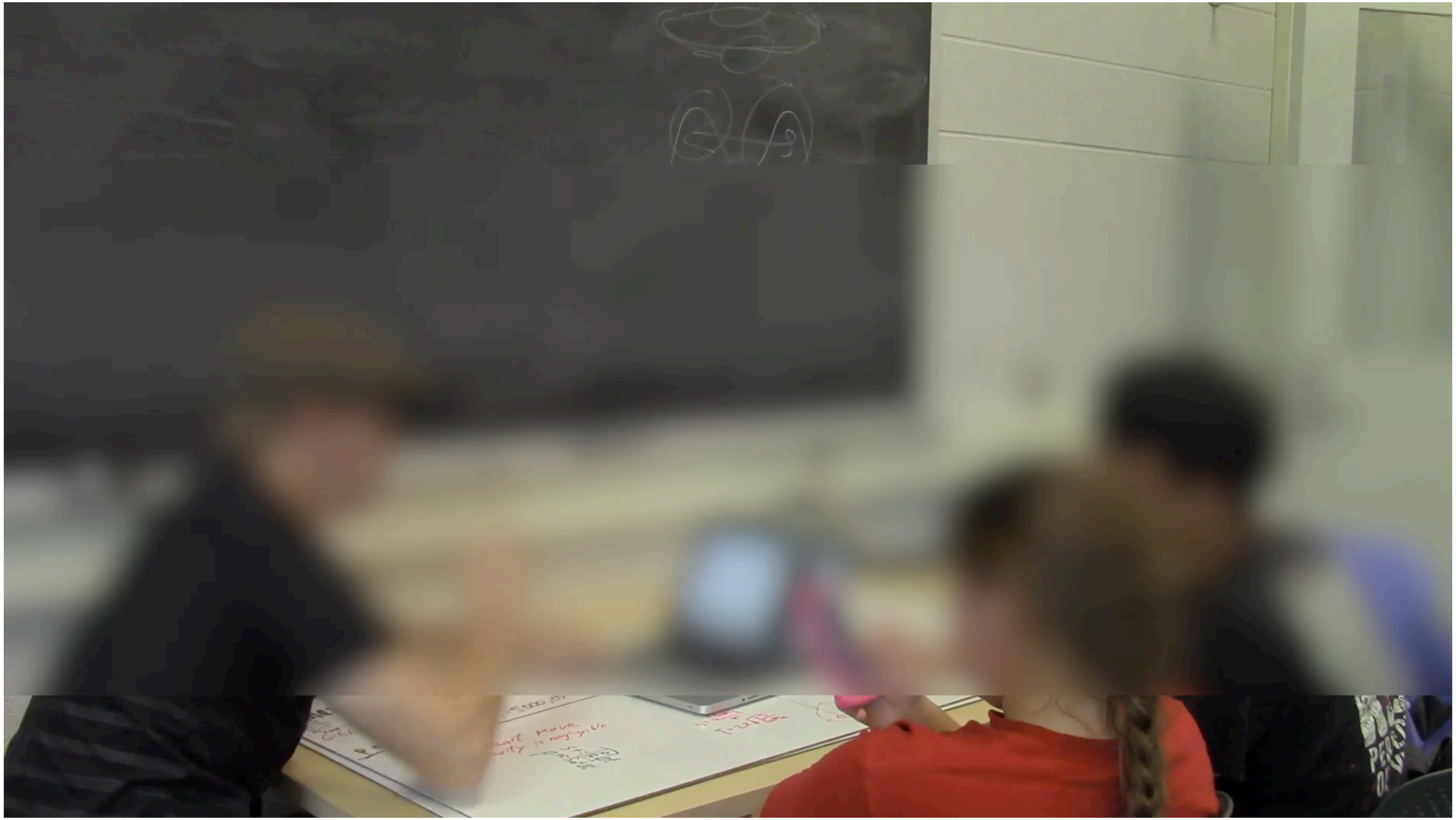
        SatelliteMotionMap.update(t, pSatellite/mSatellite)
        FnetMotionMap.update(t, Fnet)

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

        t = t +deltat
```



The group finds a "bug."



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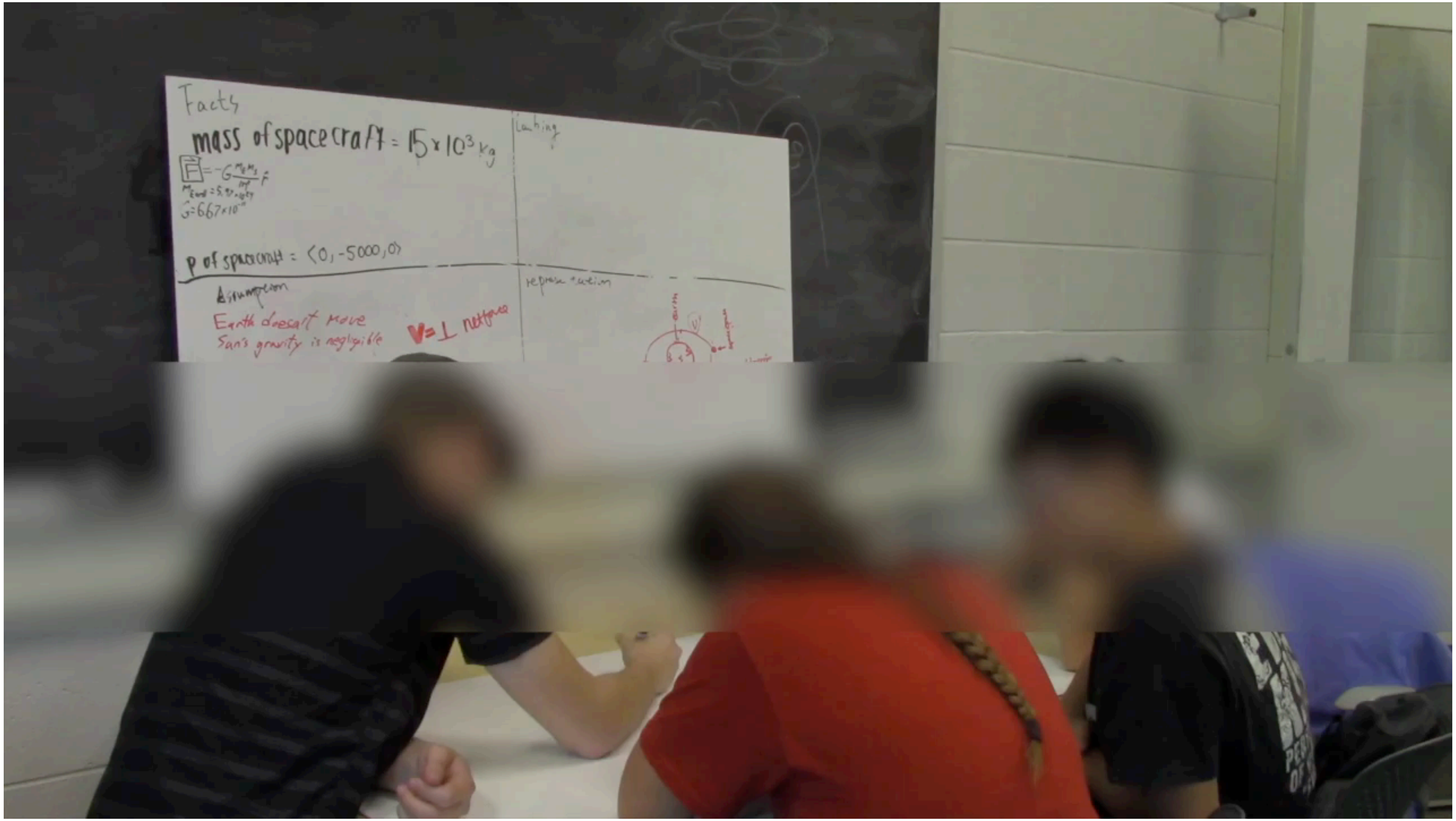
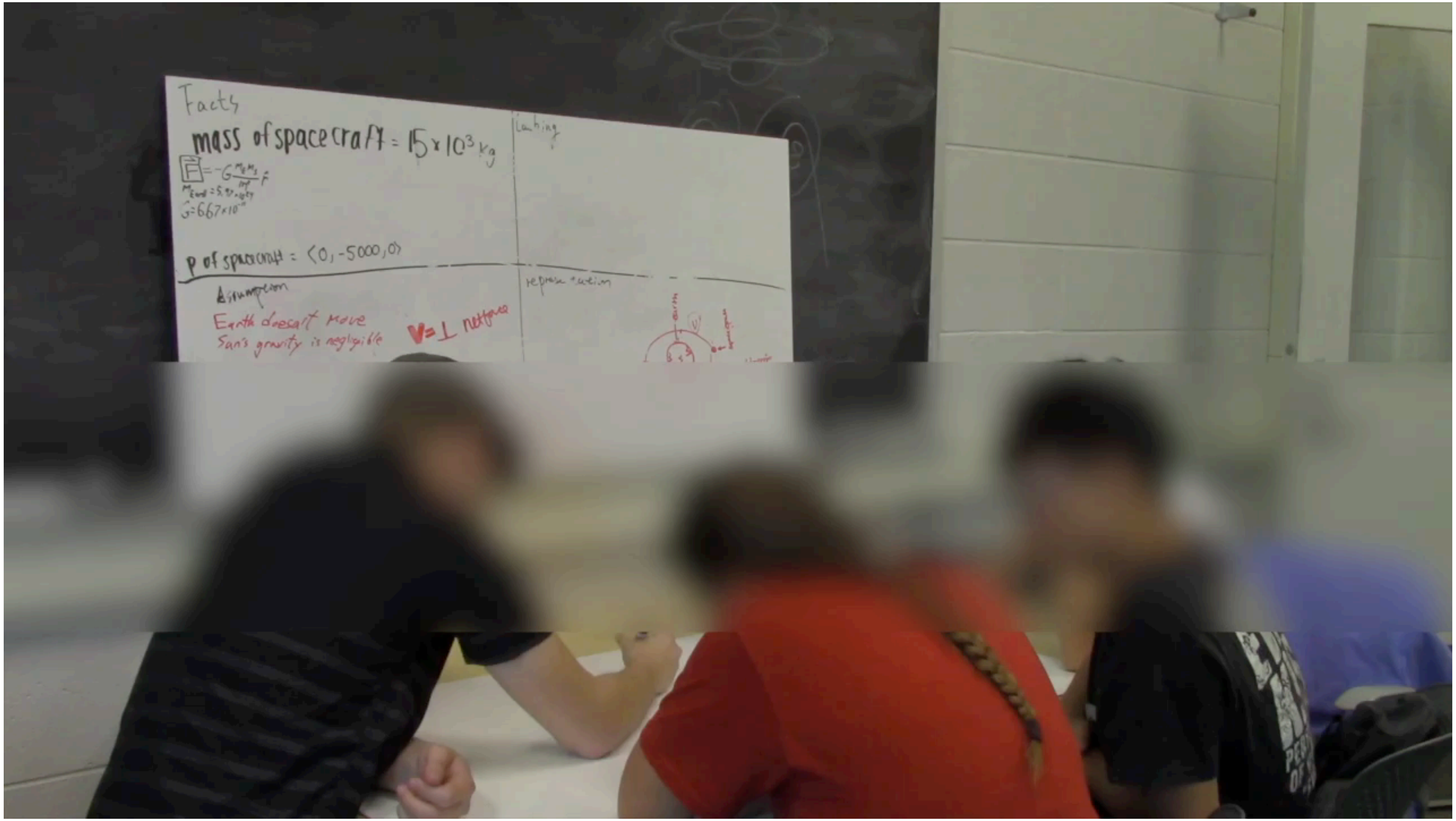


The group begins "debugging."



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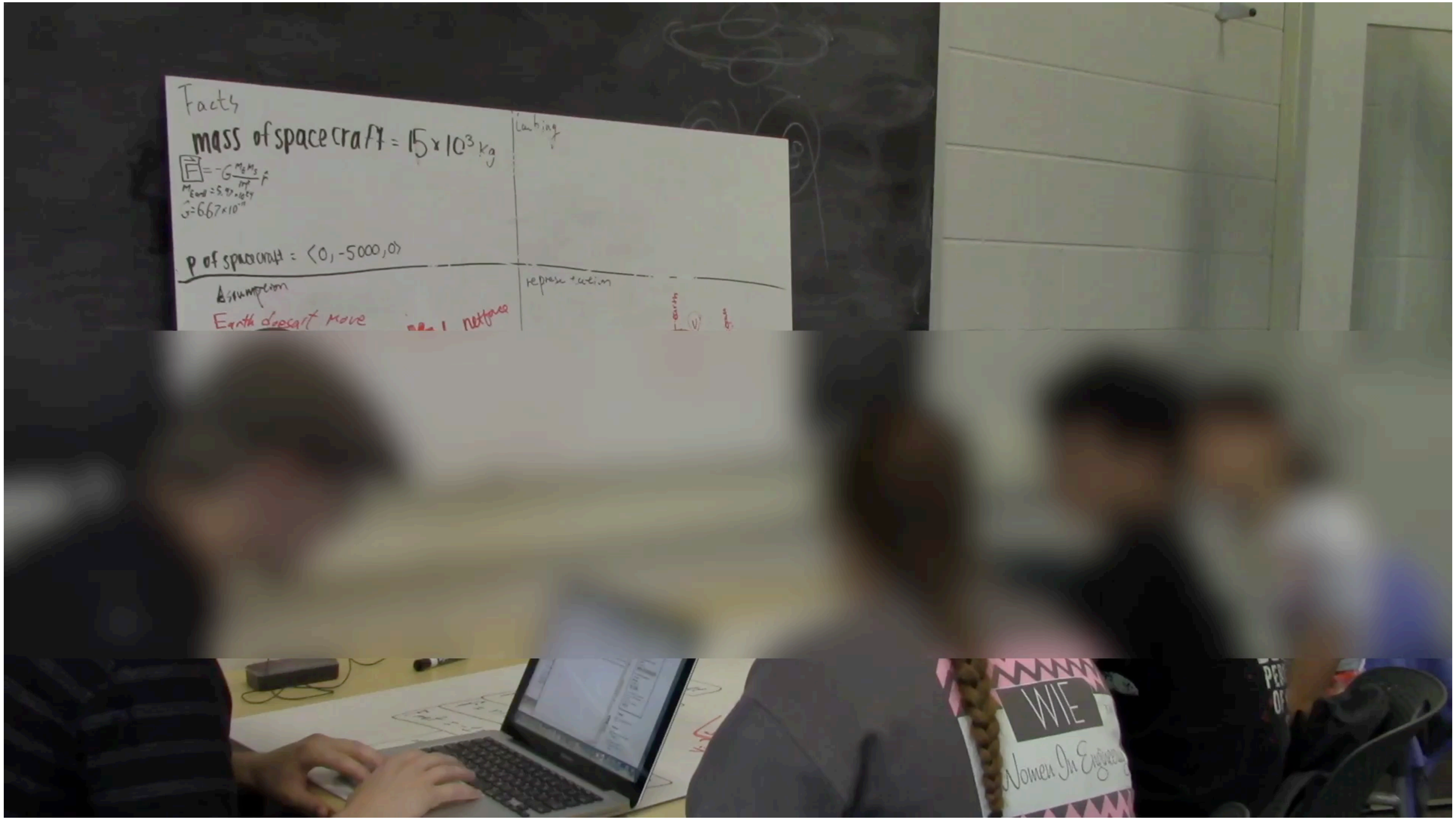
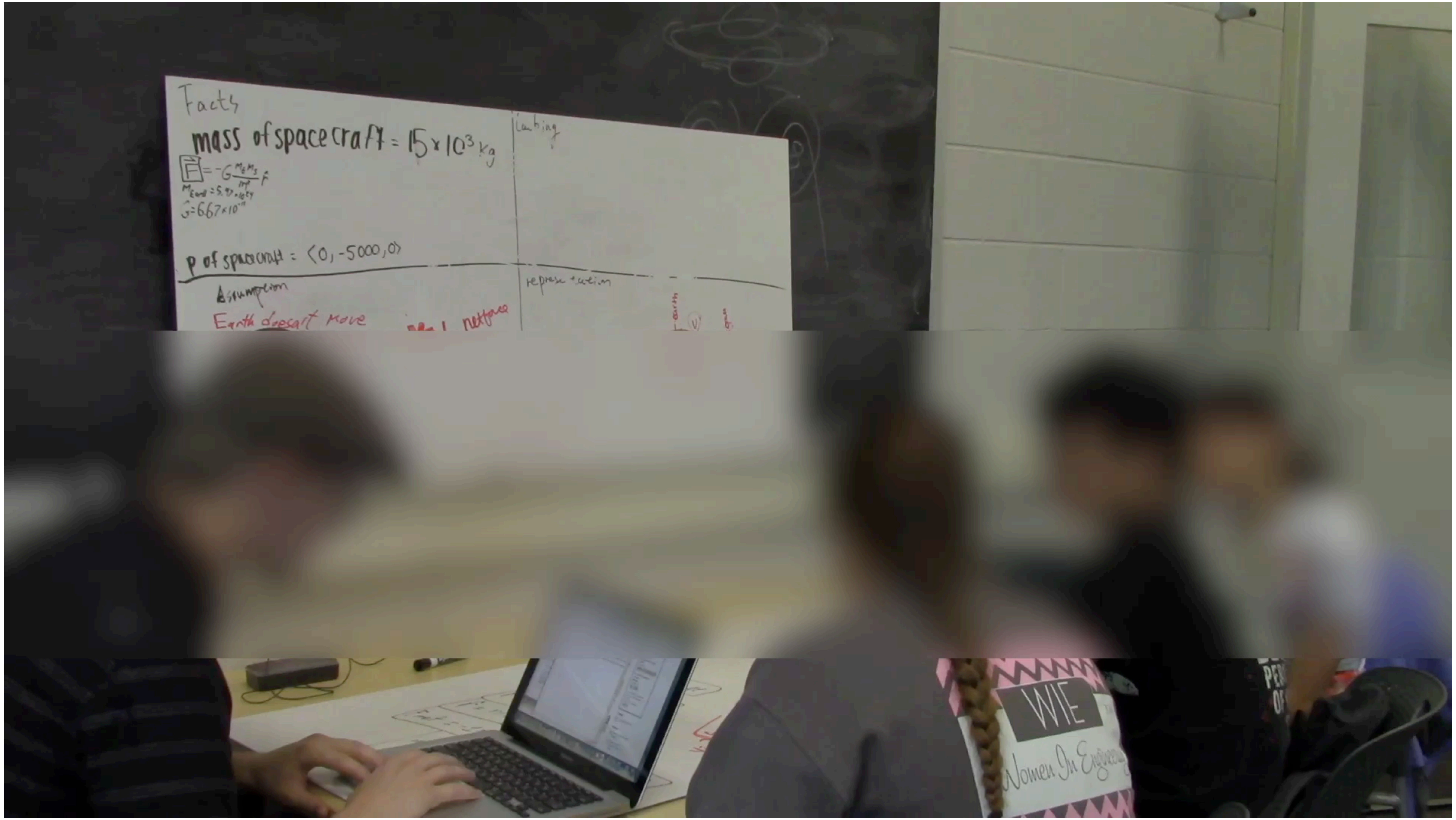
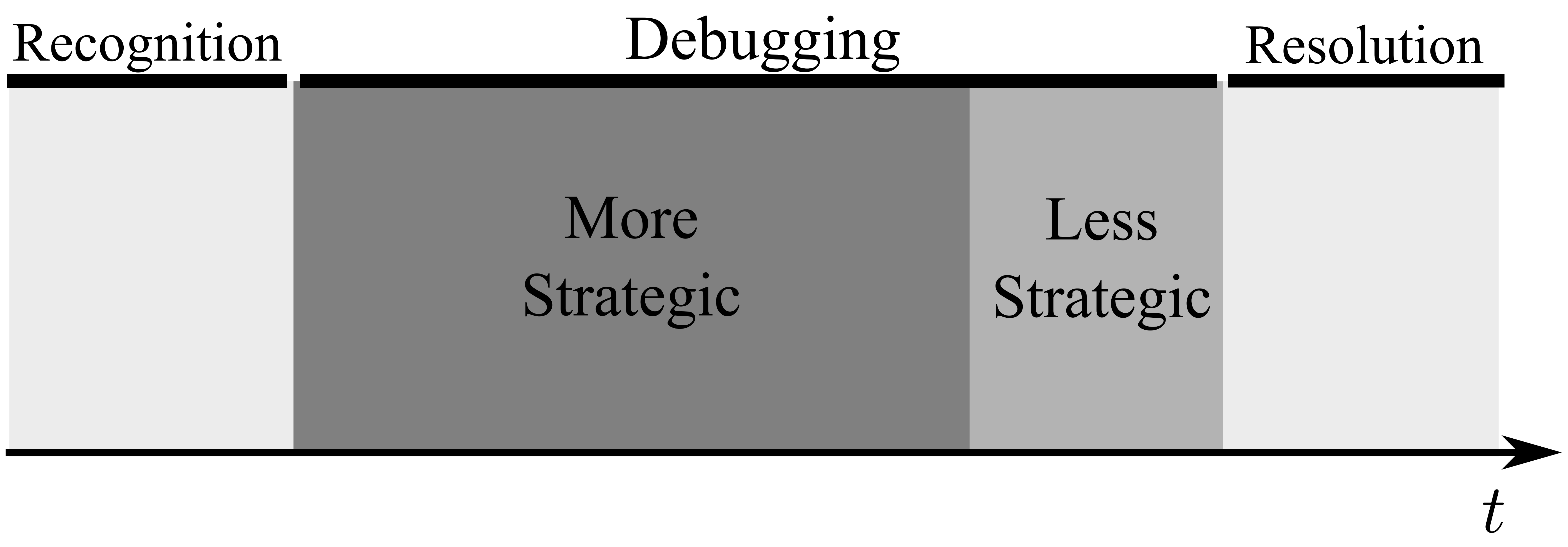


"Debugging" leads the group to doing physics.



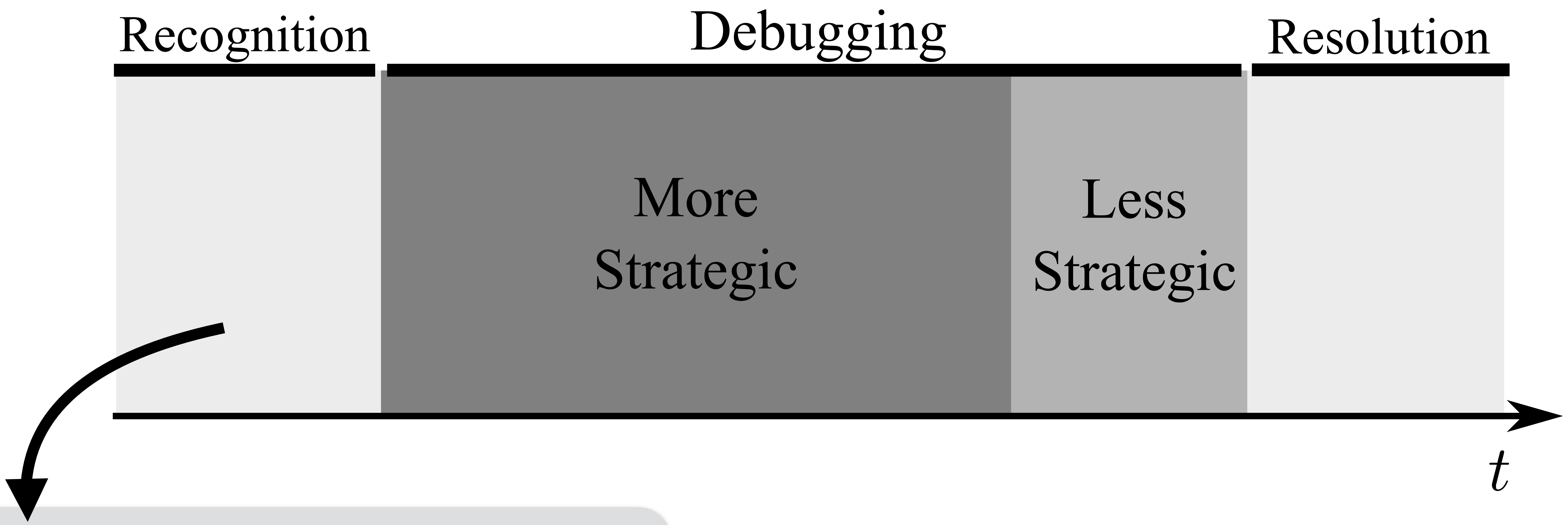
"Debugging" leads the group to doing physics.

A case study in debugging



Obsniuk, Irving, Caballero, PERC 2015

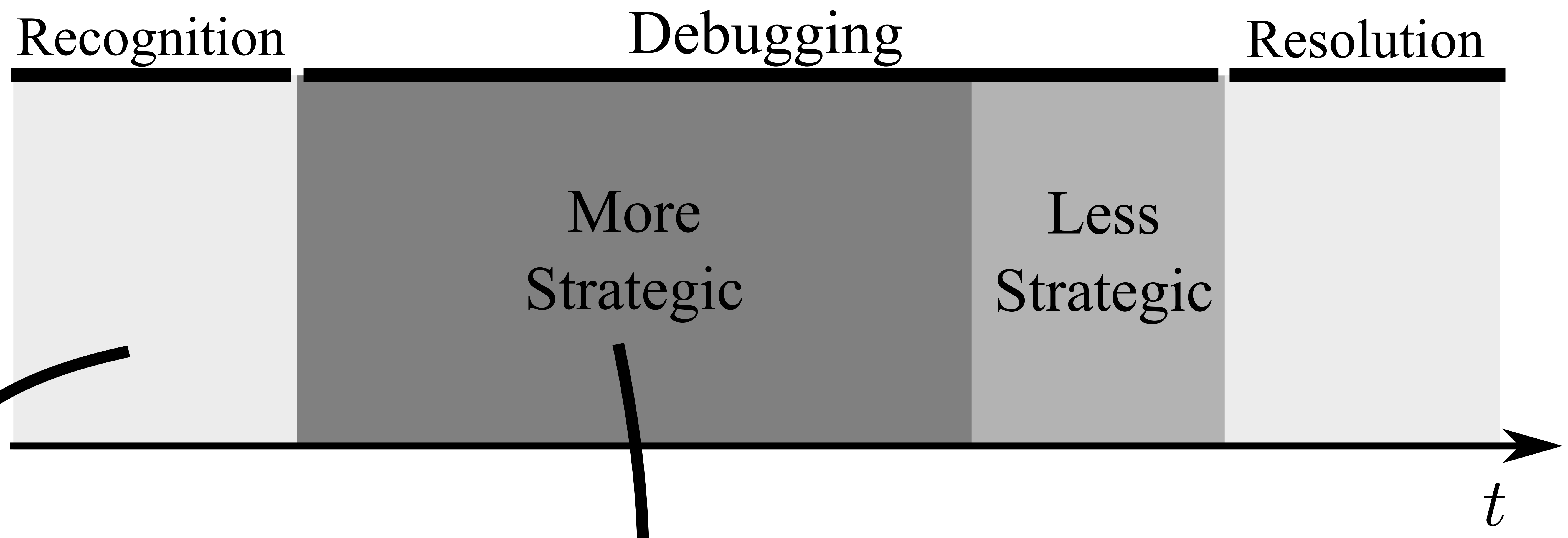
A case study in debugging



"…there's no good reason for it to be moving in that direction…"

Obsniuk, Irving, Caballero, PERC 2015

A case study in debugging



"...there's no good reason for it to be moving in that direction..."

"Final momentum equals initial momentum plus net force times delta t. True?"

Obsniuk, Irving, Caballero, PERC 2015

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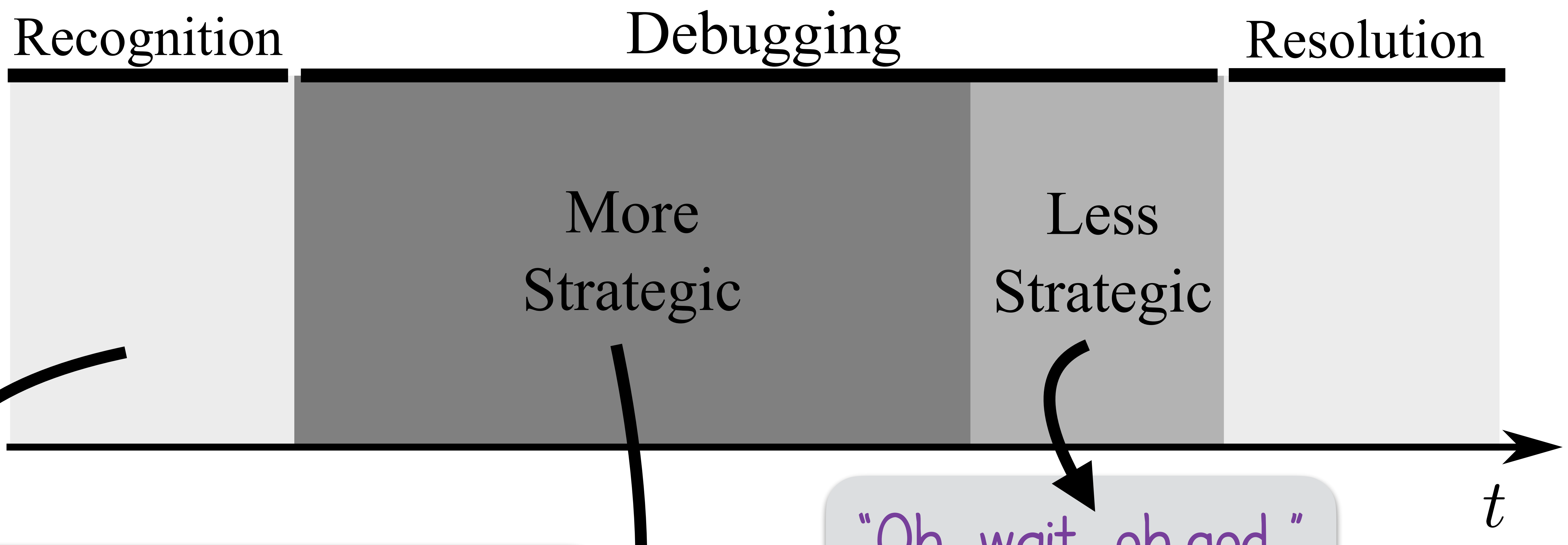

"…there's no good reason for it to be moving in that direction…"

"Final momentum equals initial momentum plus net force times delta t. True?"

"Oh, wait…oh god."

"Did you change it?"

Obsniuk, Irving, Caballero, PERC 2015

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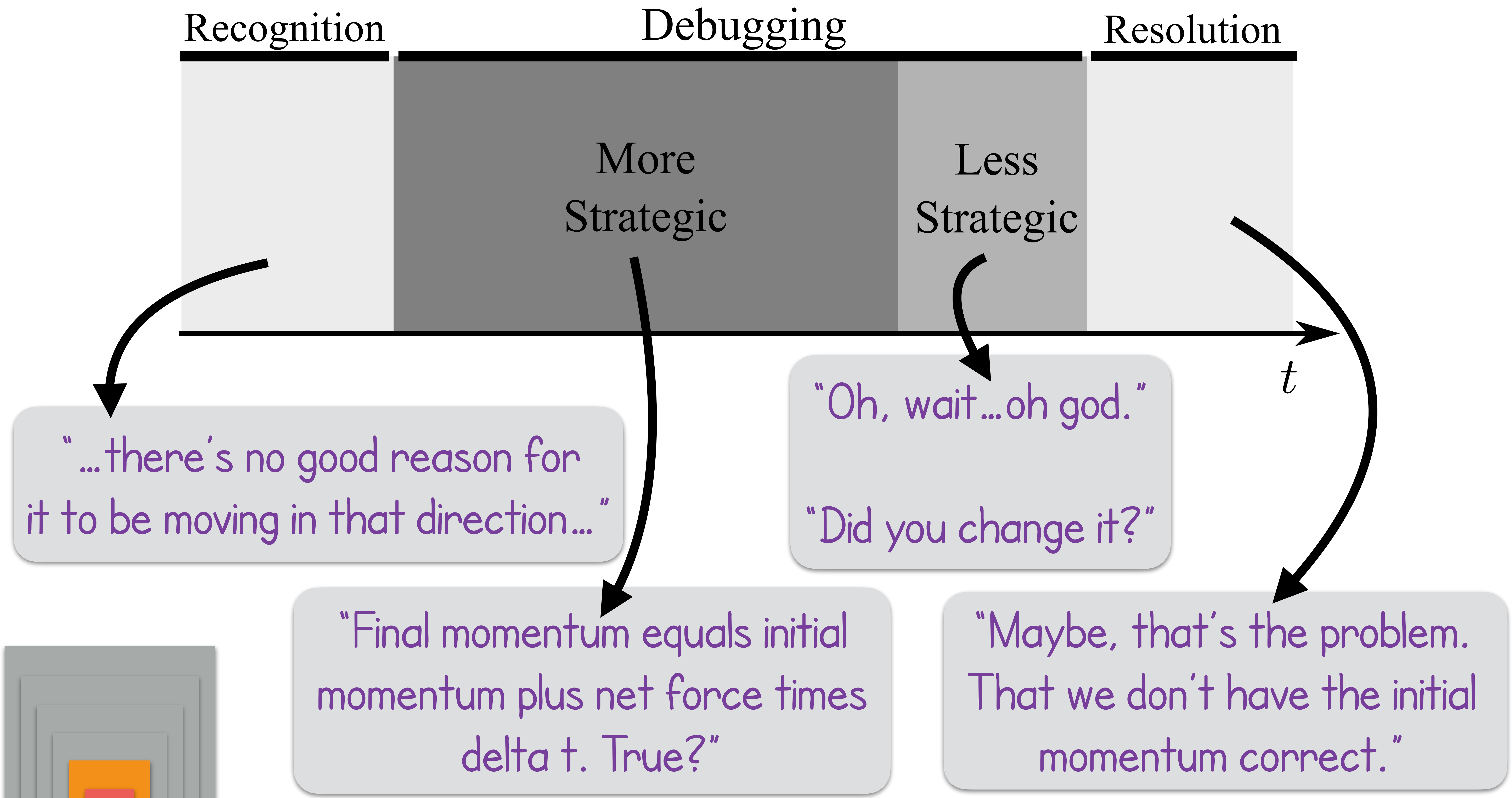

Obsniuk, Irving, Caballero, PERC 2015

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

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

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

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

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

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

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

sepgraph = gcurve(color=color.red)

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

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

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

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

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

        t = t +deltat
```

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

Obsniuk, PhD Thesis (2019, in progress)

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

$$\vec{F}_{grav} = -G\frac{m_{sat}M_{Earth}}{r^2}\hat{r}$$

Obsniuk, PhD Thesis (2019, in progress)

How do students construct the direction vector?

Step (Sub-Task)	Associated Code
Construct separation vector between interacting objects	`sep = obj2.pos - obj1.pos`
Construct the unit vector	`usep = sep/mag(sep)`
Construct the net force vector	`Fnet = -G*m1*m2*usep /mag(sep)**2`
Integrate the net force over time into momentum	`obj.p = obj.p + Fnet*dt`

```
Fgrav = mSatellite*vSatellite**2/mag(Satellite.pos)
```

```
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```

$$F_{grav} = \frac{m_{sat} v_{sat}^2}{R}$$

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$$F_{grav} = \frac{m_{sat} v_{sat}^2}{R}$$

Shelley: *But ummm wait, hold on, remember this? The uniform circular is equal to the gravity is equal to the net? So we could just do what you did, except instead of using the uniform circular motion equation we use that gravity equation [points to equation].*

Joe: *Yeah...*

Chuck: *Okay, yeah, that sounds good.*

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```
Fgrav = G*mEarth*msat/R**2
```

$$F_{grav} = G\frac{M_{Earth} m_{sat}}{R^2}$$

Chuck: *How do we, okay, how do we define a direction?*

Cody: *I don't know...*

Chuck: *Isn't the direction like, okay, so here I'm gonna give like four points on a circle [drawing on whiteboard] so this is the center, and this is a b c and d. Isn't it always just the position vector of a, so ummm what is it, like satellite dot position minus position dot Earth, and then you can divide that by magnitude?*

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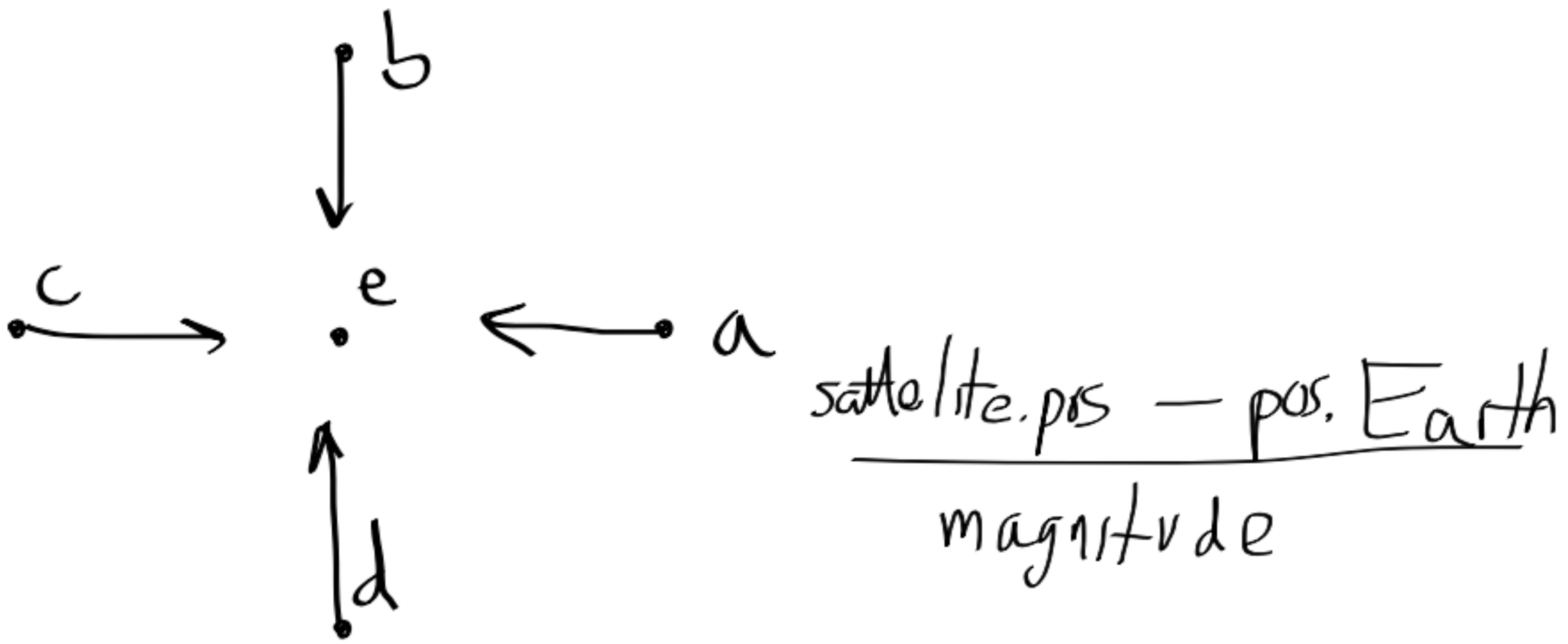

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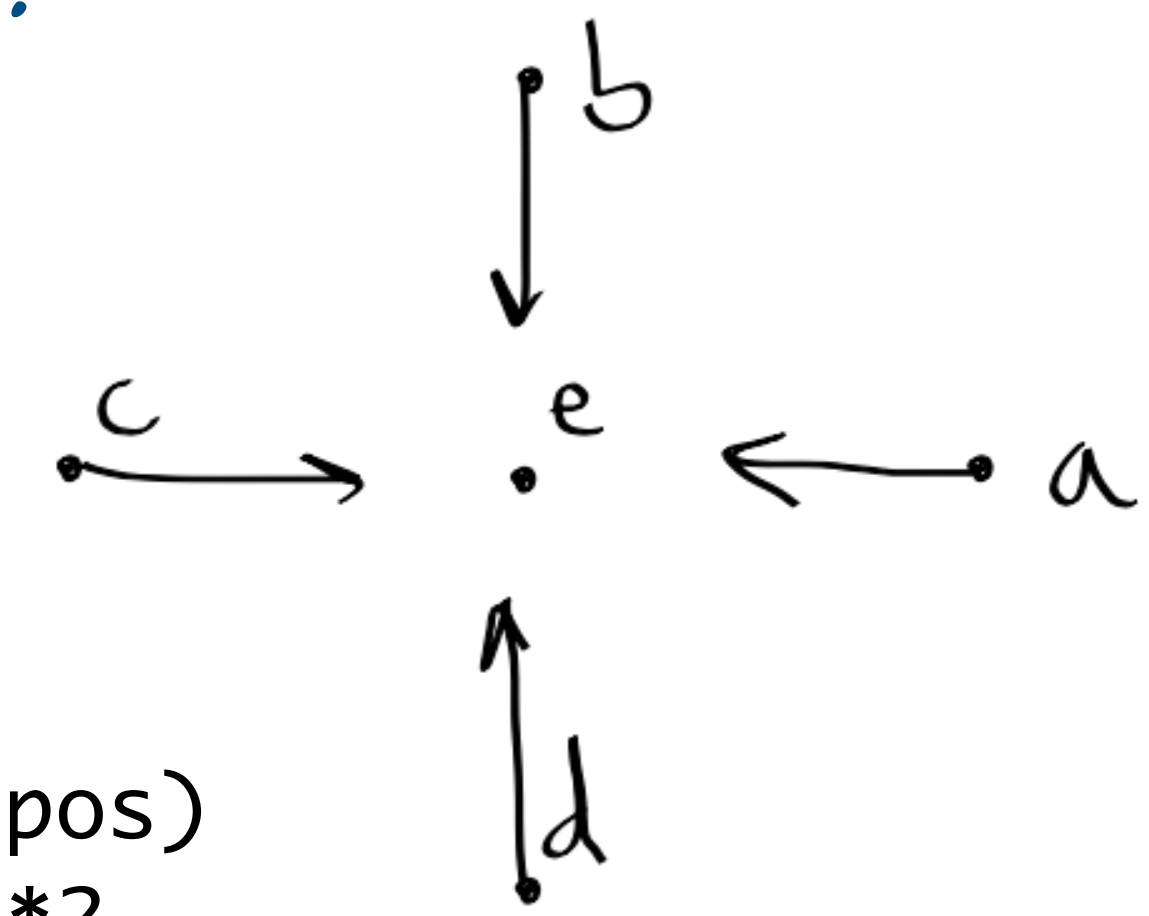

$$\frac{\text{sattelite.pos} - \text{pos. Earth}}{\text{magnitude}}$$

```
dir = sat.pos/mag(sat.pos)
Fnet = -G*m1*m2*dir/R**2
```

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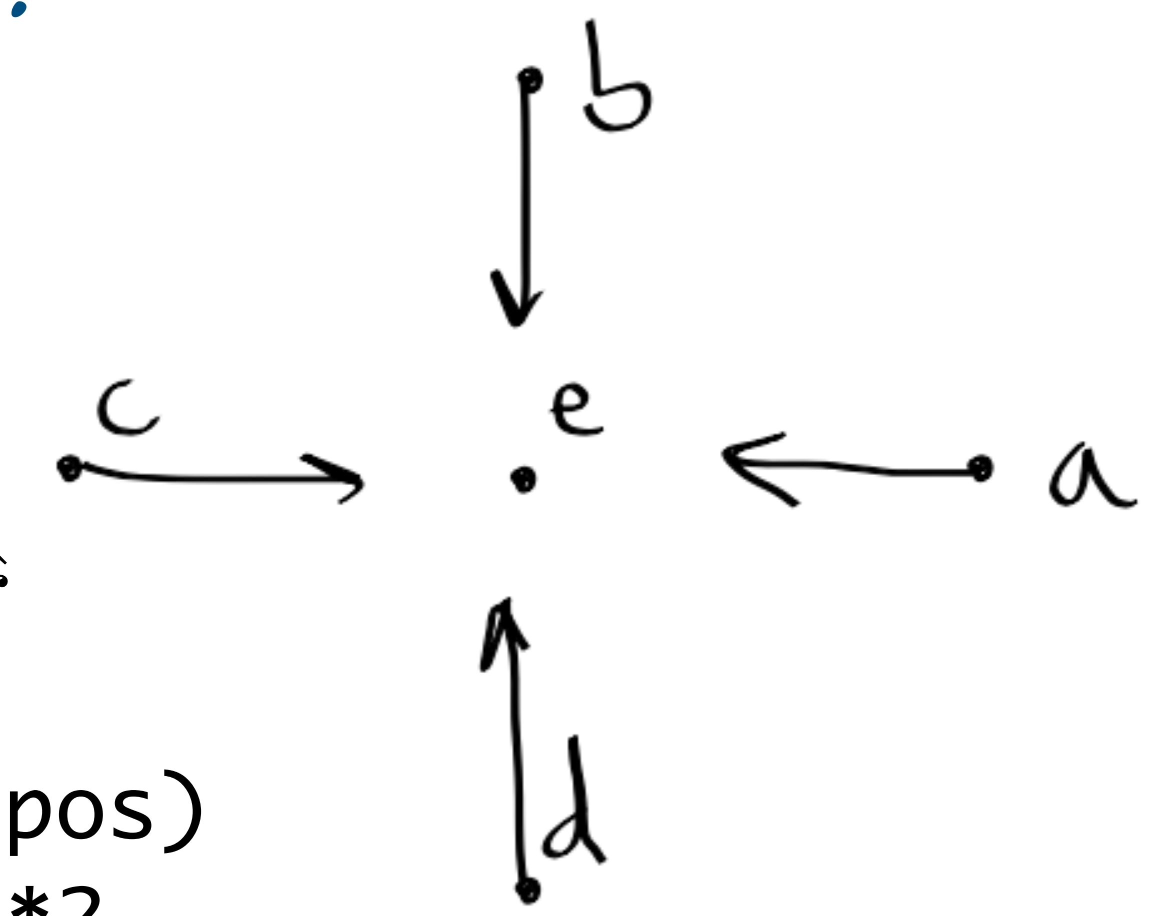

$$\vec{F}_{grav} = -G\frac{m_{sat}M_{Earth}}{r^2}\hat{r}$$

$$\frac{\text{satellite.pos} - \text{pos. Earth}}{\text{magnitude}}$$

```
dir = sat.pos/mag(sat.pos)
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```
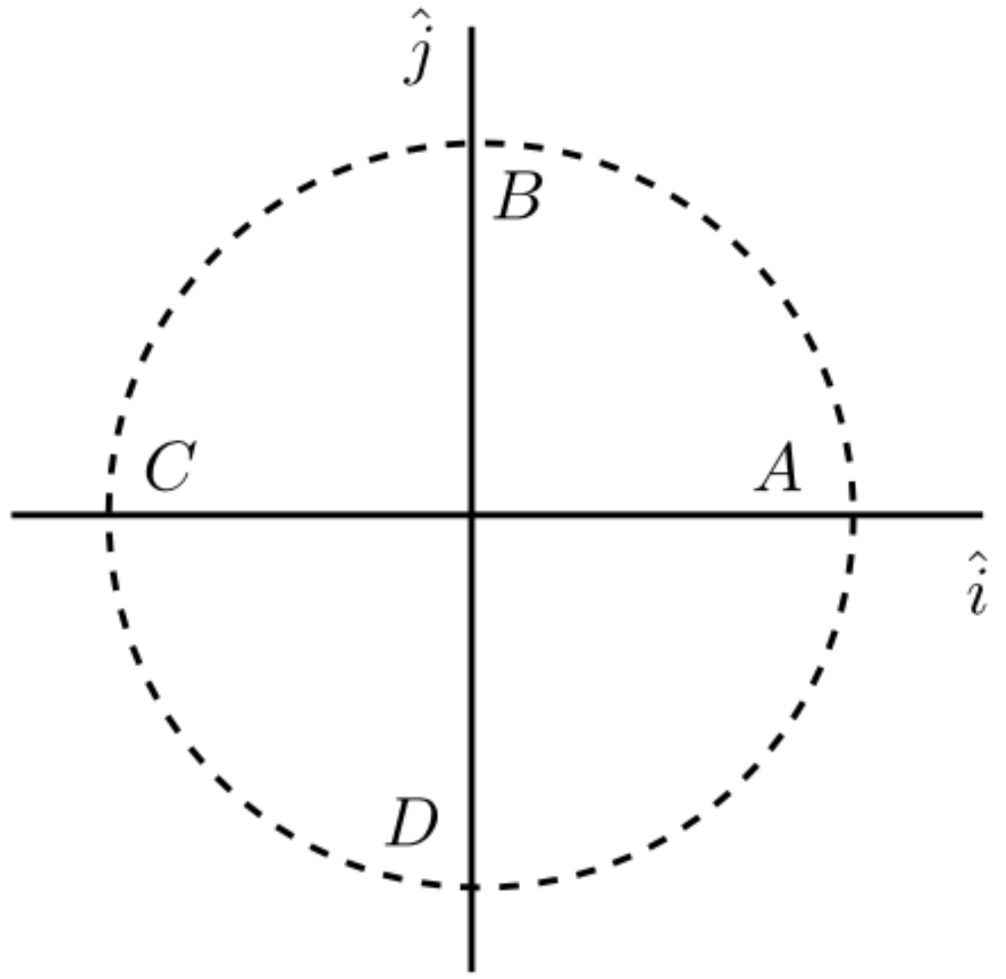

A stationary star is located at $\langle 1,3,0\rangle \times 10^{14}\,\mathrm{m}$ and a planet moving with a velocity of $\langle 2,-1,0\rangle \times 10^{3}\,\mathrm{m/s}$ is located at a position $\langle -4,1,0\rangle \times 10^{14}\,\mathrm{m}$. What is the vector pointing from the initial location of the star to the planet?

$\vec{r} = \langle \quad , \quad , \quad \rangle$

The Moon orbits the Earth in a roughly circular orbit. To calculate the force the Earth exerts on the Moon, you need to know the direction of the separation unit vector ($\hat{r}$) and the gravitational force unit vector ($\hat{F}$). For locations A-D, find $\hat{r}$ and $\hat{F}$.



At A:

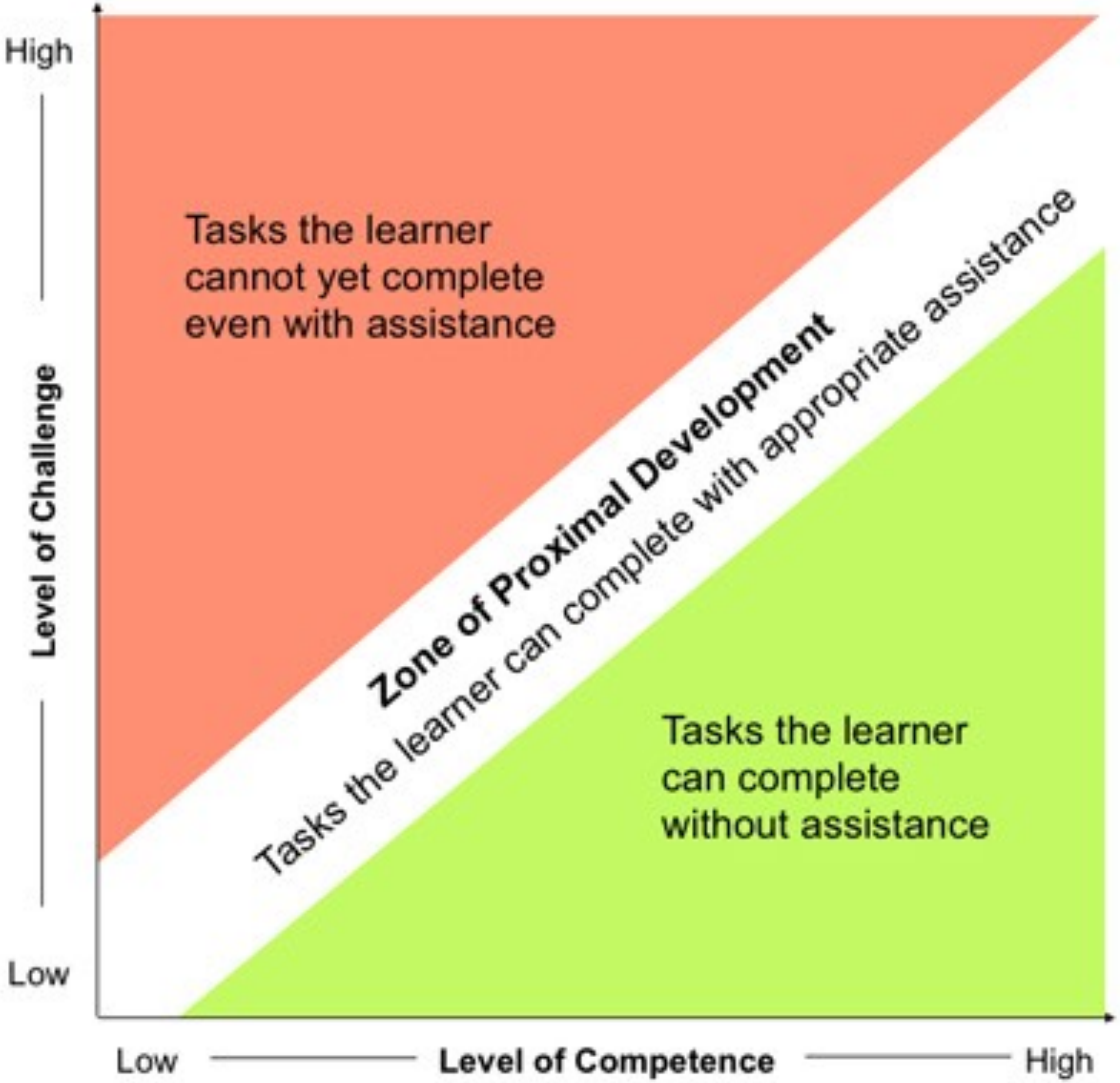
$\hat{r} = \langle \quad , \quad , \quad \rangle$

$\hat{F} = \langle \quad , \quad , \quad \rangle$

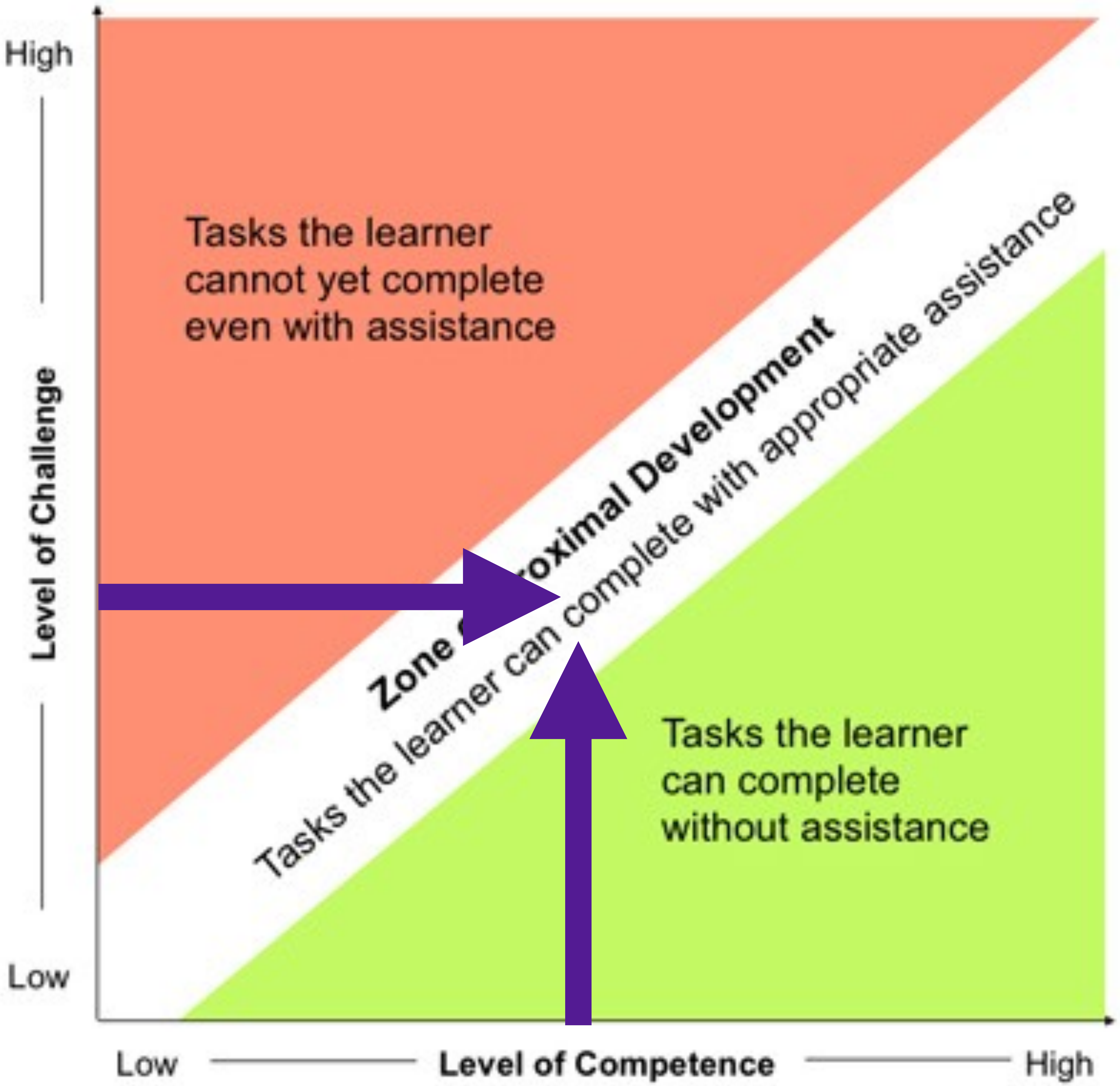
At C:

$\hat{r} = \langle \quad , \quad , \quad \rangle$

$\hat{F} = \langle \quad , \quad , \quad \rangle$



L. Vygotsky, *Mind in society* (1978)



L. Vygotsky, *Mind in society* (1978)

How do students' perceive the utility of computing?

THEME:
Computation Helps to Learn Physics

Label	Variation of Theme	N
A	Computation Helps Me to Build a Conceptual Understanding of Physics	7
B	Engaging in the Practices of Computation Helps Me to Learn Physics	14
C	Computation Helps Me to Learn Physics by Solving *Some* Problems	5
D	Computation Doesn't Help Me to Learn Physics	3
E	Computation Does Not Help to Learn Physics	4

Hawkins, Obsniuk, Irving, & Caballero, PERC 2017

Computation helps me to build a conceptual understand physics

Macku: *They were trying to* ***explain that centrifugal force is not really an actual force.*** *We* ***just use it as a concept*** *to explain things that are bigger. That was a big part, because we kept trying to say, 'oh, what kind of force are you going to need on it?' We were like, 'we only really need that force towards earth, we don't need the centrifugal force.'* ***The centrifugal force wasn't in the code.*** *I think it was not adding it to the code, but* ***it was more understanding that we don't need it.***

Computation does not help <u>me</u> solve problems

Captain: ***Two people in my group haven't taken physics****, so I think that helps a lot of them understand what they're doing.* ***They actually see a model*** *of what they [coded]. It helps a lot of the understanding what you did, when you actually get to see what you did. I would say no in my case, but it should have helped someone else.* ***Most of the things we are seeing in physics now I already learned.*** *So far* ***it's more like getting better at physics, not so much at learning physics*** *for me. I would say what I did so far is something I already did in high school.*