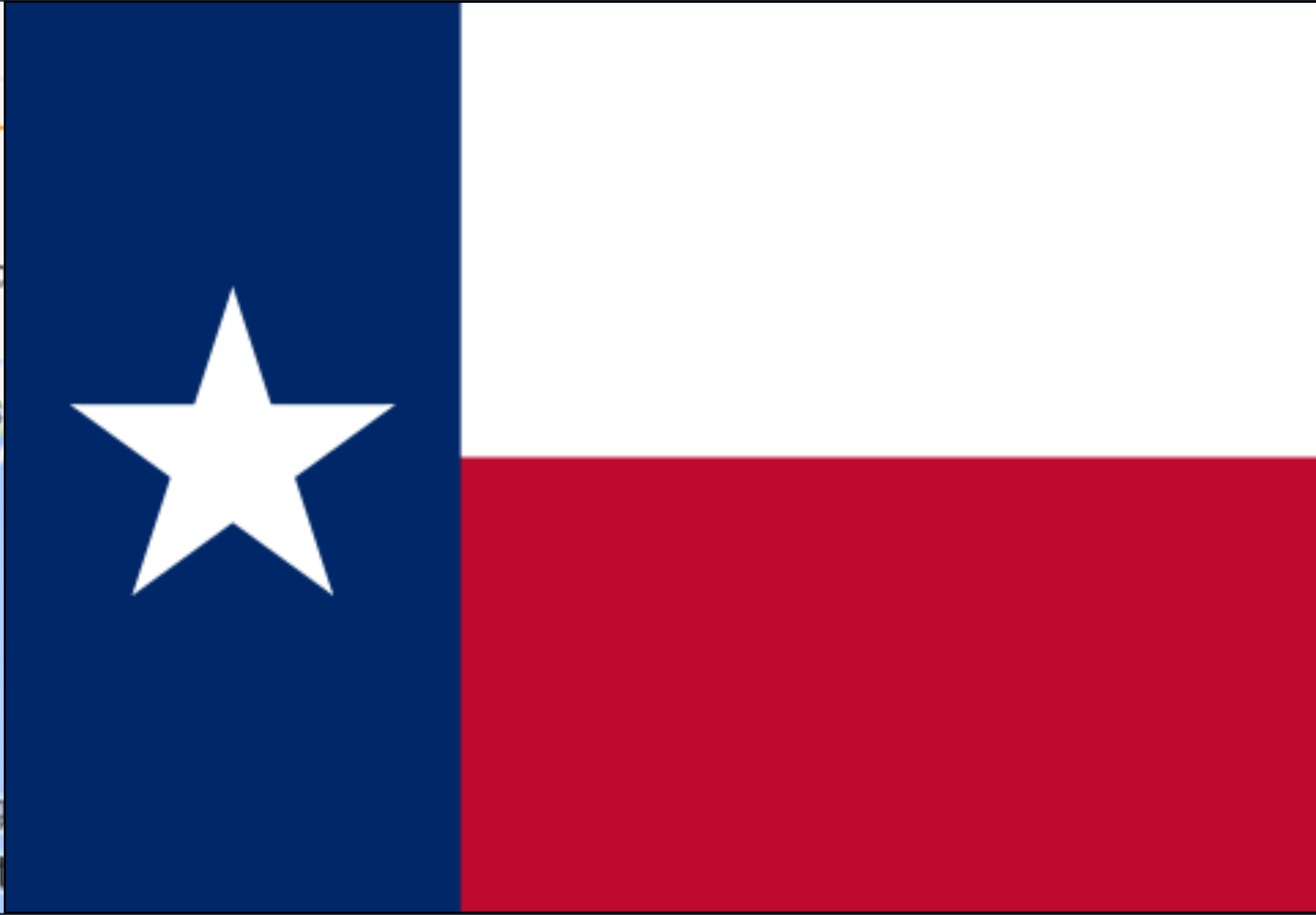
MICHIGAN STATE UNIVERSITY

Supporting the integration of computing in physics education

Danny Caballero (he/they)
Department of Physics and Astronomy
Department of Computational Mathematics, Science, and Engineering
CREATE For STEM Institute

CMSE


Ciudad Acuña
San Antonio
Piedras Negras
Victo
Corpus Christi
Nuevo Laredo
Monclova
A
Harling
Reynosa
Monterrey
Mat

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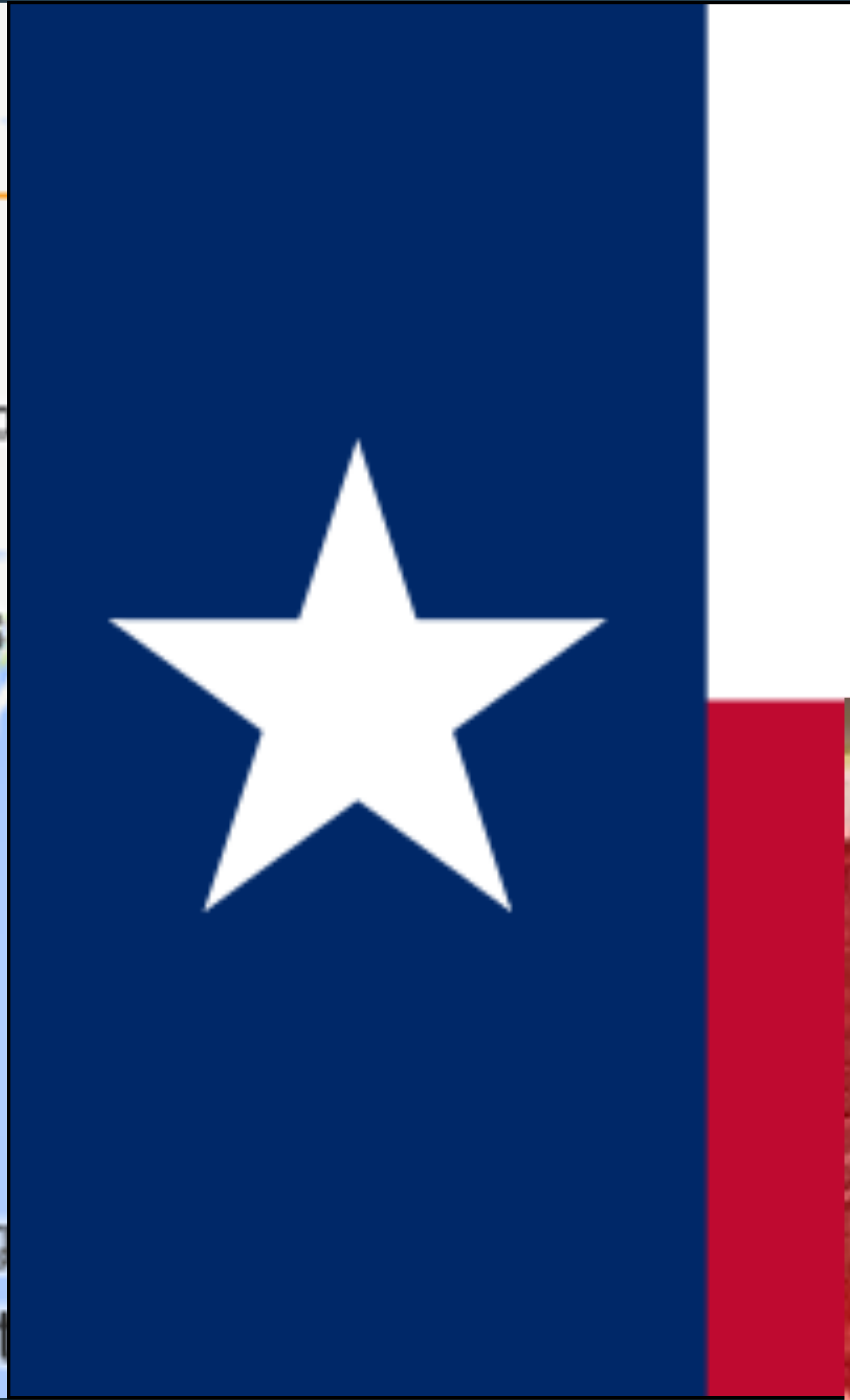
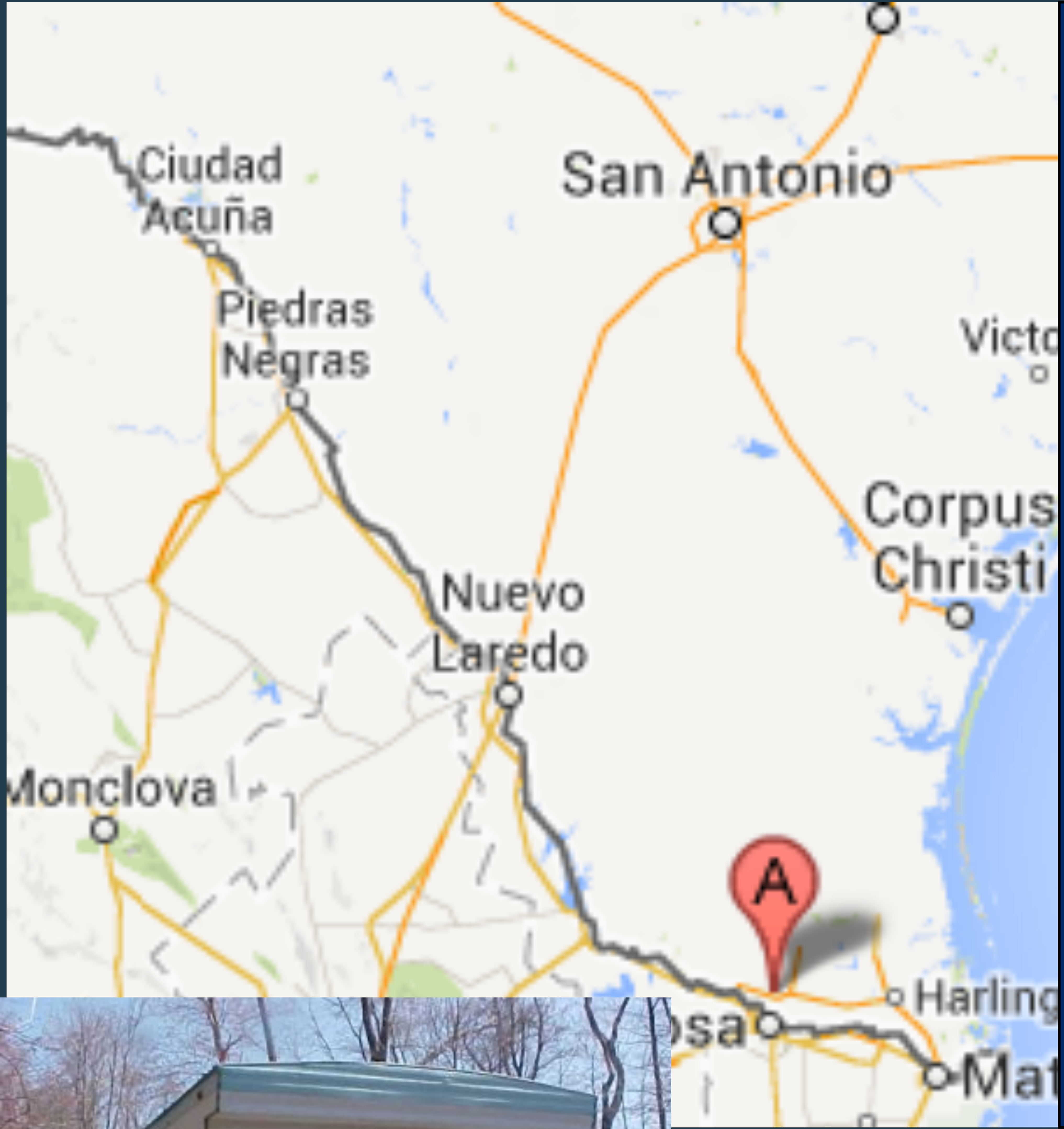
Monterrey




Ciudad
Acuña
San Antonio
Piedras
Negras
Corpus
Christi
Nuevo
Laredo
Monclova
A

Pop with the boys


THE UNIVERSITY OF TEXAS
PRAESIDIUM
DISCIPLINA CIVITATIS
AT AUSTIN

THE UNIVERSITY OF TEXAS AT AUSTIN


CROWN & ANCHOR PUB
LONGHORN NETWORK
SAMUEL ADAMS
FAT TIRE


CROWN & ANCHOR PUB
SAMUEL ADAMS
FAT TIRE
LONGHORN NETWORK
BUD LIGHT


THE GEORGIA INSTITUTE OF TECHNOLOGY
PROGRESS
AND
SERVICE
SEAL OF
1885
TECH
TECH


THE GEORGIA INSTITUTE OF TECHNOLOGY
PROGRESS AND SERVICE
SEAL OF 1885
TECH TECH


(Old) North Atlanta HS


UNIVERSITY OF COLORADO
LET YOUR LIGHT SHINE
1876


UNIVERSITY OF COLORADO
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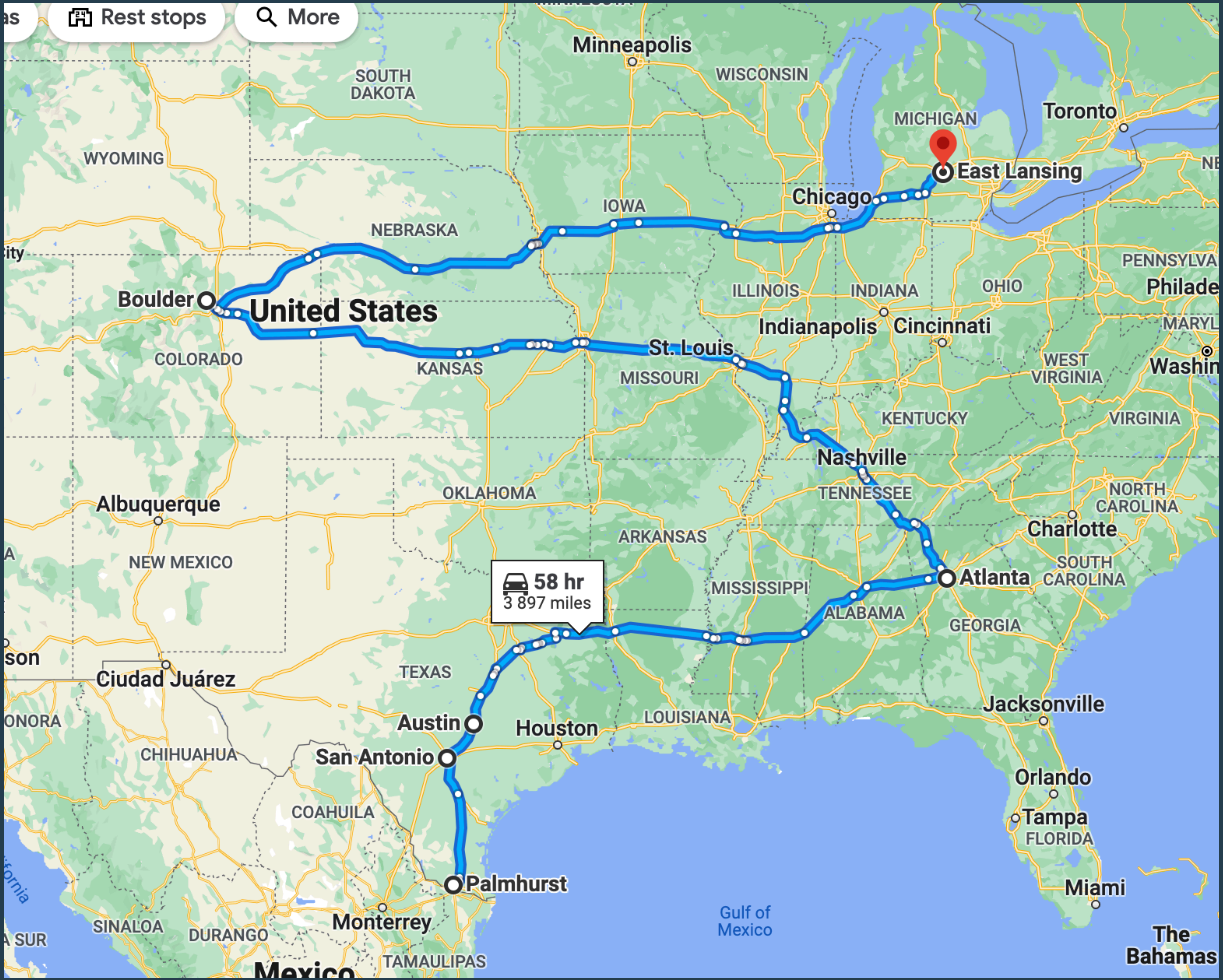
1876
This is the Physics building!

STEM Teaching and Learning Building

In summary...

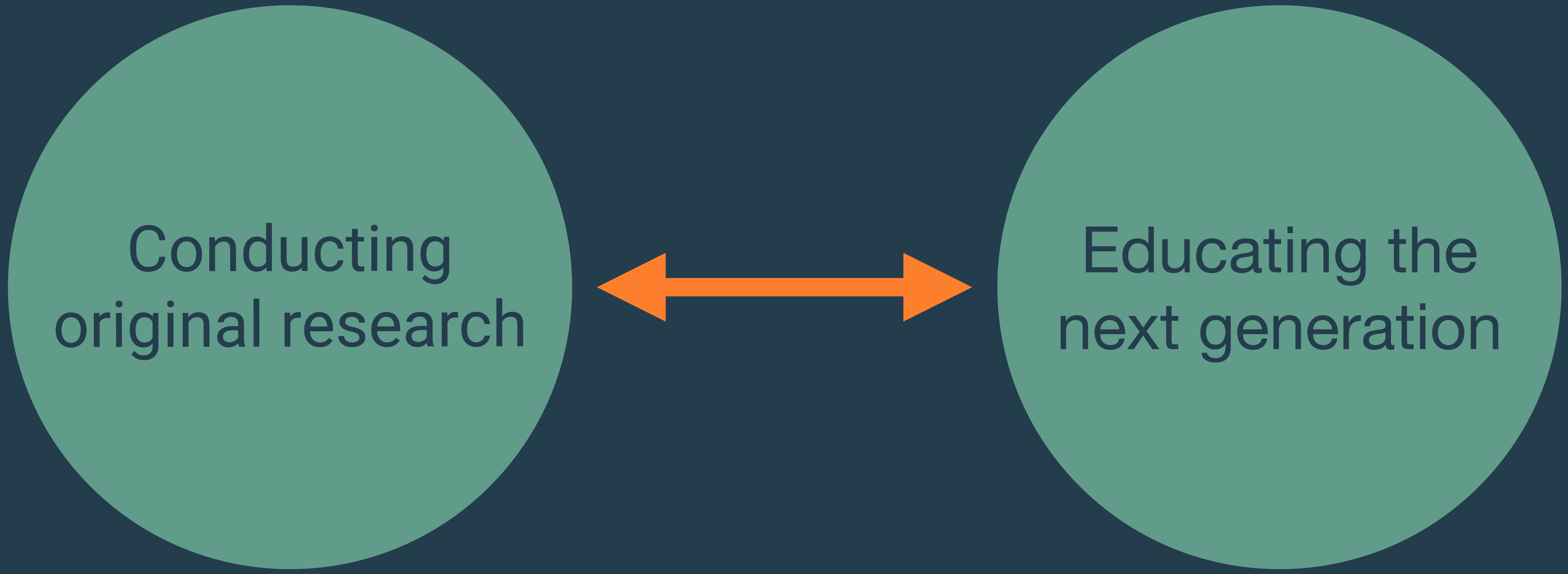

Rest stops
More
Minneapolis
SOUTH DAKOTA
WISCONSIN
MICHIGAN
Toronto
WYOMING
East Lansing
Chicago
IOWA
NEBRASKA
Boulder
United States
ILLINOIS
INDIANA
OHIO
COLORADO
Indianapolis
Cincinnati
St. Louis
KANSAS
MISSOURI
WEST VIRGINIA
KENTUCKY
VIRGINIA
Nashville
TENNESSEE
Albuquerque
OKLAHOMA
NORTH CAROLINA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

Twin goals of our department

MICHIGAN STATE UNIVERSITY

Conducting Original Research

Educating the Next Generation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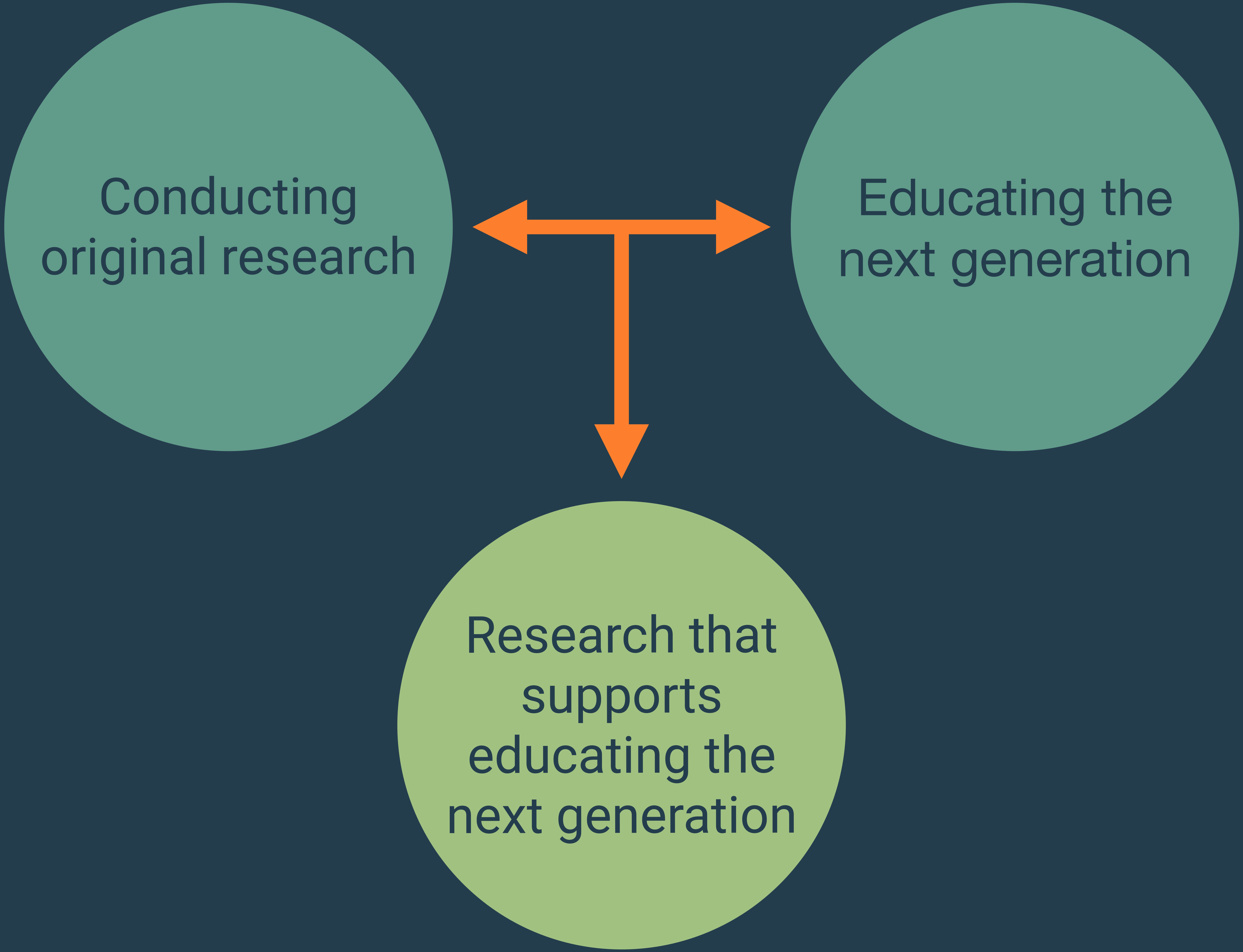
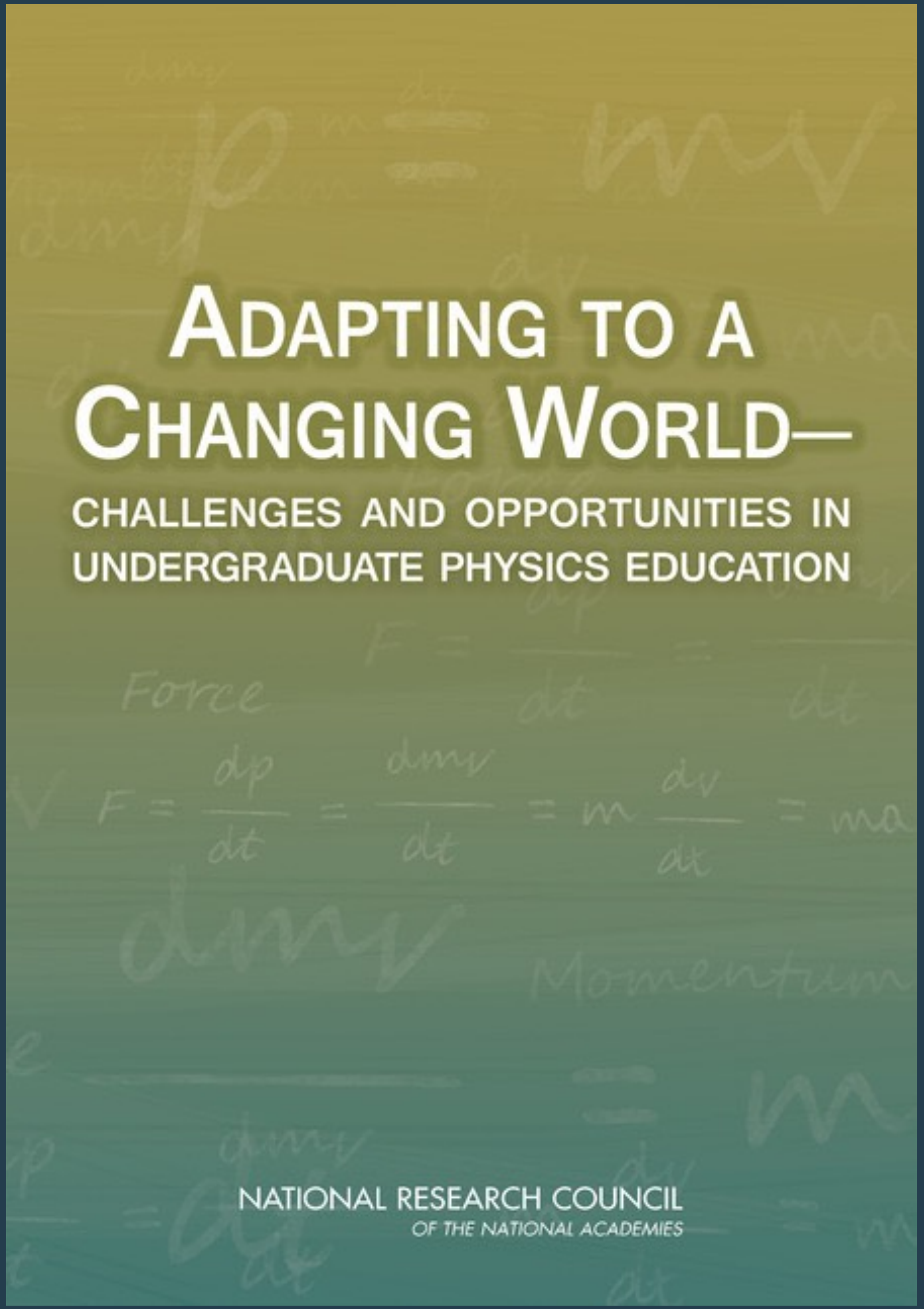
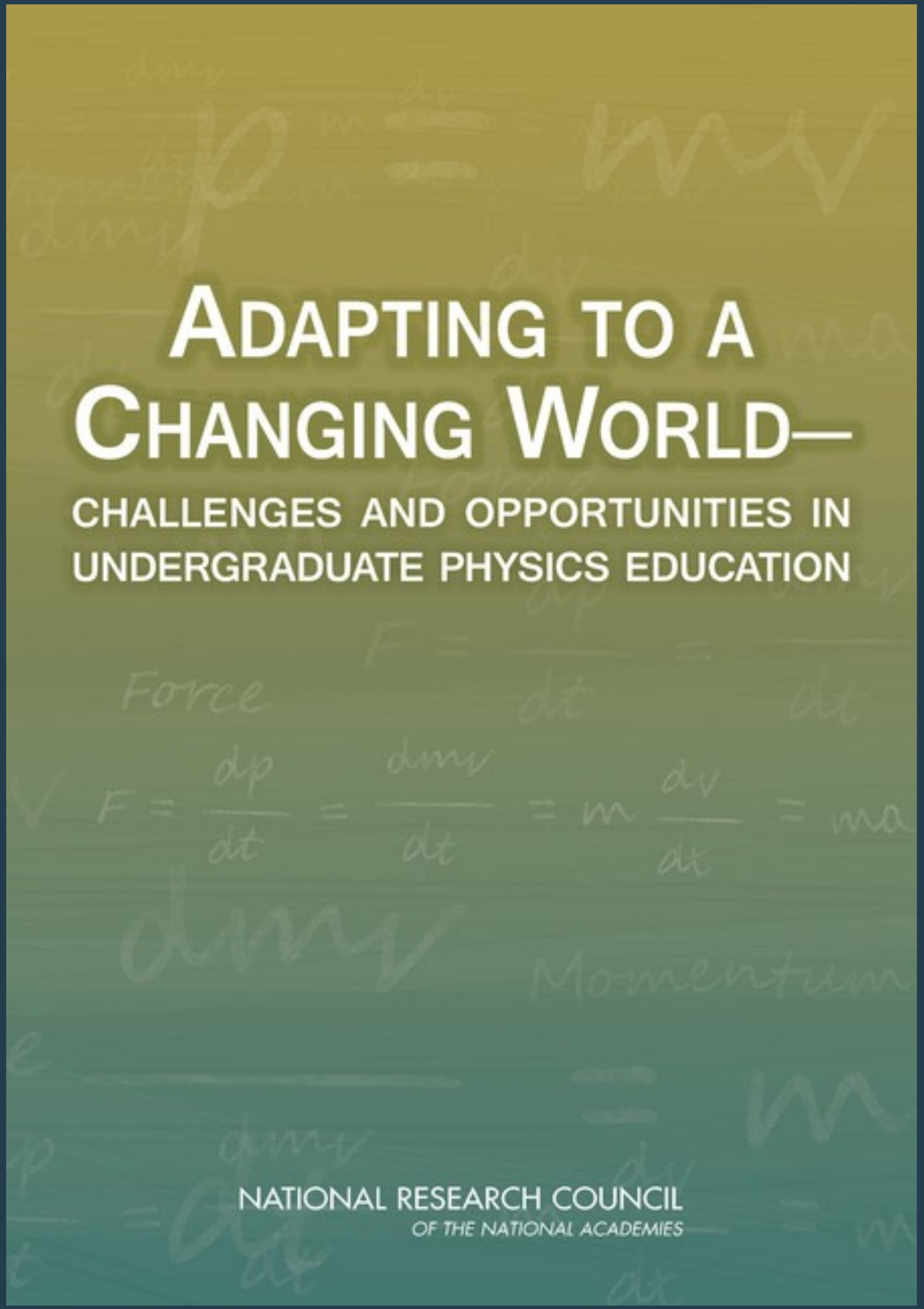

Conducting original research
Educating the next generation
Research that supports educating the next generation

Physics Education Research studies:



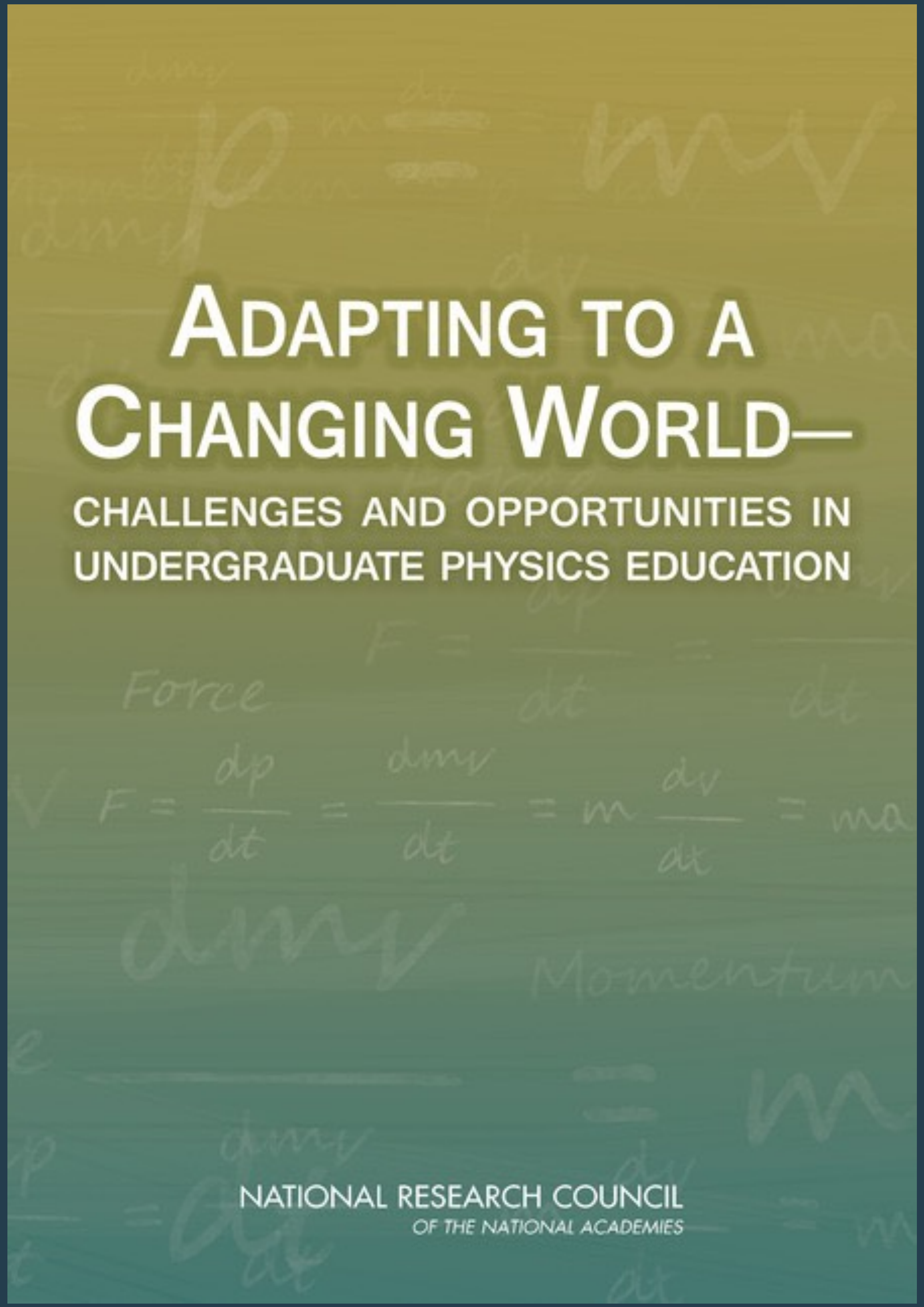
Physics Education Research studies:

- student learning and engagement



Physics Education Research studies:

- student learning and engagement
- pedagogical and curricular impacts



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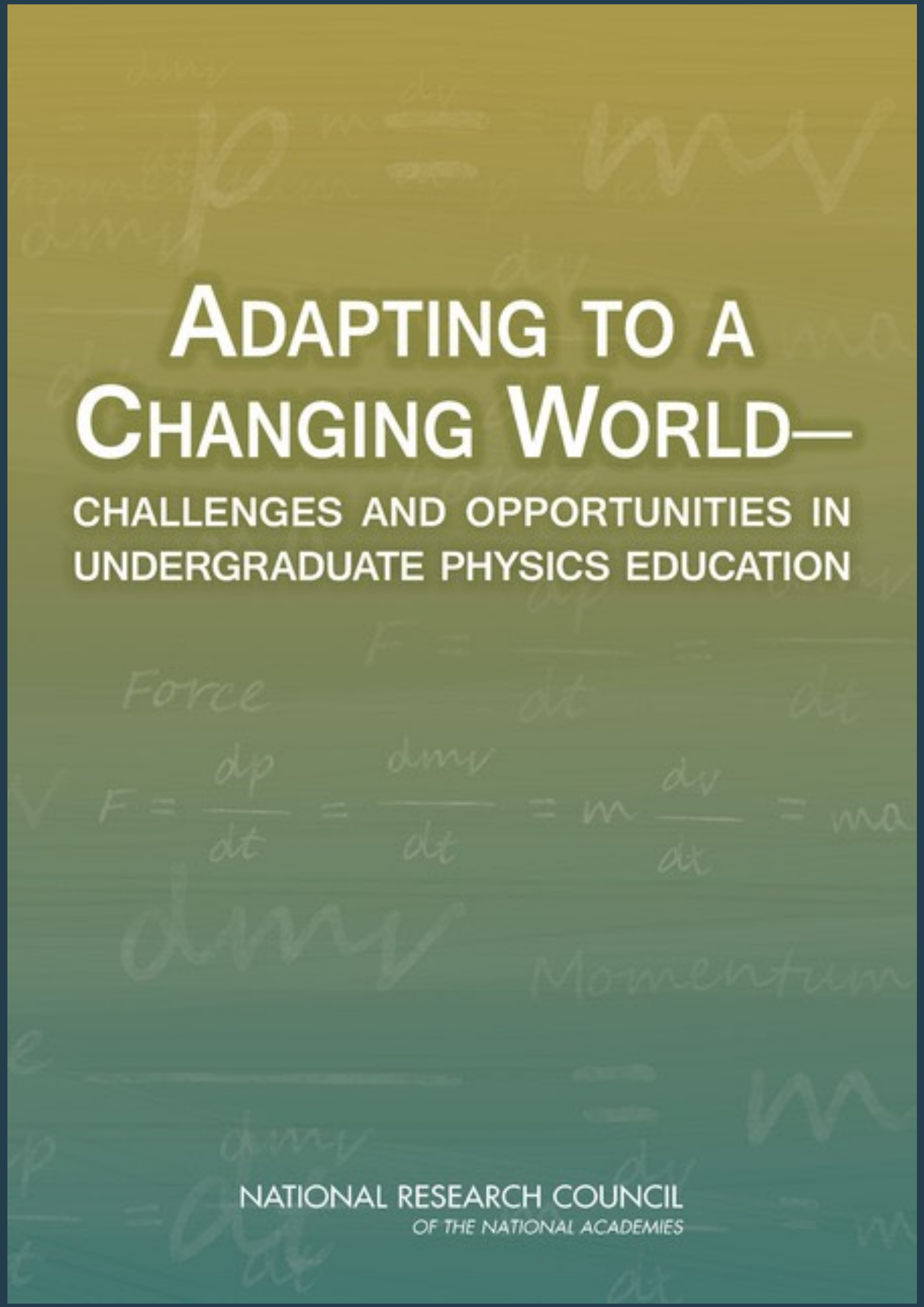
- recruitment and retention of students



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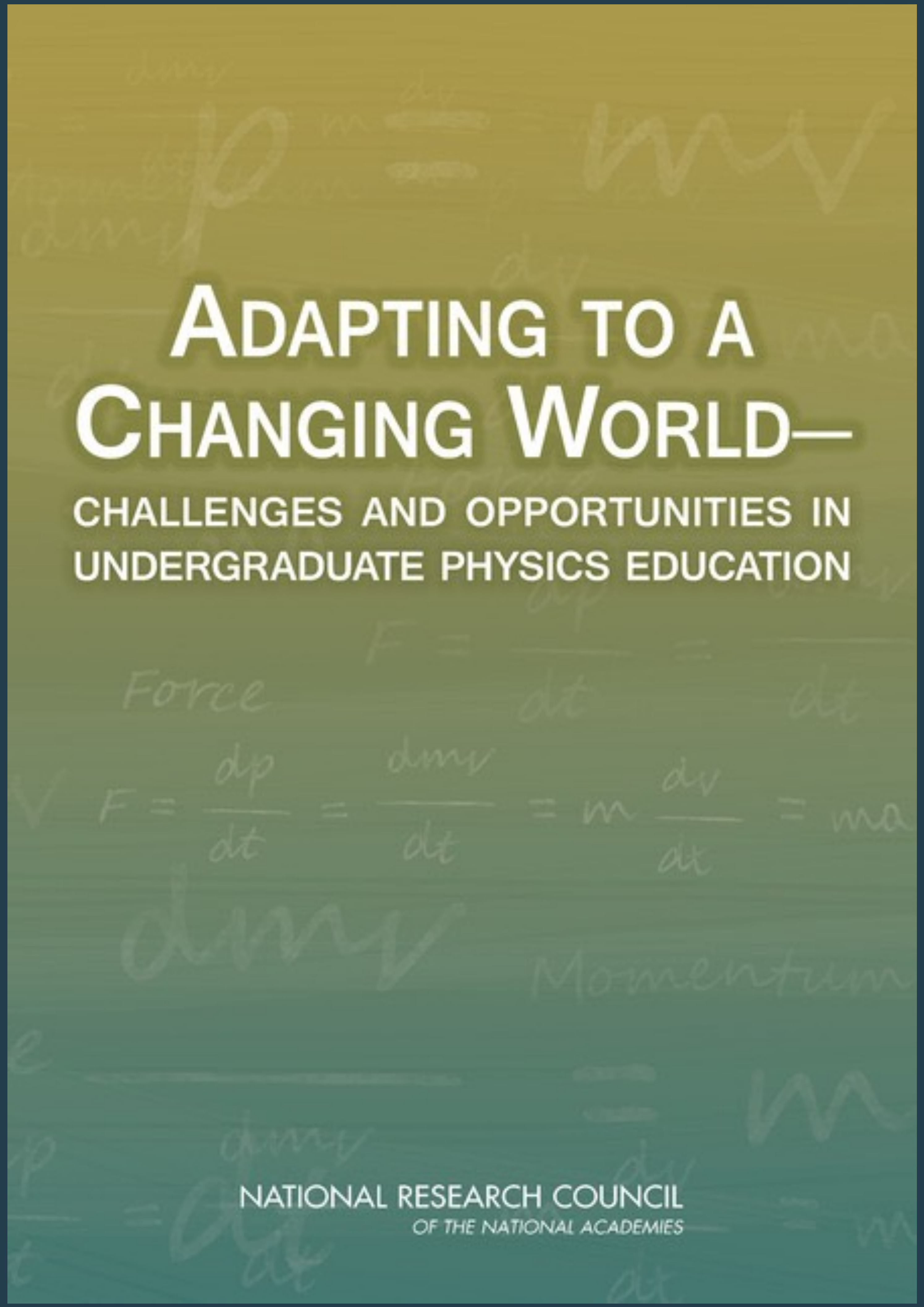

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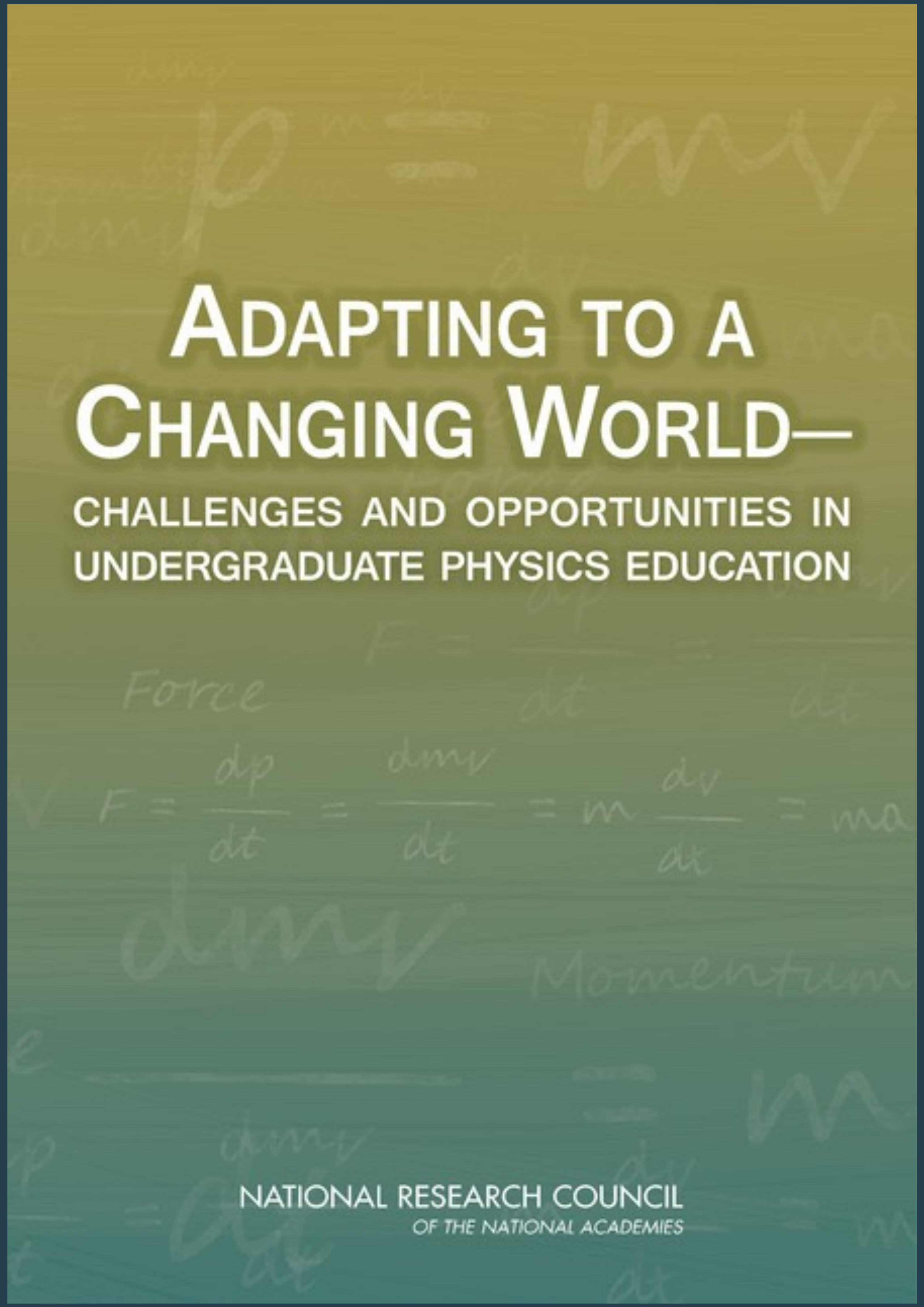

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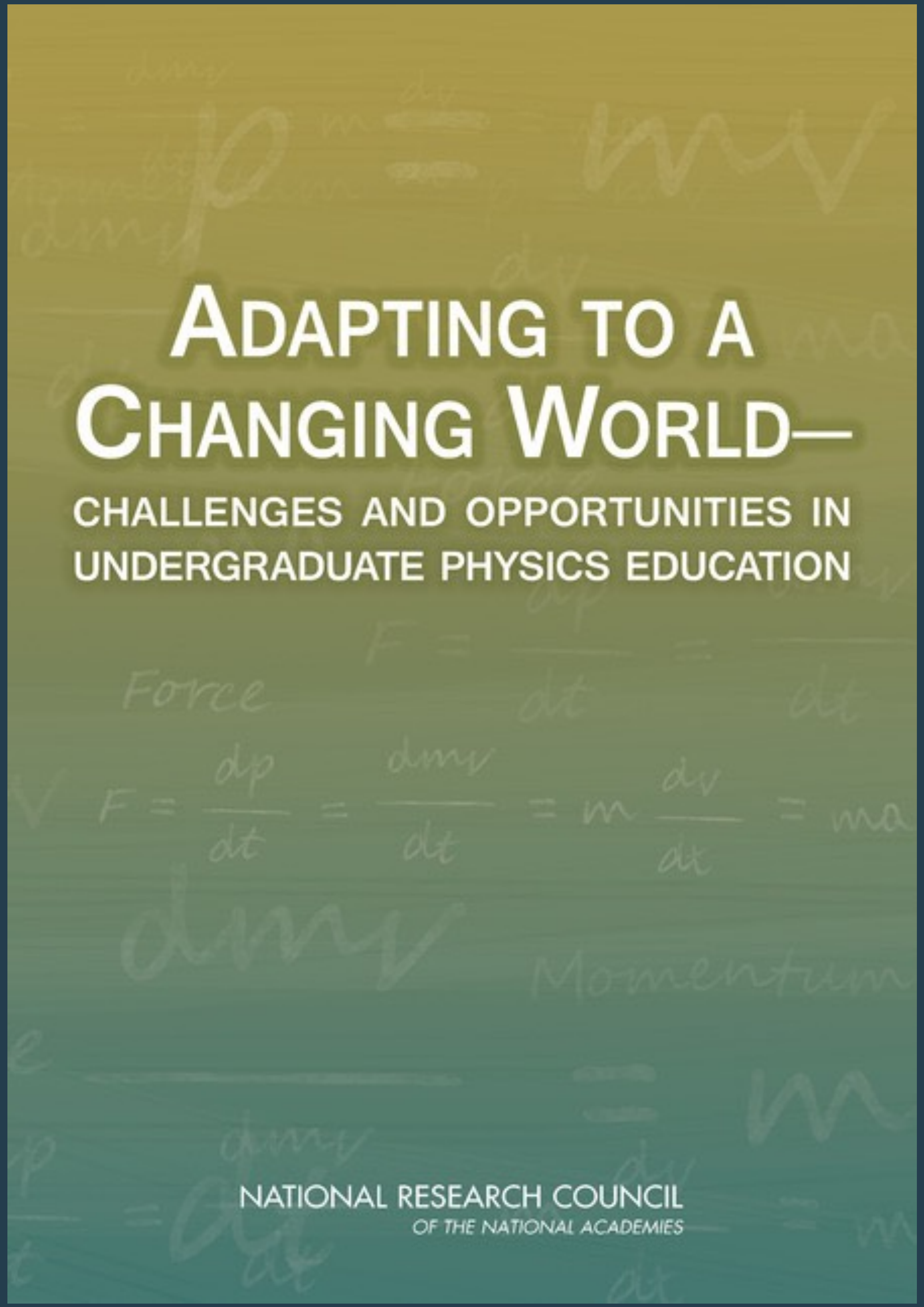

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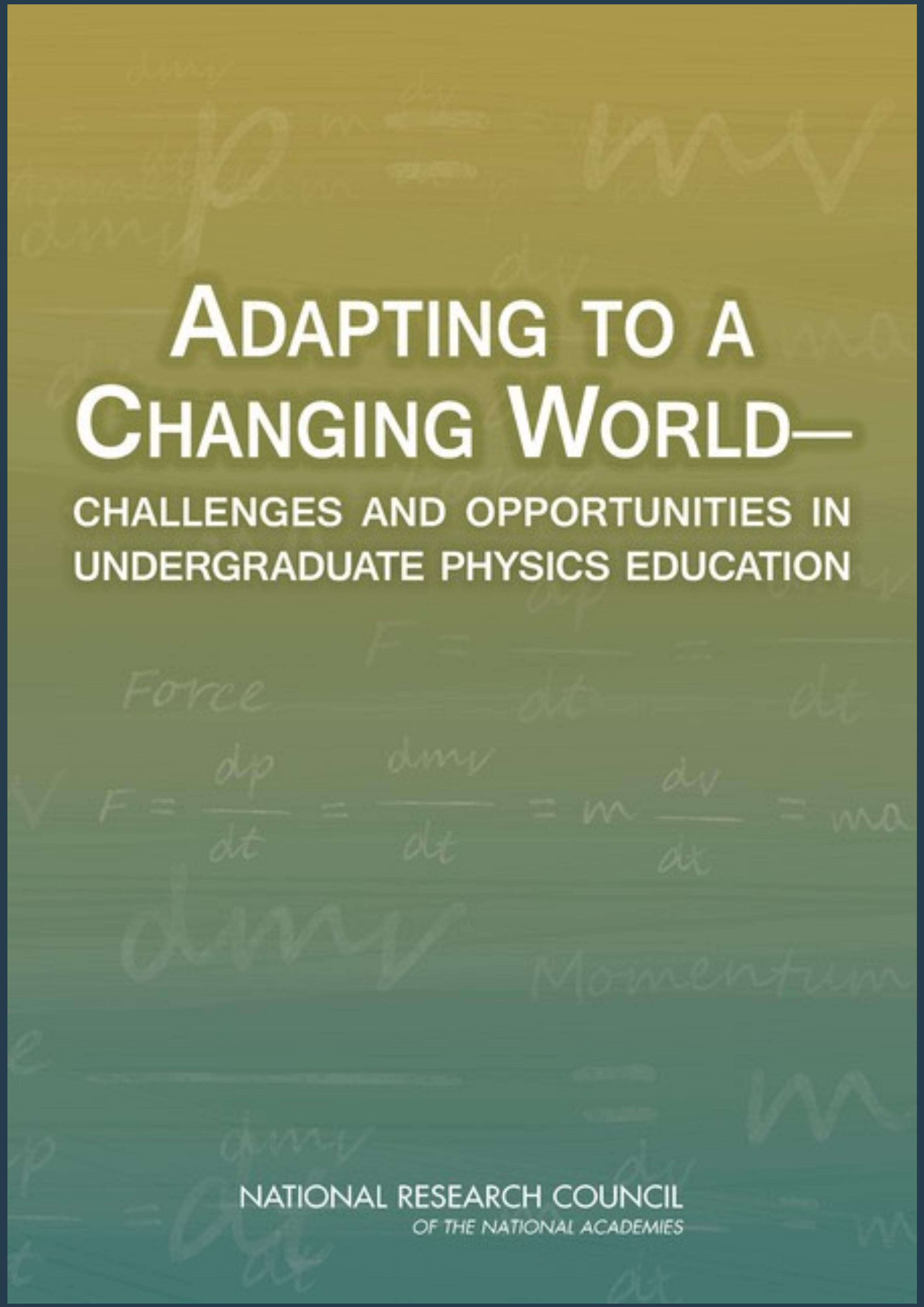
- national landscapes surrounding physics



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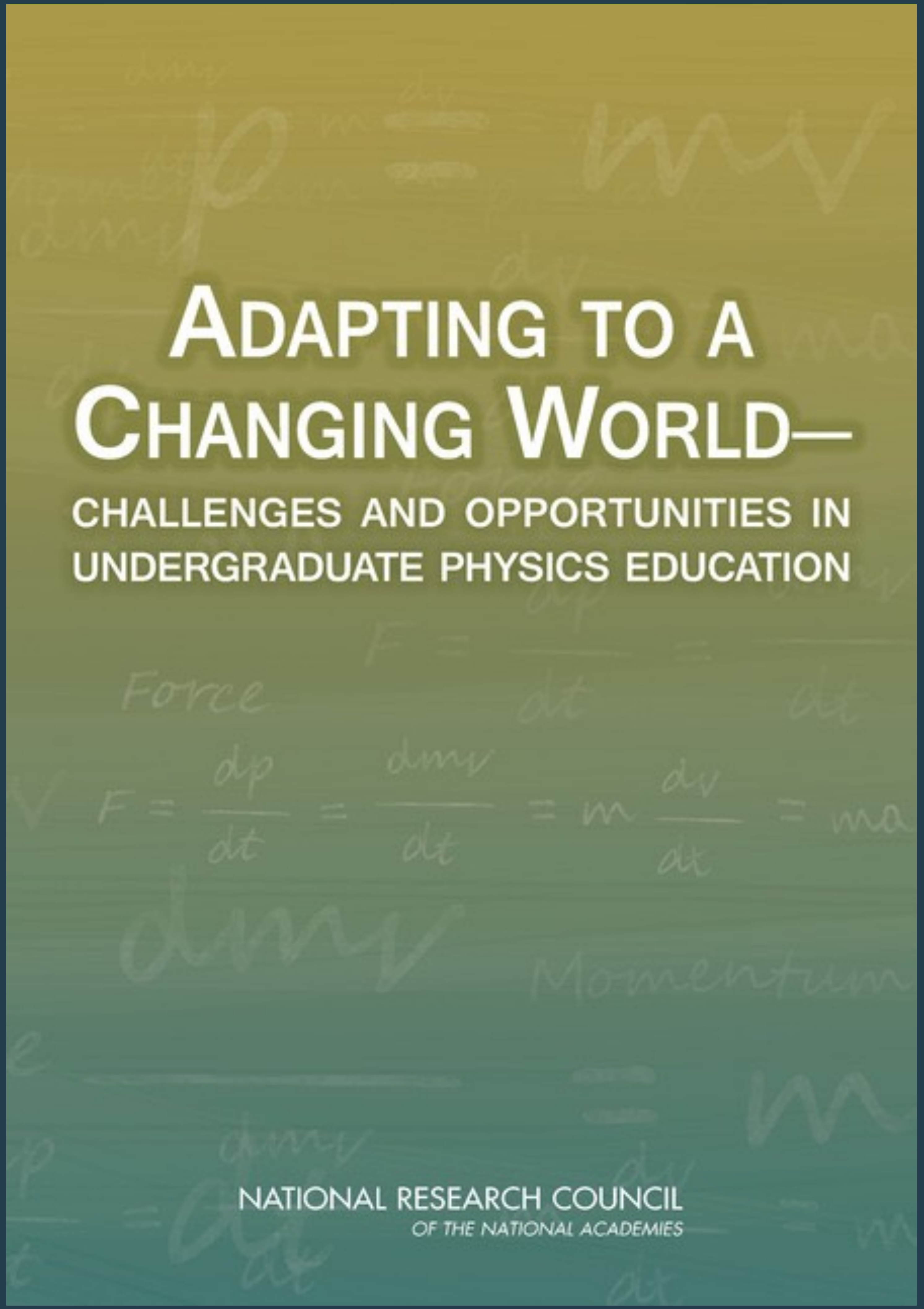
Theory, Experiment, and Applied



Physics Education Research in the US & MX

MICHIGAN STATE
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** - wide breadth of DBER; large PER group

STEM in Michigan

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> 75% of MSU students are Michiganders.

Michigan State Physics and Astronomy

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

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

Physics and Astronomy

NSCL/FRIB

Challenges and Opportunities in Physics Education

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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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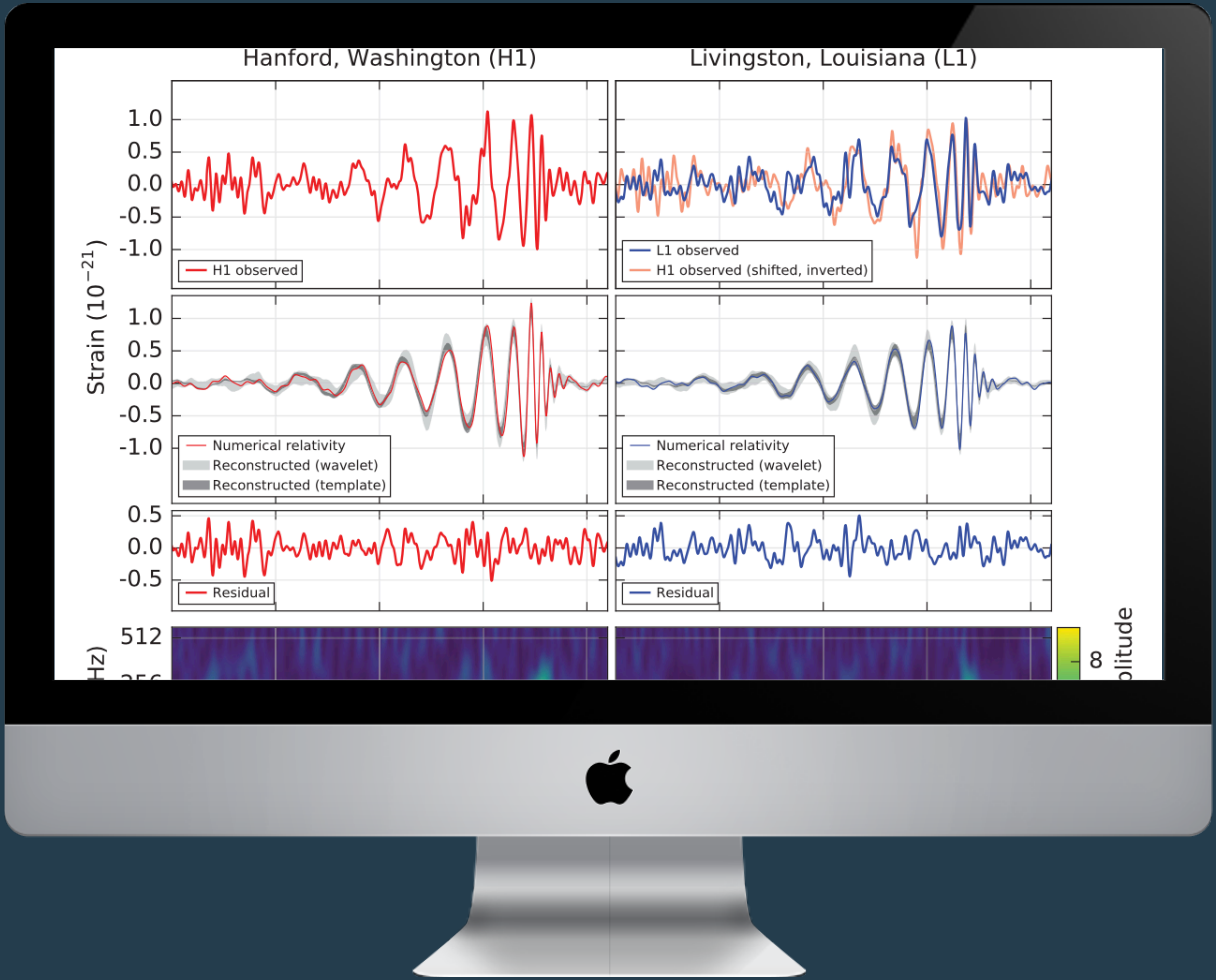
Physics is changing; new tools, new techniques

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



Abbott, Benjamin P., et al. PRL 116.6 (2016): 061102.

Computing in physics is:

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

Implementing and assessing computational modeling in introductory mechanics

Marcos D. Caballero,[1,*] Matthew A. Kohlmyer,[2,†] and Michael F. Schatz[1,‡]

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

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

(Received 26 July 2011; published 14 August 2012)

```
from __future__ import division
from visual import *

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

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

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

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

while t < tf:

    r = craft.pos-Earth.pos
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    pcraft = pcraft+Fgrav*deltat
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print 'Craft final position: ', craft.pos, 'meters.'
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Initial Conditions

Force Calculation

Newton's Second Law

Position Update

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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

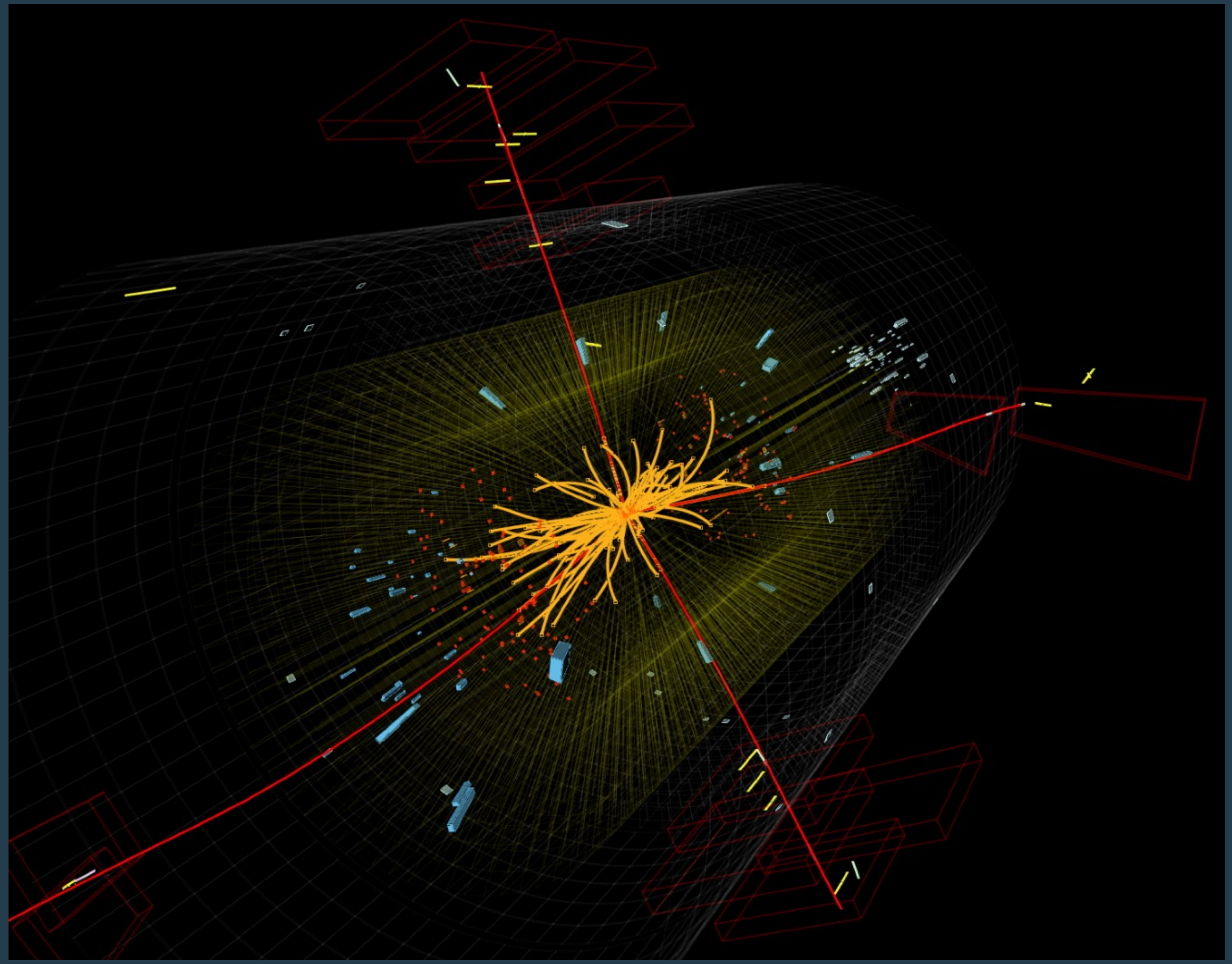
THE LEDE BLOG
What in the World Is a Higgs Boson?
JULY 4, 2012

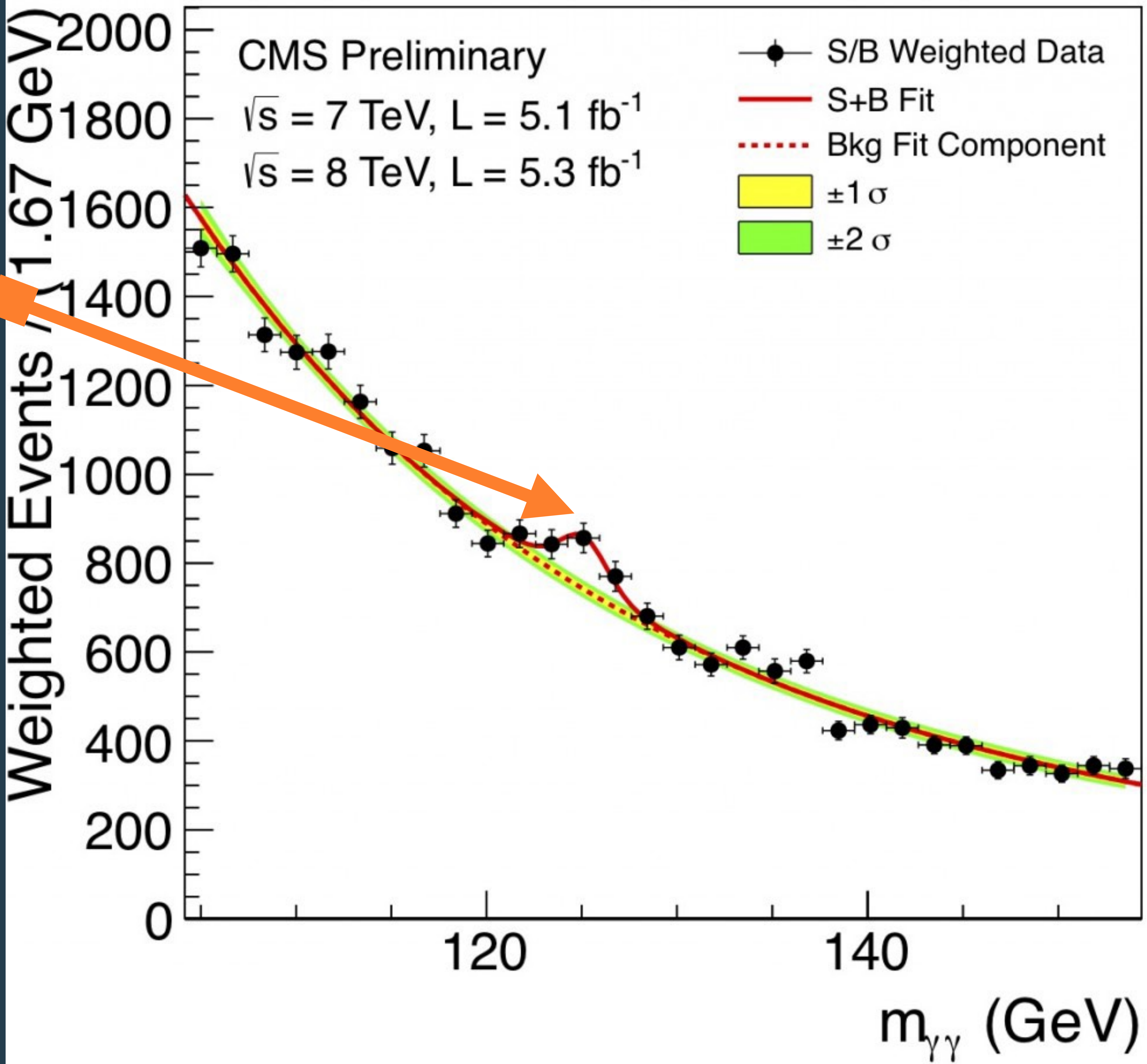
Opinion | Op-Ed Contributor
Why the Higgs Boson Matters JULY 13, 2012

RECENT COMMENTS

Robert L. Oldershaw July 5, 2012

Higgs detected!



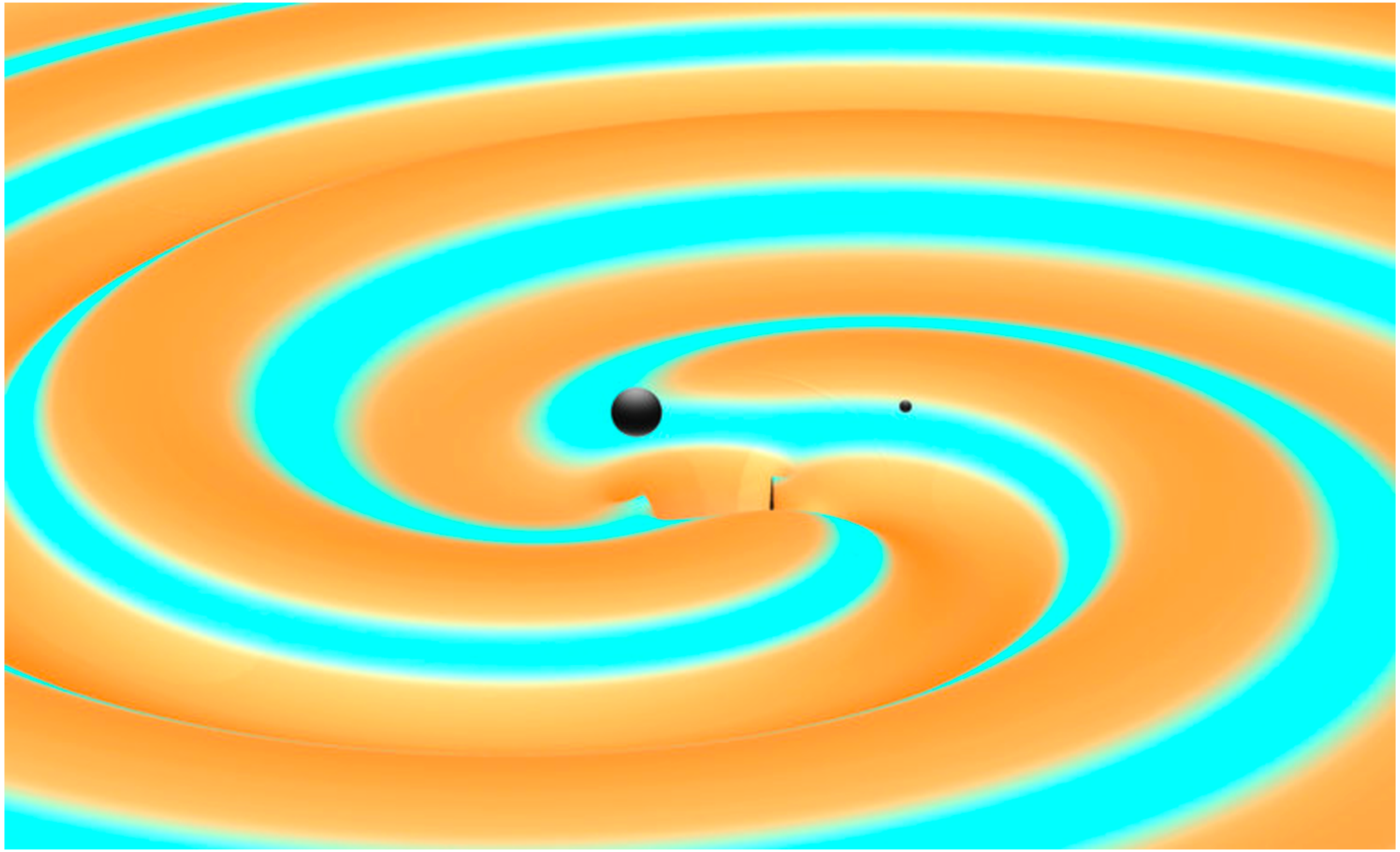


Aad, Georges, et al. Physics Letters B 716.1 (2012): 1-29.

SCIENCE

Scientists Hear a Second Chirp From Colliding Black Holes

By **DENNIS OVERBYE** JUNE 15, 2016

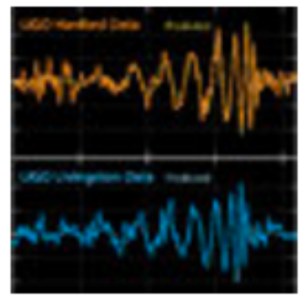


A depiction of two black holes just moments before they collided and merged with each other, releasing

RELATED COVERAGE

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

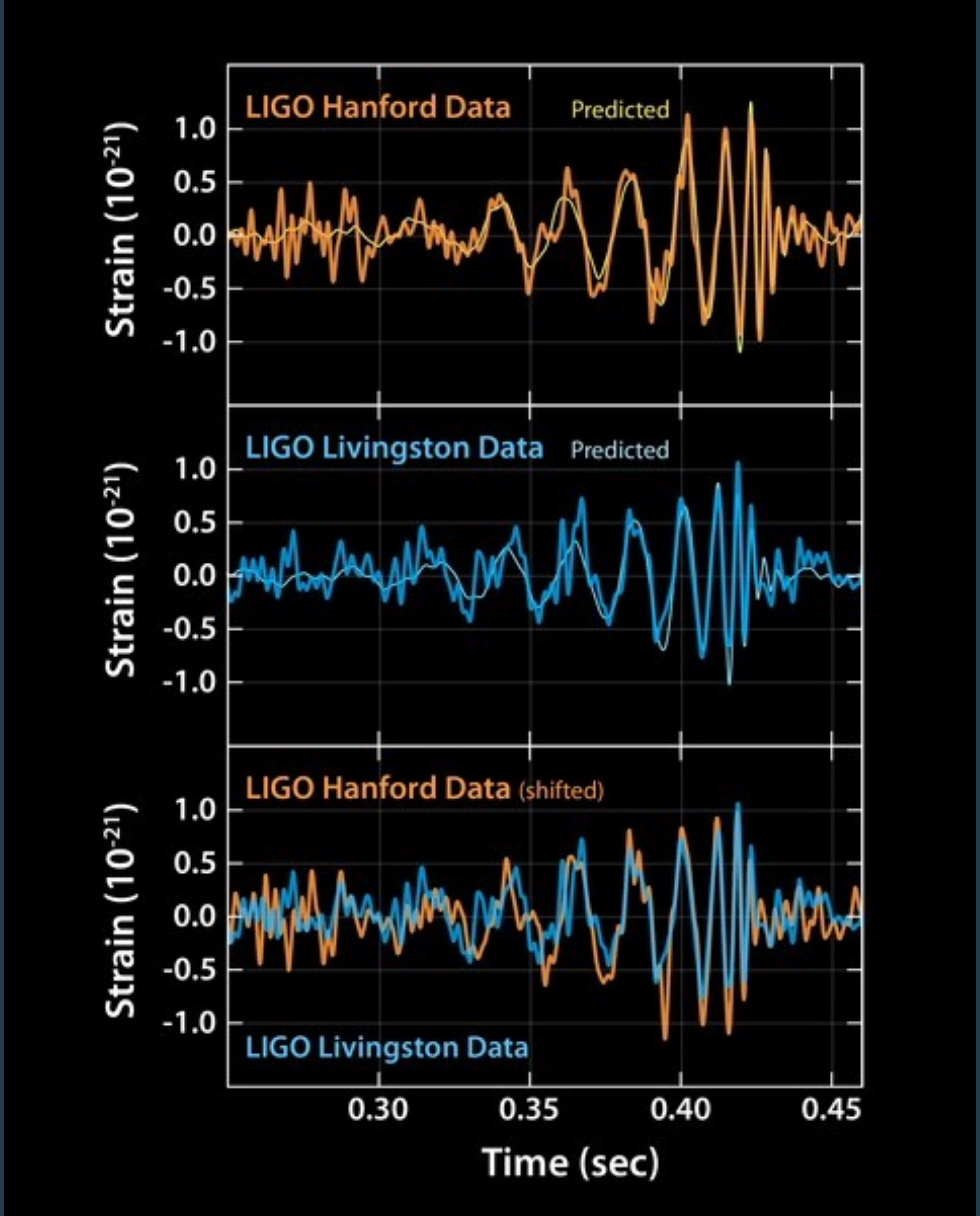
OUT THERE
Gravitational Waves Detected, Confirming Einstein's Theory FEB. 11, 2016



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

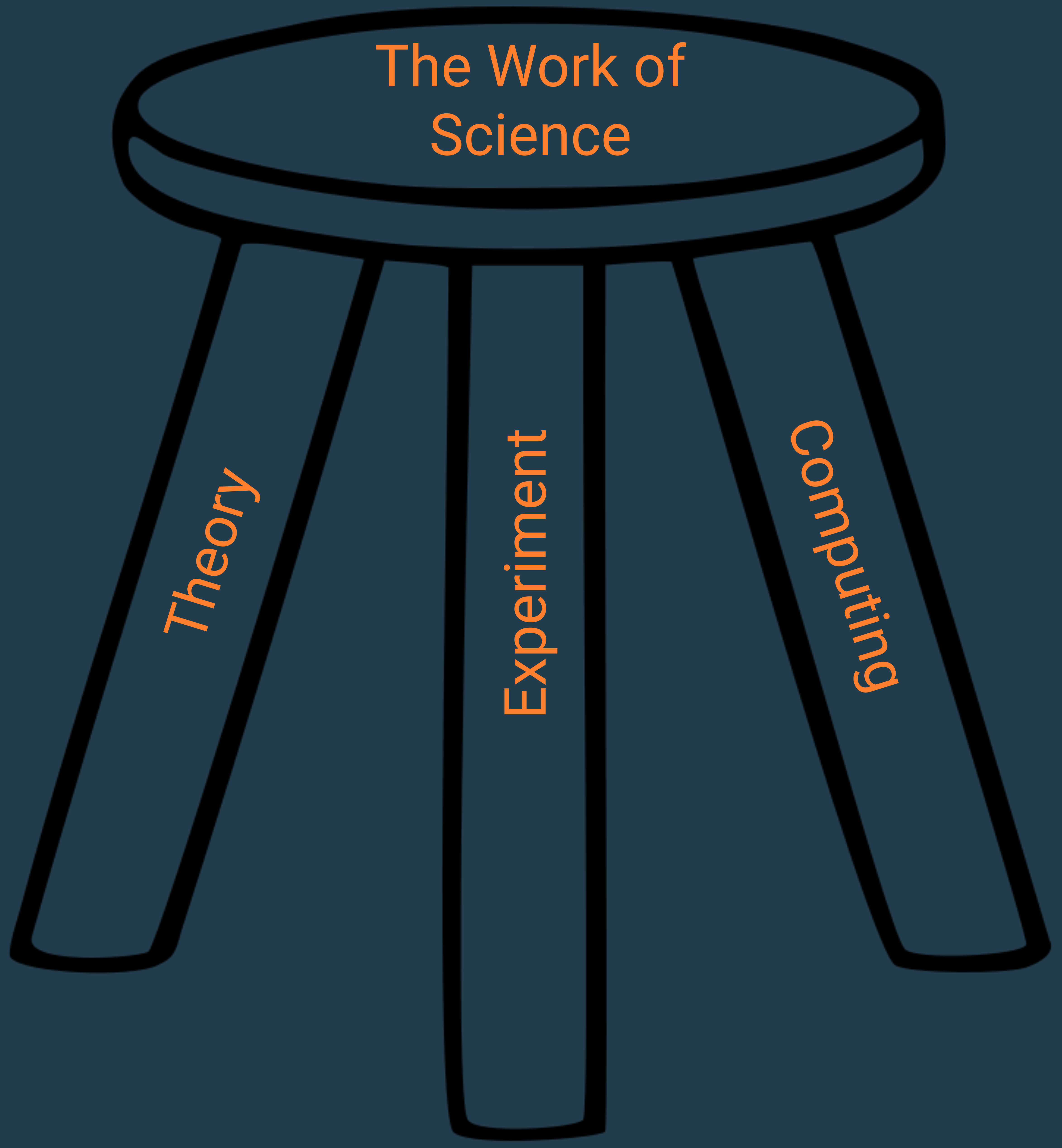
No Escape From Black Holes? Stephen Hawking Points to a Possible Exit JUNE 6, 2016

Black hole Merger Ringdown



Abbott, Benjamin P., et al. PRL 116.6 (2016): 061102.

Computing is how science is done.



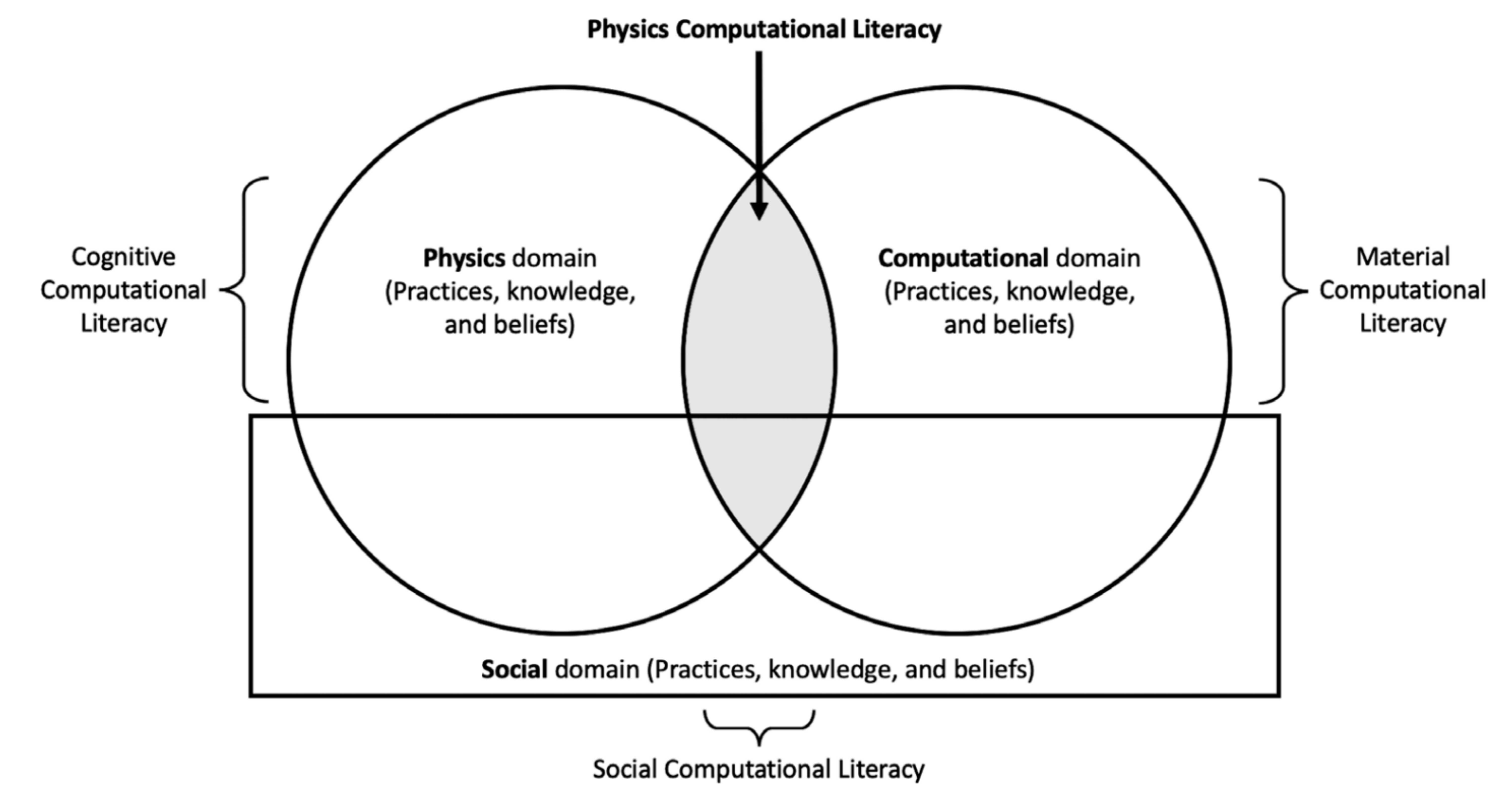
PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **15,** 020152 (2019)

Editors' Suggestion

Physics computational literacy: An exploratory case study using computational essays

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

[1]*Center for Computing in Science Education, University of Oslo, 0316 Oslo, Norway*
[2]*Department of Mathematics, Oregon State University, Corvallis, 97331 Oregon, USA*
[3]*Department of Physics and Astronomy & CREATE for STEM Institute, Michigan State University, East Lansing, 48824 Michigan, USA*



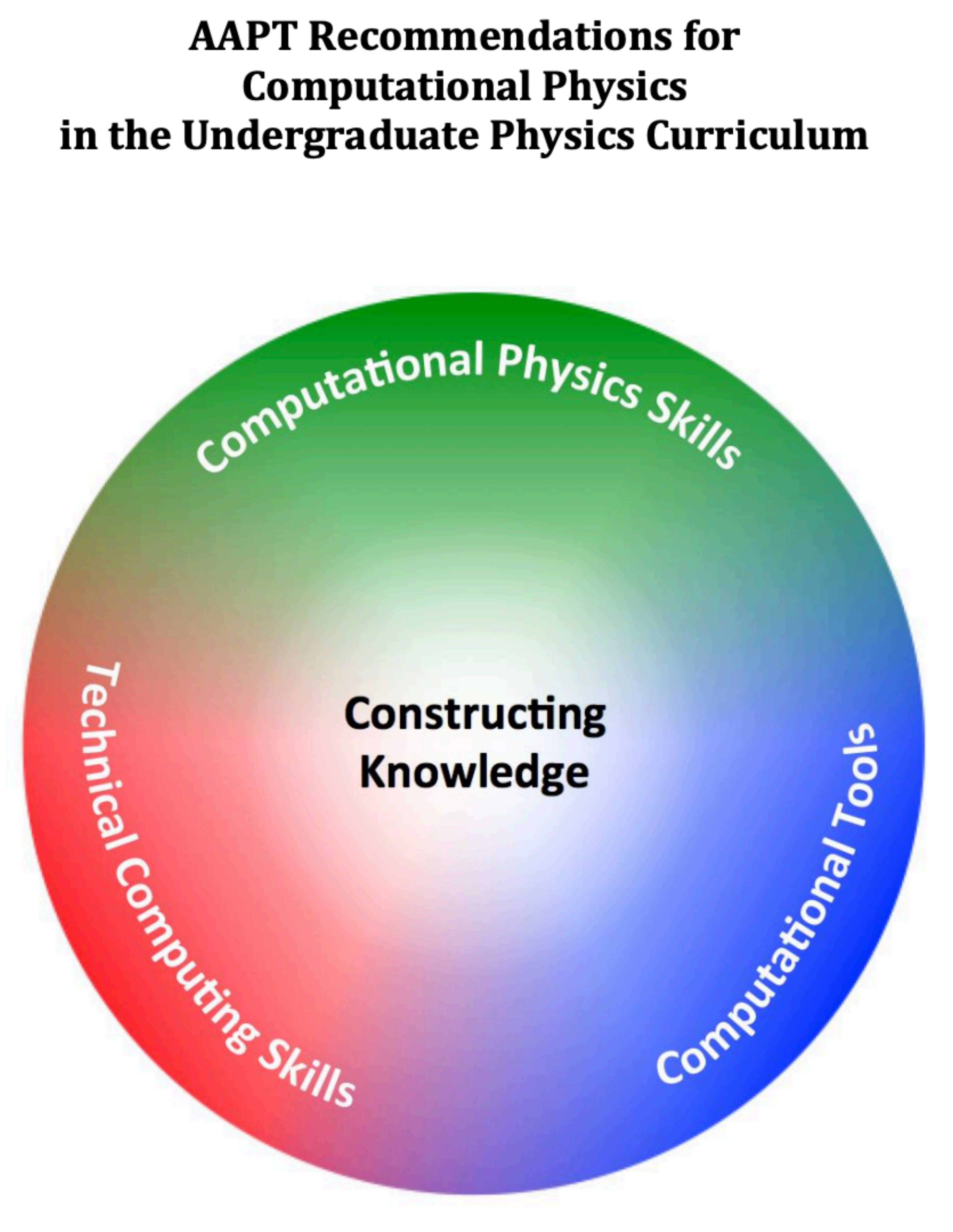
The Research Council of Norway

NSF

Computational Literacy involves cognitive, material, and social literacies

Overlapping practices, knowledge, and beliefs

Requires further R&D



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

What should students know and be able to do with computing in physics?

Computational Physics Skills
Translate a model into code
Subdivide a model into a set of manageable computational tasks

Technical Computing Skills
Process data
Represent data visually

Computational Tools
Spreadsheets
MATLAB, Mathematica
Python, C, Fortran

2019 K12 Computing in Science Visioning Report

Integration of computation must **emphasize values native to the discipline in which computing is being integrated** and demonstrate a clear alignment with existing standards

Educational leaders need to **recognize that relevant computing content differs across the sciences**, ruling out a "one size fits all" notion of integrating computing in science.

Diversity, Equity and Inclusion must be built into all efforts to integrate computation with science education.

K-12 teachers need **sustained professional development and support** to learn and teach science while leveraging computing.

Research is needed to understand and assess computational integration. There are **relatively few theories of how computation impacts science learning.** There are also **very few useful assessments** for charting progress.

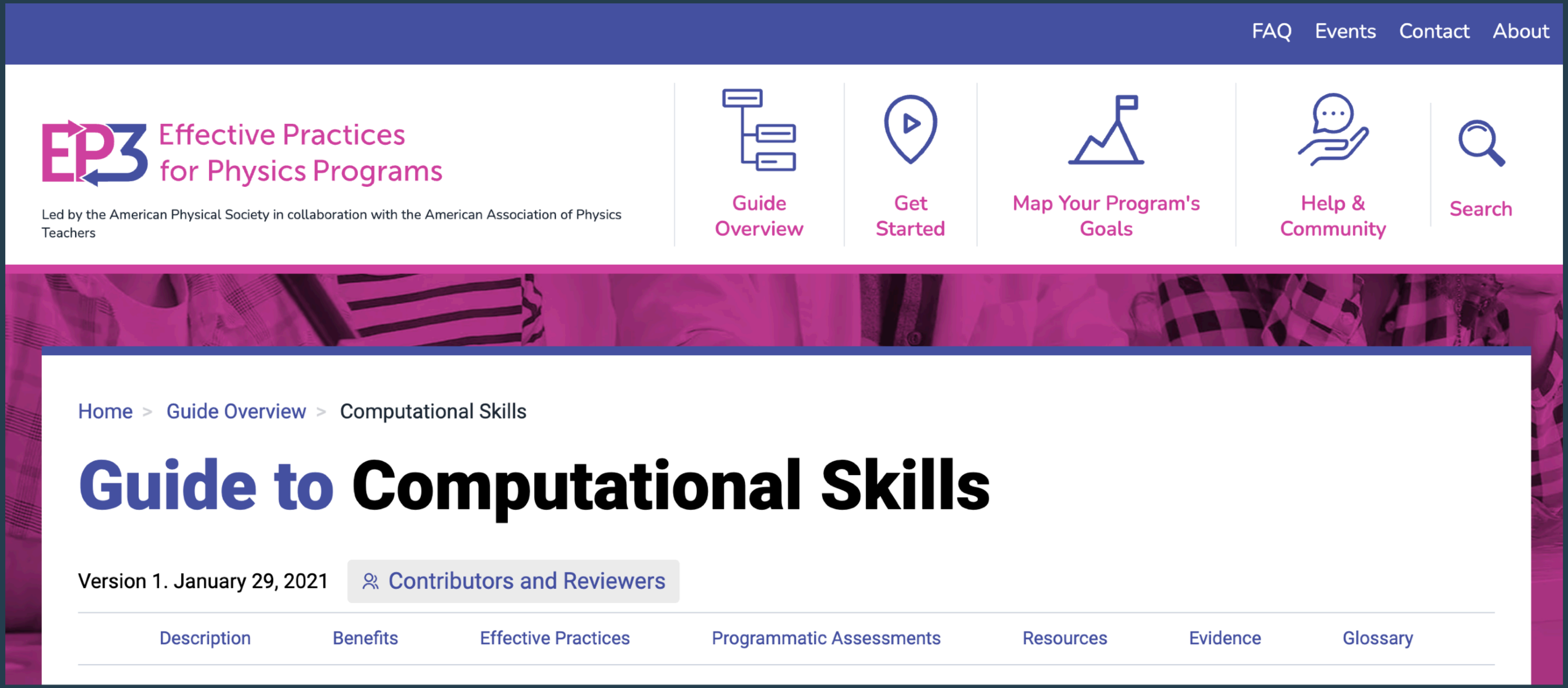
https://www.aapt.org/Resources/upload/Computational_Thinking_Conference_Report_Final_200212.pdf

2021 PICUP Virtual Capstone Report

"Directions for the next decade"

- Better defined learning goals for computation in each course.
- Development and testing student assessments
- Developing and testing department-wide integration
- Expanding number and diversity of departments and faculty

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



EP3 Guide for Departments

Shared effective practices for physics programs to adopt

Departments should strive to:

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

https://ep3guide.org/

Physics education requires computing education

$\hat{Q}]\rangle + \langle\frac{\partial Q}{\partial t}\rangle$

$|10\rangle = \frac{1}{\sqrt{2}}(\uparrow\downarrow+\downarrow\uparrow)$

$|1\,-1\rangle = \downarrow\downarrow$ triplet

symmetric
lower energy

$|00\rangle = \frac{1}{\sqrt{2}}(\uparrow\downarrow-\downarrow\uparrow)$ singlet, $|s\,m\rangle = \sum_{m_1+m_2=m} C^{s_1 s_2 s}_{m_1 m_2 m}|s_1\, m_1\rangle|s_2\, m_2\rangle$

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

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

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

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

$j=(l+s),($

fine structu

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

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

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

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

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

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

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

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

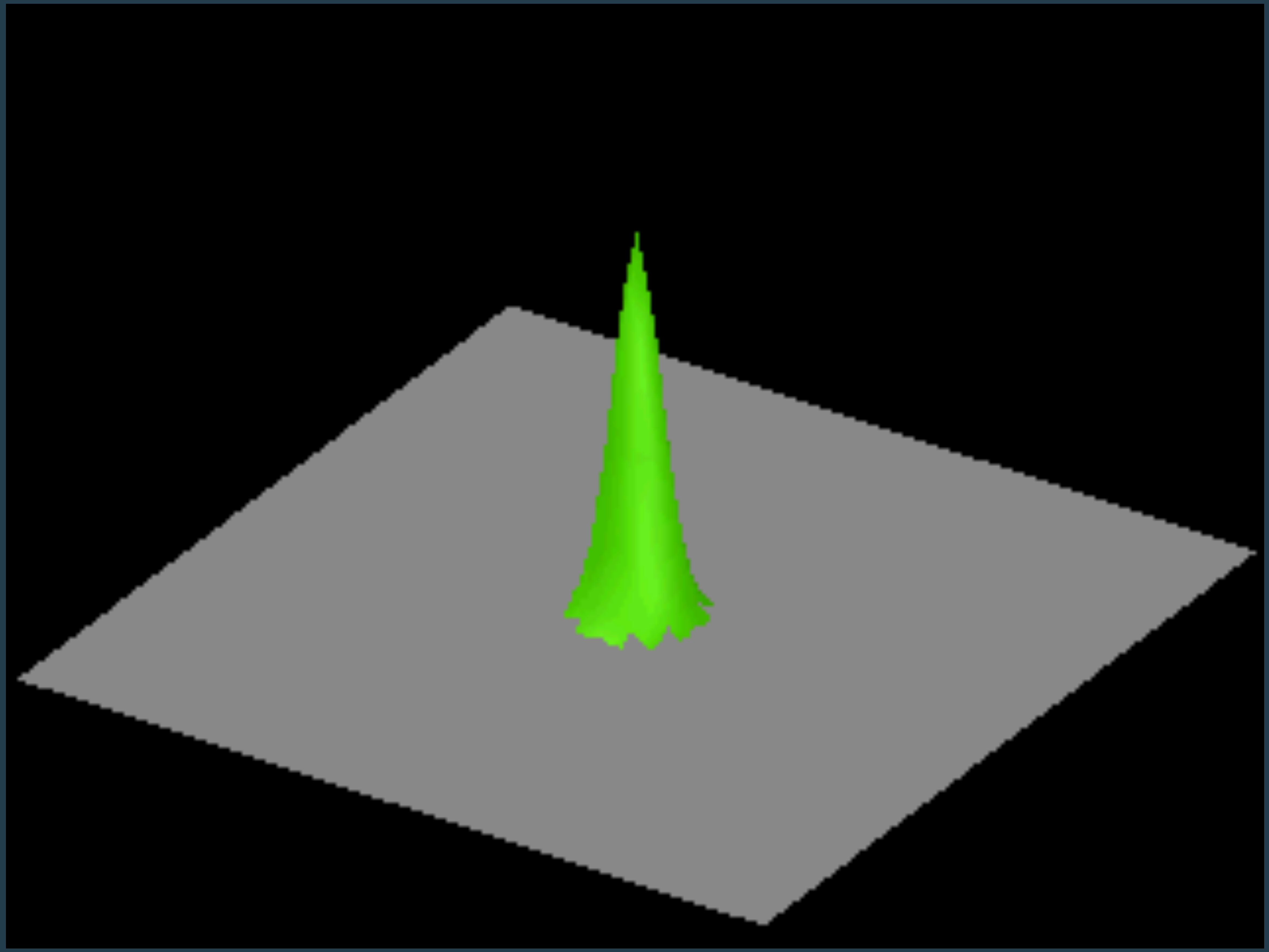
$\cos\theta=\frac{1}{2}(e^{+i\theta}$

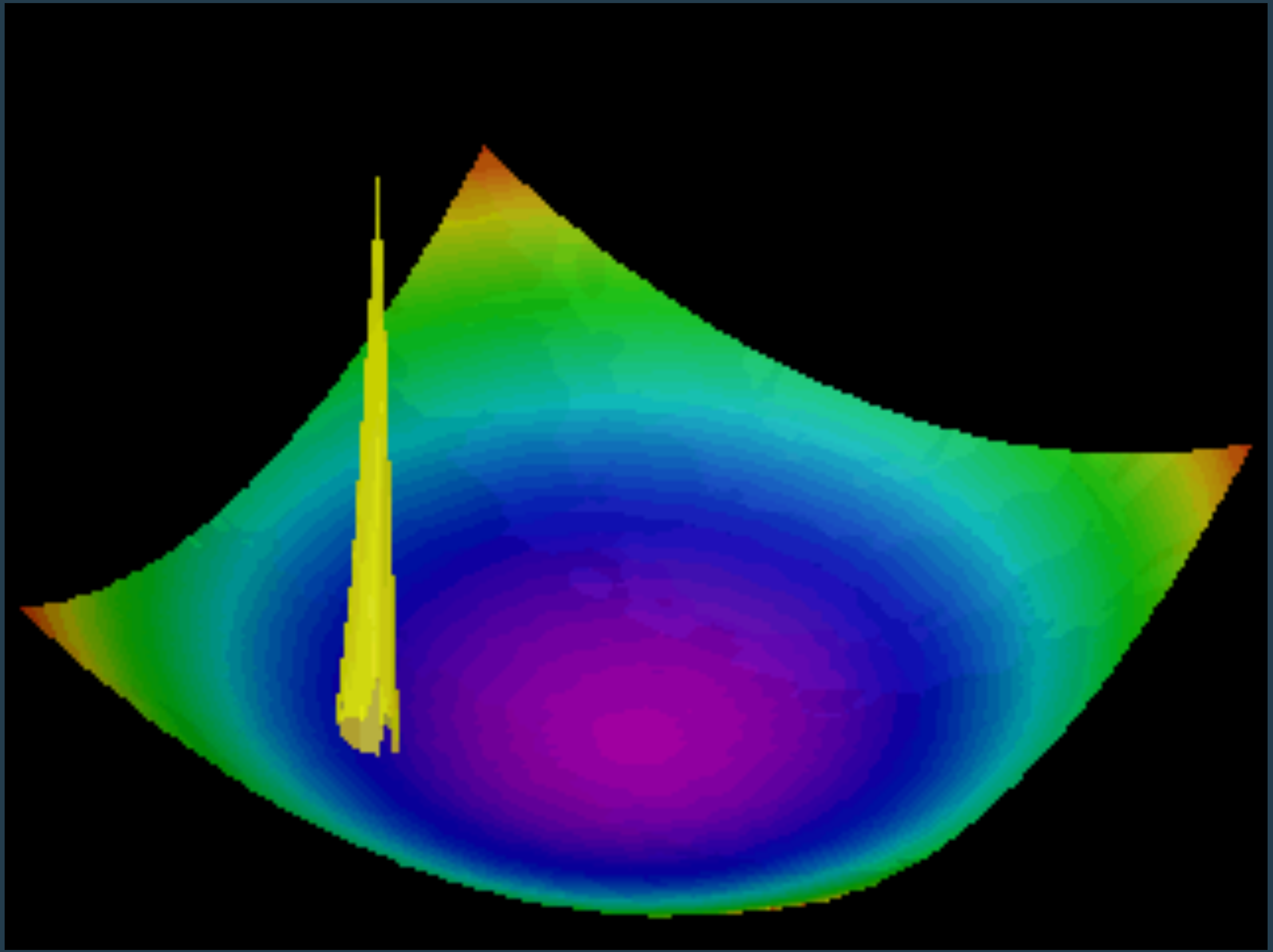
$\sin\theta=\frac{1}{2i}(e^{+i\theta}$

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

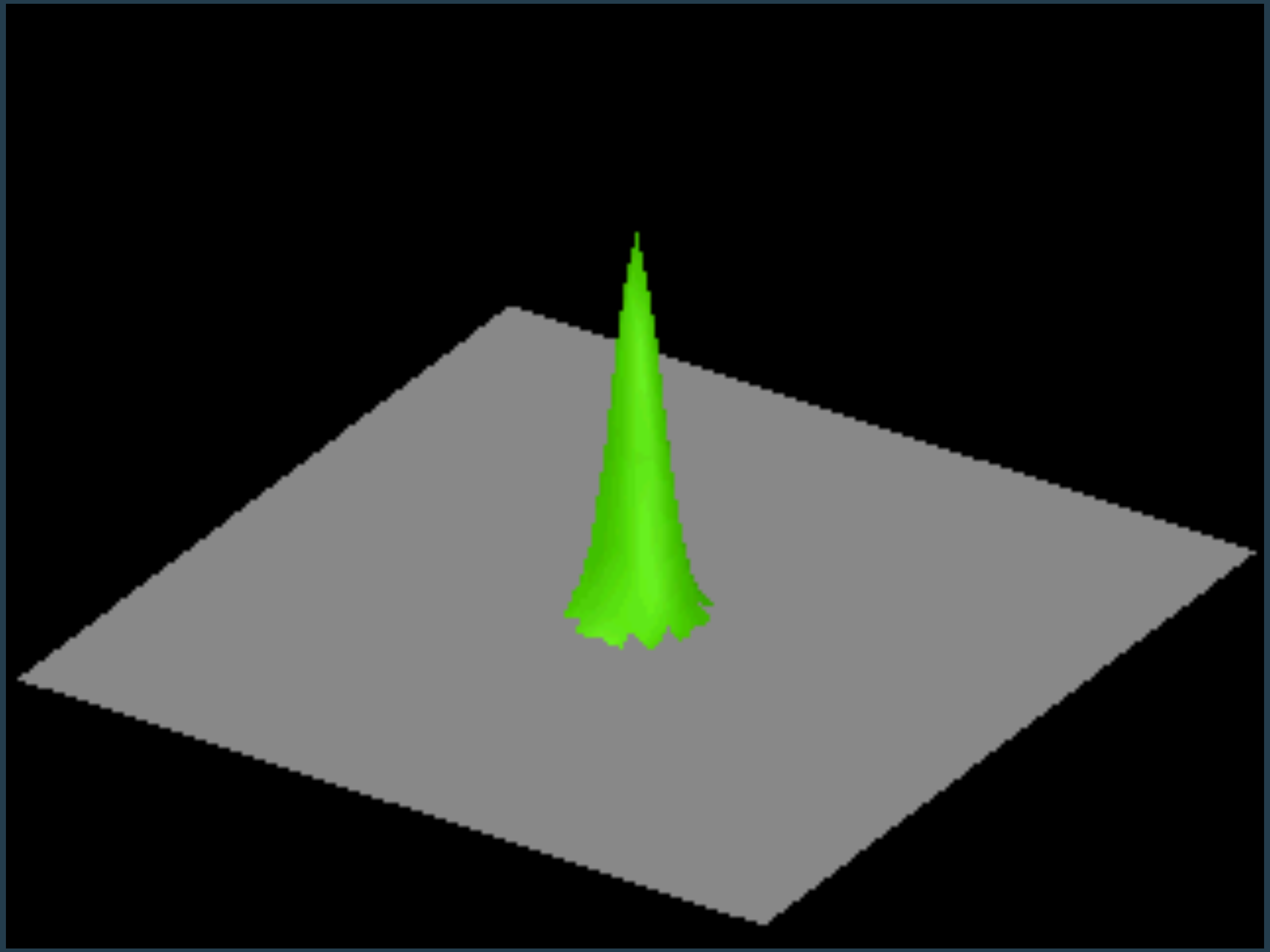
$)$, $E_{n,m_l,m_s}=\frac{-13.6\,eV}{n^2}+\mu_B B_{ext}(m_l+2m_s)$ ← (iii), $E^1_{fs}=\frac{13.6\,eV\alpha^2}{n^3}\left\{\frac{3}{4n}-\left[\frac{l(l+1)-m_lm_s}{l(l+1/2)(l+1)}\right]\right\}$ ← (iv), $E_{tot}(strong)=$ (iii) + (iv)

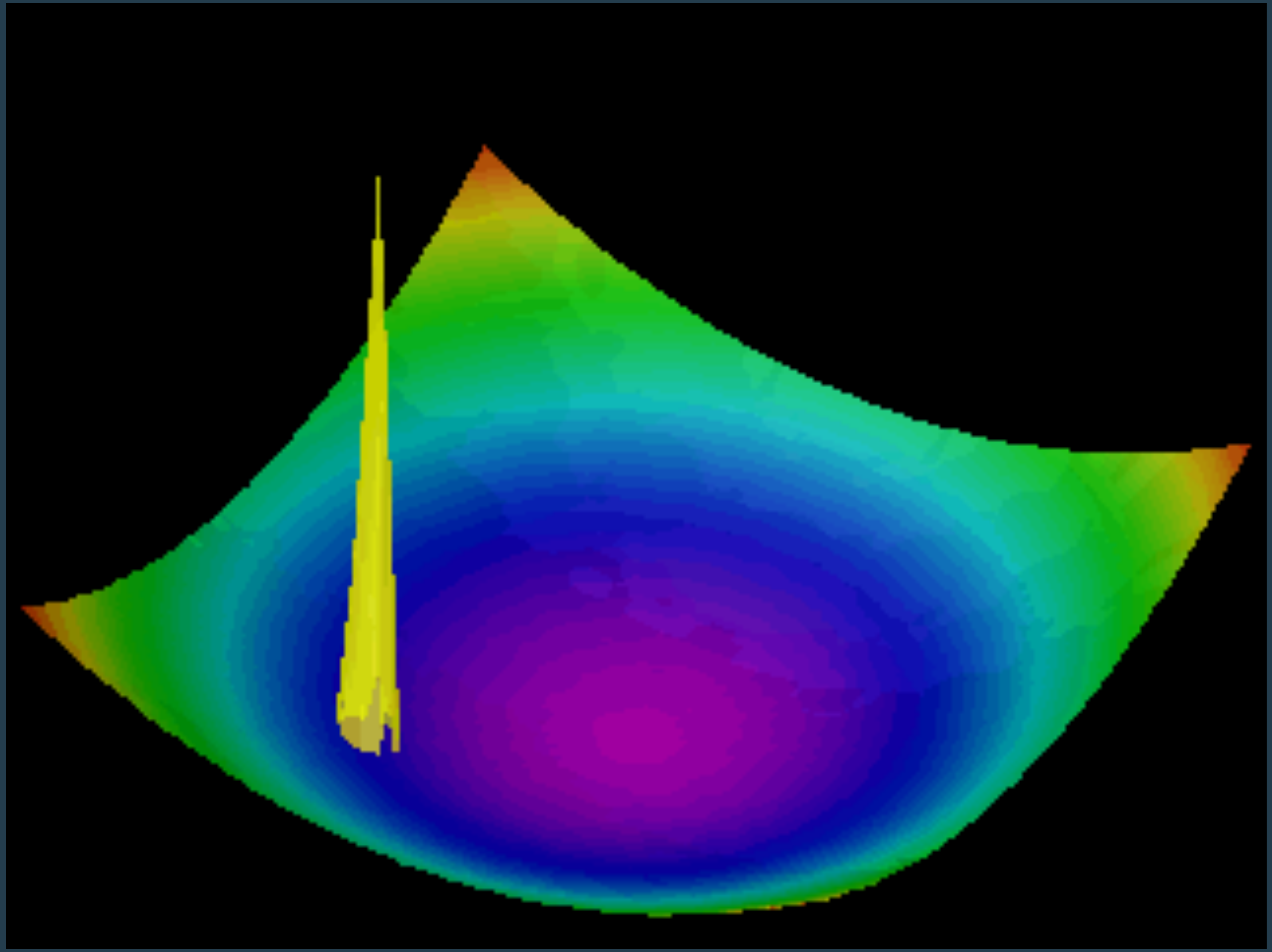
$m_j)$, $H'=H'_Z+H'_{FS}=\frac{e\hbar}{2m}B_{ext}(m_l+2m_s)+\frac{13.6\,eV}{64}\alpha^2\left(3-\frac{8}{j+1/2}\right)$





Michielson and De Raedt, 2012





Michielson and De Raedt, 2012

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

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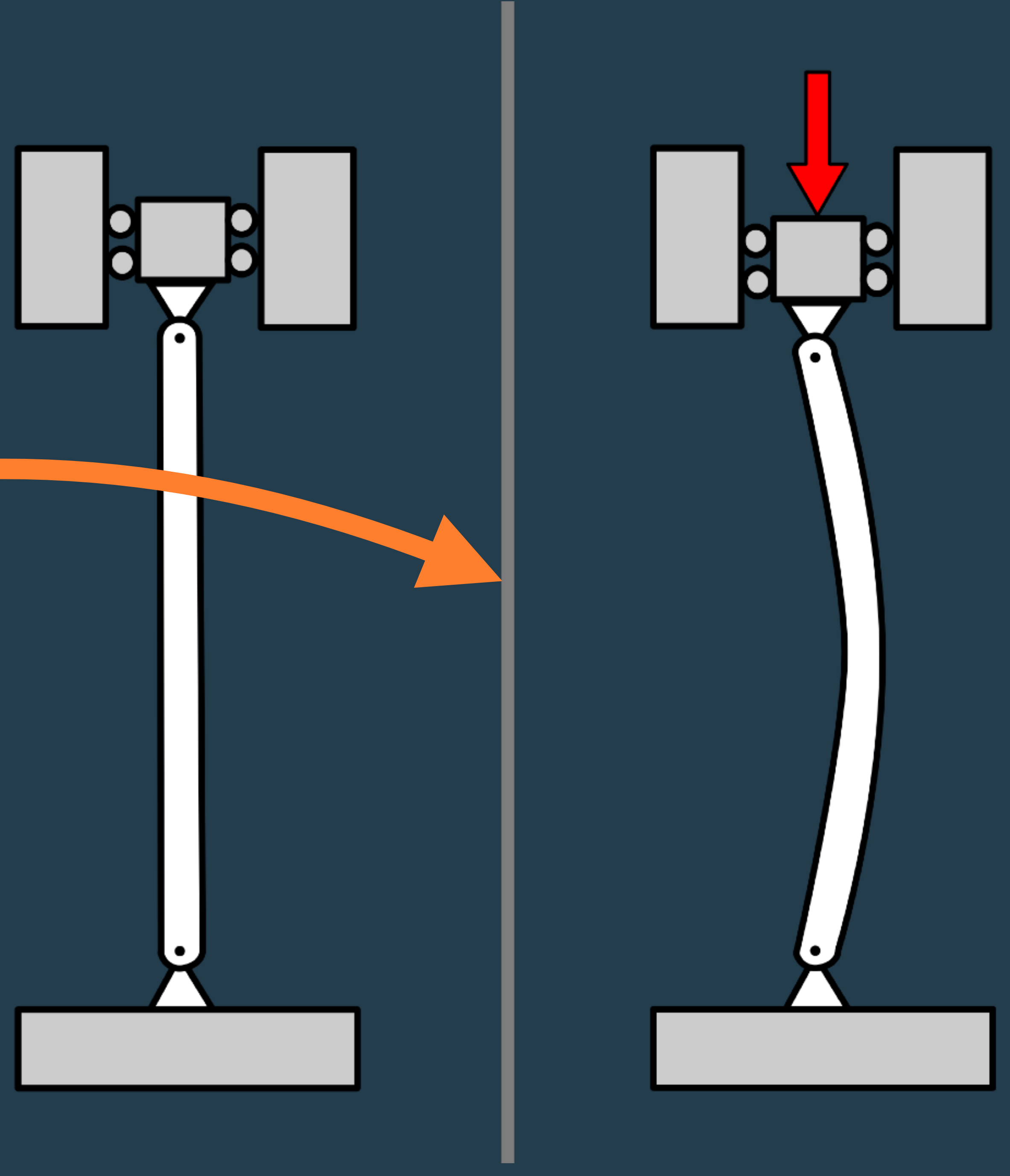

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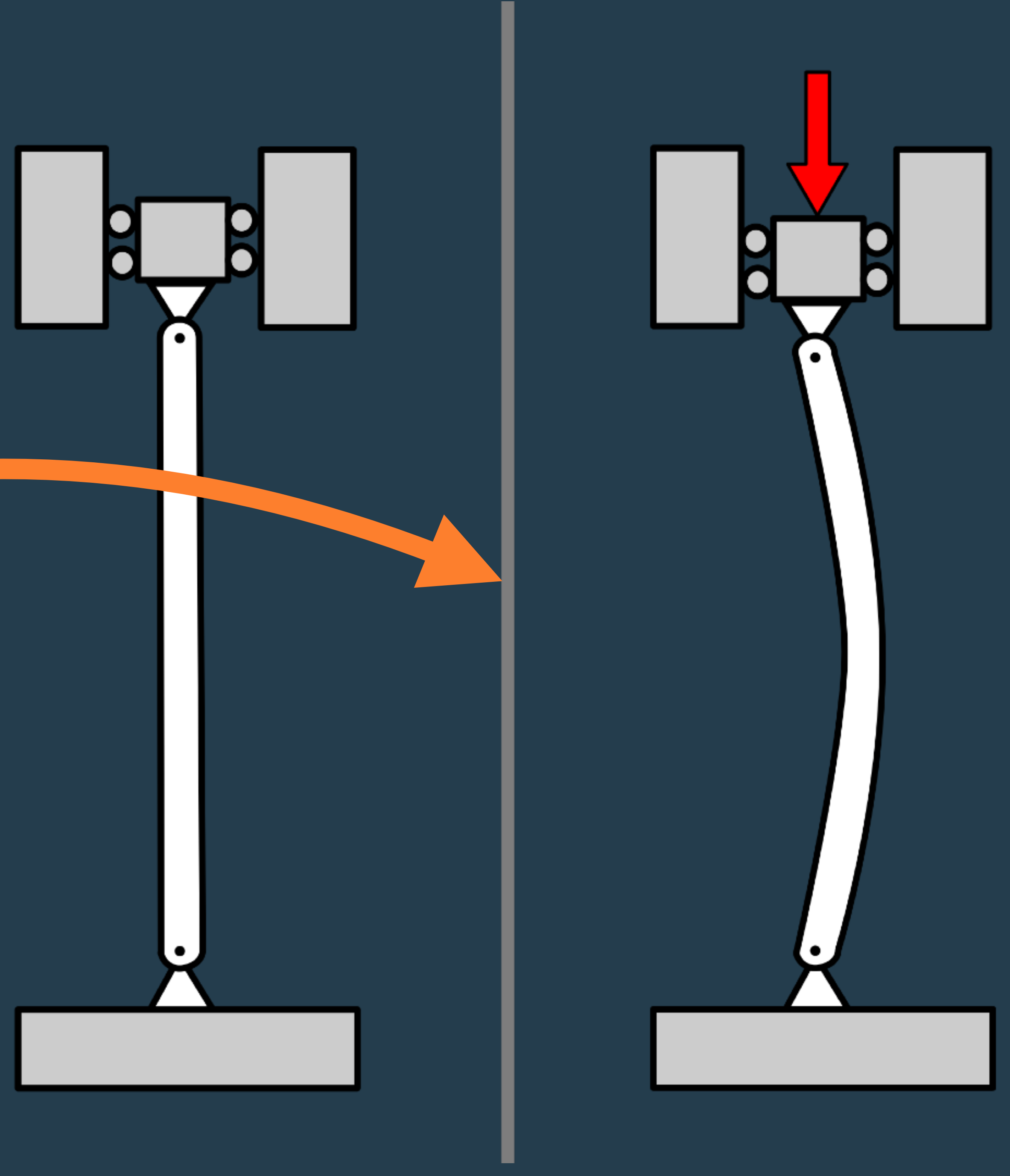

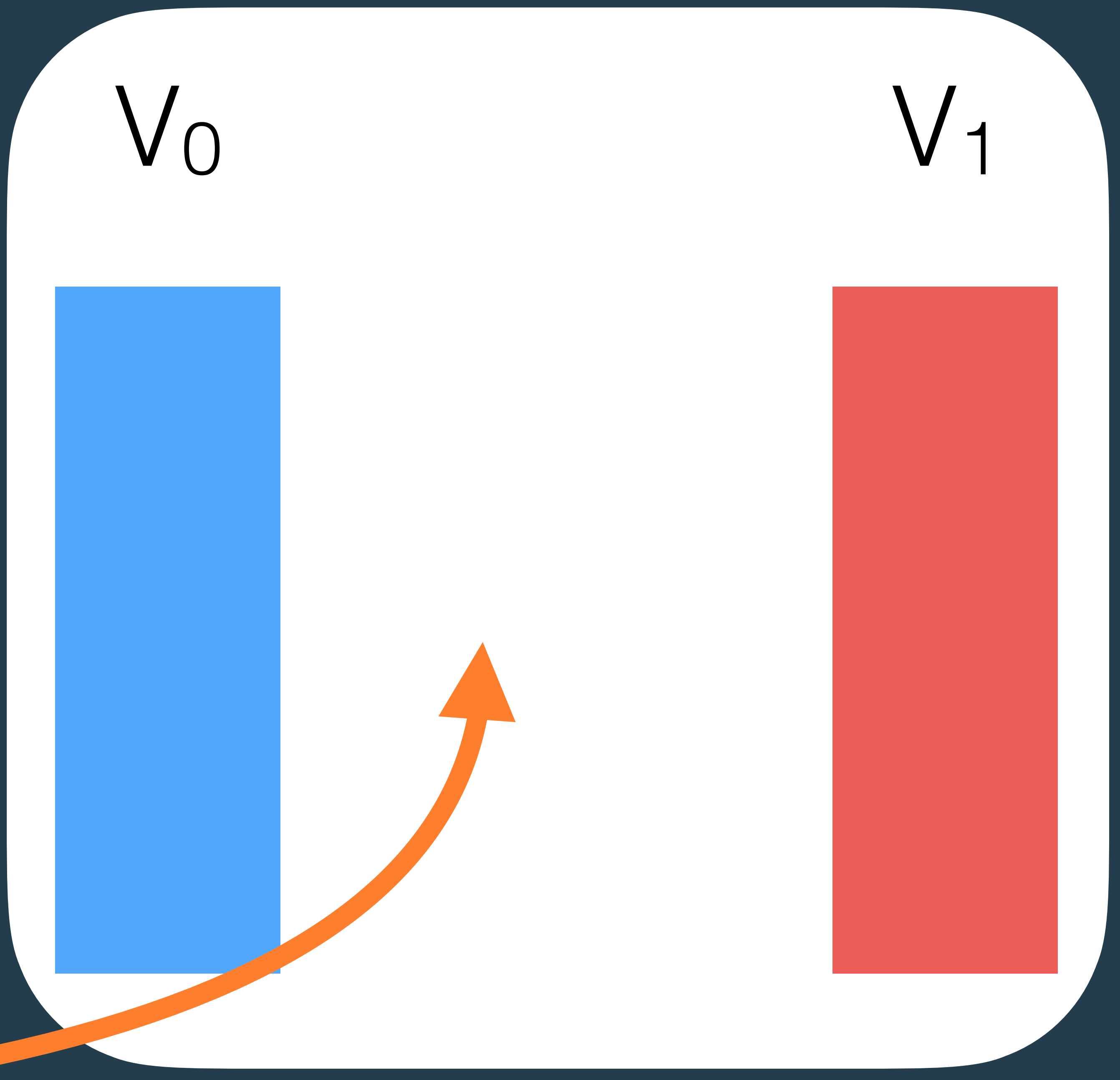

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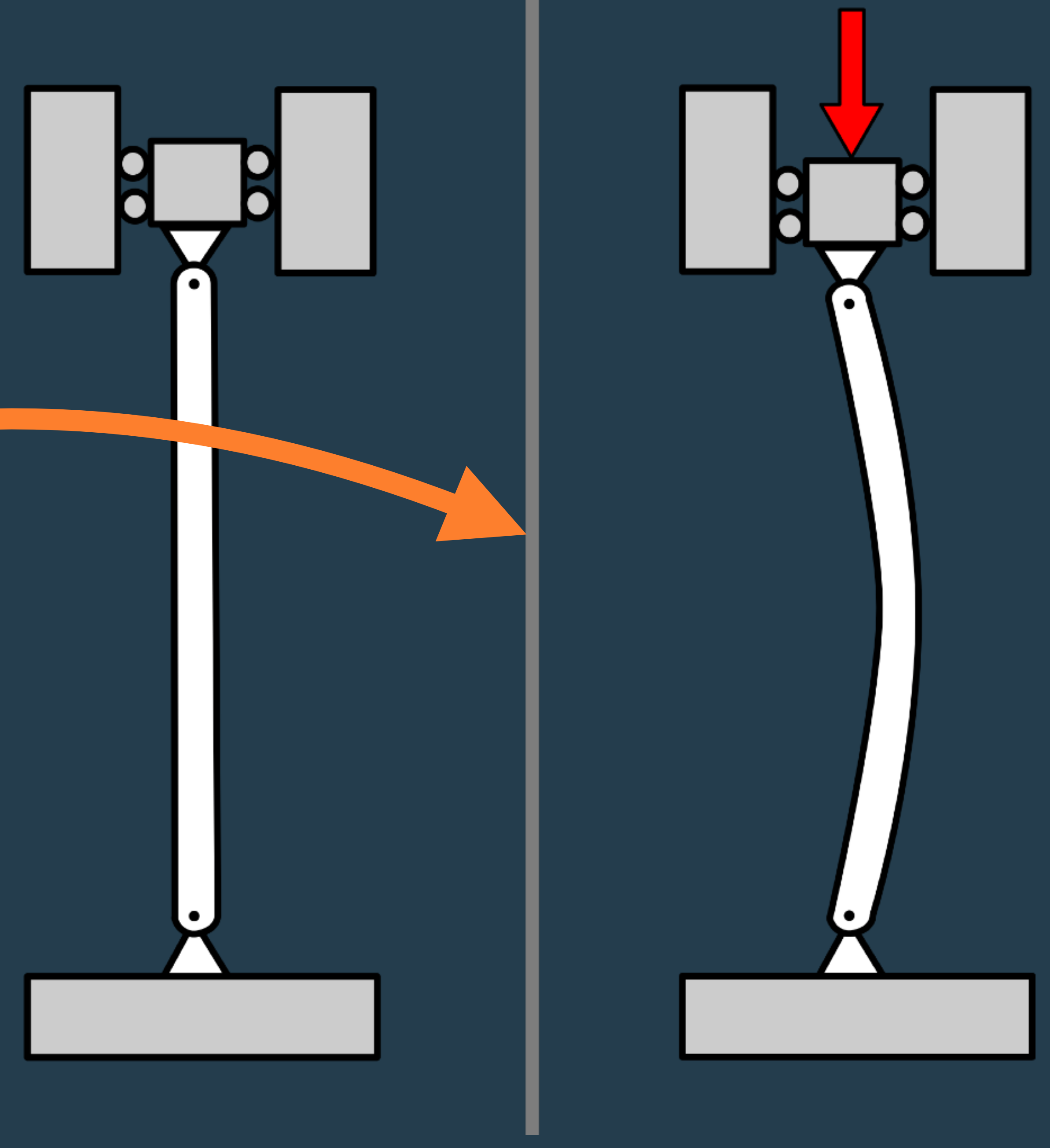

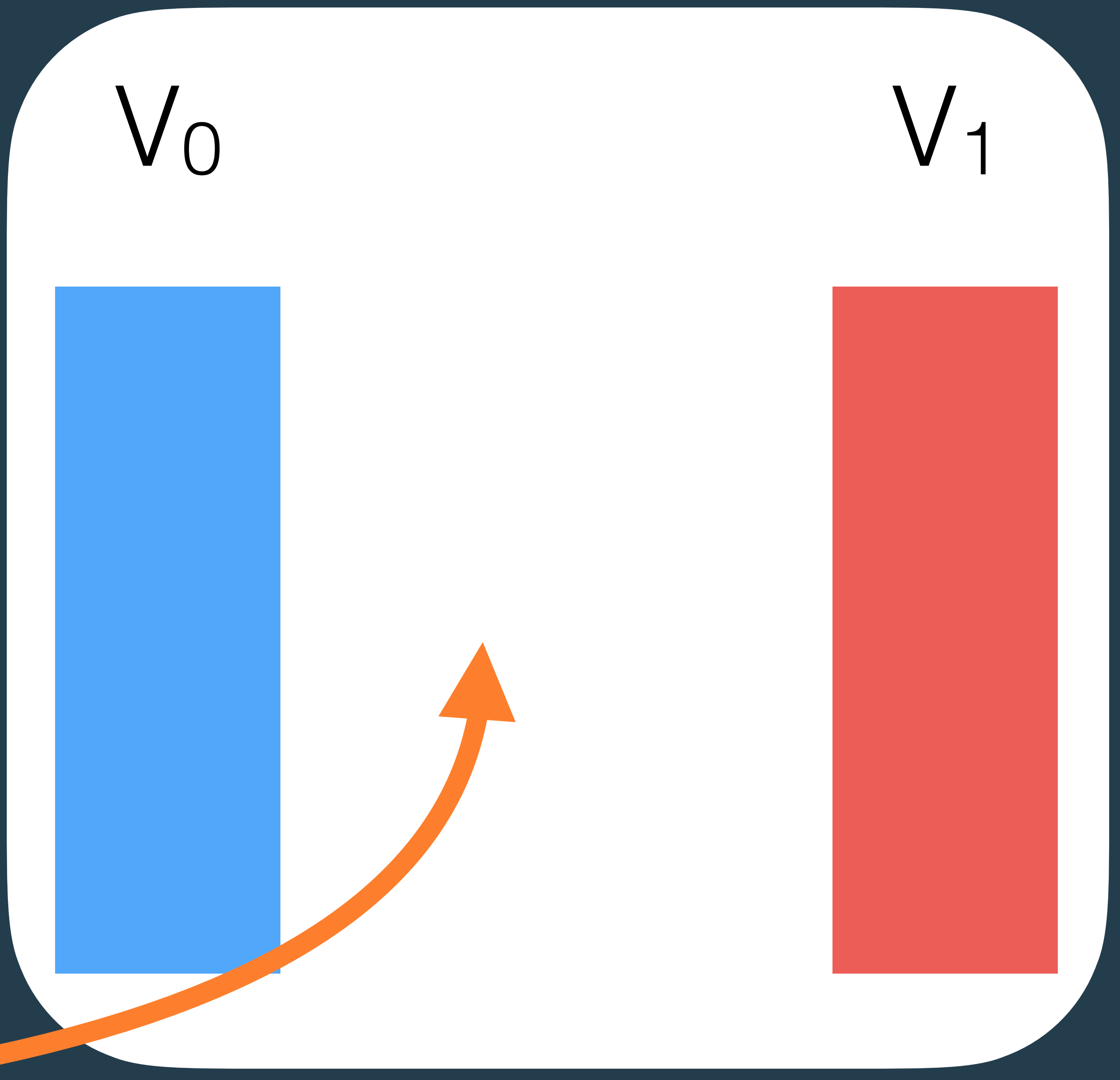

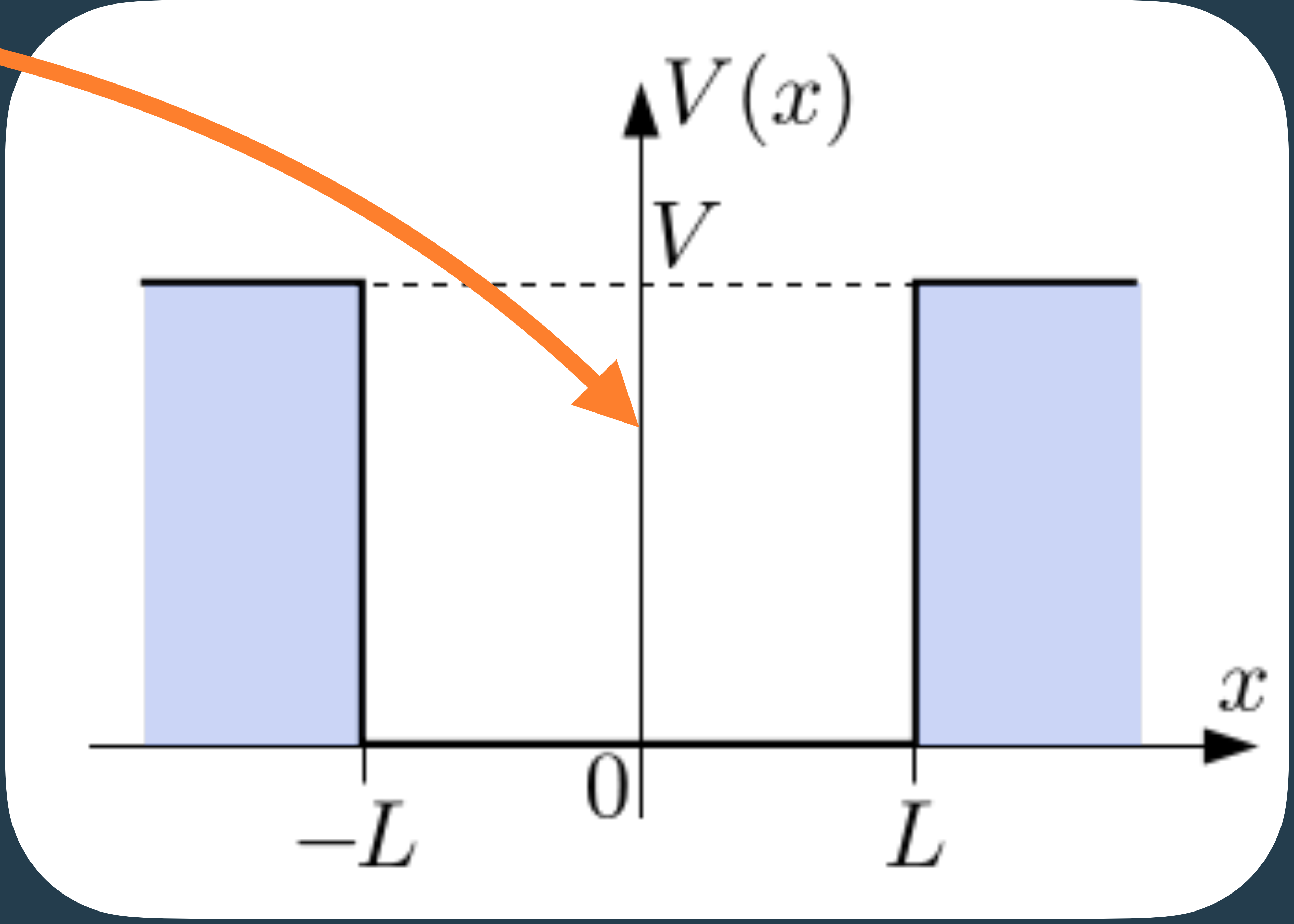

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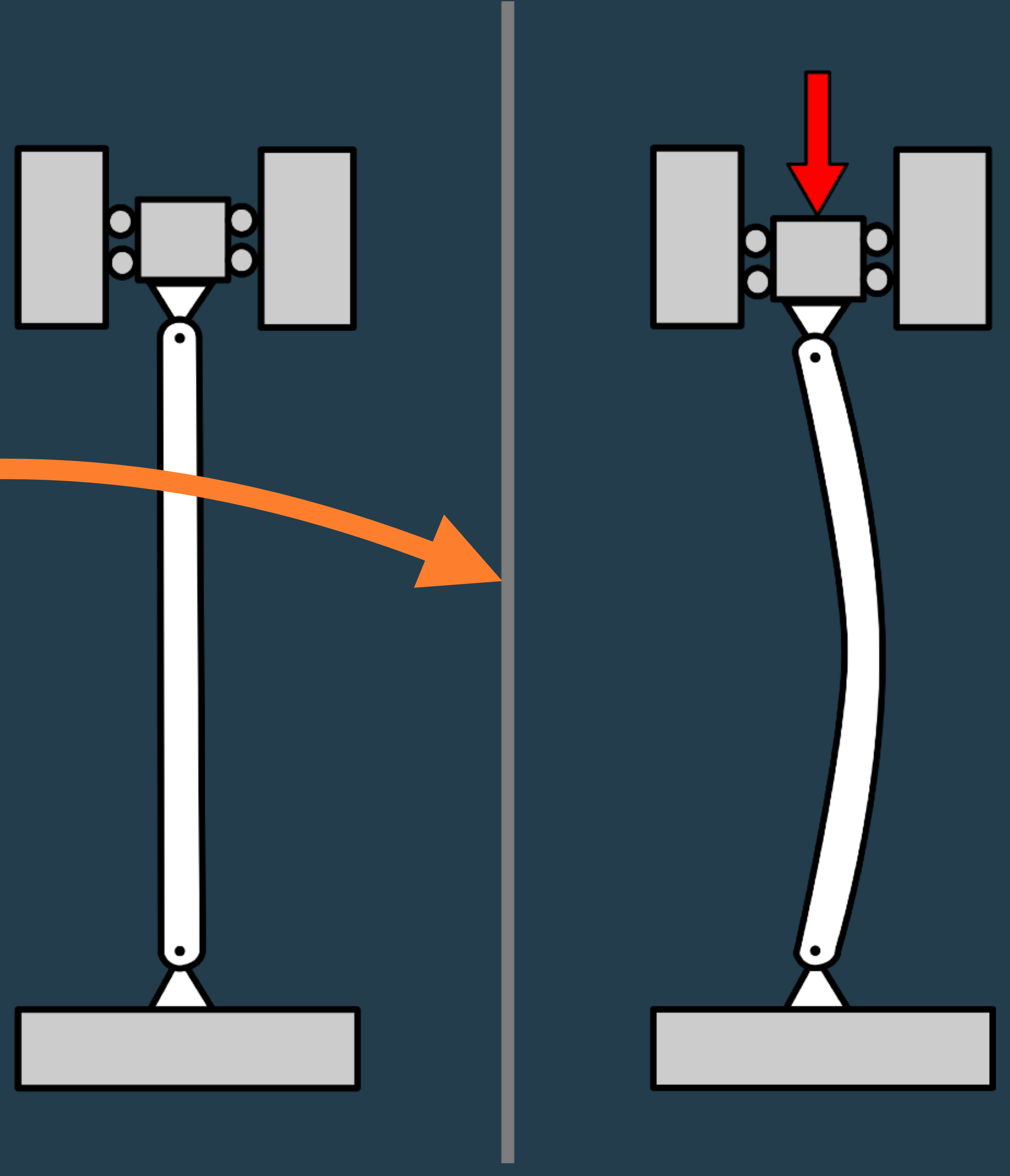
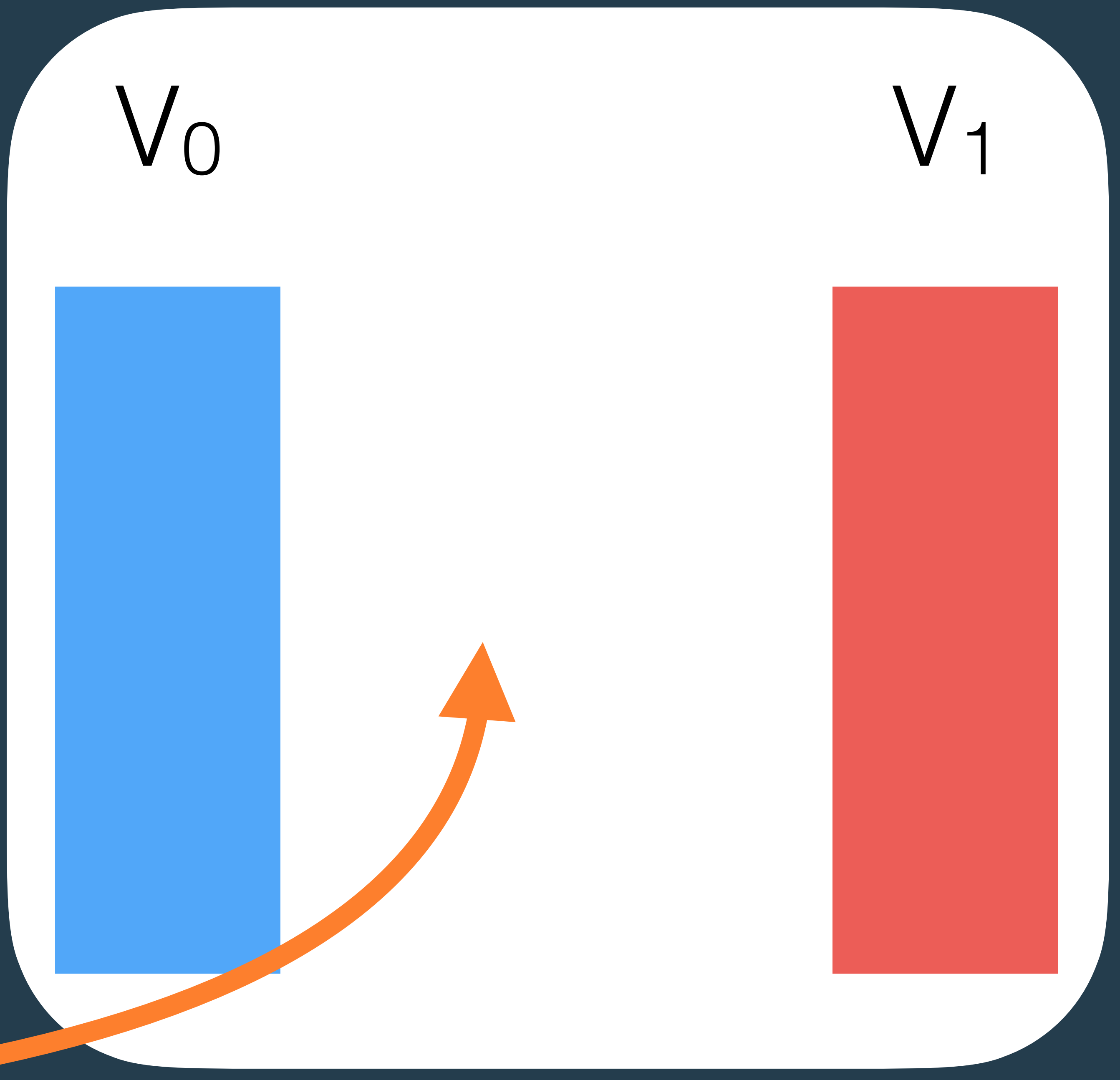
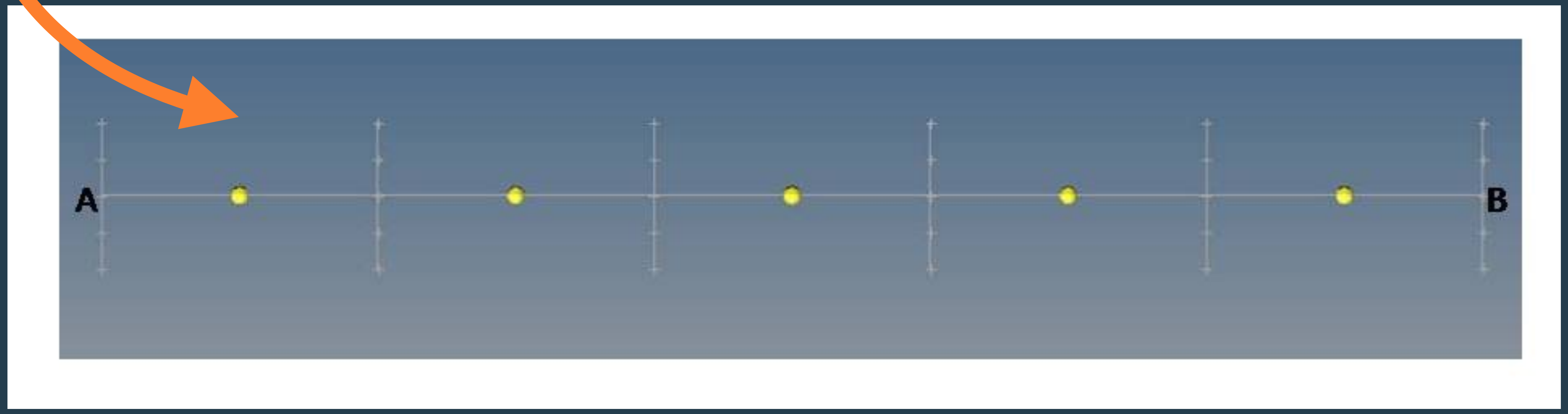
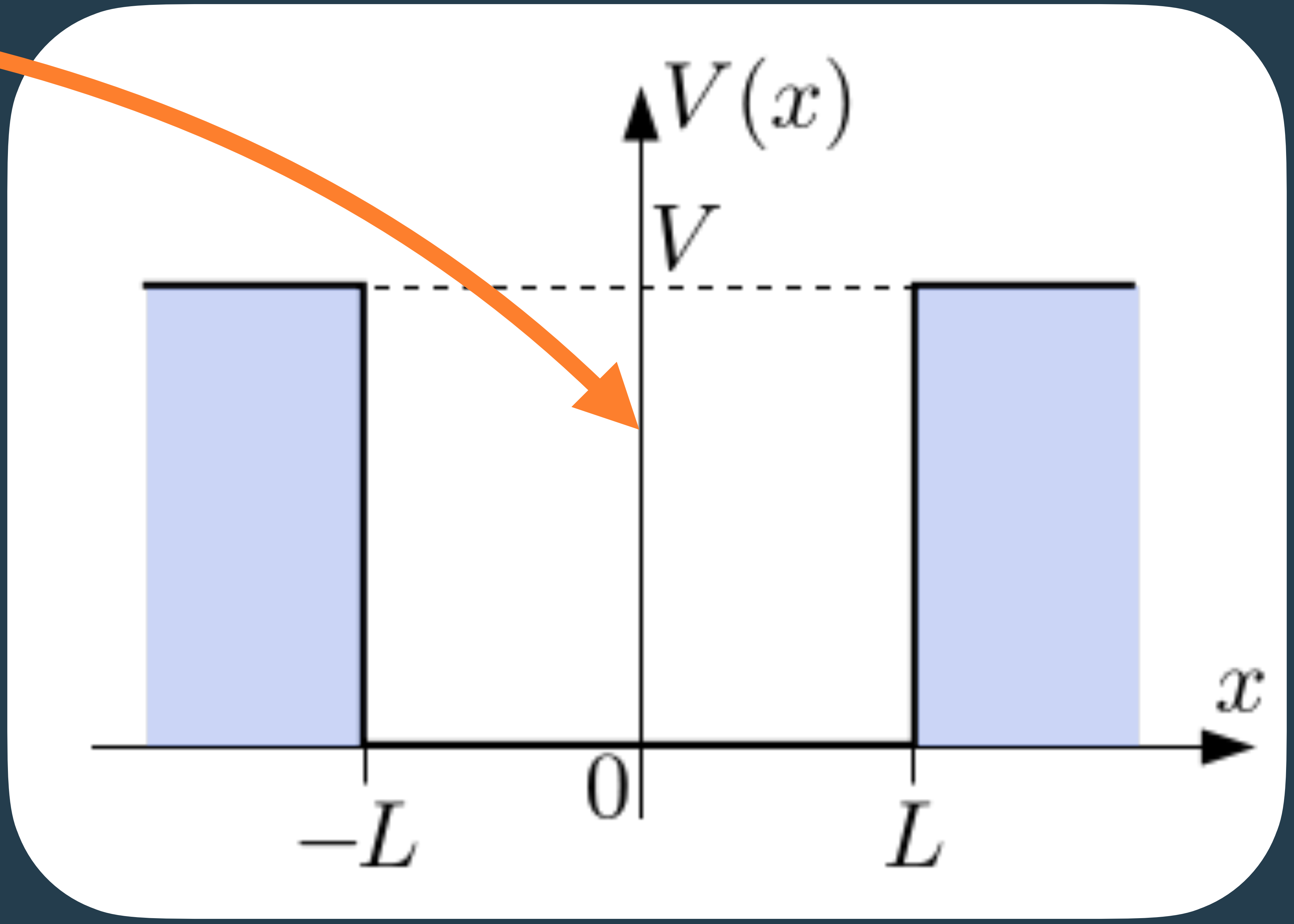




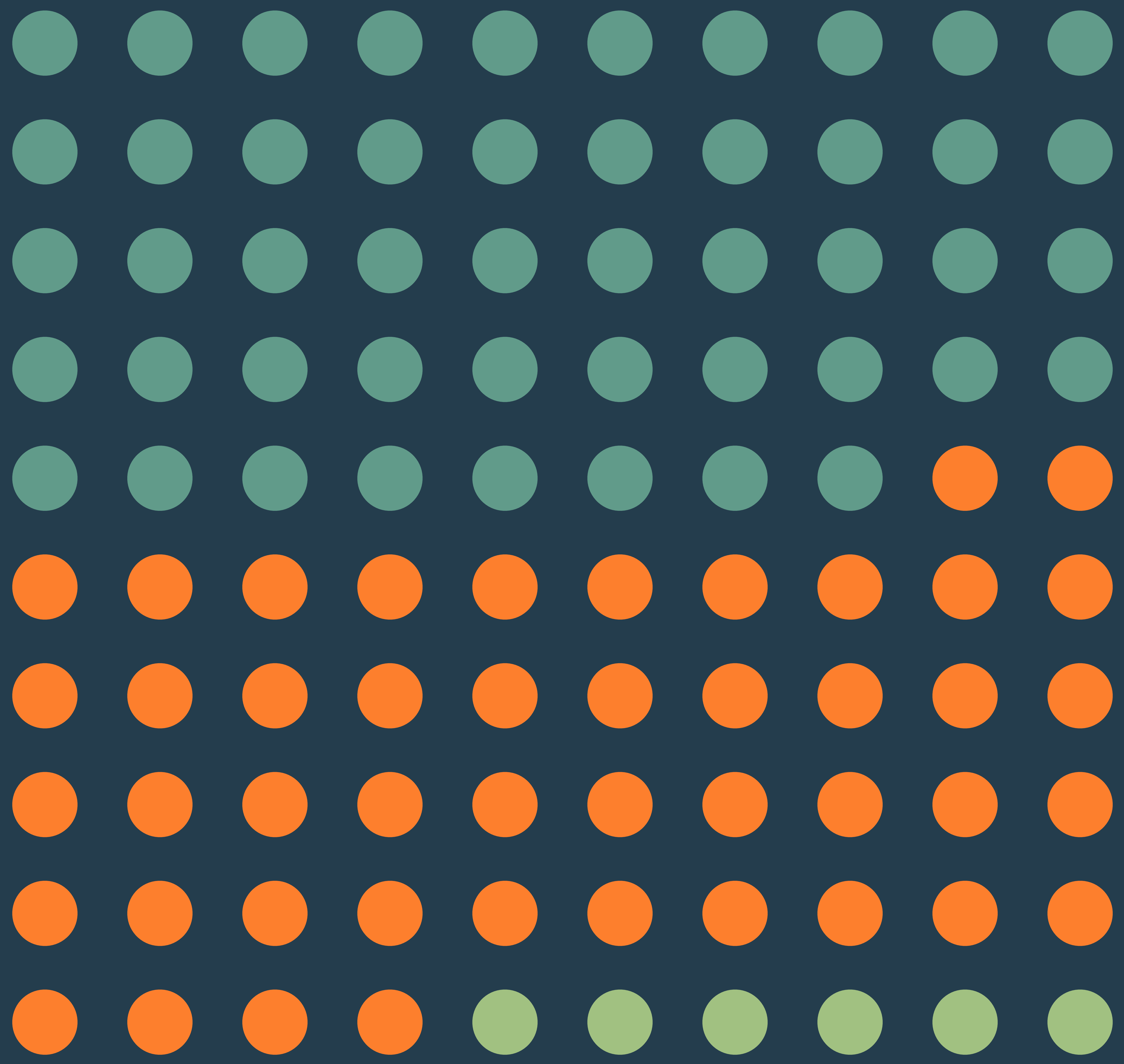




Consider 100 US Physics Bachelor's graduates

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

In the US, what happens to physics grads?



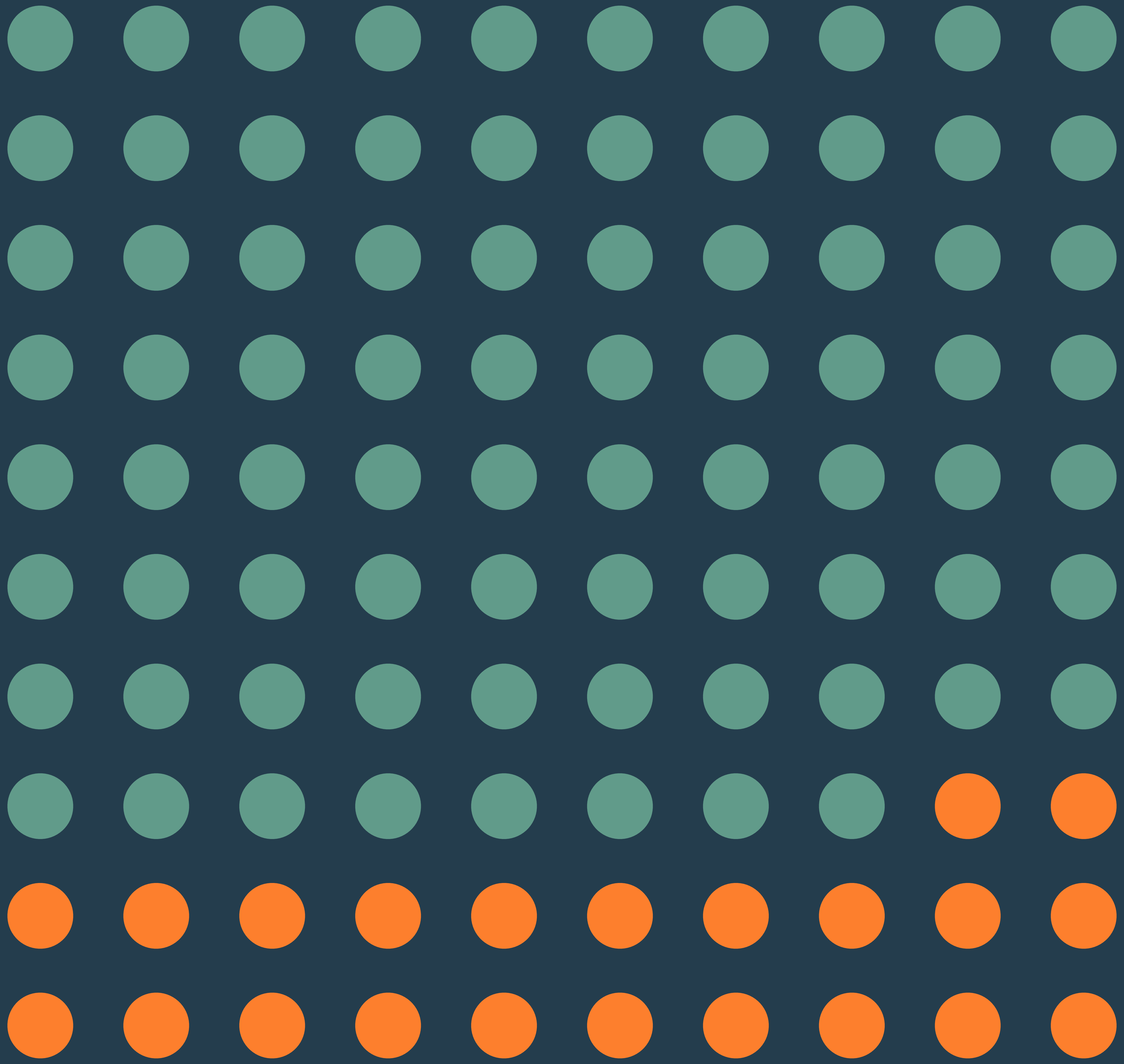
Graduate Study

Workforce

Not Employed

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

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

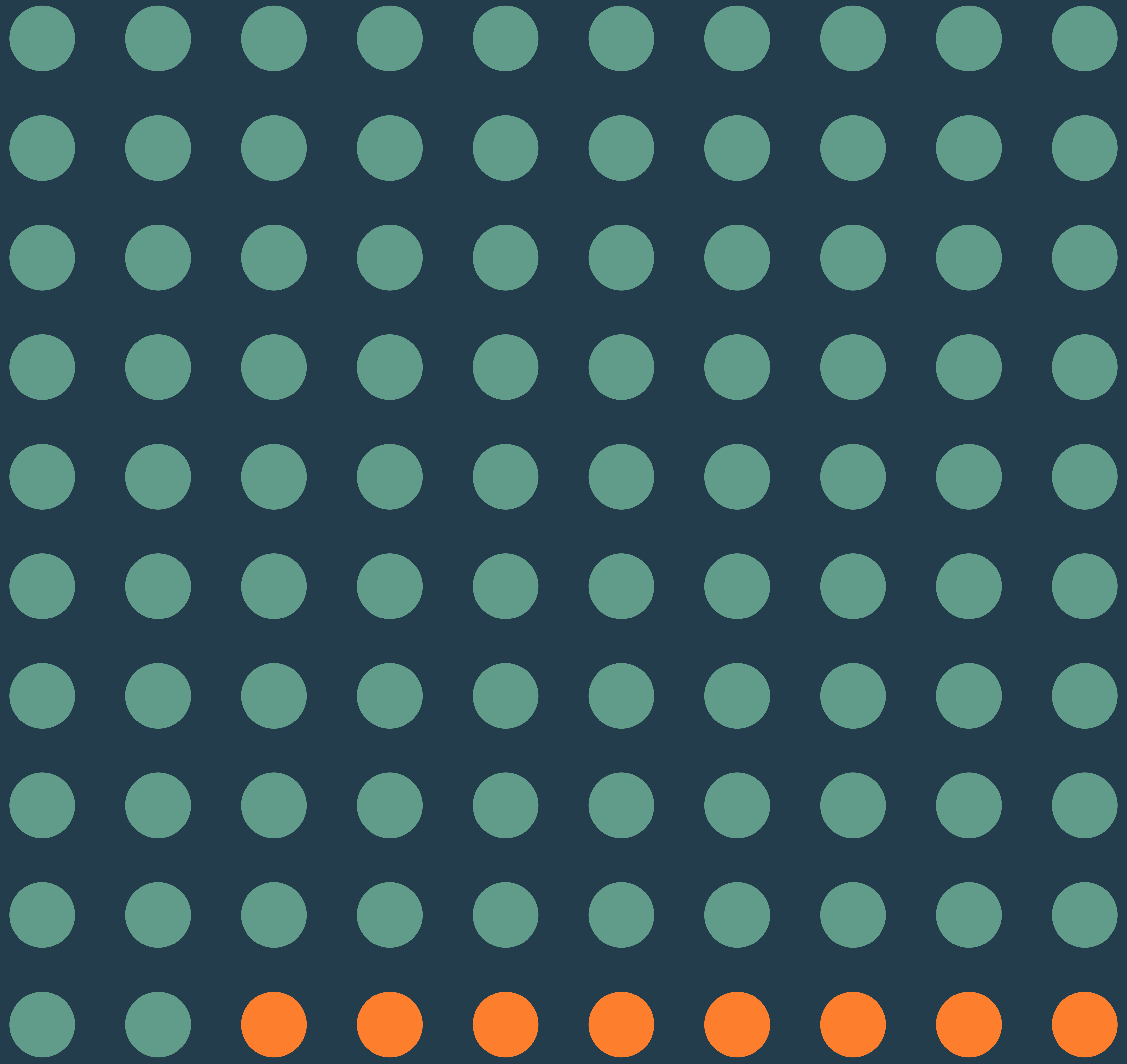


STEM Work

Non-STEM Work

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

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



STEM Enabled Work

Non-STEM Work

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

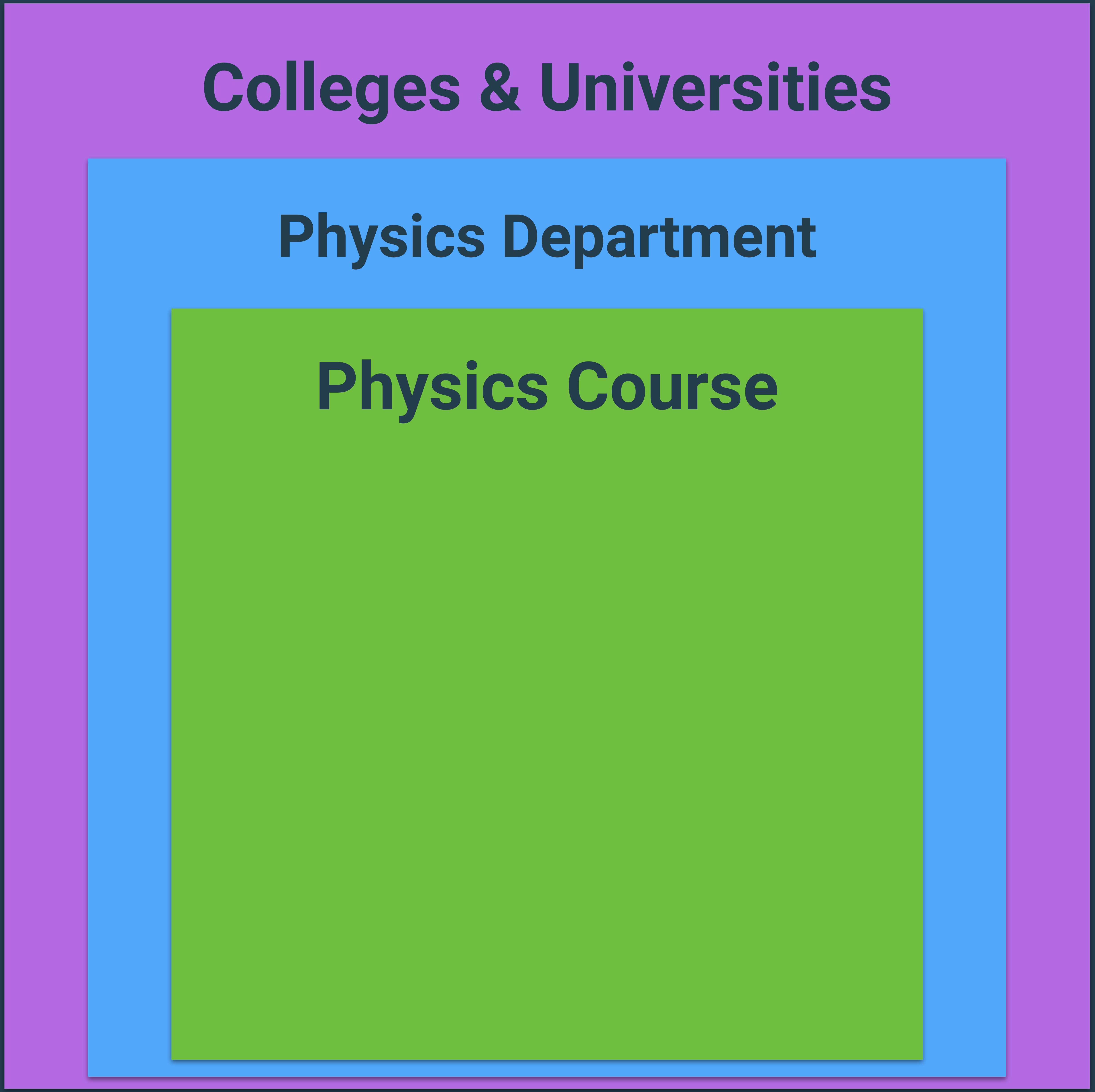
How do we sustainably integrate computing in physics learning environments?

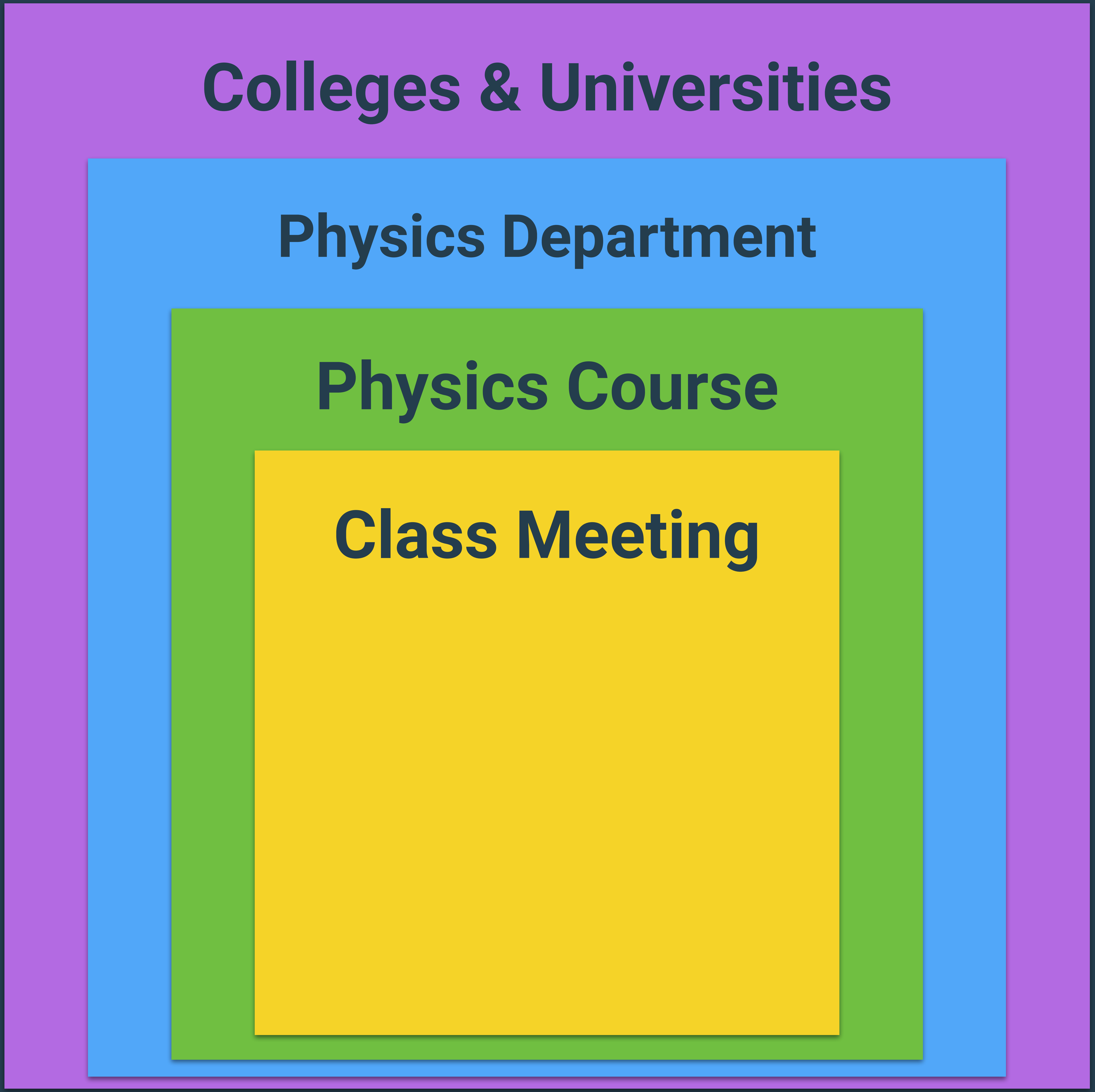
Answer:
It’s complicated

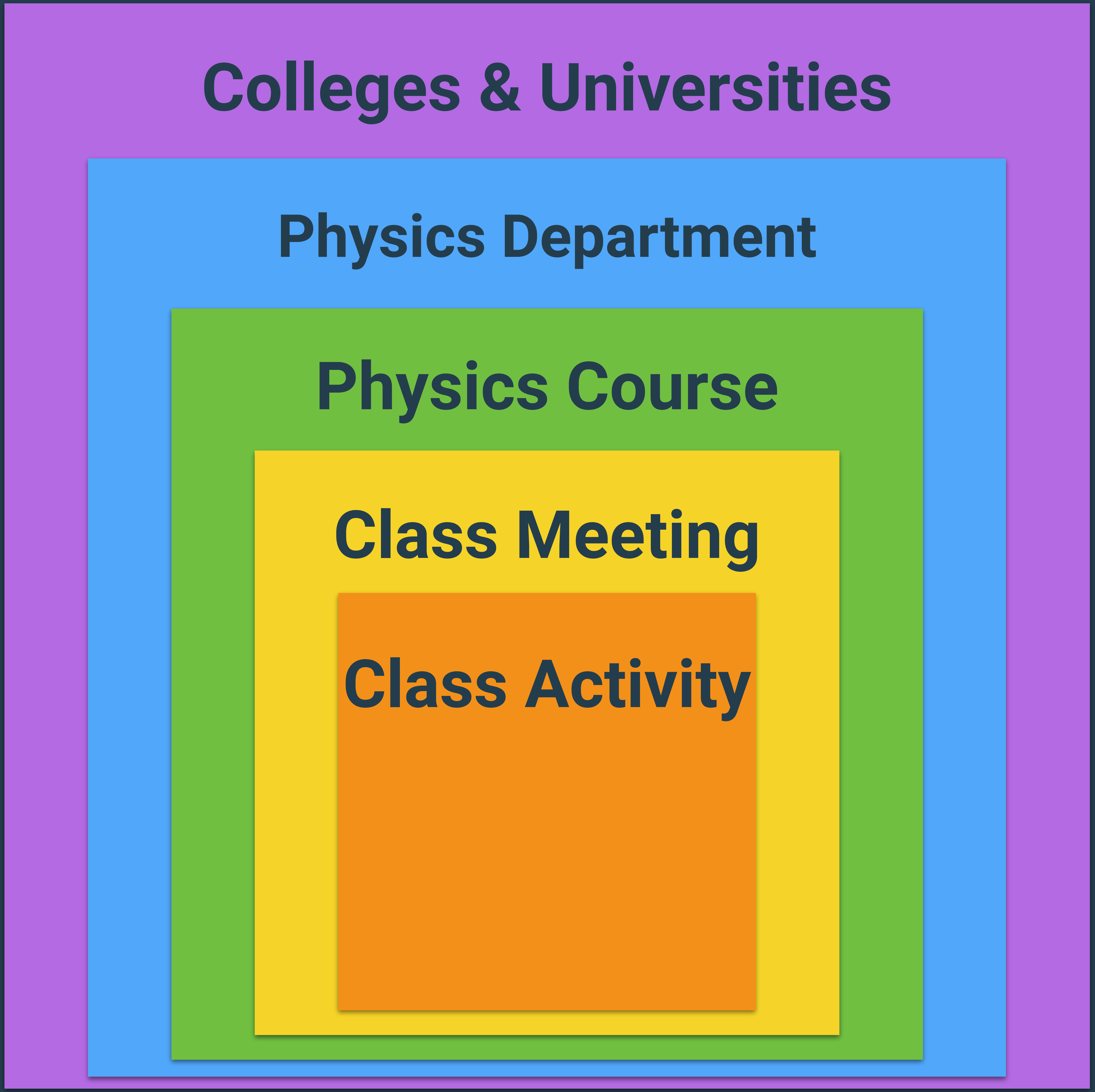
Colleges & Universities

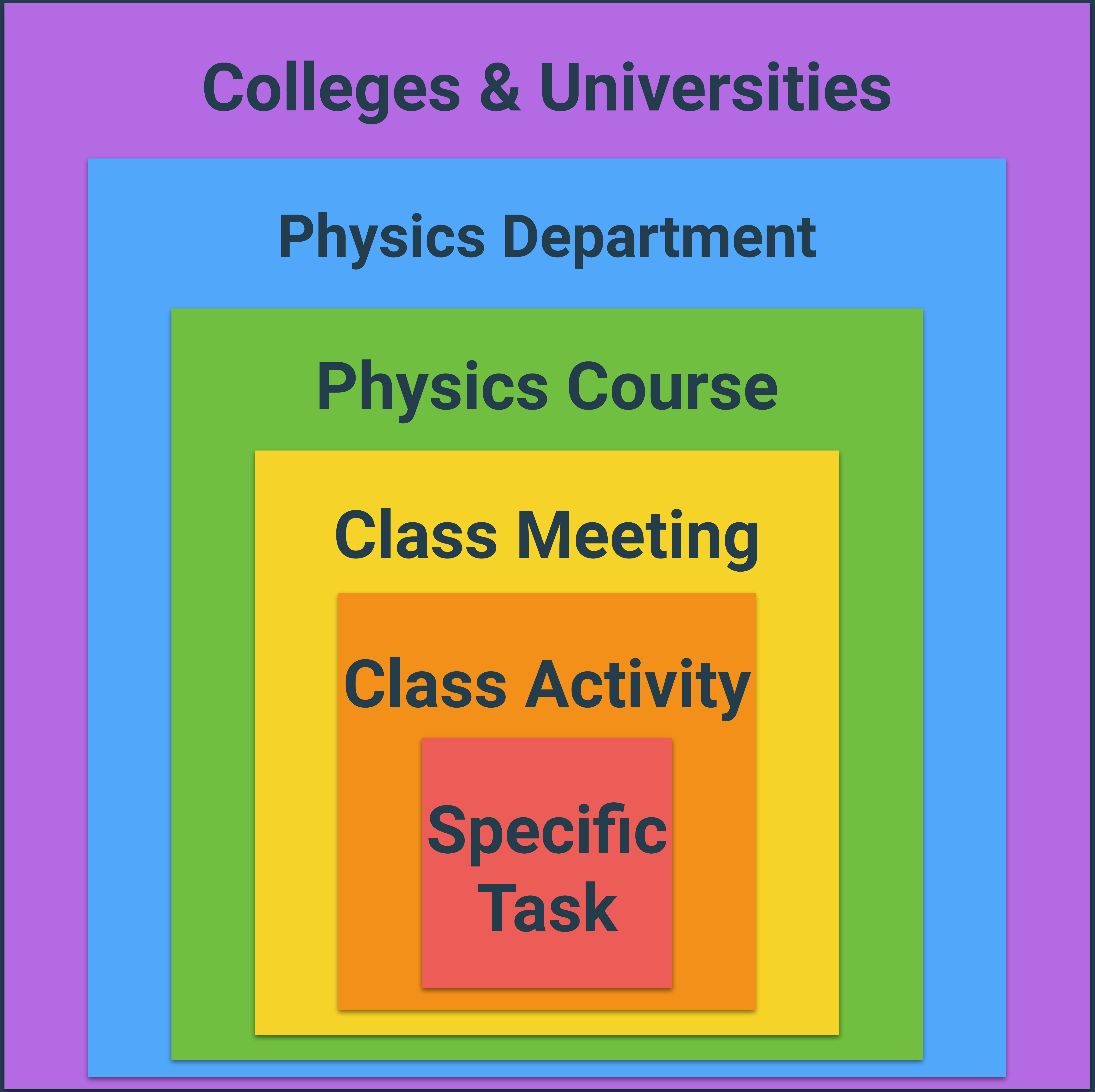
Colleges & Universities

Physics Department


Colleges & Universities
Physics Department
Physics Course


Colleges & Universities
Physics Department
Physics Course
Class Meeting

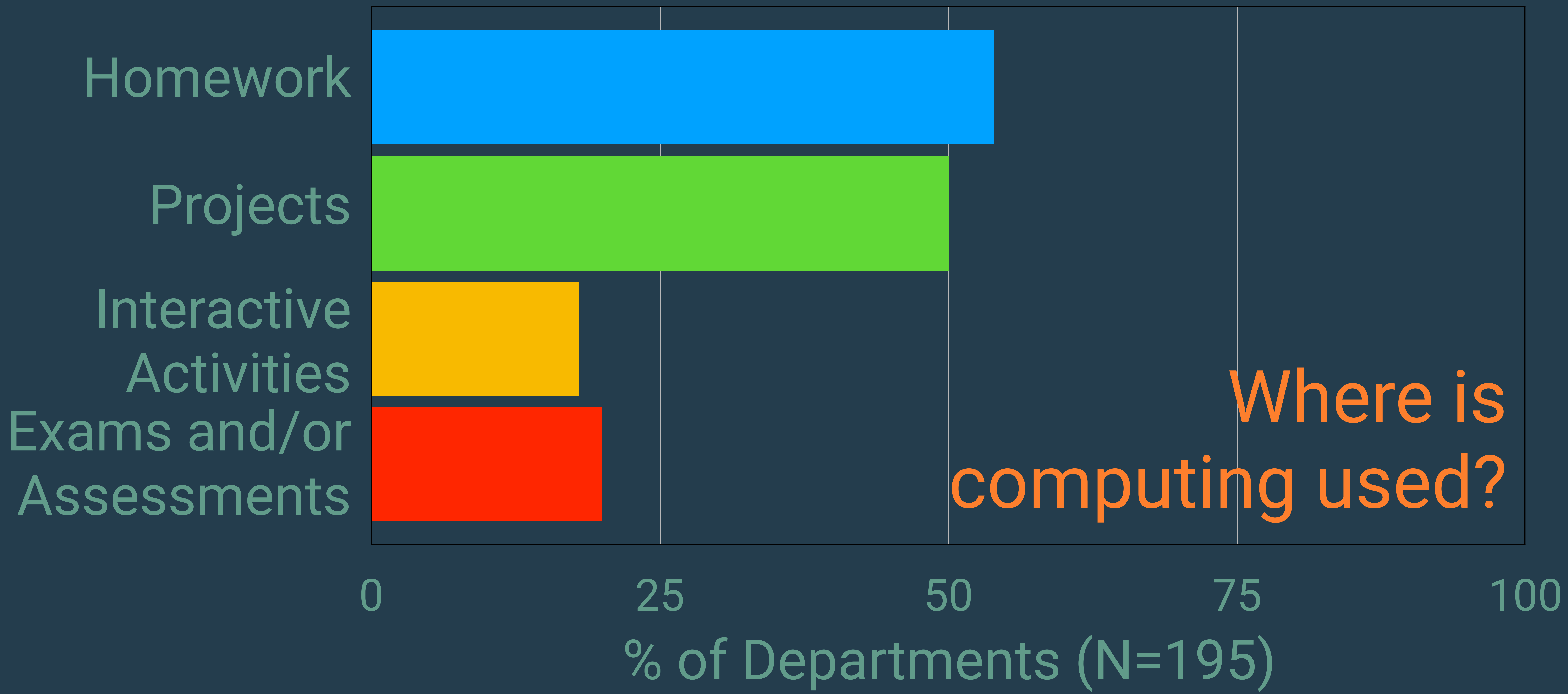

Colleges & Universities
Physics Department
Physics Course
Class Meeting
Class Activity


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

Who teaches computing in physics?

>50% departments report experience with teaching computing in physics

No prevalence differences between intro & advanced courses



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Caballero & Merner, Phys. Rev. PER, 2018

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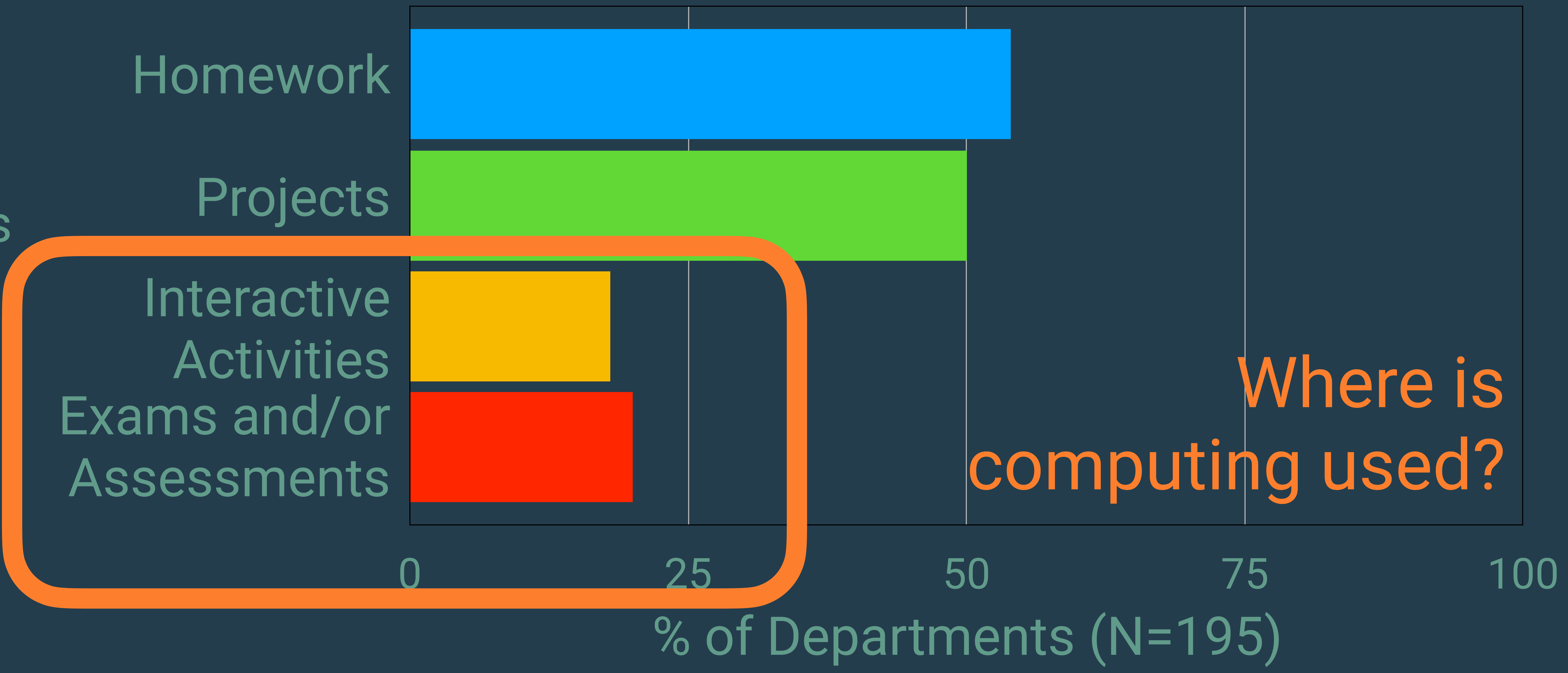

Caballero & Merner, Phys. Rev. PER, 2018

Take-Aways

Caballero & Merner, Phys. Rev. PER, 2018

Take-Aways

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

Caballero & Merner, Phys. Rev. PER, 2018

Take-Aways

- A majority of faculty report having experience teaching undergraduate students computation
- Computational instruction is more prevalent than in the past[1]

Caballero & Merner, Phys. Rev. PER, 2018

[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)

Caballero & Merner, Phys. Rev. PER, 2018

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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

Caballero & Merner, Phys. Rev. PER, 2018

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

But “who” teaches computation?

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

Computational physics is hard to teach in the classroom.

My department rewards me for teaching computation.

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

…

But “who” teaches computation?

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

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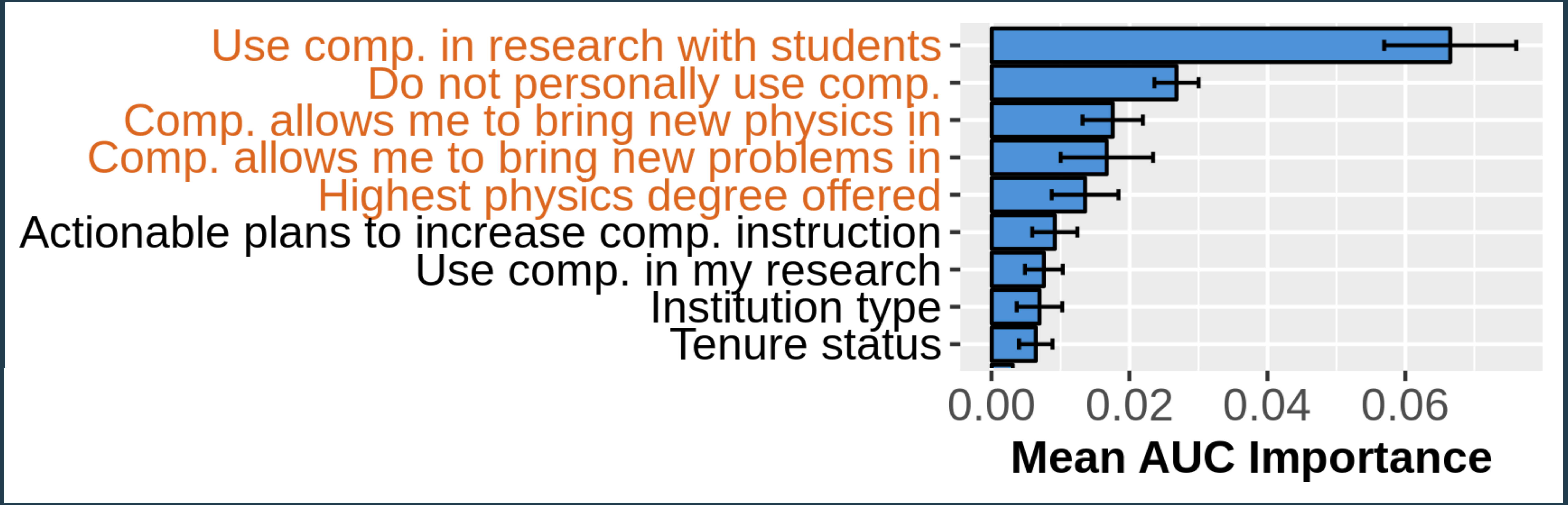
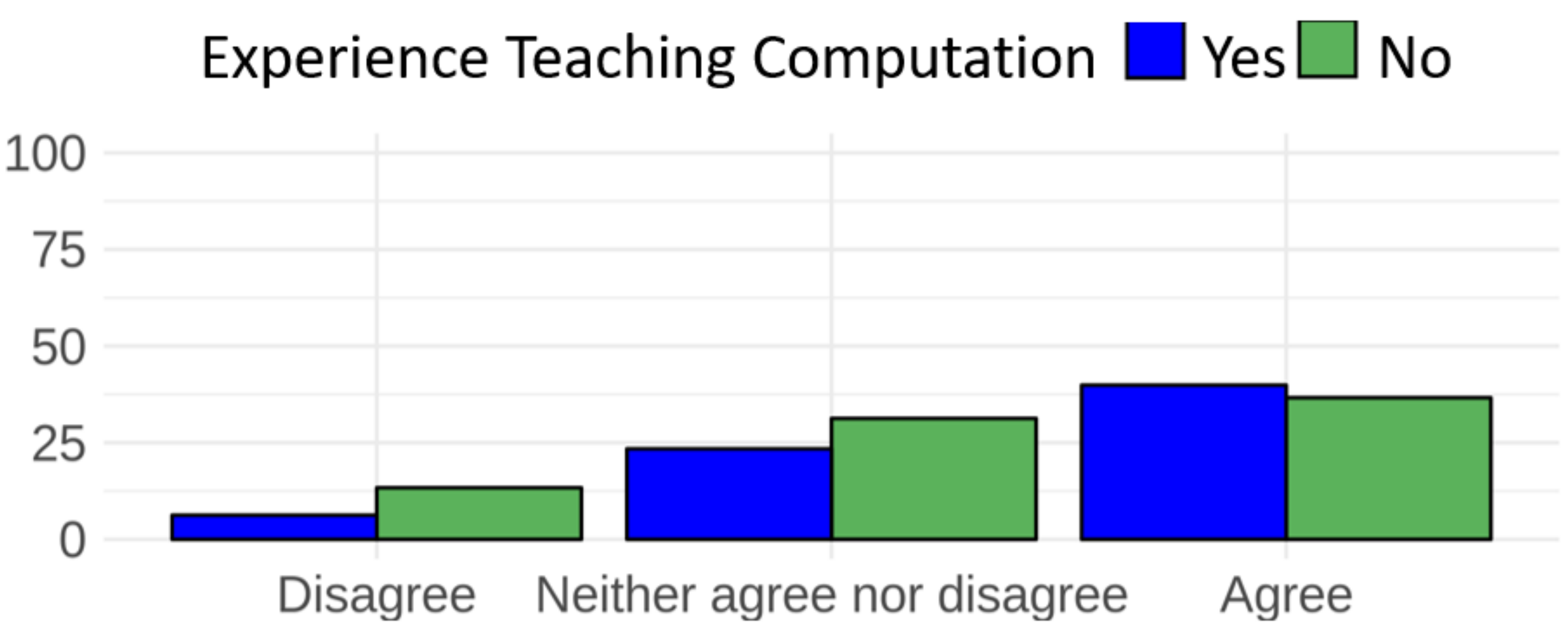
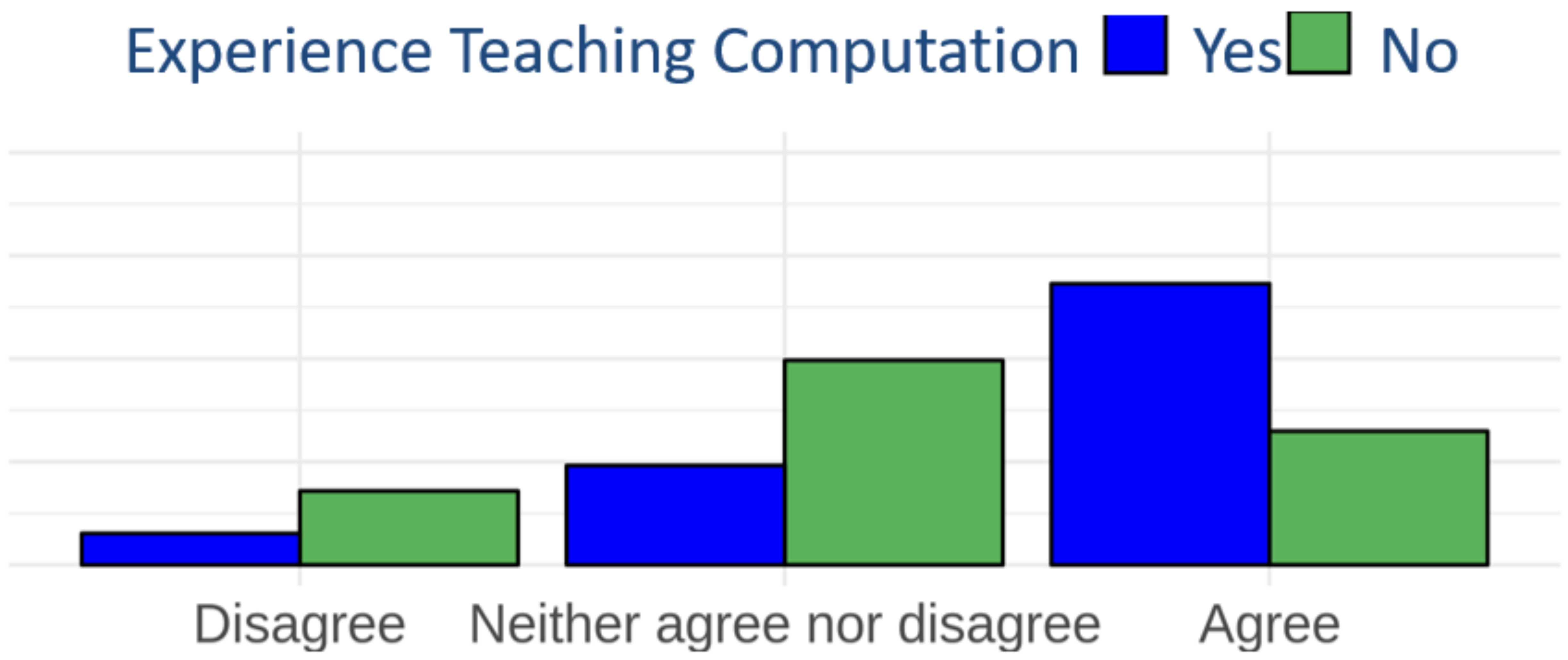


Young, et. al. Phys Rev. PER, 2019

Do these factors make sense? ✅



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



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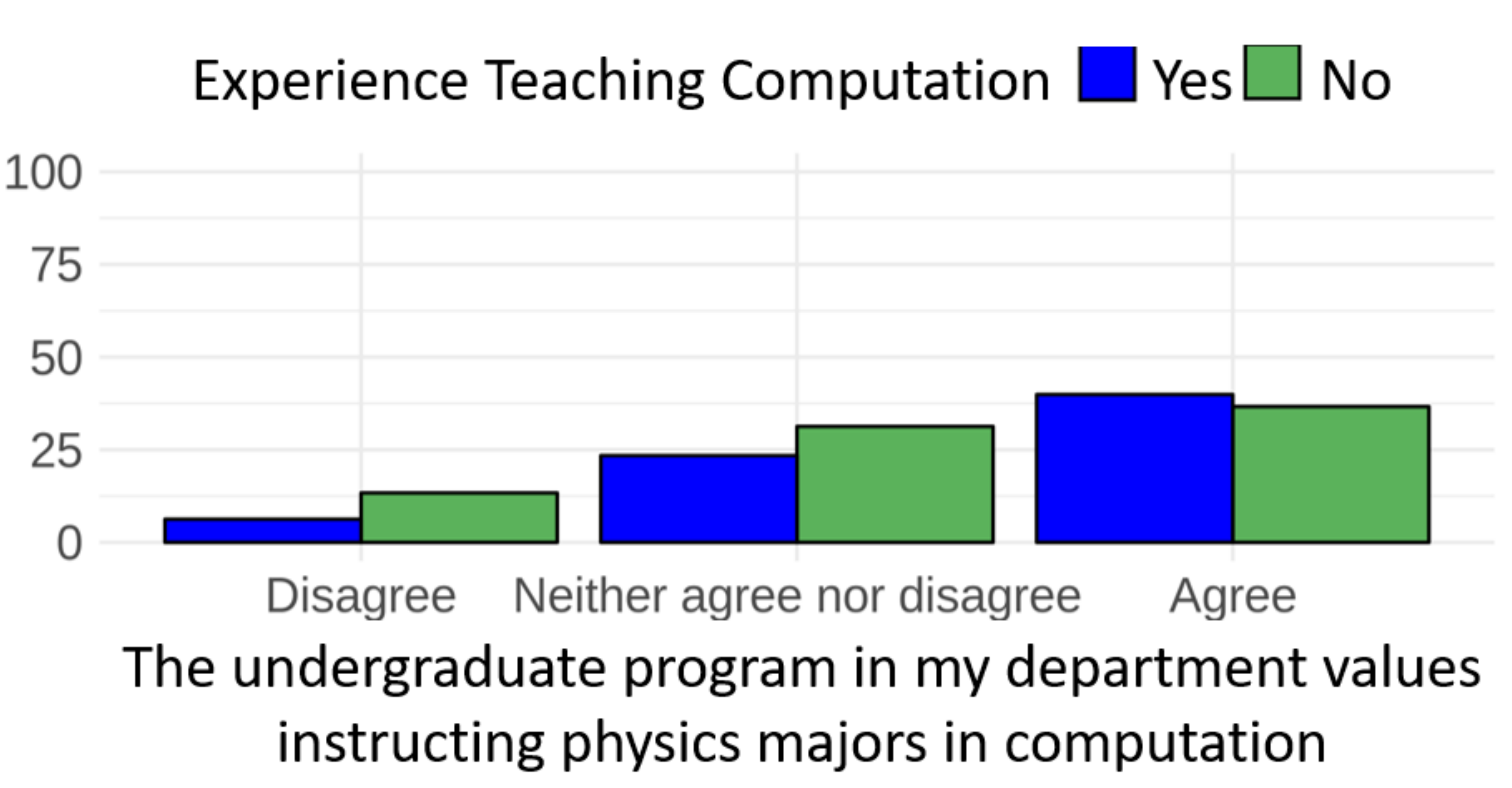
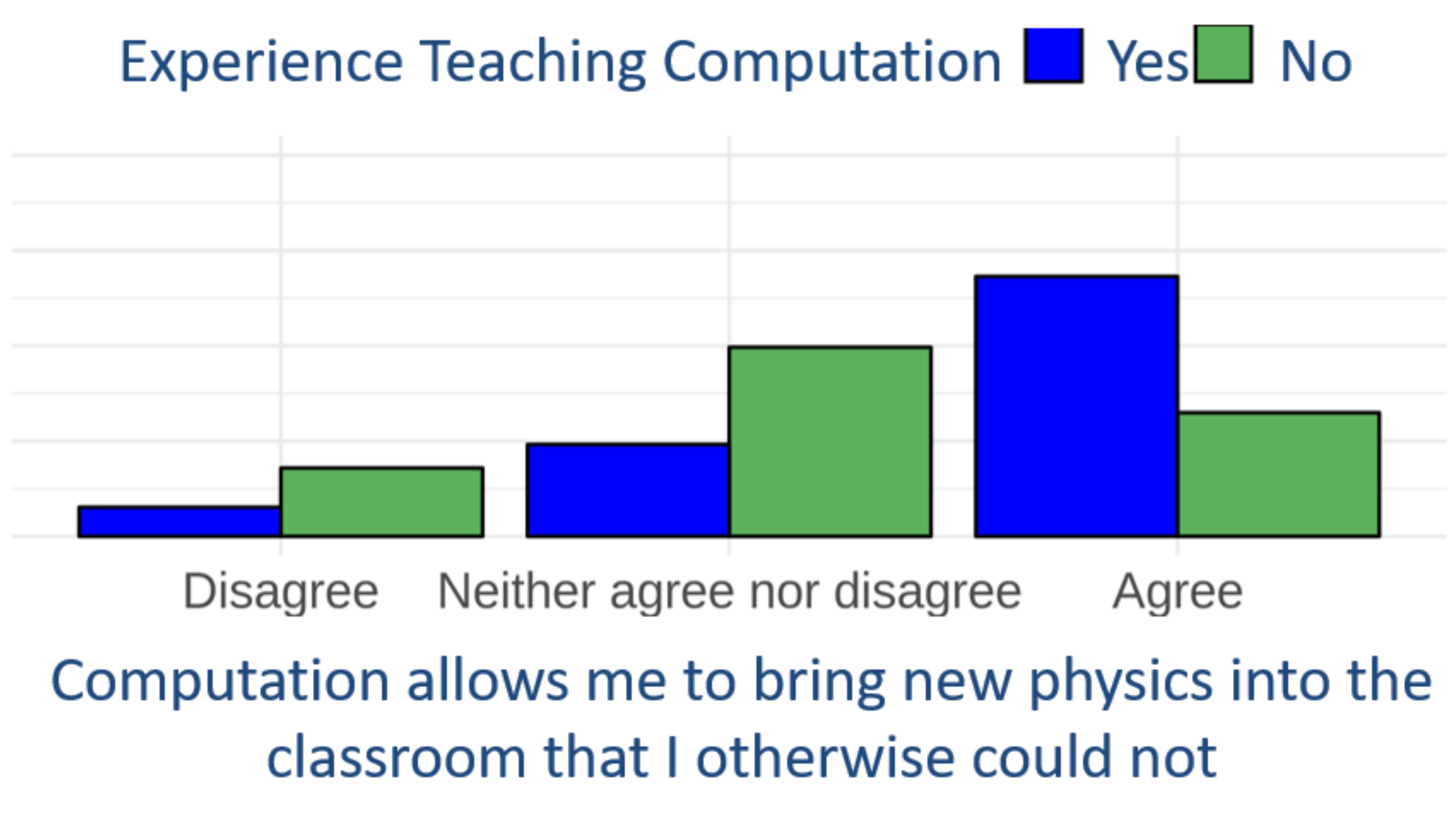


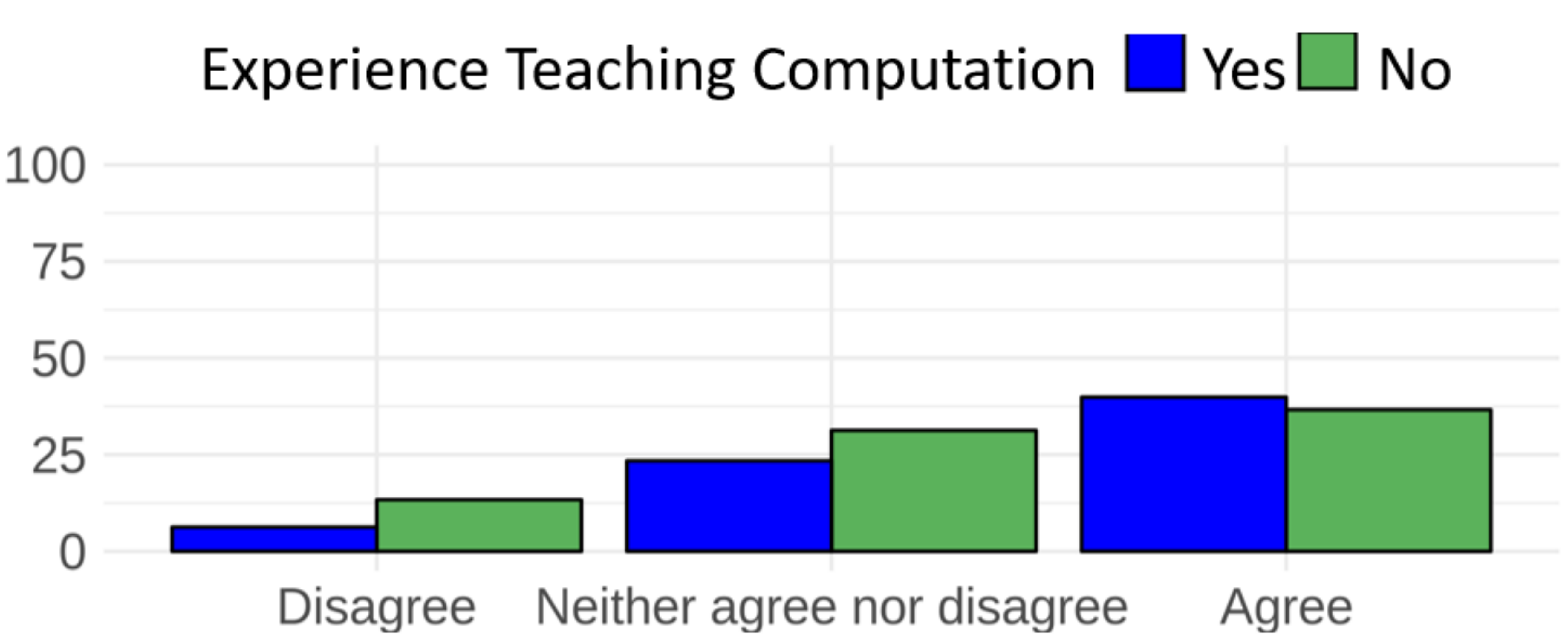


(At the moment)

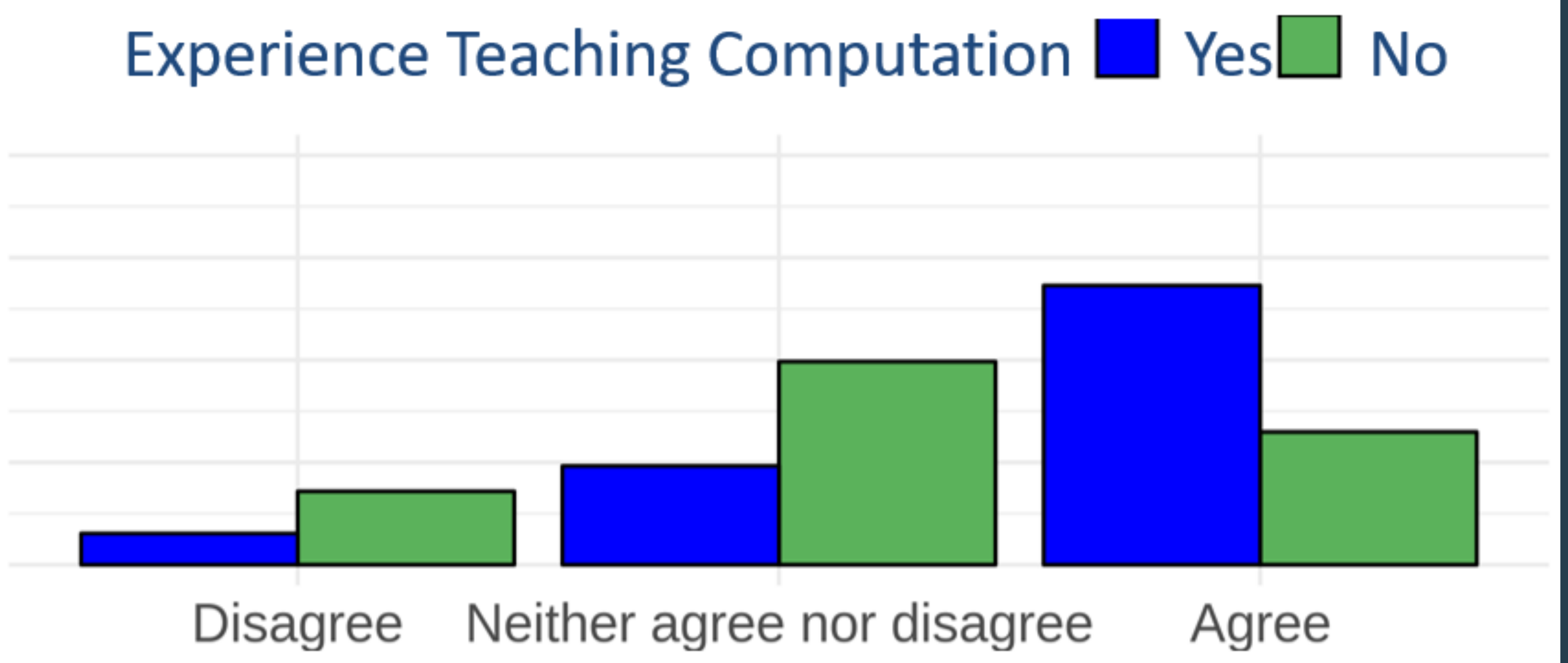
Faculty that teach computation tend to:

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

Do these factors make sense? ✅



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



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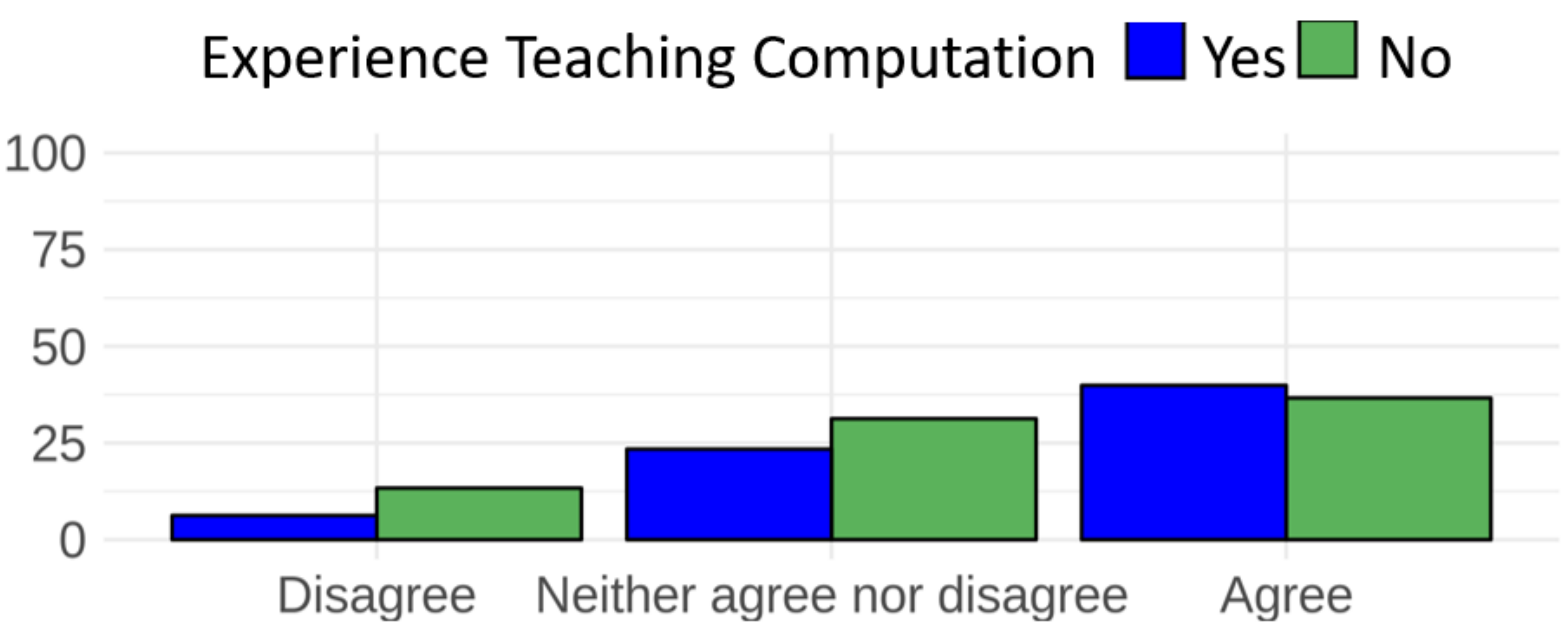

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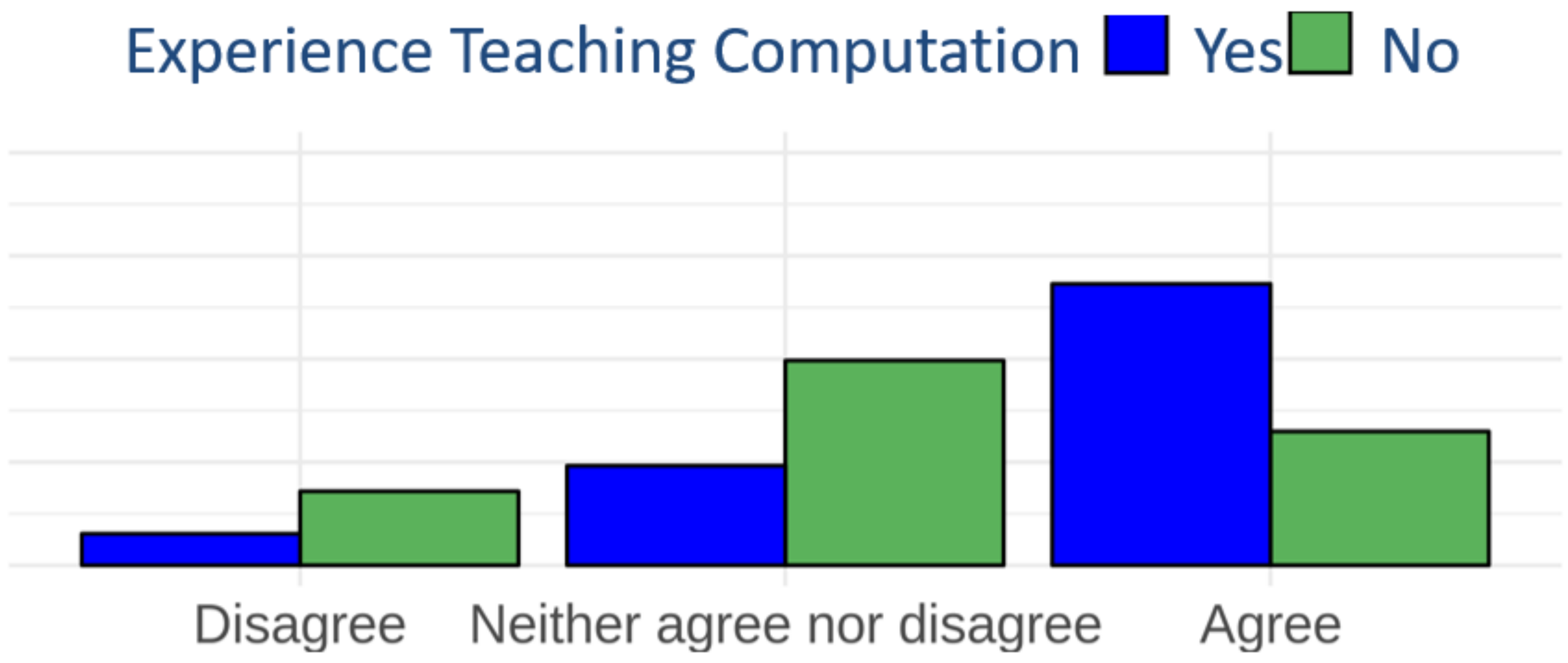

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Faculty that teach computation tend to:

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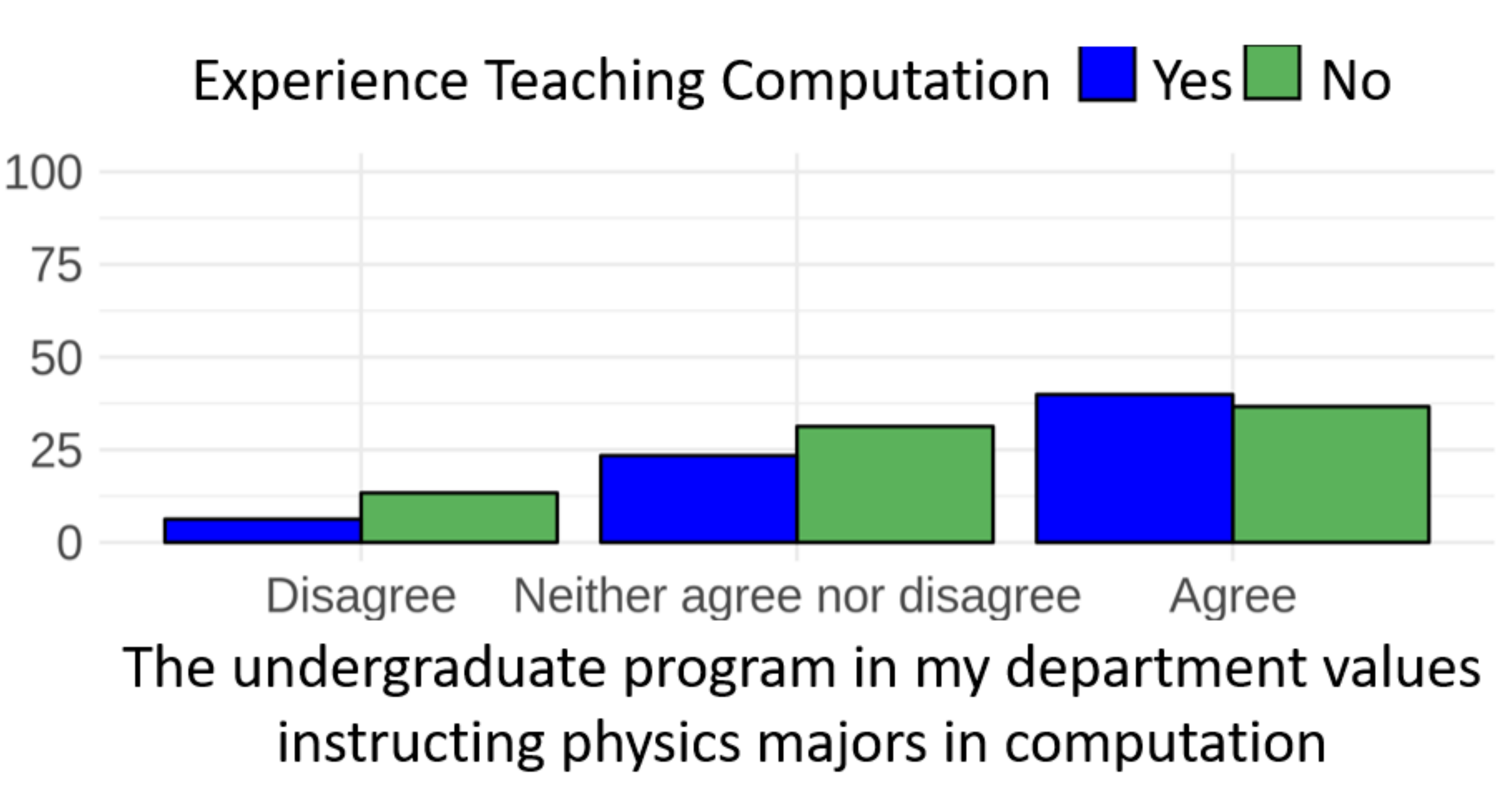
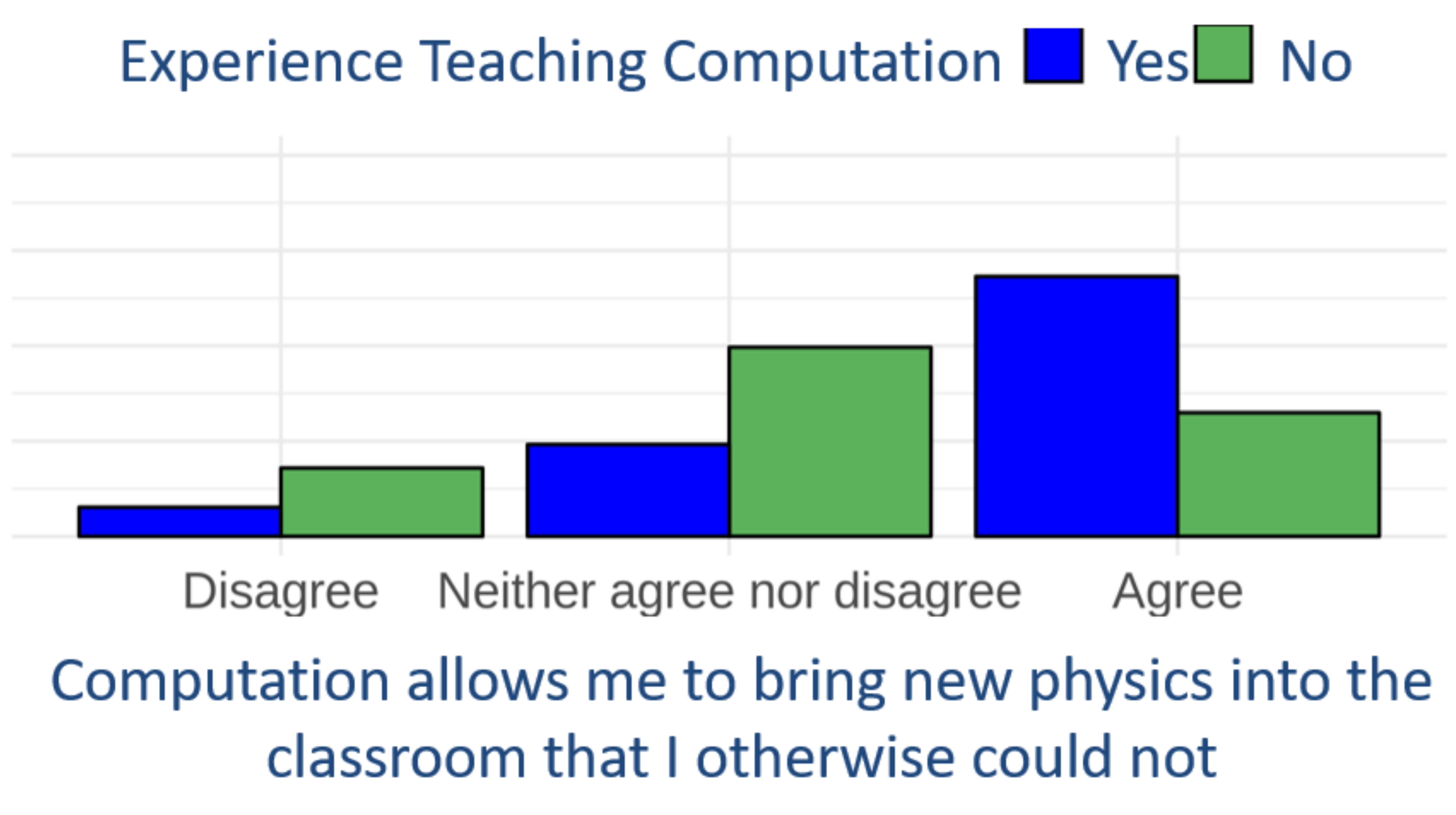
- Teach at institutions that offer at least a physics bachelor's degree

Do these factors make sense? ✅





(At the moment)

Faculty that teach computation tend to:

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- Believe computation brings new physics and problems into the curriculum
- Teach at institutions that offer at least a physics bachelor's degree

Faculty treat teaching computation as an individual choice

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

Open Questions

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- How do we support a broader cross-section of physics faculty to integrate computing?

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- What can physics departments do to support moves to integrate computing?

Open Questions

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

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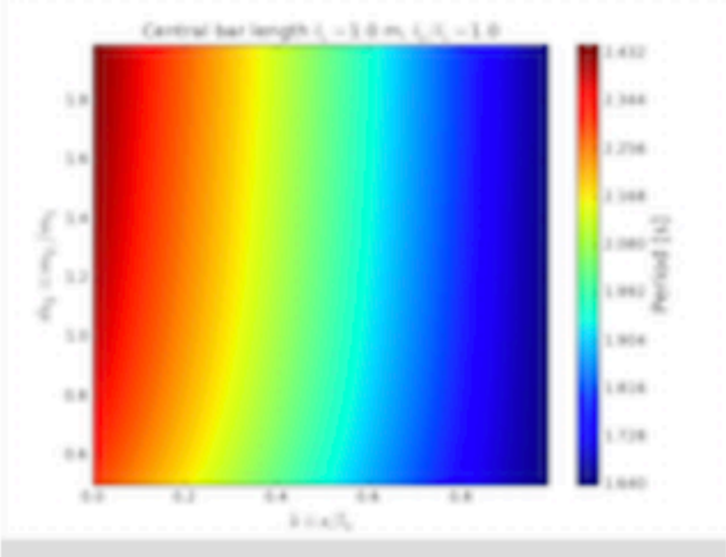
PARTNERSHIP FOR INTEGRATION OF COMPUTATION INTO UNDERGRADUATE PHYSICS

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 caled variables (**Exercises 1 and 2**);
- erive the equation of motion for the pendulum (**Exercise 3**);
- omputationally model the motion of a three-bar pendulum with damping using ne 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

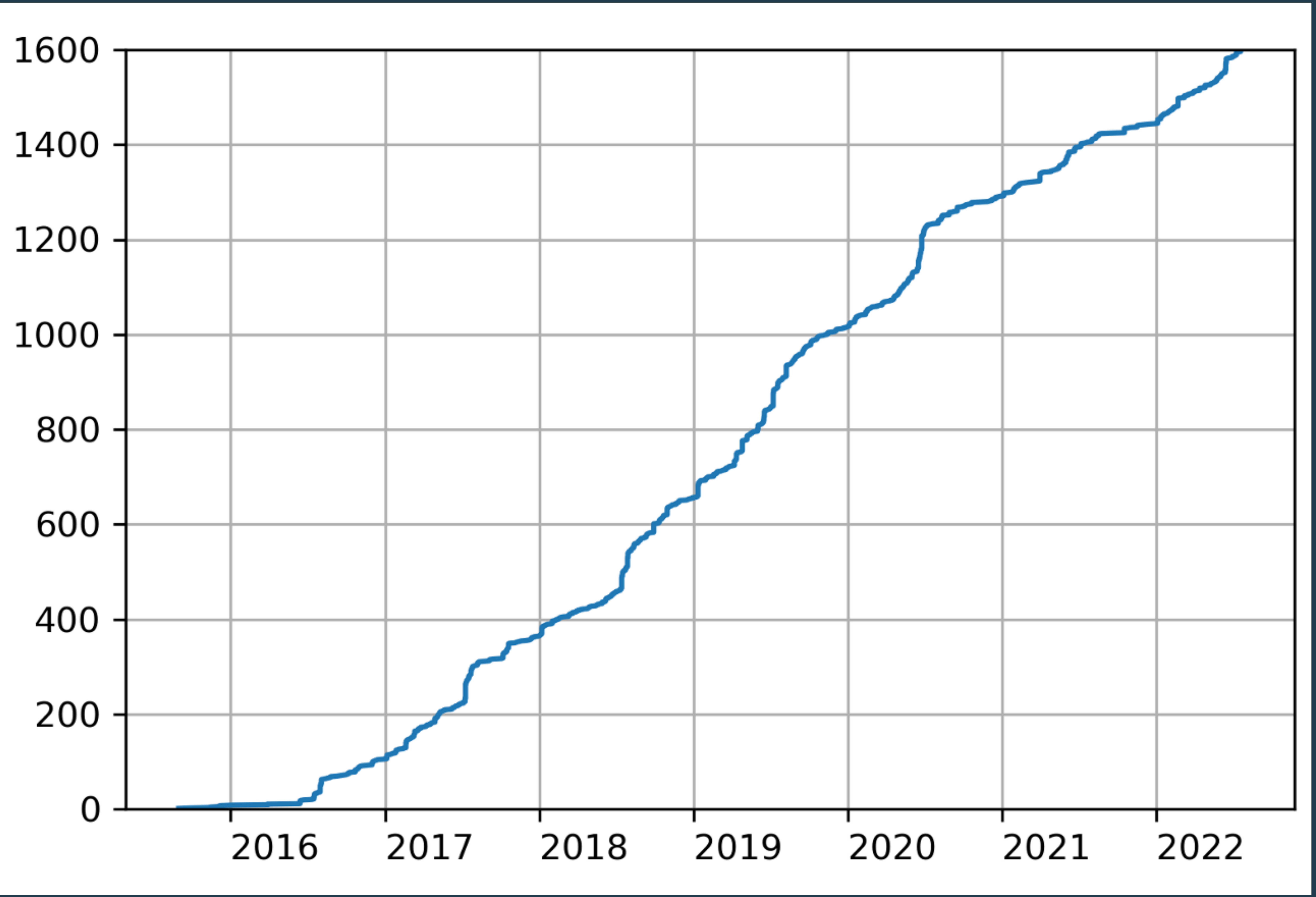
E. Behringer, "A Rigid Three-bar Pendulum," Published in the PICUP Collection, July 2016.

gopicup.org

PICUP Verified Educators

Verified educators submit academic documentation to gain access to:

- Solutions & Source Codes
- Implementation Guides
- Additional Materials



gopicup.org

Map of Verified Educators in the US

Map of 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?

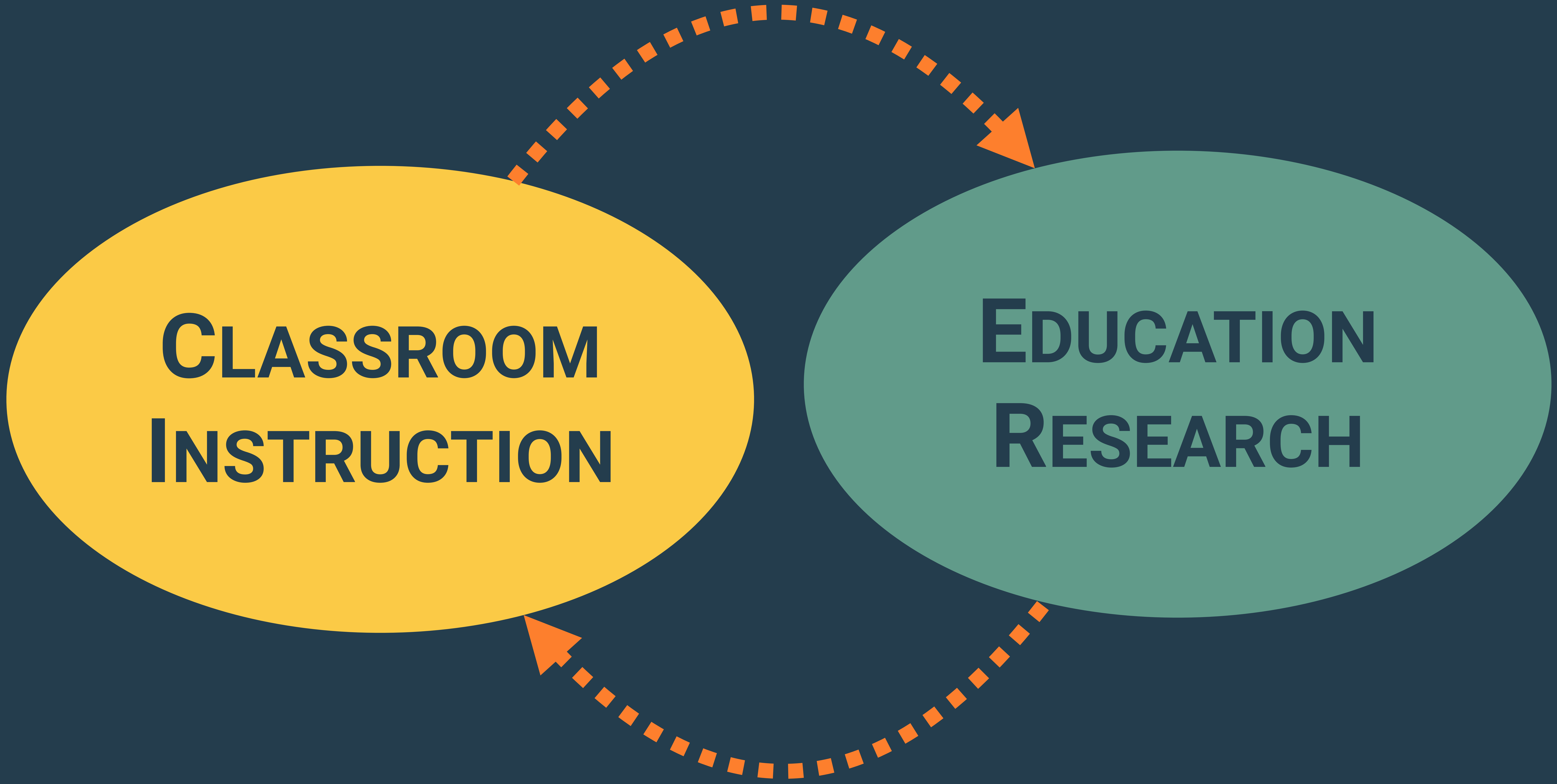
What is the best format to teach computation to my students?

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…

WHAT CAN COMPUTATIONAL INSTRUCTION LOOK LIKE?


Classroom Instruction
Education Research

Projects and Practices in Physics

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Projects & Practices in Physics

a community-based learning environment

Trace: • 183_projects • project_1a • start • **project_3_2015_semester_1**

183_projects:project_3_2015_semester_1

Project 3: Geosynchronous Orbit: Part A

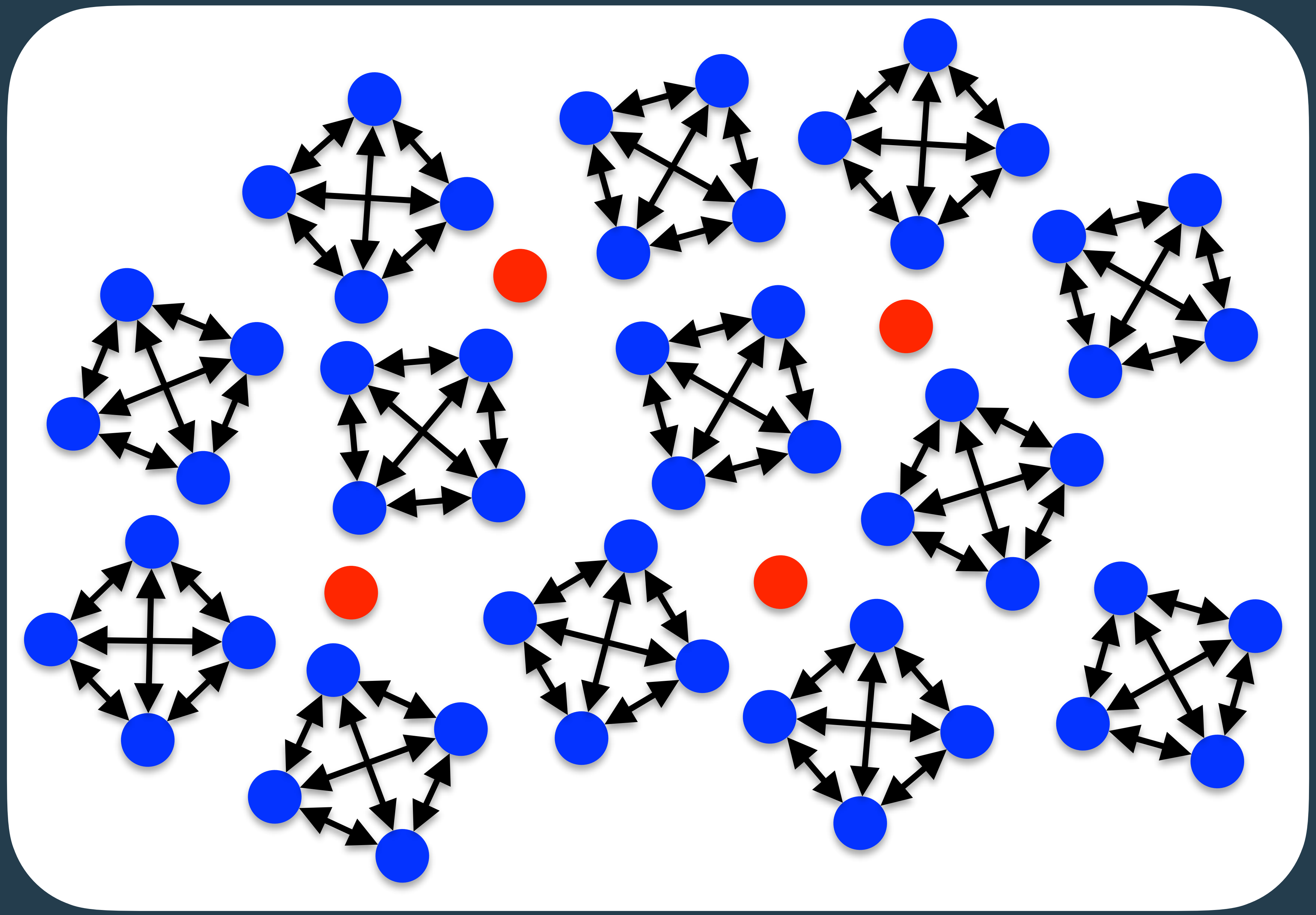
The Carver Media Group is planning the launch of a new communications satellite. Elliot Carver (head of Carver Media Group) is concerned about the launch. This is a $200,000,000 endeavor. In particular, he is worried about the orbital speed necessary to maintain the satellite's geosynchronus orbit (and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

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

Code for Project 3:
geosync.py
PhysUtil Module

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



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

msuperl.org/wikis/pcubed/

Investigating Learning Assistants' Instructional Approaches

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

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

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

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

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

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

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

        SatelliteMotionMap.update(t, pSatellite/mSatellite)

        t = t + deltat
```

How do learning assistants approach teaching computational problems?

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

Results

12 LAs Interviewed

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

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

Results

12 LAs Interviewed

Theme and Variation

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

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Category of Description

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

Teaching strategy

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

Kendra

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

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

Teaching strategy

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

Molly

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

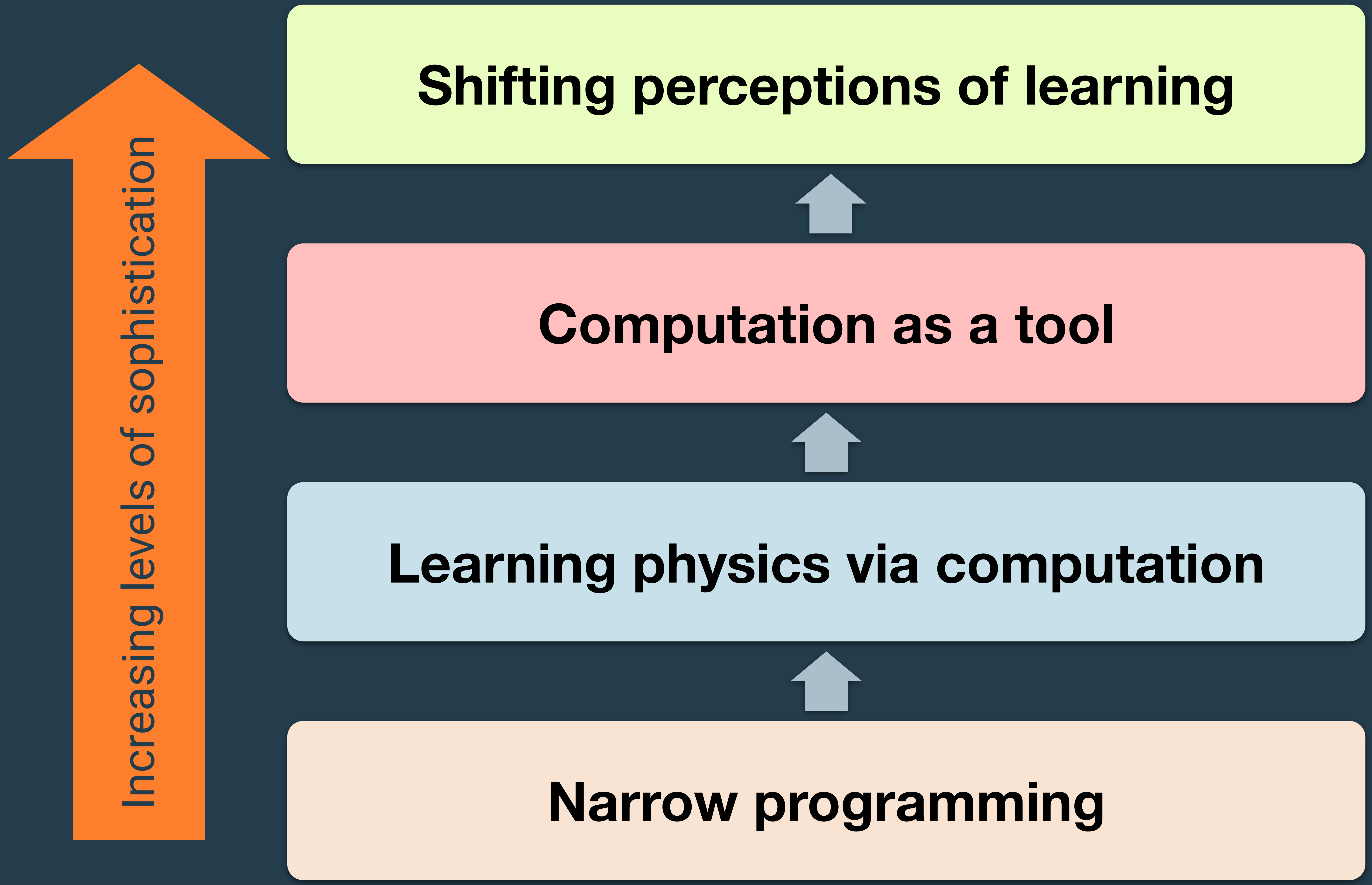
Pawlak, Irving, & Caballero, Phys. Rev. PER (2020)

Categories of description

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

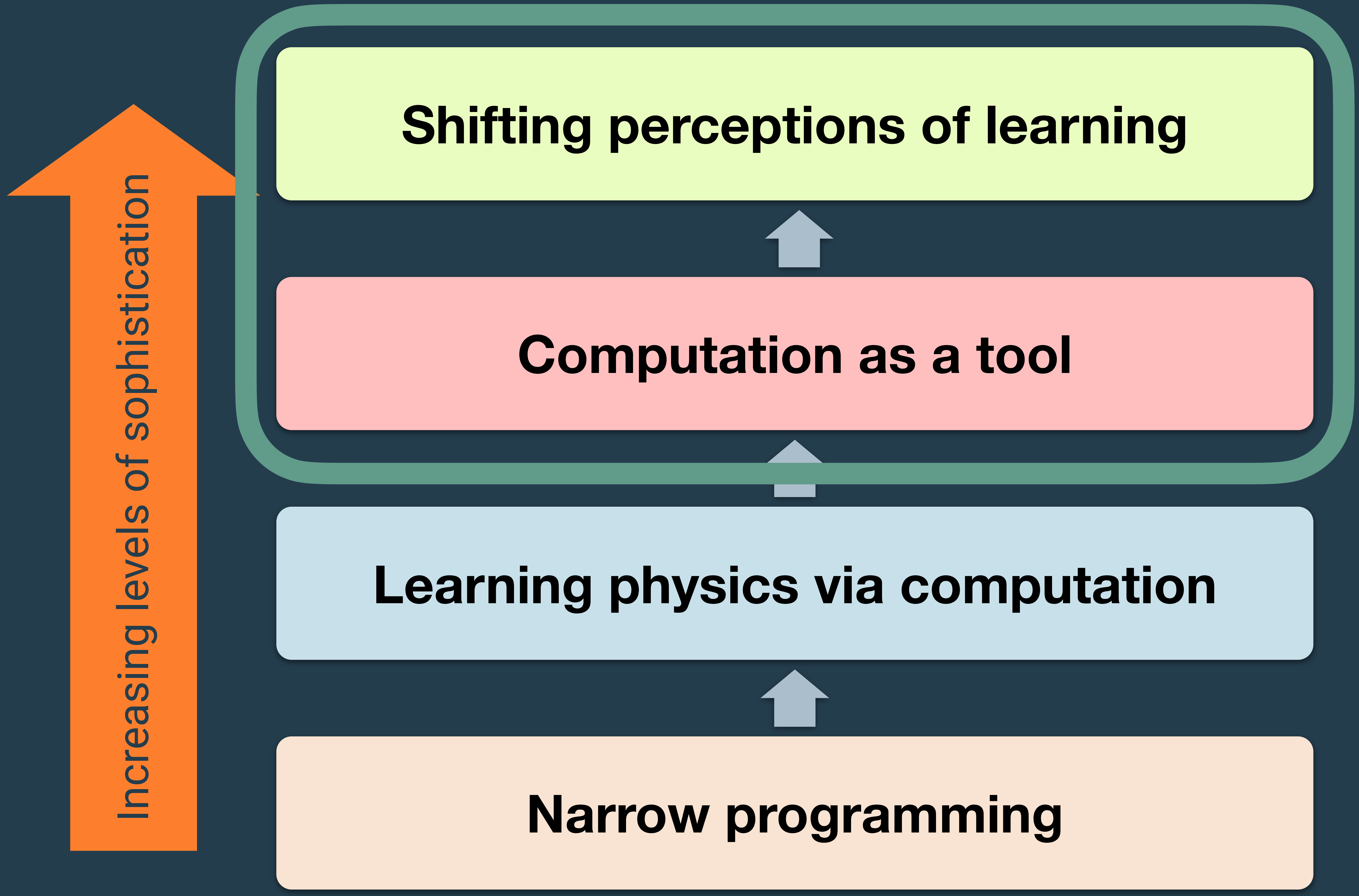
Pawlak, Irving, & Caballero, Phys. Rev. PER (2020)

Outcome space



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

Outcome space



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

Open Questions

Open Questions

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

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?

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?

How might you integrate computing across a physics department?


Disclaimer

Your mileage may vary.

Challenges for an R1 school

Challenges for an R1 school

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

Challenges for an R1 school

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

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Research Demand/Expectations
Time, energy, and interest vary
Instruction by TAs/LAs

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Time, energy, and interest vary
Big Changes -> Big Discussion

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inc. Dean/Chair/Undergrad Chair

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Diverse expertise and experience
Strong interest in computing

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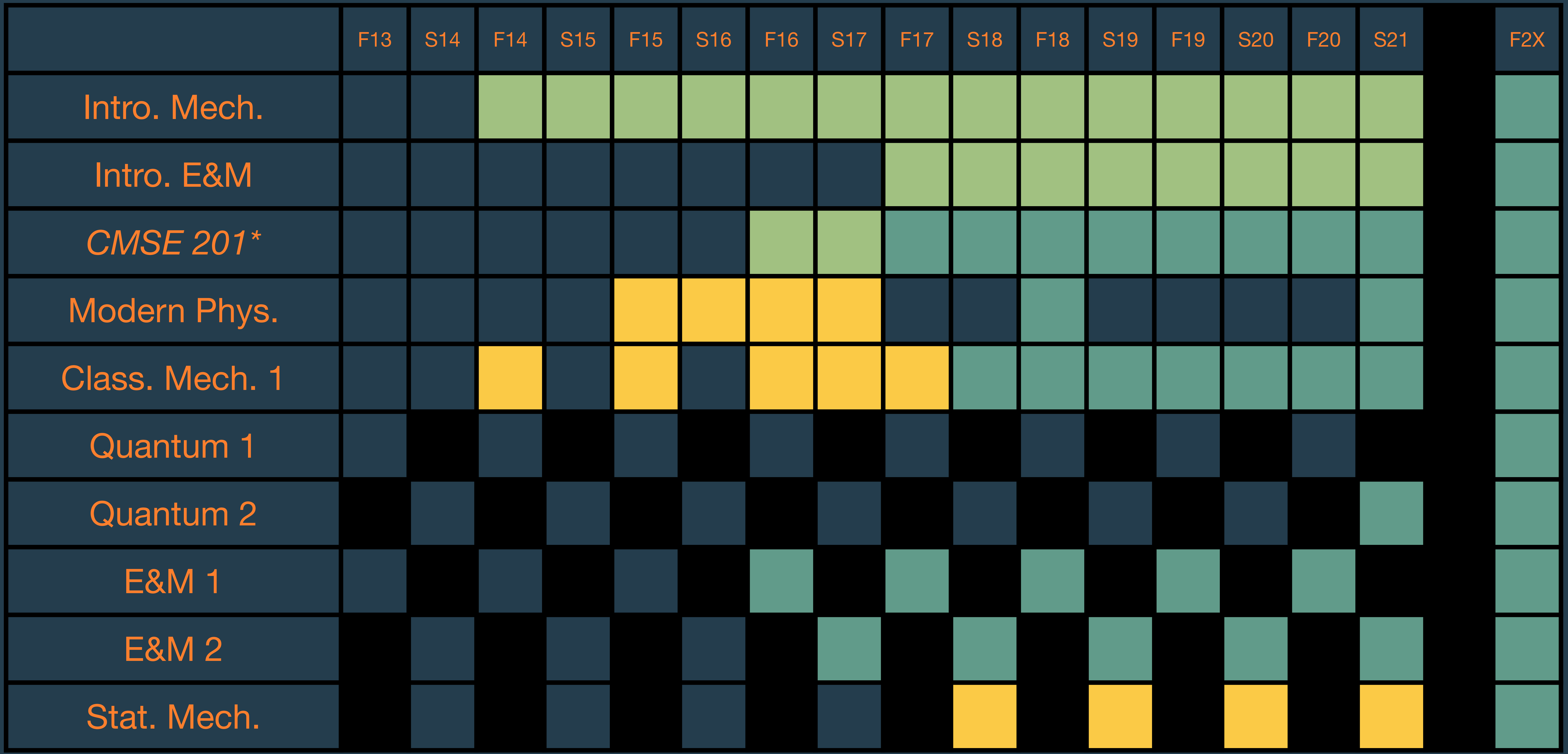
Physics Education Research Group

State-level Investment
New STEM Teaching Building

Timeline of Integrating Computation at MSU

Typical Course Progression



Timeline of Integrating Computation at MSU


Timeline of Integrating Computation at MSU
F13
S14
F14
S15
F15
S16
F16
S17
F17
S18
F18
S19
F19
S20
F20
S21
F2X
Intro. Mech.
Intro. E&M
CMSE 201*
Modern Phys.
Class. Mech. 1
Quantum 1
Quantum 2
E&M 1
E&M 2
Stat. Mech.
Typical Course Progression
COVID-19 Pandemic
Use of computational environment (e.g., plotting)
Instruction in computation (some sections)
Instruction in computation
Not offered


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
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Intro. E&M
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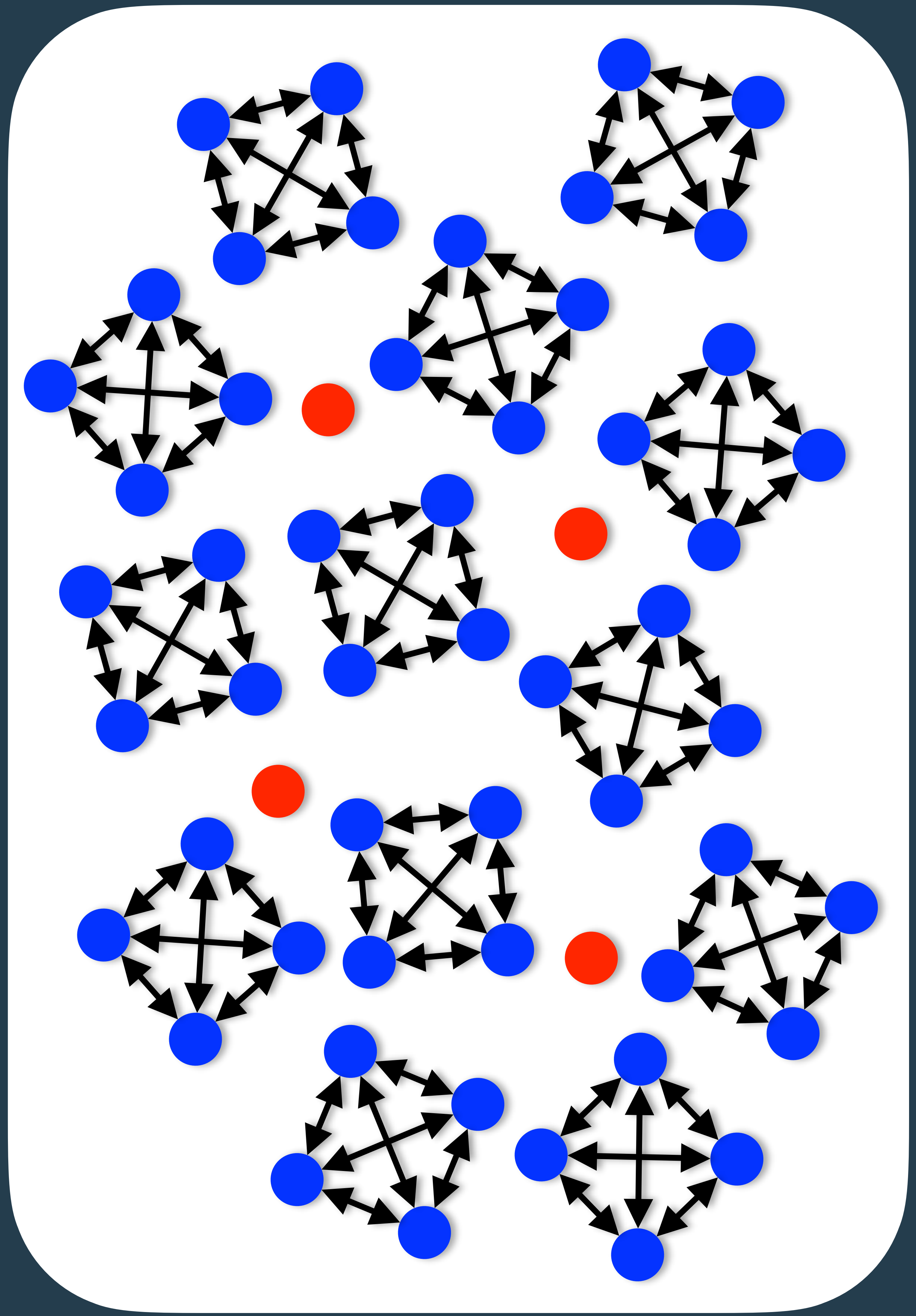
Not offered
PER Faculty

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

50-70 students/section



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

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


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.
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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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Part 4: Modeling a bungee jumper

Now required for PA students Before Classical Mechanics 1

Computing Education Research Lab

CMSE Research Program

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

Computing Education Research Lab

CMSE Research Program

- How do students develop an understanding of modeling, data science, and machine learning?

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

Computing Education Research Lab

CMSE Research Program

- How do students develop an understanding of modeling, data science, and machine learning?
- How do students' expectations, experiences, and sentiments shape their learning and participation in computational and data science?

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

Computing Education Research Lab

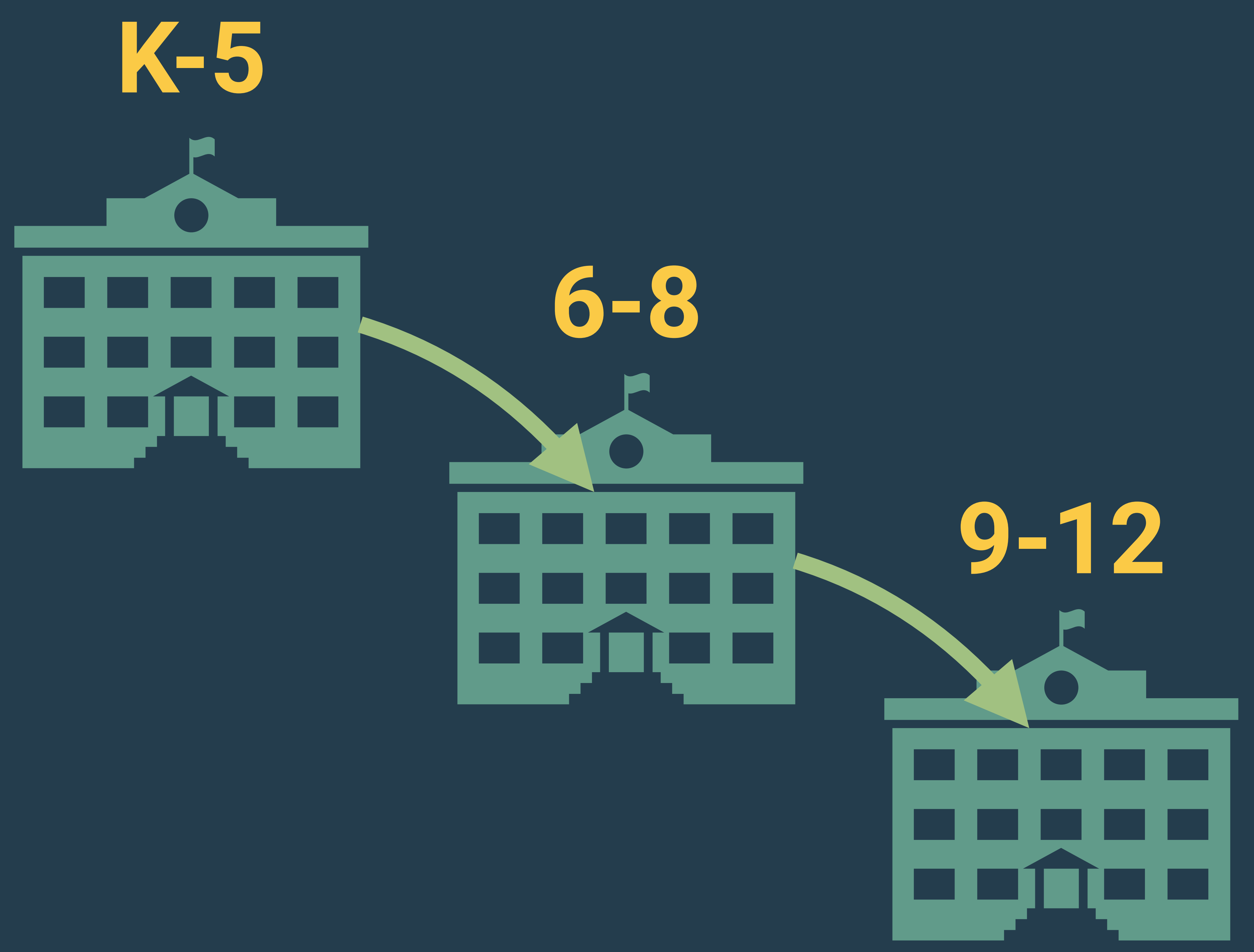
CMSE Research Program

- How do students develop an understanding of modeling, data science, and machine learning?
- How do students' expectations, experiences, and sentiments shape their learning and participation in computational and data science?
- What pedagogical and curricular elements are useful for learning data science and machine learning?

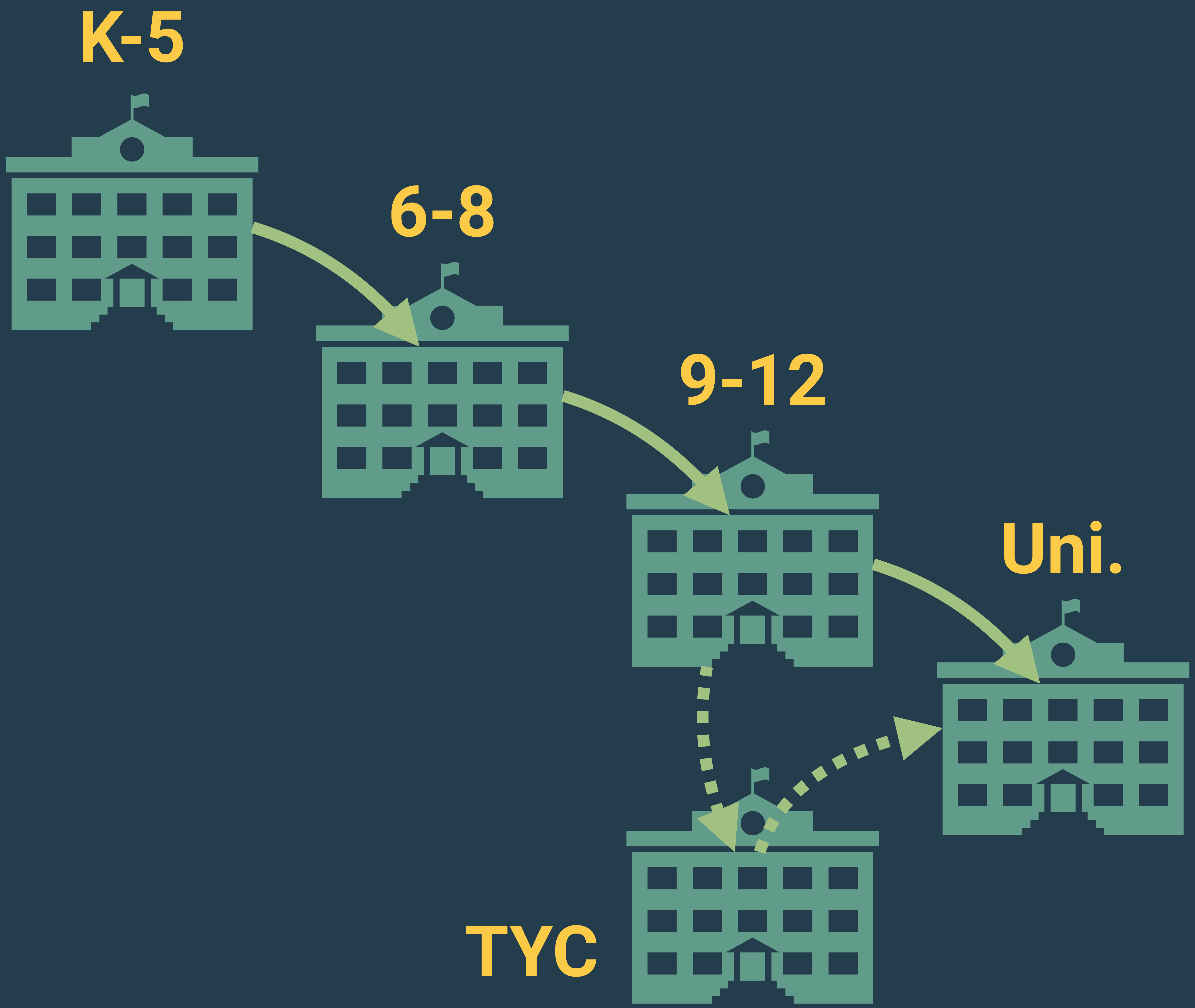
https://msu-cerl.github.io/

K-5


K-5
6-8


K-5
6-8
9-12


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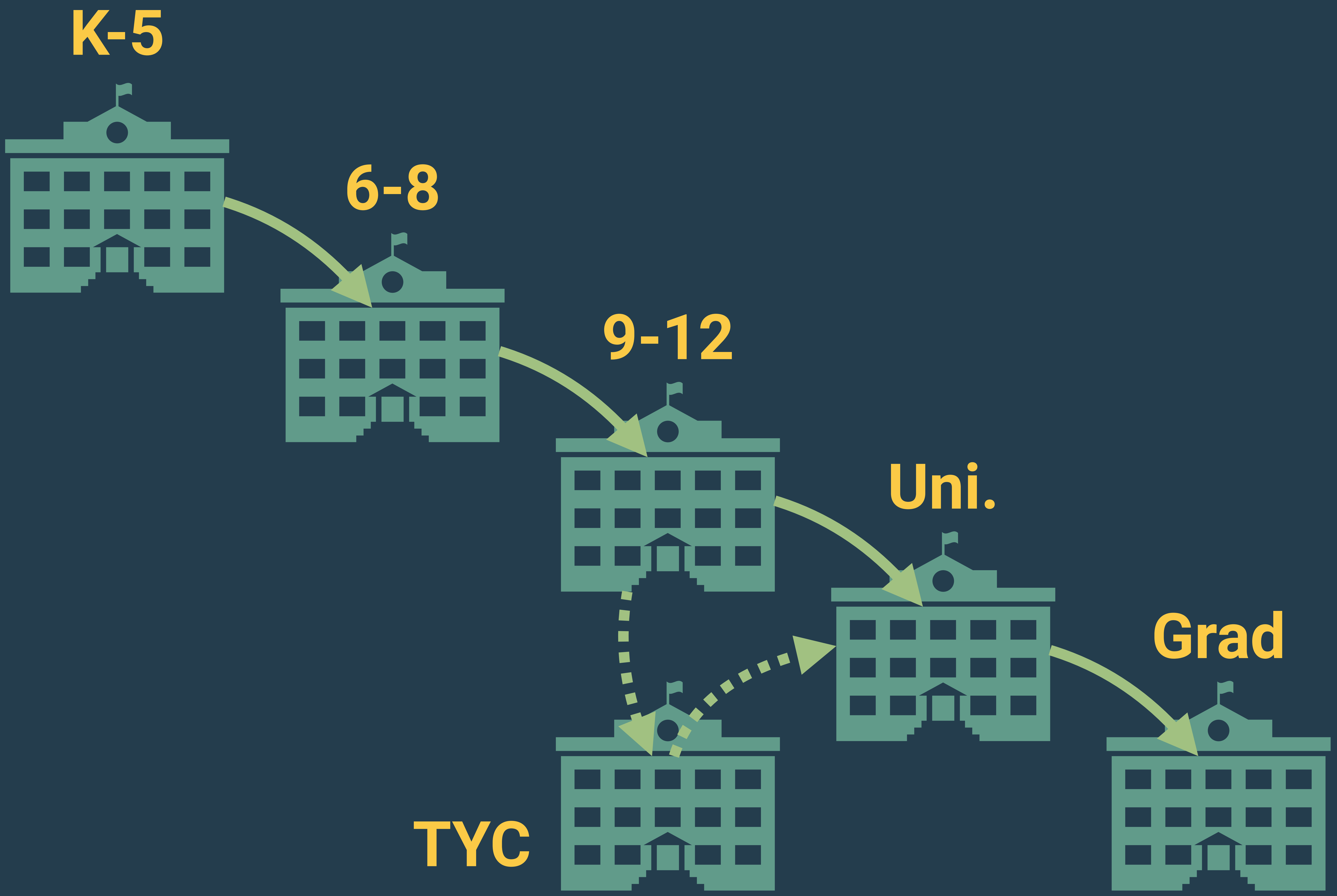
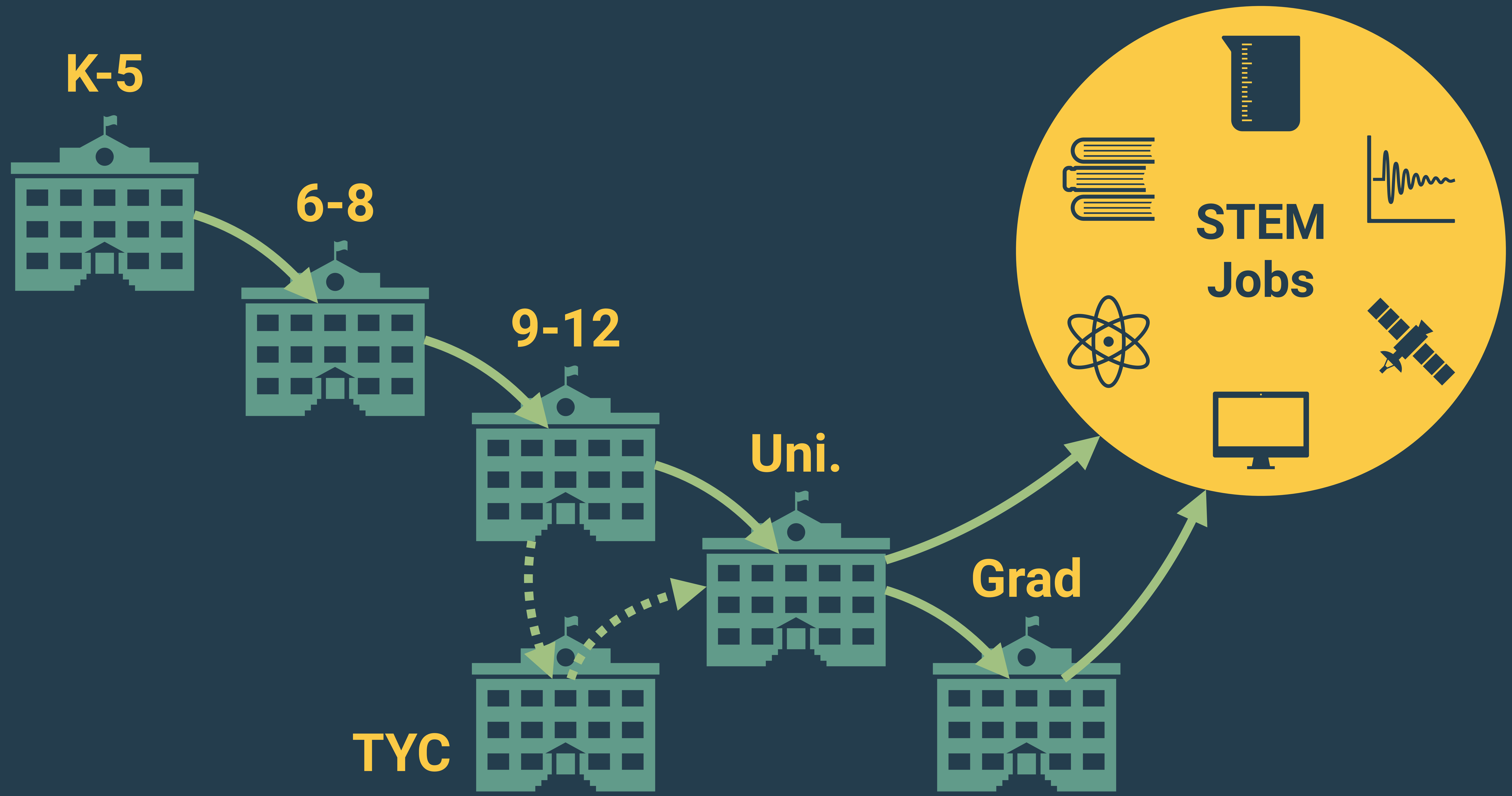
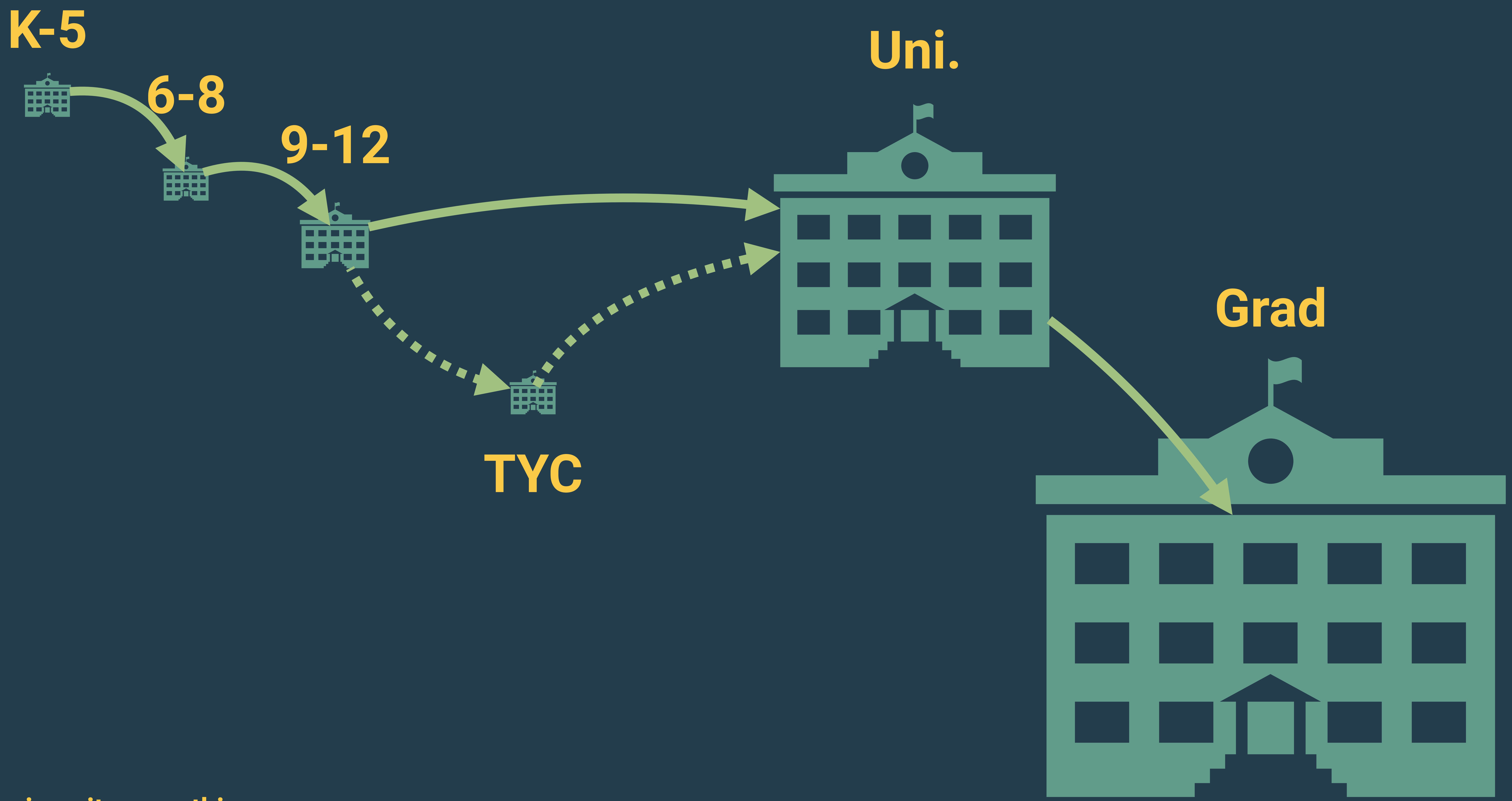
TYC


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


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



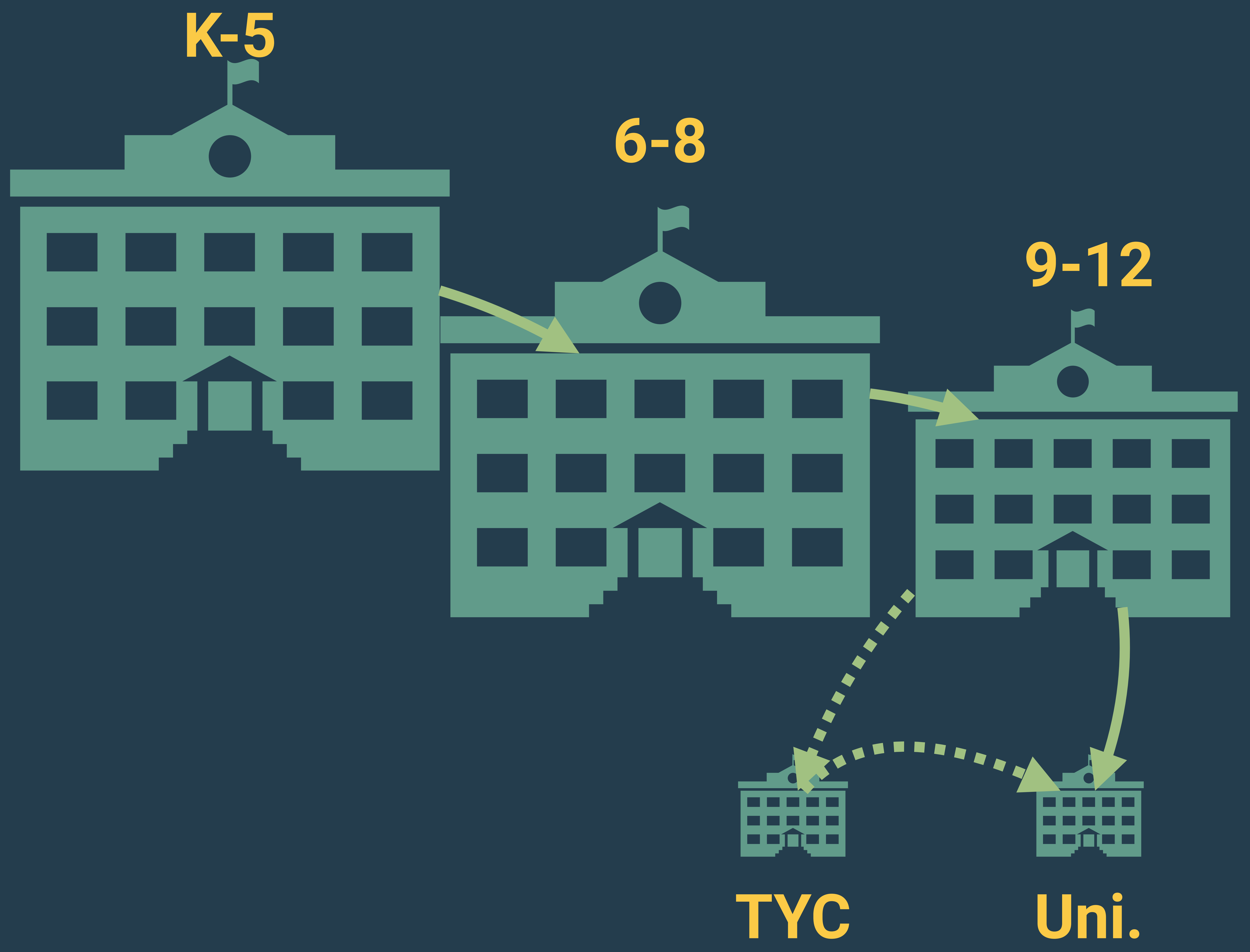
How a university sees things

How numbers of students are distributed

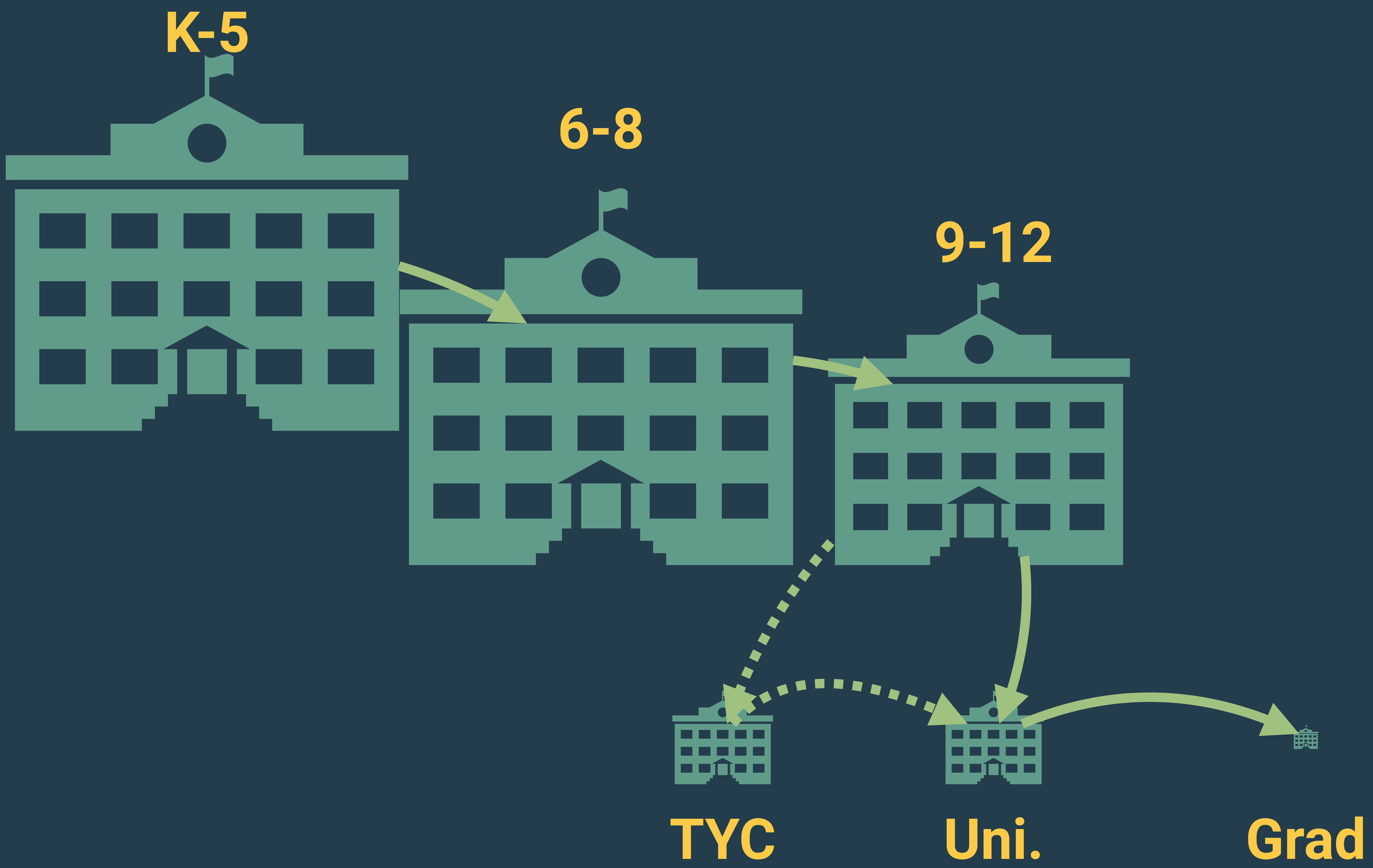
How numbers of students are distributed

How numbers of students are distributed

How numbers of students are distributed



How numbers of students are distributed



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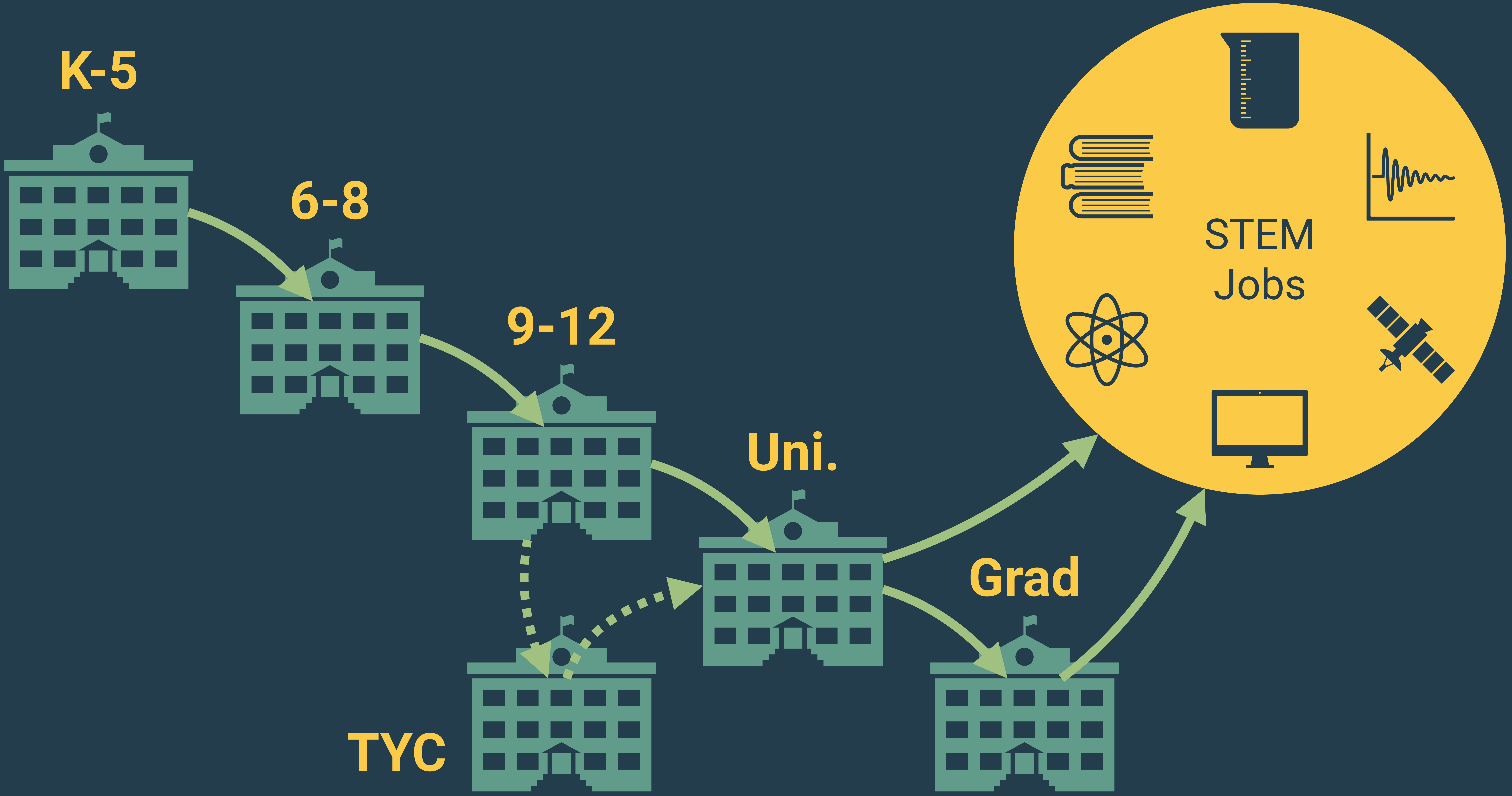
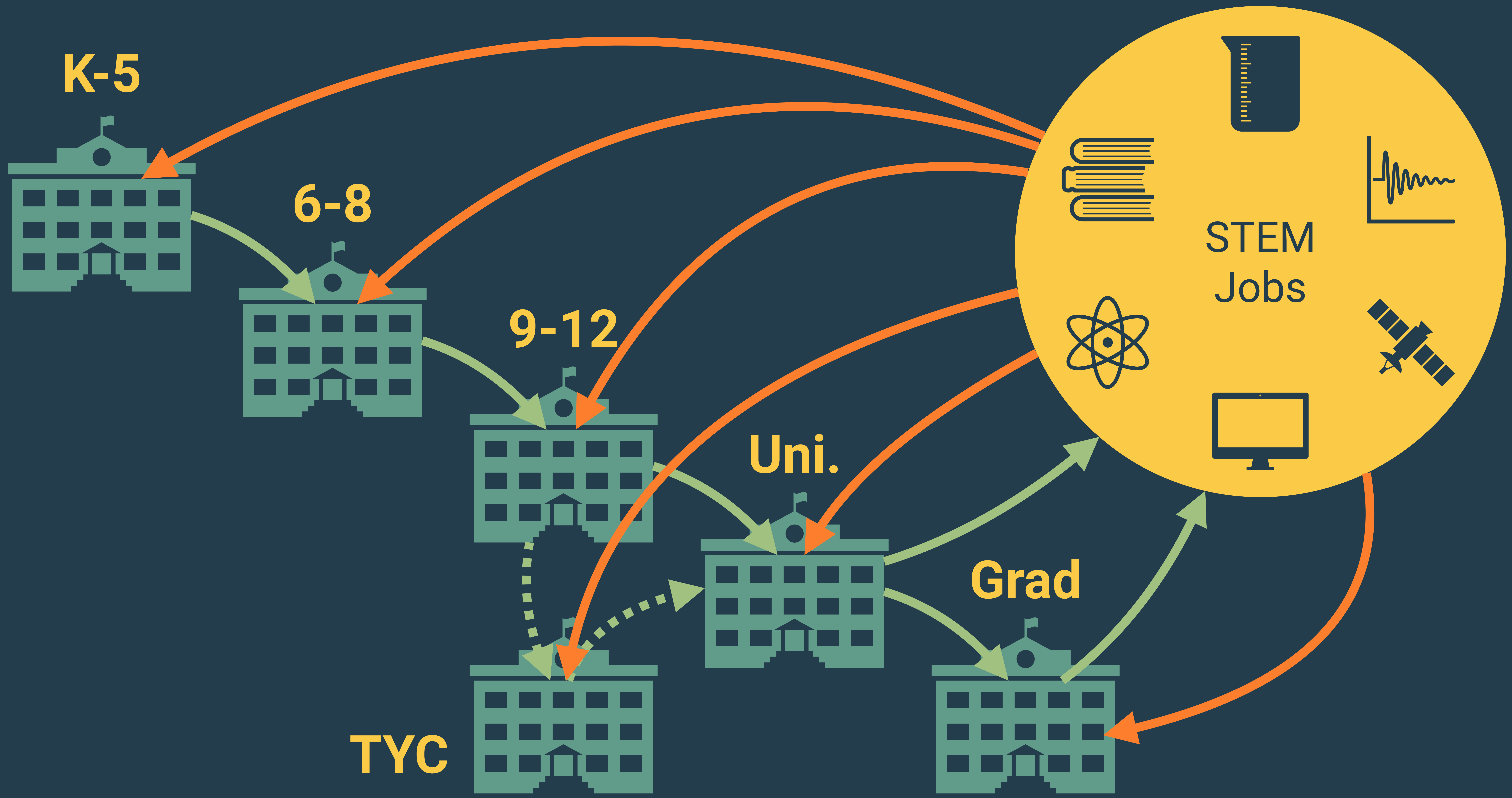


There's feedback in the system



There's feedback in the system


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

Integrating Computing in Science Across the Mitten

Create a computational model to calculate…

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

Use mathematical or computational representations to predict the motion…

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

ICSAM Workshop

Weeklong Summer Camp for High School Teachers

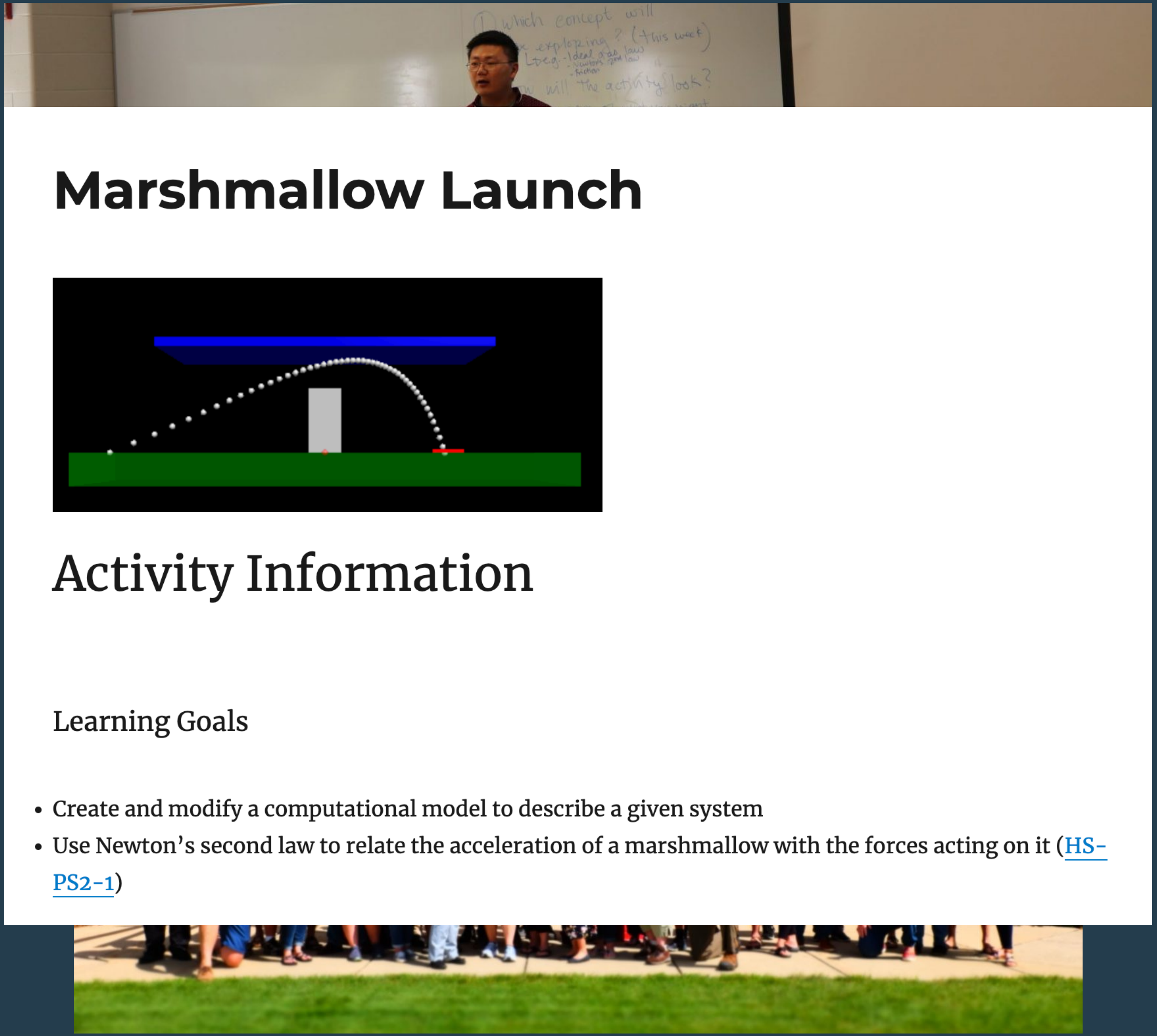
- Introduce computing
- Develop materials
- Grow community
- Focus on equity

Return to MSU (virtual during COVID)

- Addressing problems of practice
- Community building

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

ICSAM Workshop


Marshmallow Launch

Activity Information

Learning Goals

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

Weeklong Summer Camp for High School Teachers

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

Return to MSU (virtual during COVID)

- Addressing problems of practice
- Community building

Many teacher-developed materials!

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

ICSAM is also a research lab

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

Editors' Suggestion

Students' perspectives on computational challenges in physics class

Patti C. Hamerski,[1] Daryl McPadden,[1] Marcos D. Caballero,[1,2] and Paul W. Irving[1]

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

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

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

Daniel P. Weller,[1,2] Theodore E. Bott,[1] Marcos D. Caballero,[1,3,4] and Paul W. Irving[1]

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

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

Routledge
Taylor & Francis Group

Check for updates

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

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

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

ABSTRACT

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

ARTICLE HISTORY
Received 31 October 2019
Accepted 31 July 2020

KEYWORDS

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

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

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

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

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

EQUIP: Equity QUantified In Par[...]

Analysis Framework for Computing Practices

Extracting Computational Insight
- Decomposing
- Highlighting and foregrounding

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

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

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

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

Analysis Framework for Computing Practices

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

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

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

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

Analysis Framework for Computing Practices

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

Practice	P1	P2	R1	R2	S1	S2
Decomposing			2	1	2	1
Highlighting and foregrounding			2	3	5	4
Translating physics into code			2		6	4
Algorithm building	2		5	3	1	
Applying conditional logic	1	1	1	1	2	
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- What do teachers learn from doing computing in physics classes?
- How do we grow and replicate this program for more teachers and students?
- What issues of equity and justice are appearing in classrooms where computing has been introduced?

Final Takeaways

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- It's essential that we learn how to. The future of STEM requires it.
- It's gonna be a lot of work. But a lot of fun, too.

So many more open questions….

New methods and tools?

Machine Learning, Data Science, Quantum Computing

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Curriculum and pedagogy?

Beyond Content, Assessment, Longer Timescales

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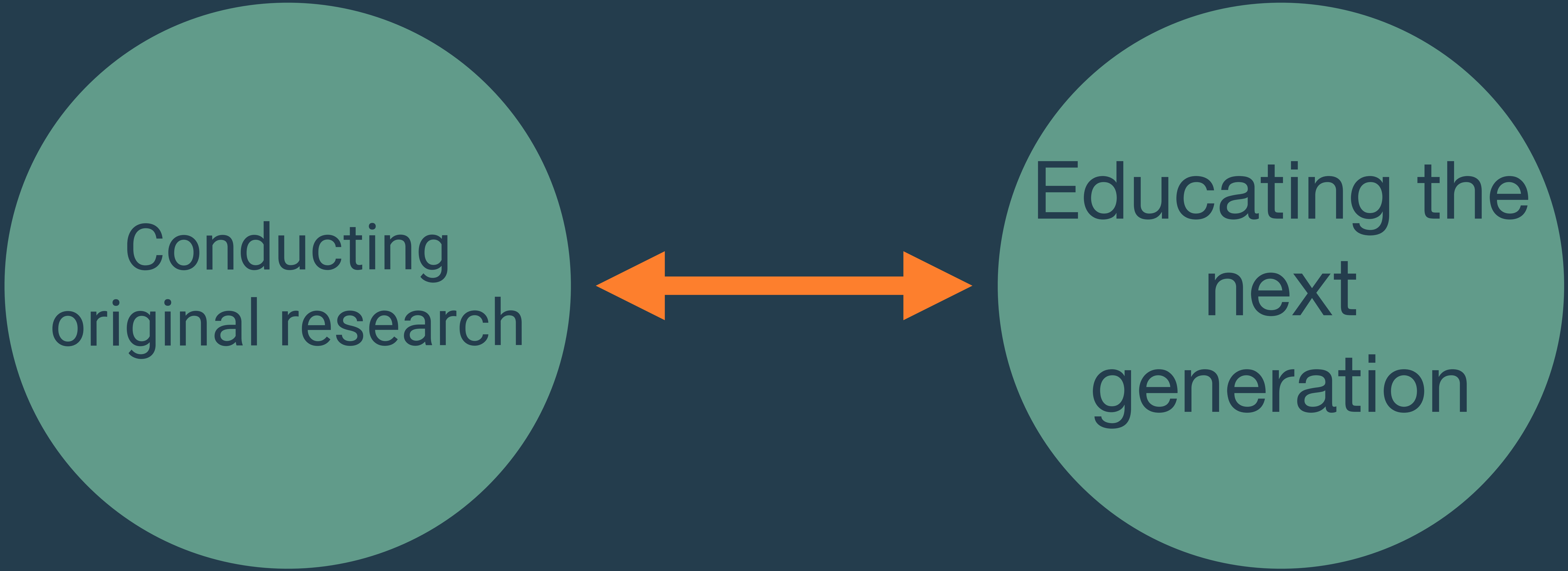
Concerns about justice?
Ethics, Bias, Equity and Inclusion

So many more open questions….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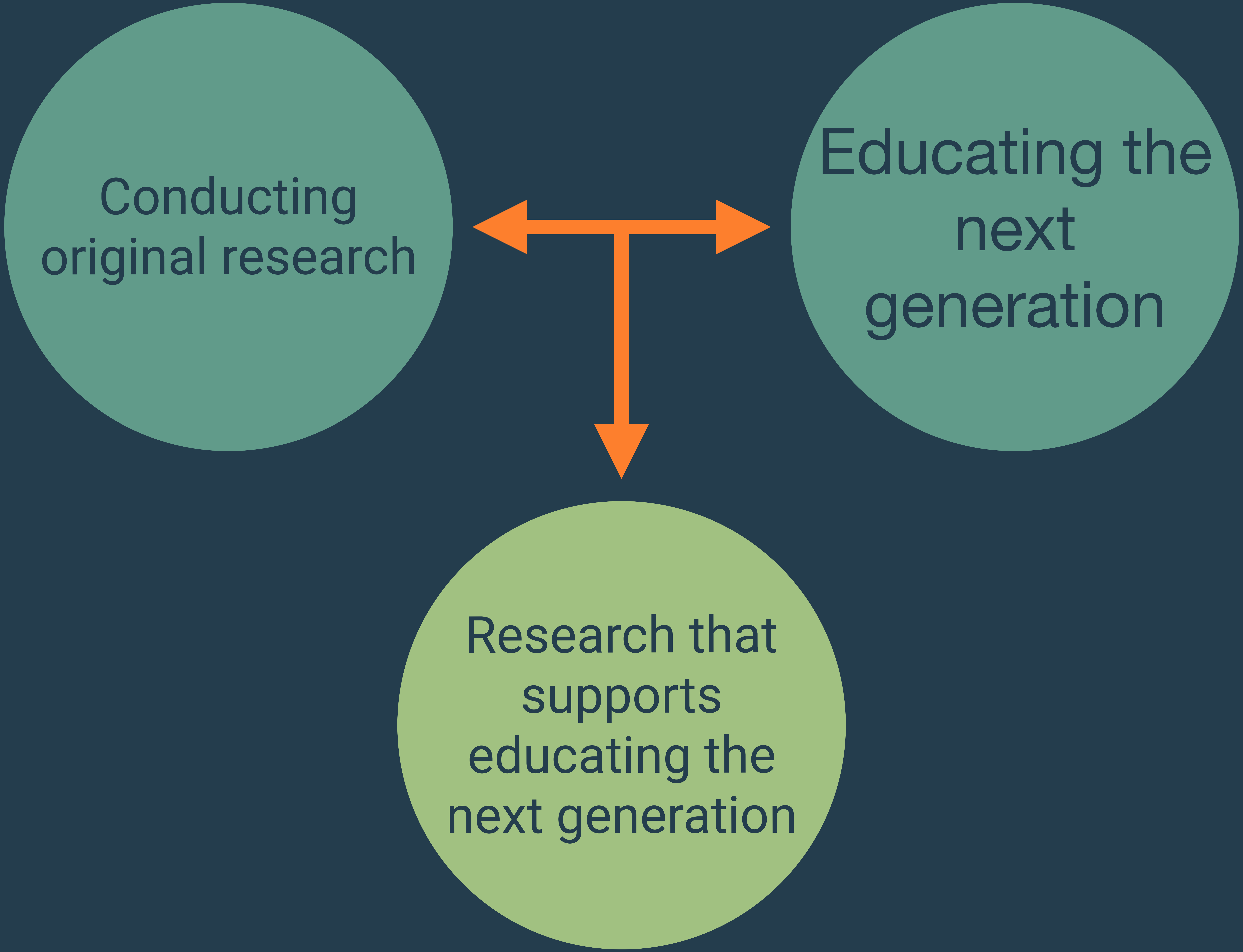
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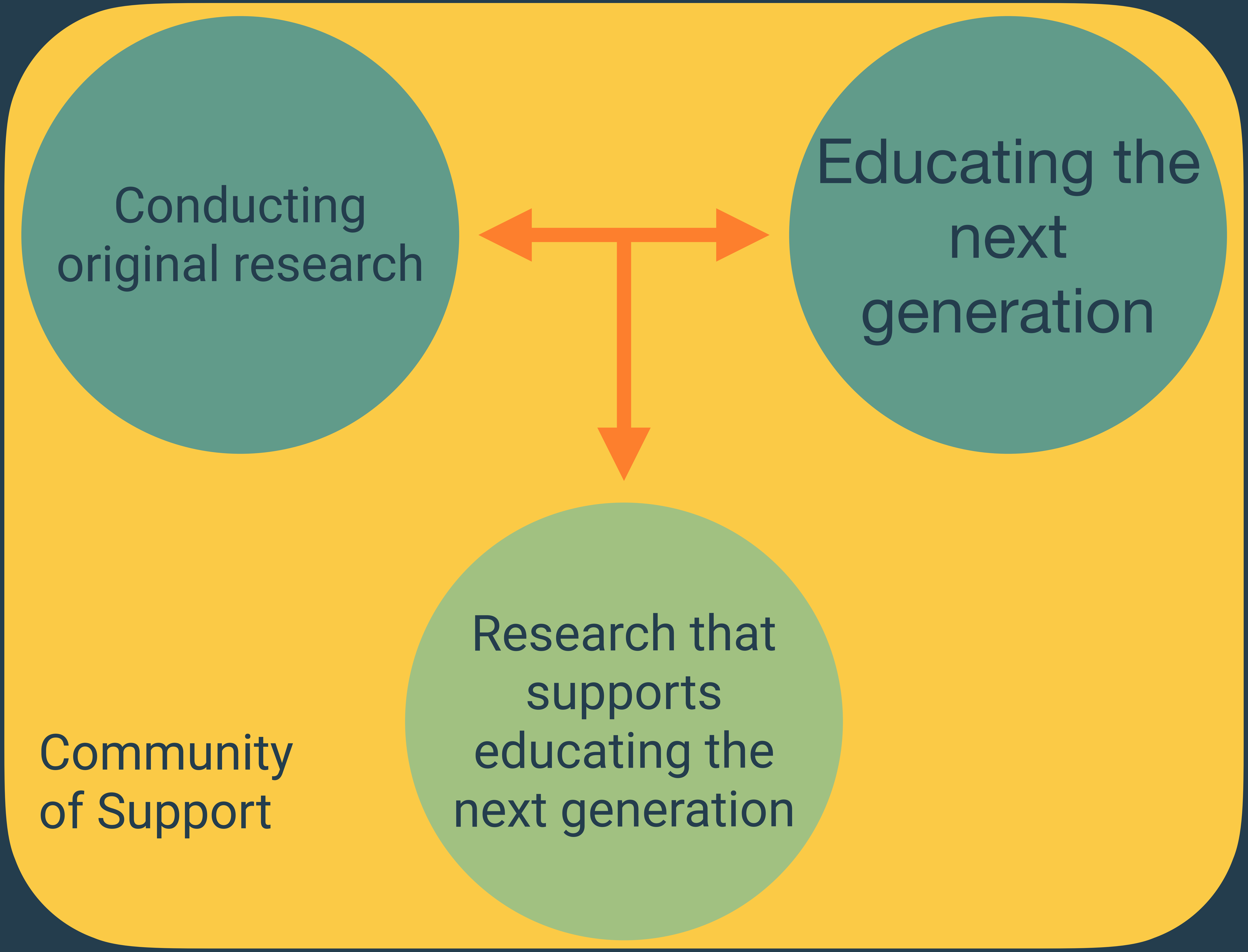

Conducting original research
Educating the next generation
Research that supports educating the next generation
Community of Support

Thank you!

Thank y’all

Questions?

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