Texas Tech - Feb 6, 2018

How might physics education research help facilitate the computational revolution in education?

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What has computation done for physics?

SCIENCE

Physicists Find Elusive Particle Seen as Key to Universe

By DENNIS OVERBYE JULY 4, 2012

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

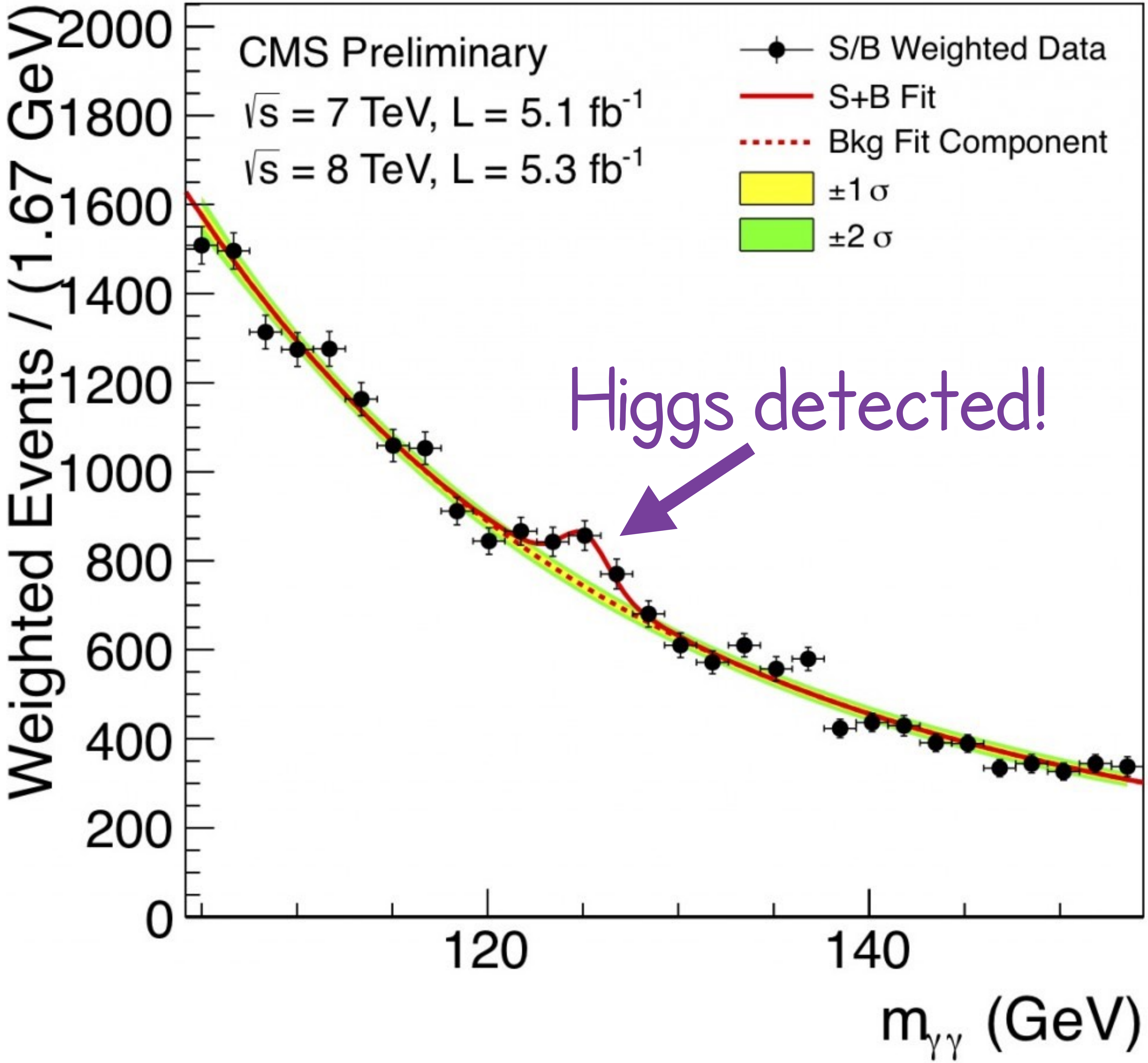
THE LEDE BLOG
What in the World Is a Higgs Boson?
JULY 4, 2012

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

RECENT COMMENTS

Robert L. Oldershaw July 5, 2012
It seems to me that theoretical particle physics is more religio
than science.If theories can avoid any predictions whatsoever
(e.g.,...

ASPEN, Colo. — Signaling a likely end to one of the longest, most expensive searches in the history of science, physicists said Wednesday that they had

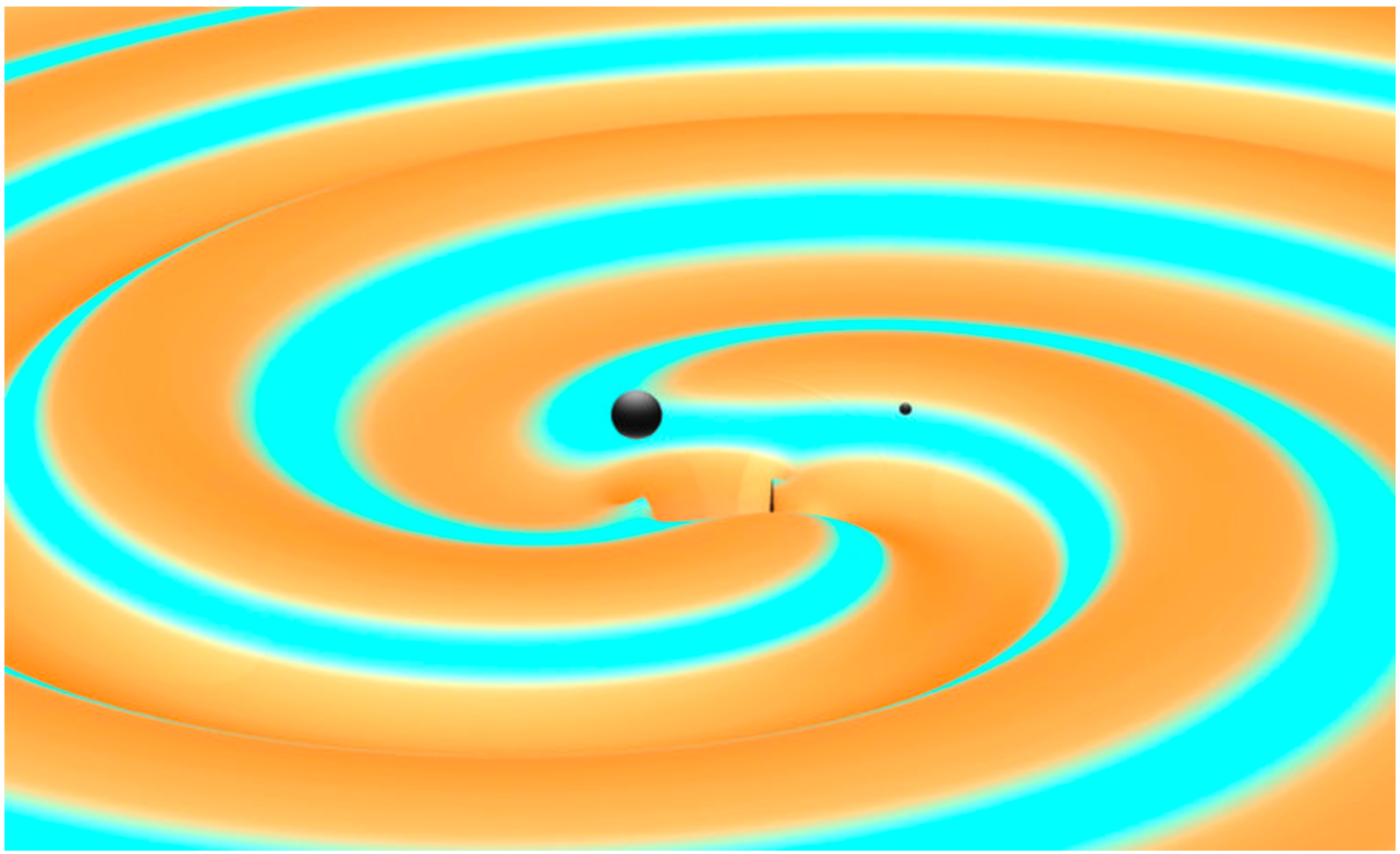


CMS Preliminary
√s = 7 TeV, L = 5.1 fb-1
√s = 8 TeV, L = 5.3 fb-1
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1 σ
±2 σ
Higgs detected!
Weighted Events / (1.67 GeV)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
120
140
mγγ (GeV)

SCIENCE

Scientists Hear a Second Chirp From Colliding Black Holes

By DENNIS OVERBYE   JUNE 15, 2016



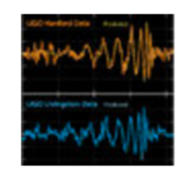
A depiction of two black holes just moments before they collided and merged with each other, releasing energy in the form of gravitational waves.

S. Ossokine, A. Buonanno, T. Dietrich, R. Haas (Max Planck Institute for Gravitational Physics), Simulating eXtreme Spacetime Project

RELATED COVERAGE

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

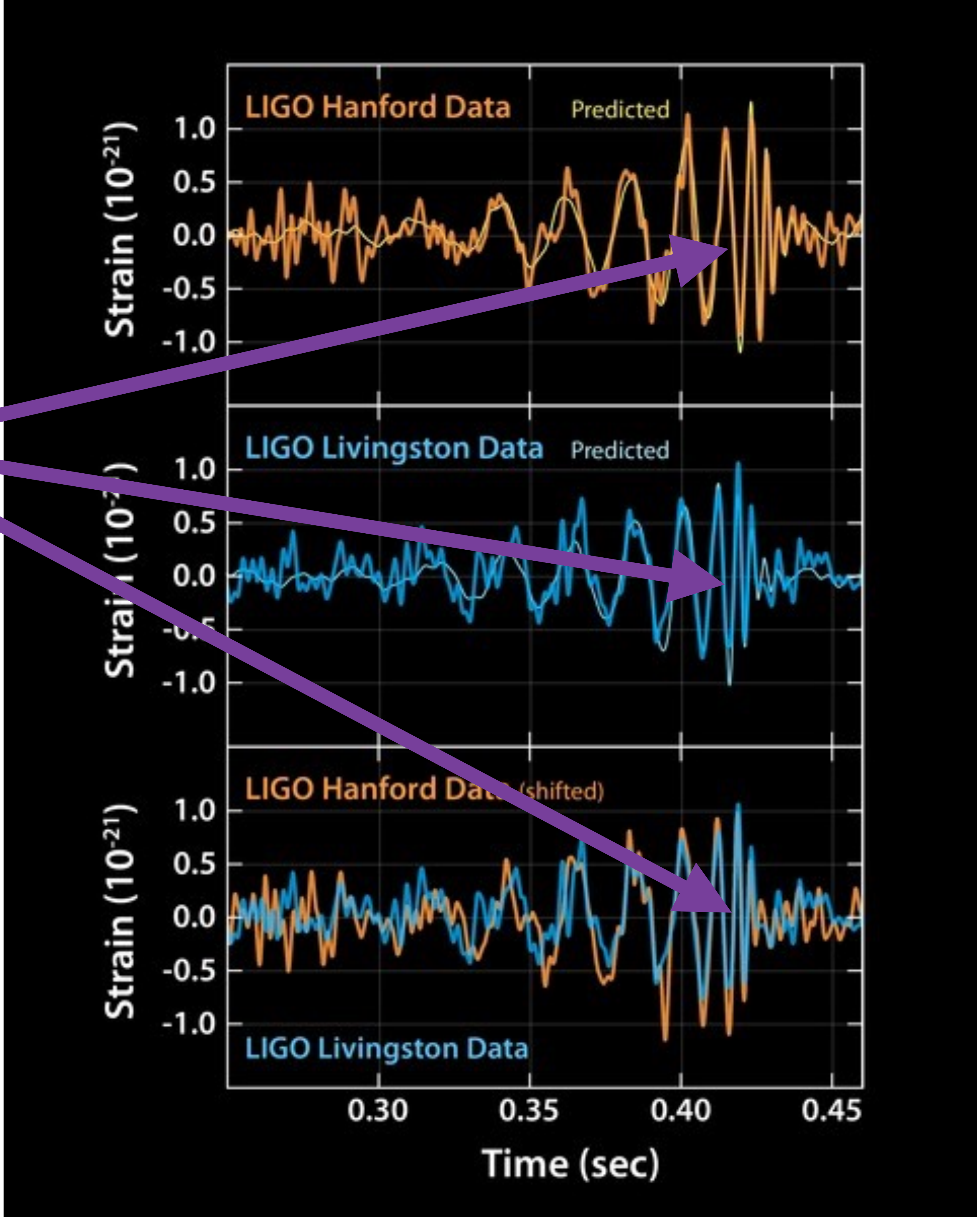
OUT THERE
Gravitational Waves Detected, Confirmi Einstein's Theory FEB. 11, 2016



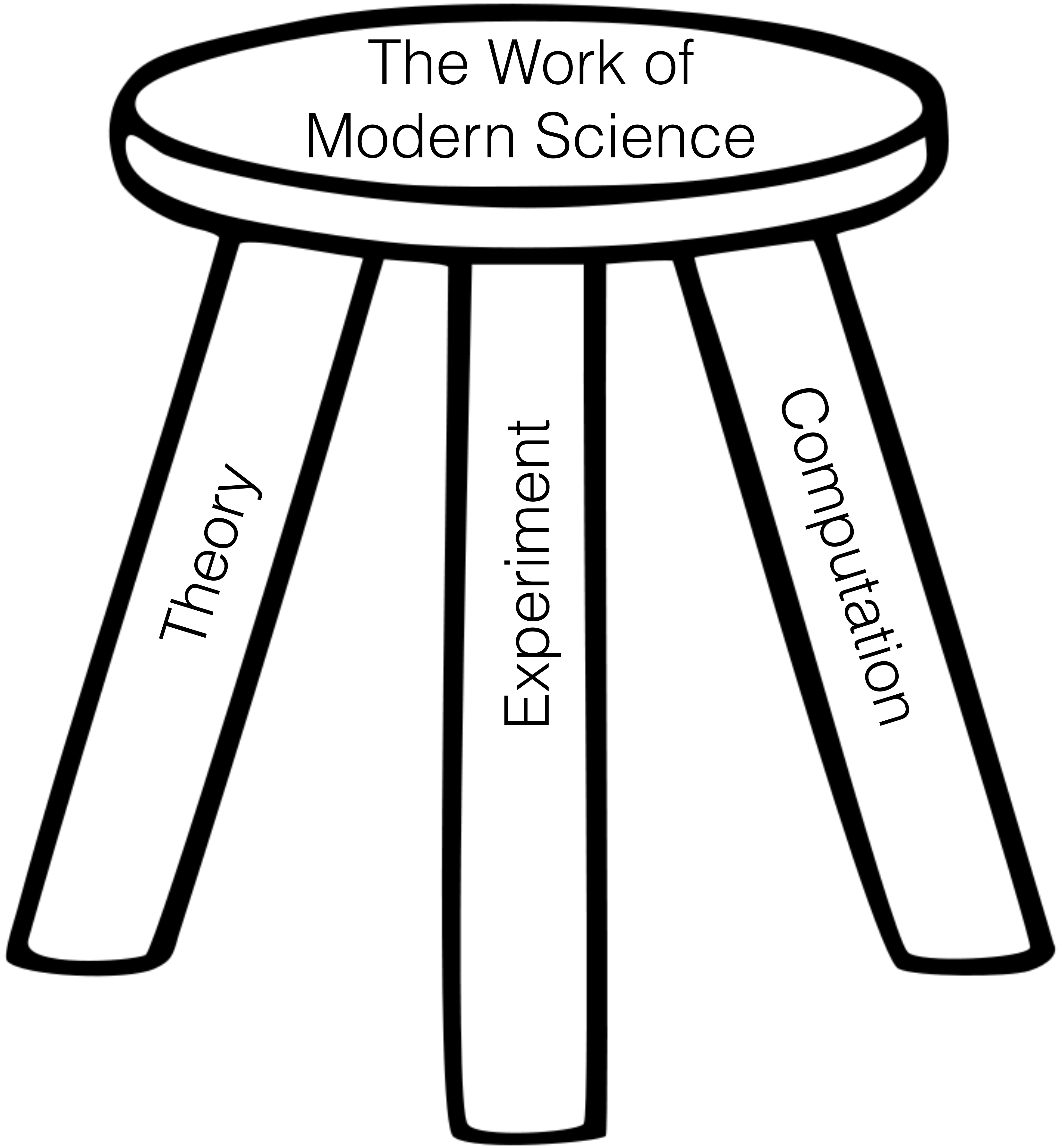
TRILOBITES
Scientists Chirp Excitedly for LIGO, Gravitational Waves and Einstein FEB. 11, 2016

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

Black hole
Merger
Ringdown!



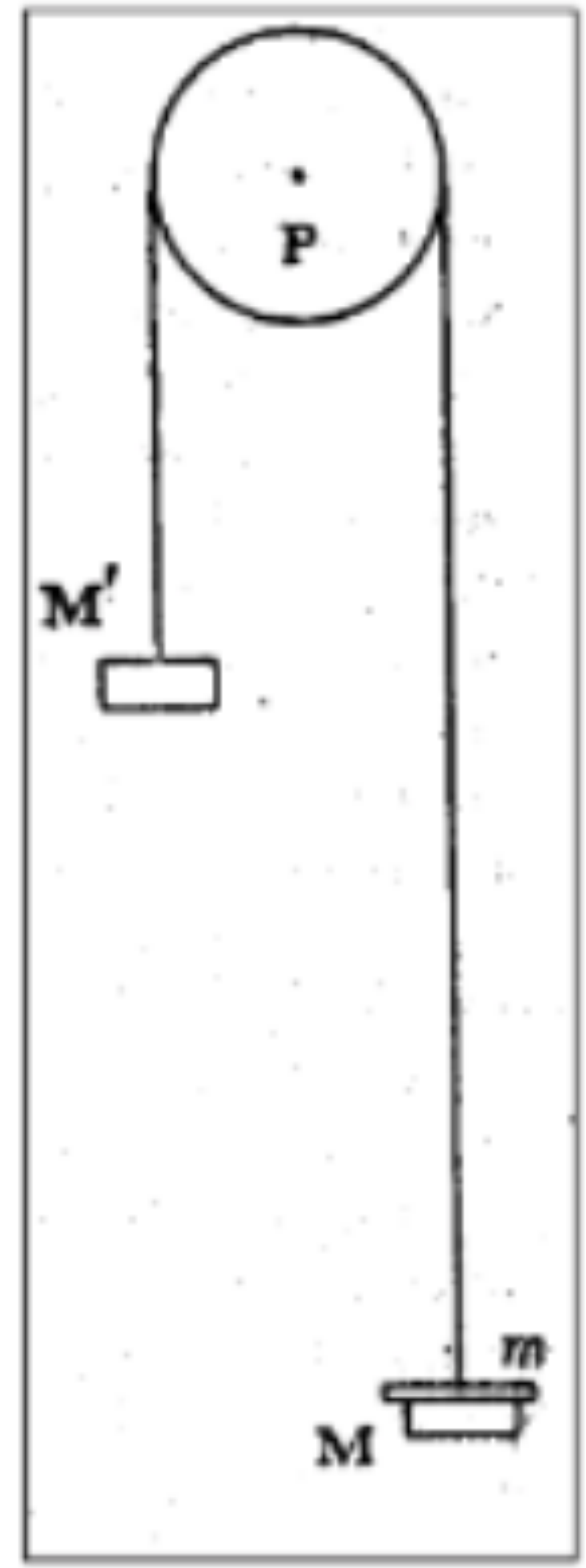
Computation is how modern science is done.



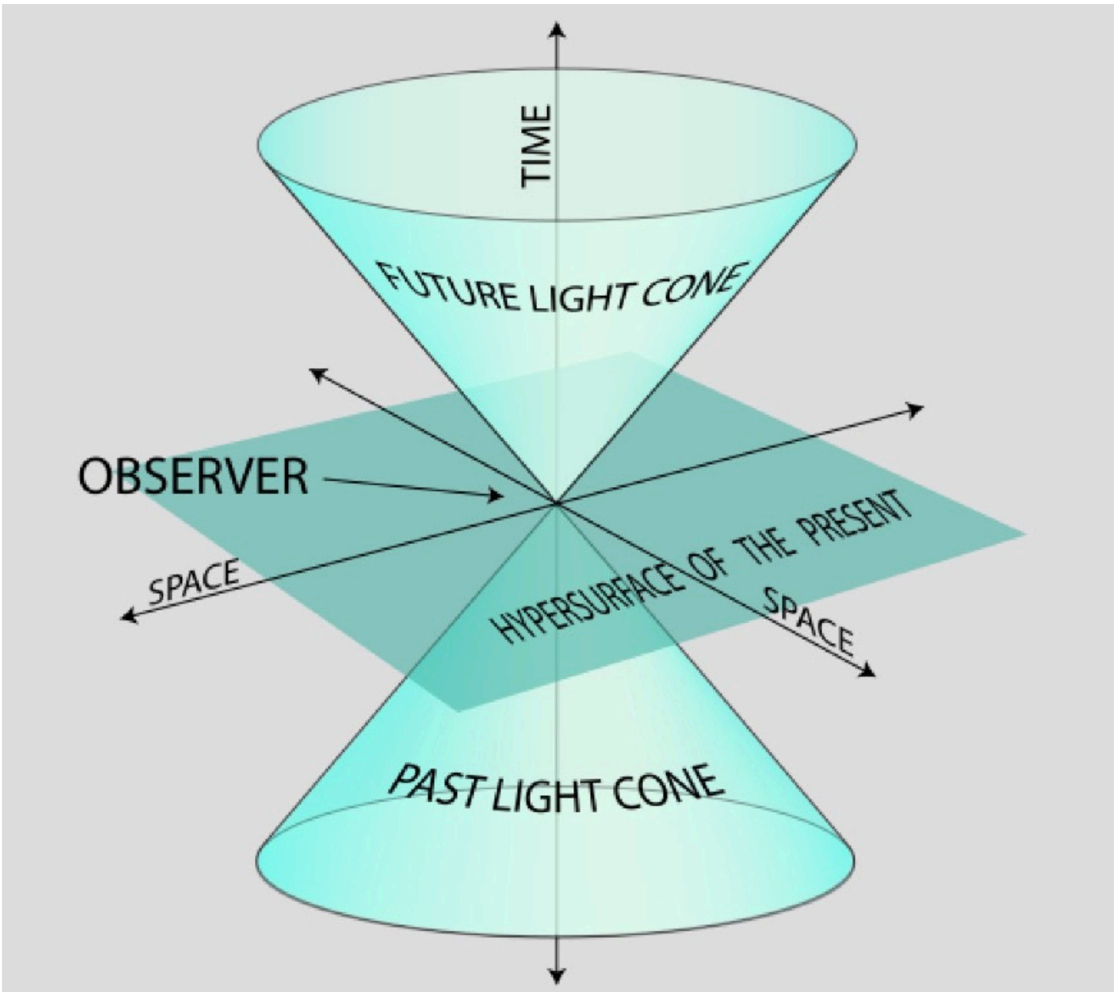
What has changed in physics education?

1860s-1880s

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$



1900s-1910s



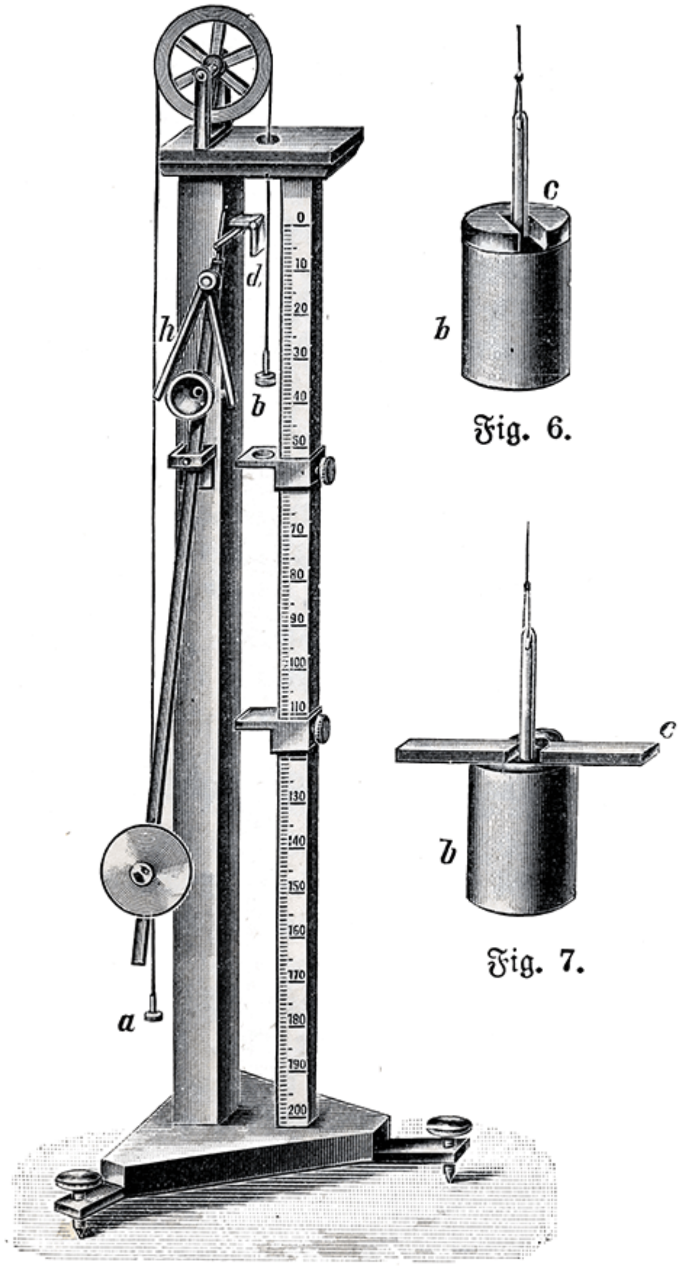
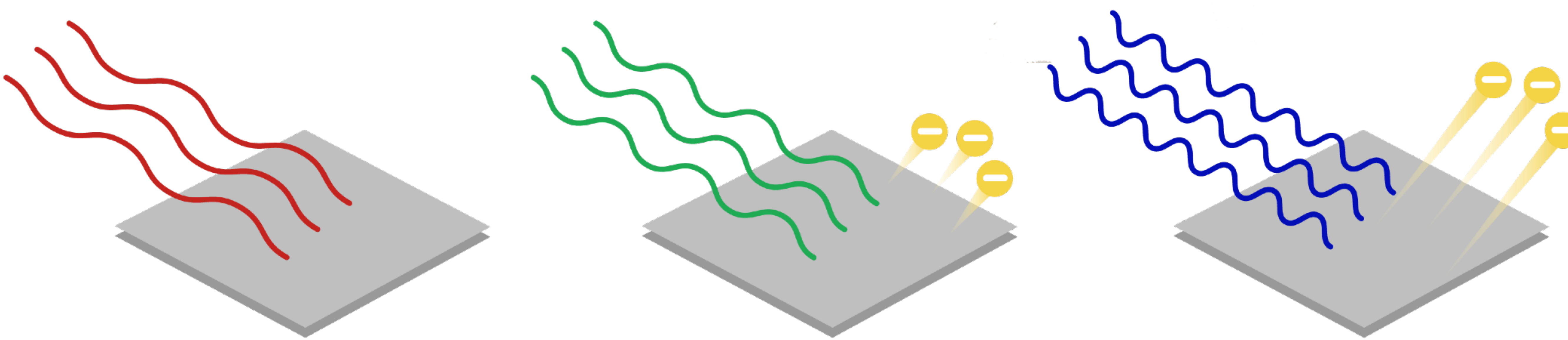
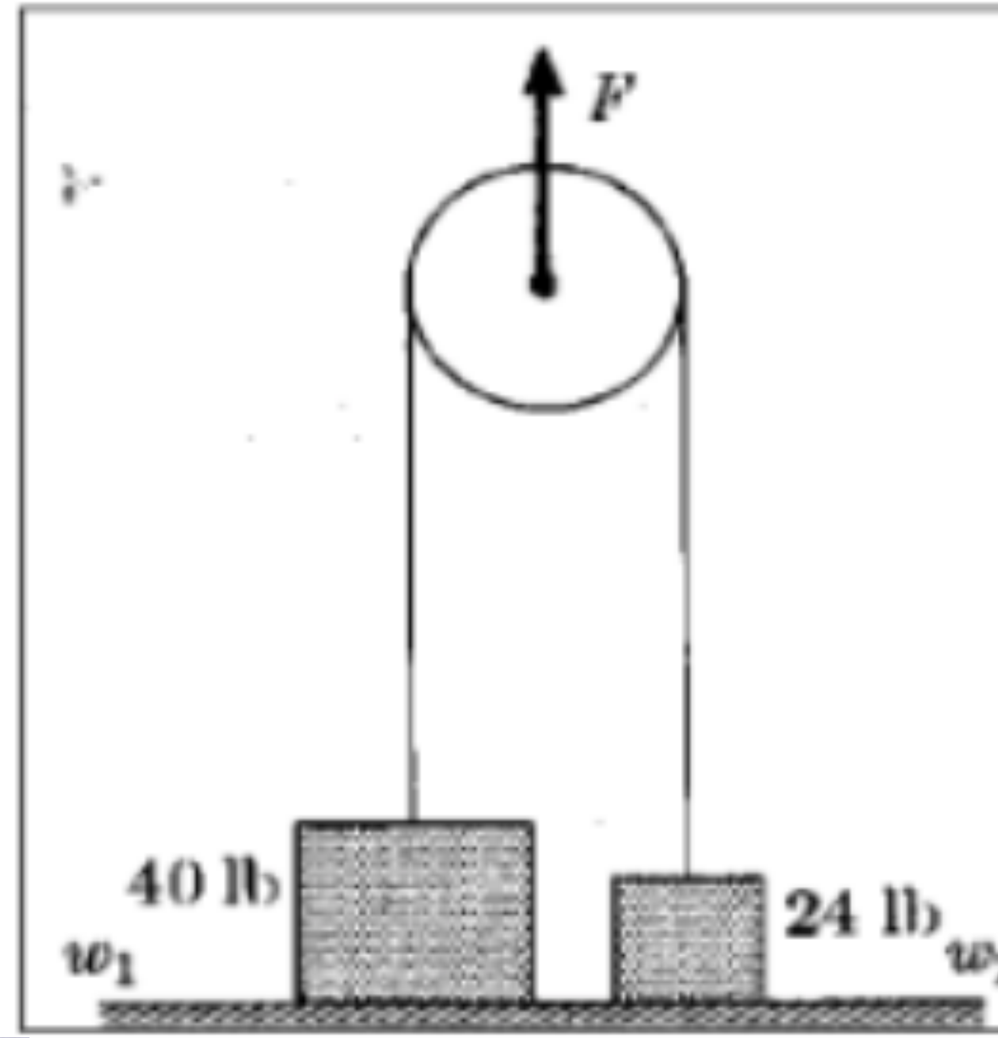


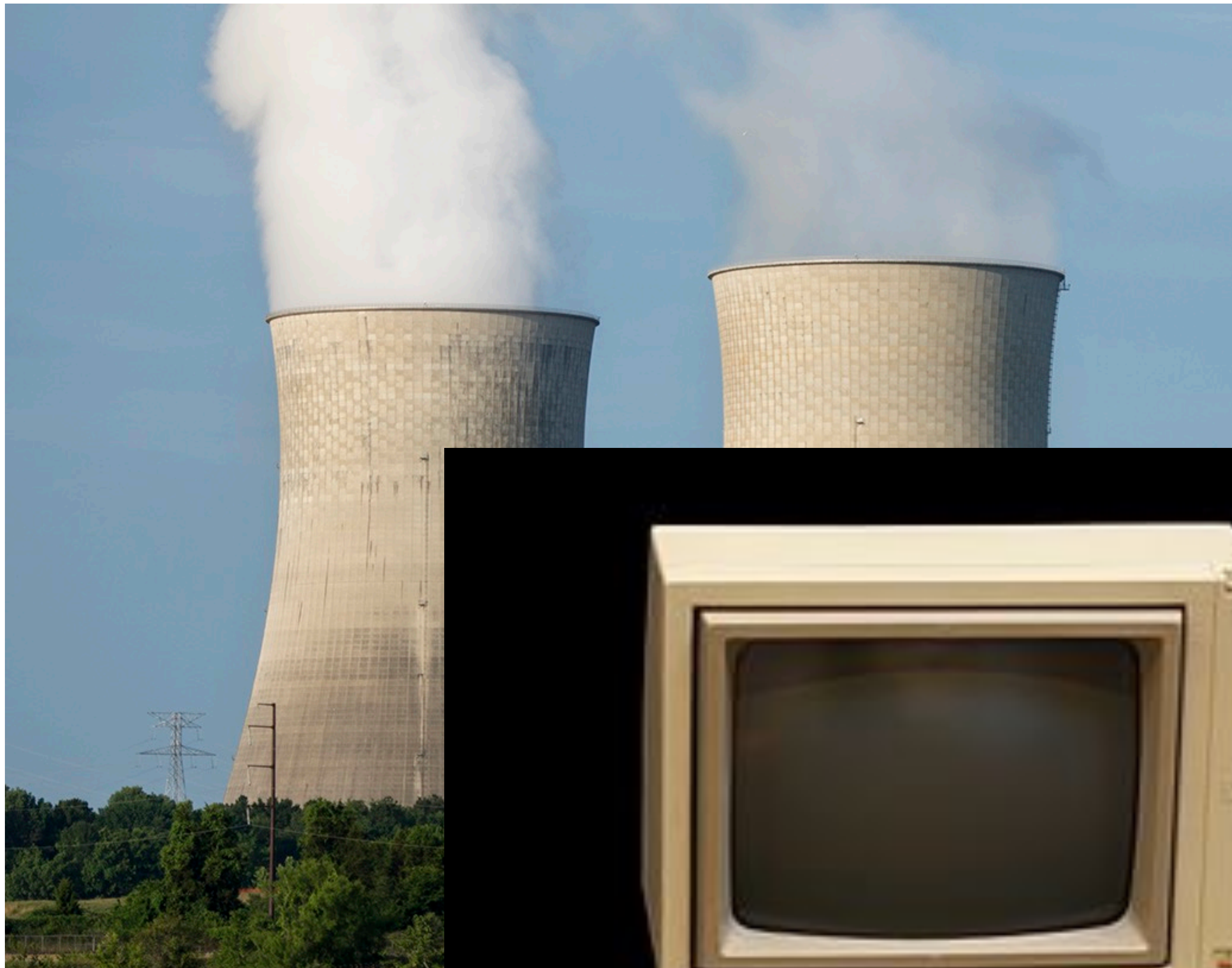
Fig. 5.
Atwoodsche Fallmaschine

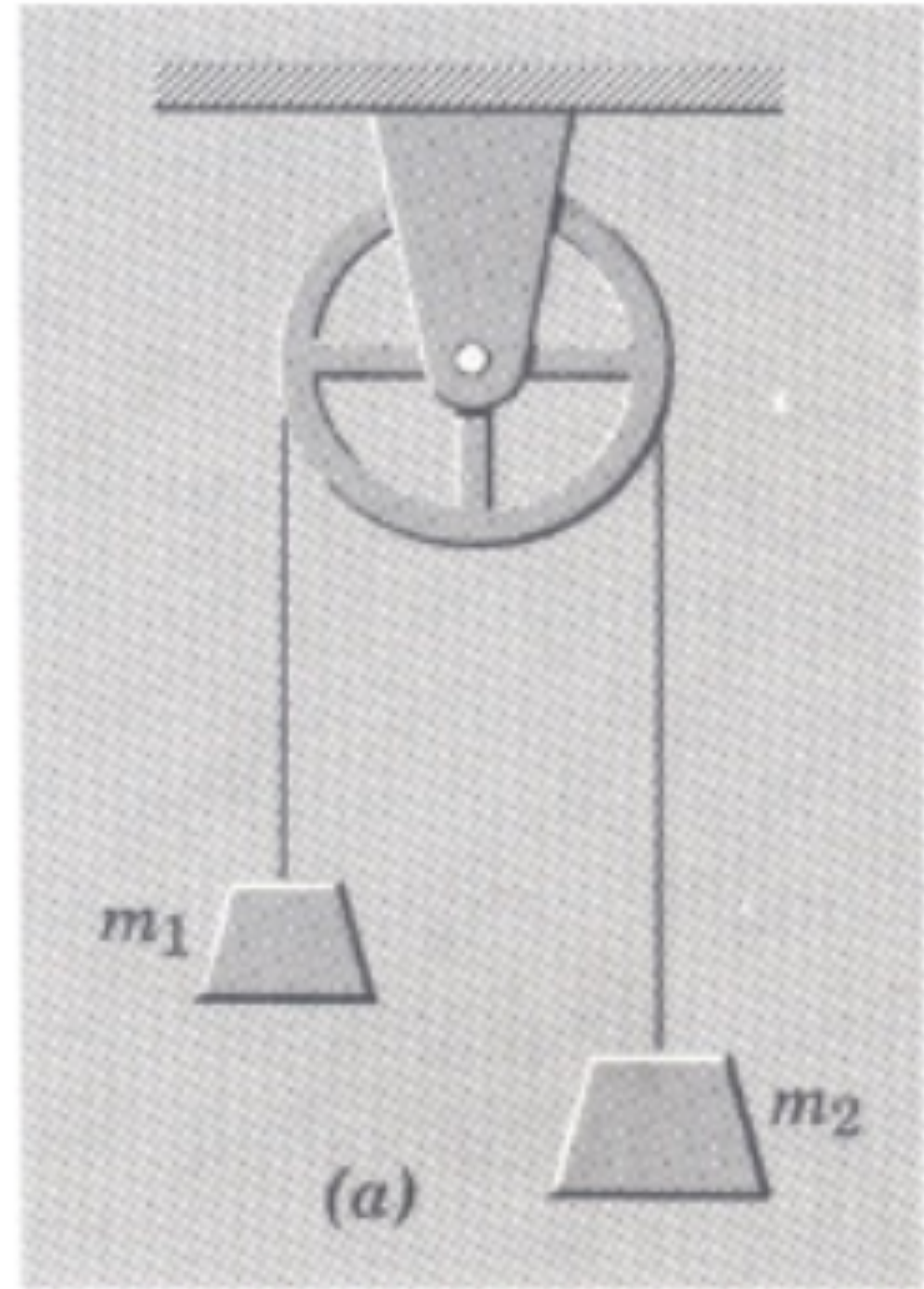


1950s-1960s



1970s-1980s





2000s-2010s


9:41 AM
100%
Tuesday
12
Mail
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iBooks
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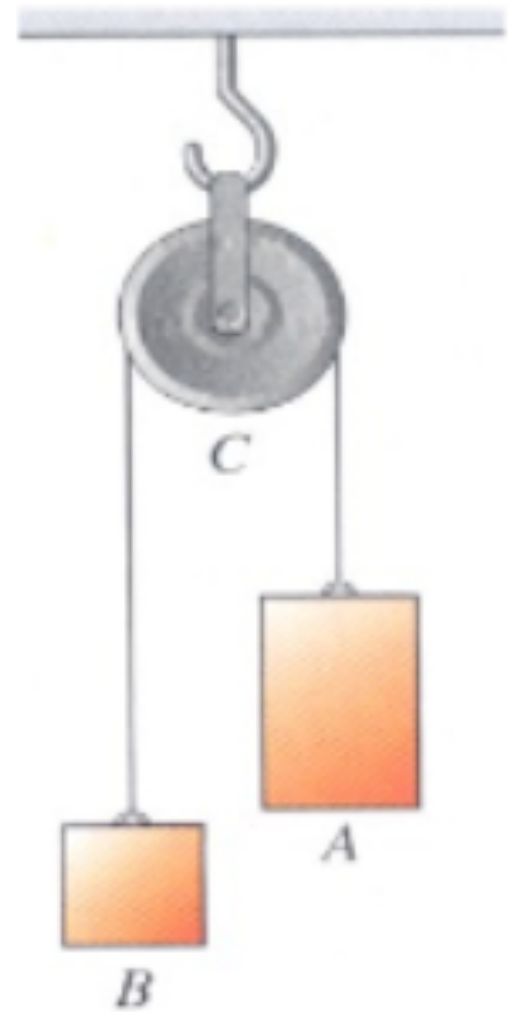
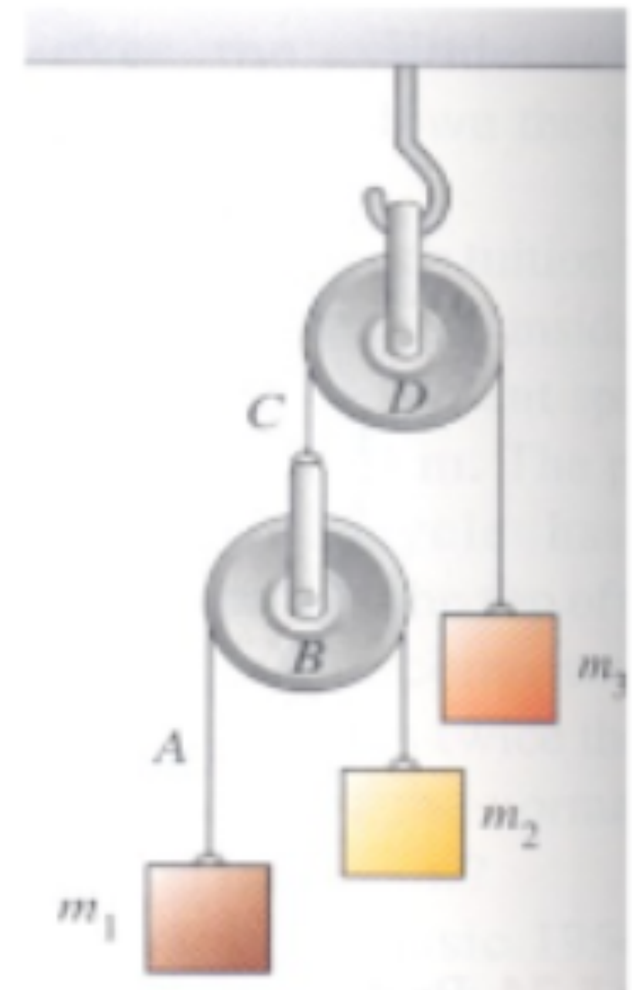
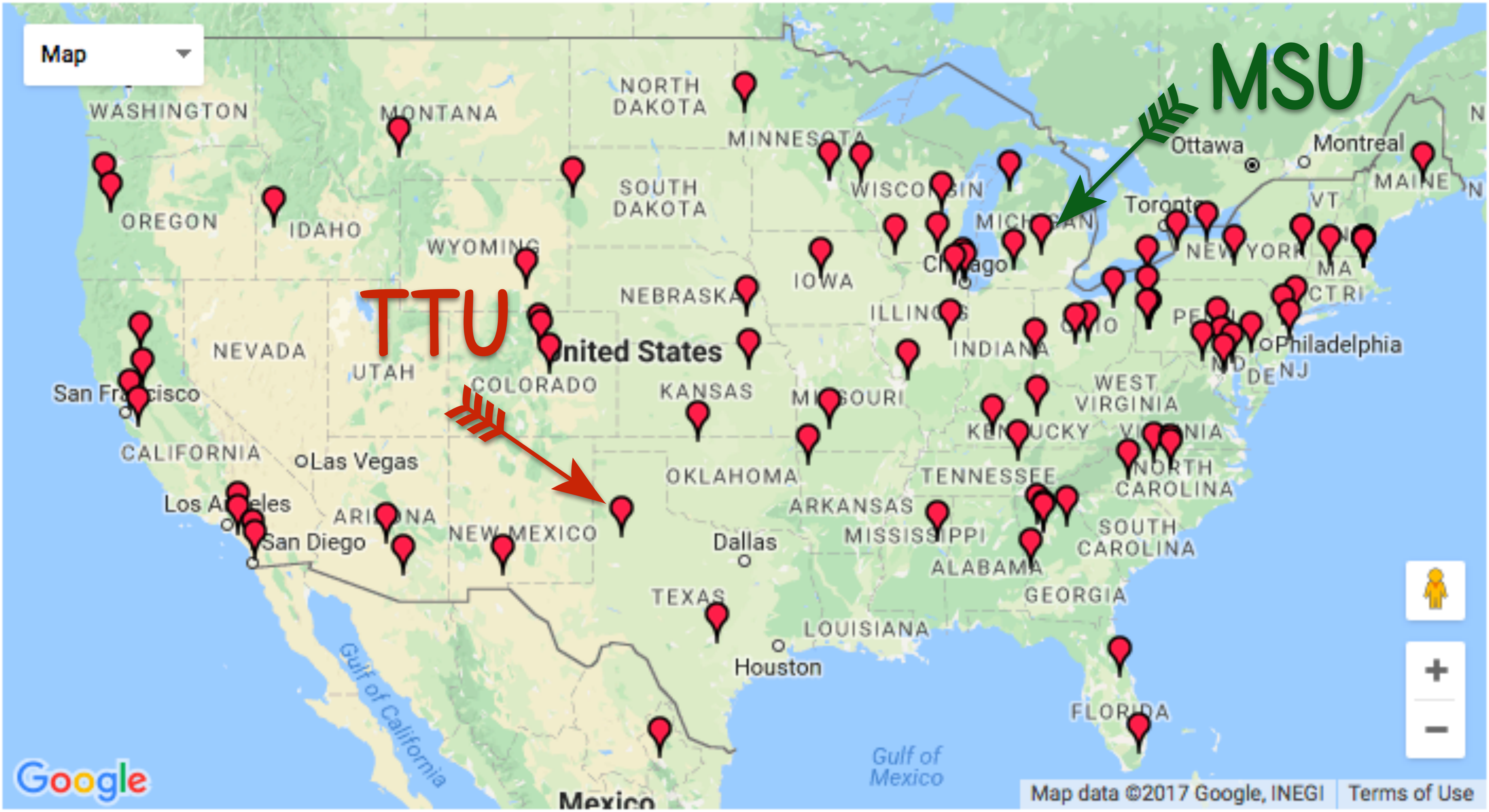
Wallet
Settings


C
A
B


C
D
B
A
m_3
m_2
m_1

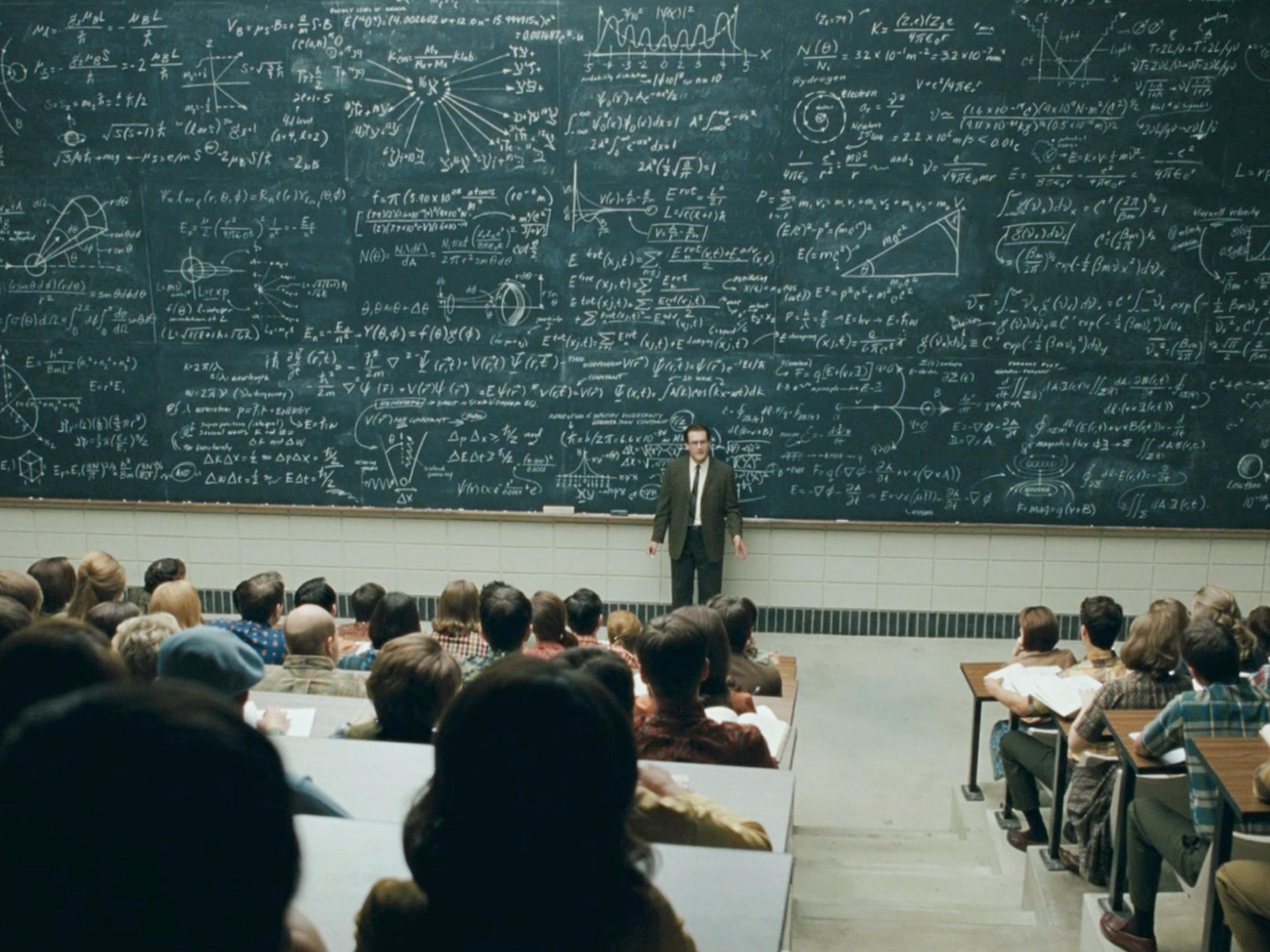
What has (really) changed in physics education?

Physics Education Research

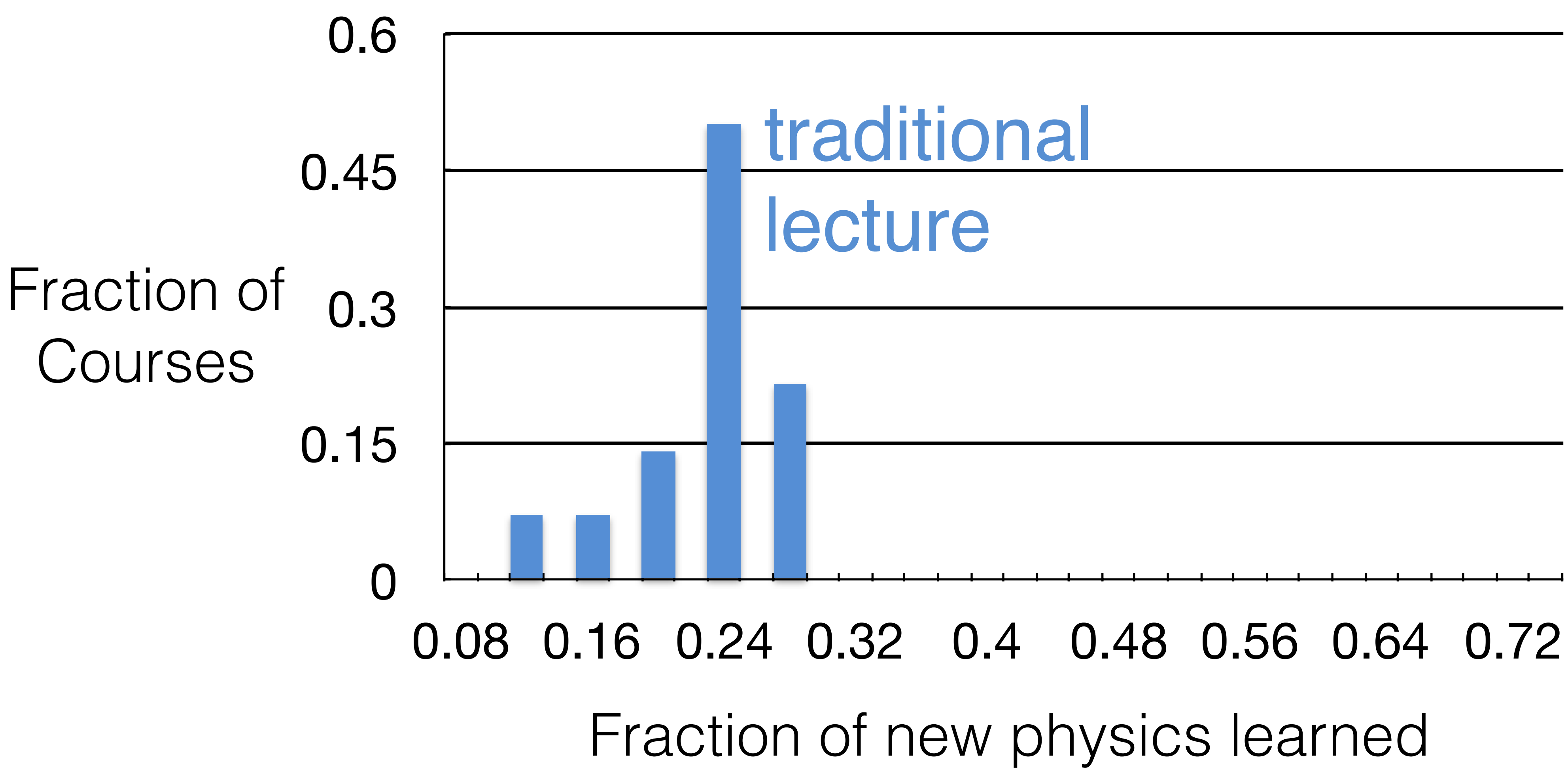


Physics Education Research studies:

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

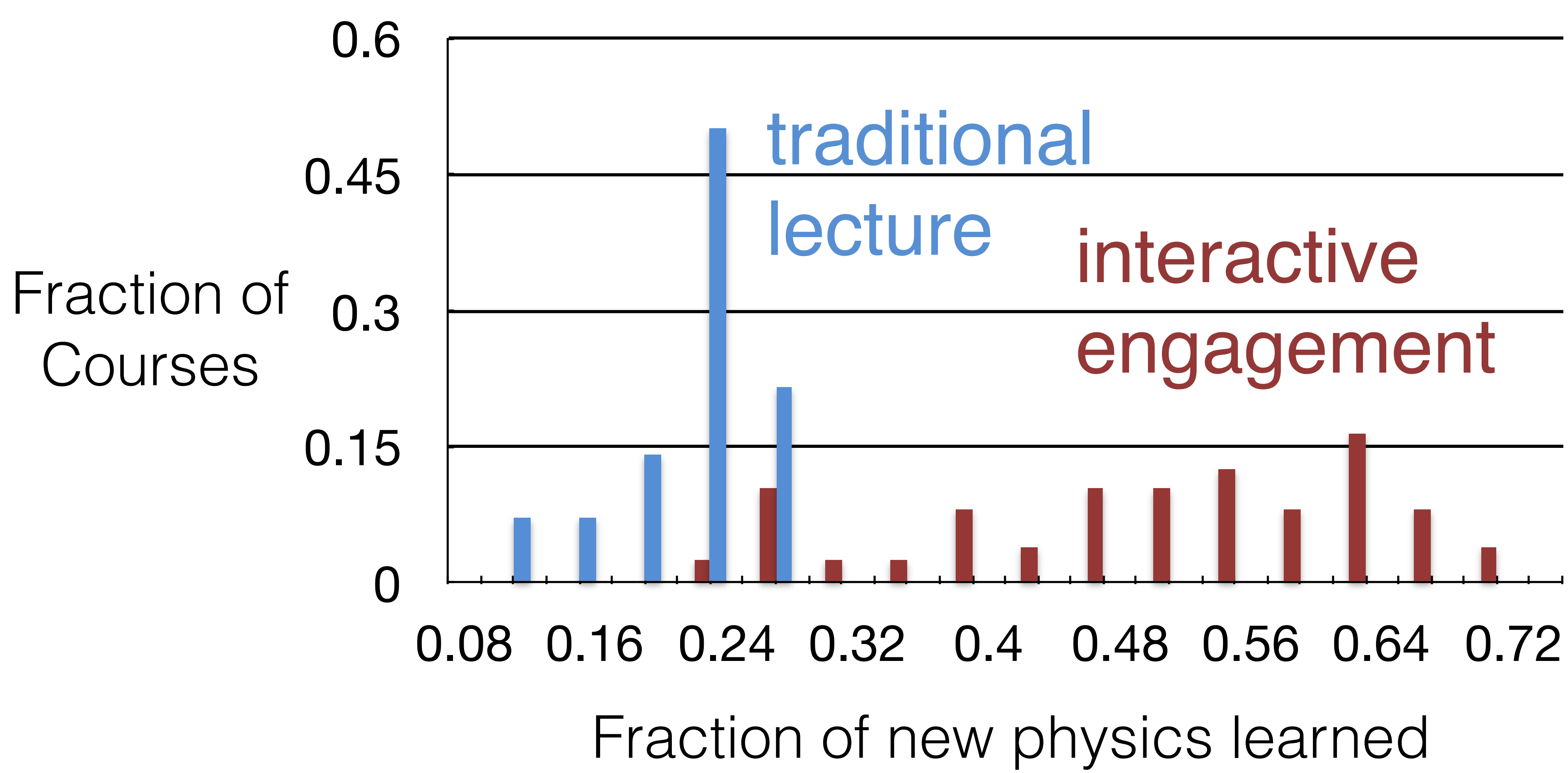

Hydrogen
Electron
$E = mc^2$
$P = \frac{h}{\lambda} = \frac{E}{c} \rightarrow E = h\nu \rightarrow E = \hbar\omega$
$F = ma = q(v \times B)$

Physics Education Research Standard Model

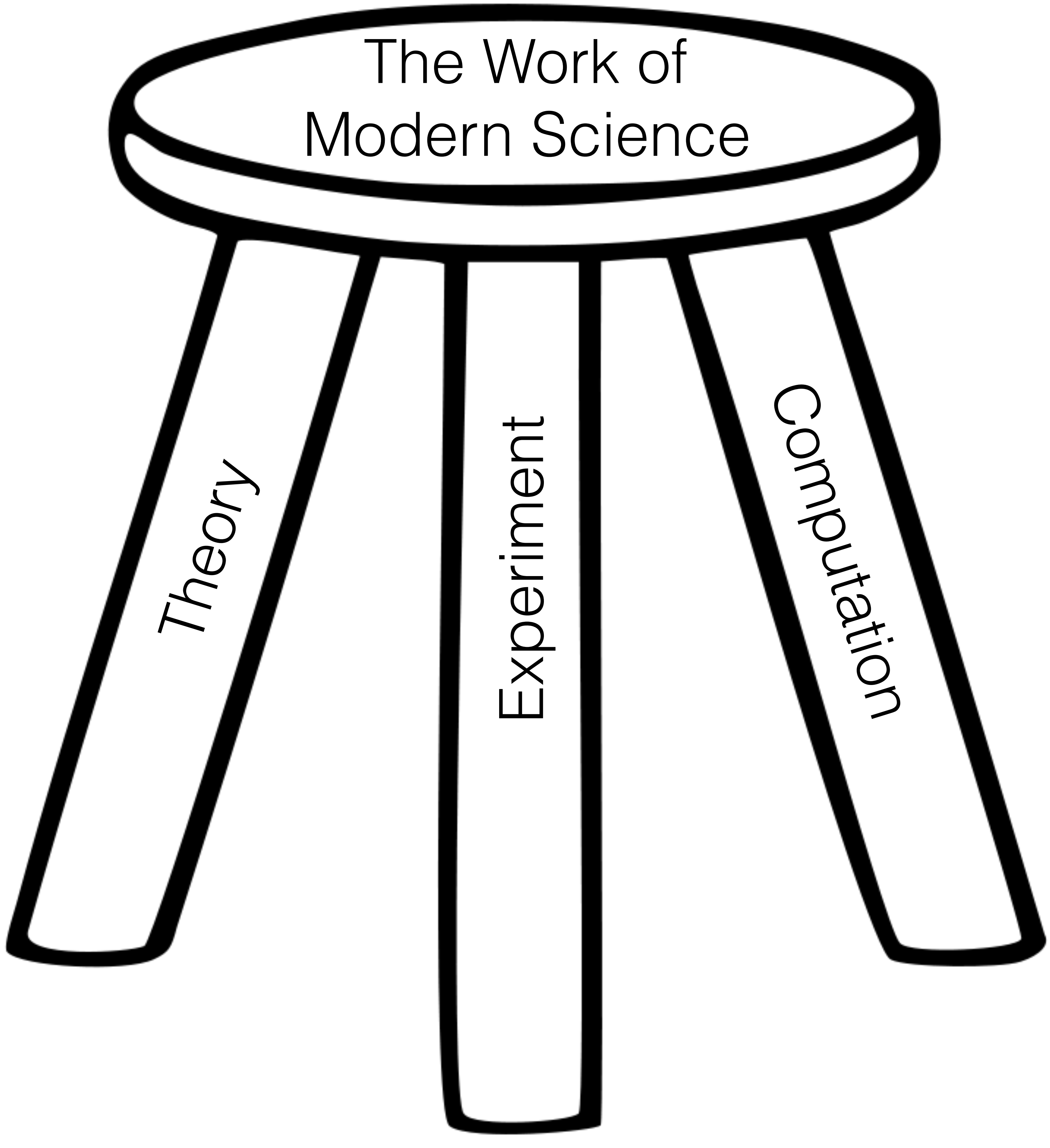


Hake, Am. J. Phys., **66**, 64 (1998)

Physics Education Research Standard Model



Hake, Am. J. Phys., **66**, 64 (1998)


The Work of
Modern Science
Theory
Experiment
Computation

Physics education requires a computational education

$e^{ipx/\hbar}\,\Phi(p,t)\,dp$

$\hat{B}])\rangle)^2$

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

$\chi = \binom{a}{b} = a\chi_+ + b\chi_-$, $S^{(n)} = \vec{n}\cdot\vec{S}$, $1 = \chi^\dagger\chi$, $\langle\vec{S}\rangle = \chi^\dagger\vec{S}\chi$, $\langle S_x^2\rangle = \frac{\hbar^2}{4}$, $S_y: \chi_+ = \frac{1}{\sqrt{2}}\binom{1}{i}, \chi_- = \frac{1}{\sqrt{2}}\binom{i}{1}$,

$P_+^{(x)} = \frac{1}{2}|a+b|^2$; $P_-^{(x)} = \frac{1}{2}|a-b|^2$, $P_+^{(y)} = \frac{1}{2}|a-ib|^2$, $P_-^{(y)} = \frac{1}{2}|a+ib|^2$, $P_+^{(z)} = |c_+^{(z)}|^2 = |(\chi_+^{(z)})^\dagger\chi|^2$, $P_+^{(z)} = |$

$$\left.\begin{aligned}|11\rangle &= \uparrow\uparrow\\ |10\rangle &= \tfrac{1}{\sqrt{2}}(\uparrow\downarrow+\downarrow\uparrow)\\ |1{-1}\rangle &= \downarrow\downarrow\end{aligned}\right\}\text{triplet}$$

symmetric
lower energy

$\underbrace{|00\rangle = \frac{1}{\sqrt{2}}(\uparrow\downarrow - \downarrow\uparrow)}_{\text{singlet}}$, $s = (s_1+s_2), (s_1+s_2-1), \ldots, |s_1-s_2|$

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

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

$\det(A - \mathbb{1}\lambda) = 0$, $H\psi = E\psi$, $\chi = a\chi_+ + b\chi_-$

$n=$
$l=$
$m_\ell=$
$m_j=$
$m_s=$

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

$j = (\ell + s),$

fine structure

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

$H_{hyd} = \frac{-\hbar^2}{2m}\nabla^2 - \frac{e^2}{4\pi\varepsilon_0}\frac{1}{r}$, $T = \frac{p^2}{2m} = \frac{-\hbar^2}{2m}\frac{d^2}{dx^2}$, $H_r' = \frac{-p^4}{8m^3c^2}$, $E_r^1 = \frac{-1}{2mc^2}[E^2 - 2\ldots$

$\ldots - 3]$, SO: $H_{SO}' = \left(\frac{e^2}{8\pi\varepsilon_0}\right)\frac{1}{m^2c^2r^3}\vec{S}\cdot\vec{L}$, $E_{SO}^1 = \frac{(E_n)^2}{mc^2}\left\{\frac{n[j(j+1) - \ell(\ell+1) - 3/4]}{\ell(\ell+1/2)(\ell+1)}\right\}$, $E_{fs}^1 = E_r^1 + E_{SO}^1 = \frac{(E_n)^2}{2mc^2}\left(3 - \frac{4n}{j+1/2}\right)$

$\ldots j)$: $E_{nj} = \frac{-13.6\,eV}{n^2}\left[1 + \frac{\alpha^2}{n^2}\left(\frac{n}{j+1/2} - \frac{3}{4}\right)\right] \leftarrow (i)$, $\alpha = \frac{e^2}{4\pi\varepsilon_0\hbar c}$

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

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

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

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

$E_{n,m_\ell,m_s} = \frac{-13.6\,eV}{n^2} + \mu_B B_{ext}(m_\ell + 2m_s) \leftarrow (iii)$, $E_{fs}^1 = \frac{13.6\,eV\alpha^2}{n^3}\left\{\frac{3}{4n} - \left[\frac{\ell(\ell+1) - m_\ell m_s}{\ell(\ell+1/2)(\ell+1)}\right]\right\} \leftarrow (iv)$, $E_{tot}(\text{sterk}) = (iii) + (iv)$

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

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

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

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

$\ldots(\vec{r}_1,\vec{r}_2) = \pm\psi(\vec{r}_2,\vec{r}_1)$. $E_{FERMI} = \frac{\hbar^2}{2m}(3\rho\pi^2)^{2/3}$

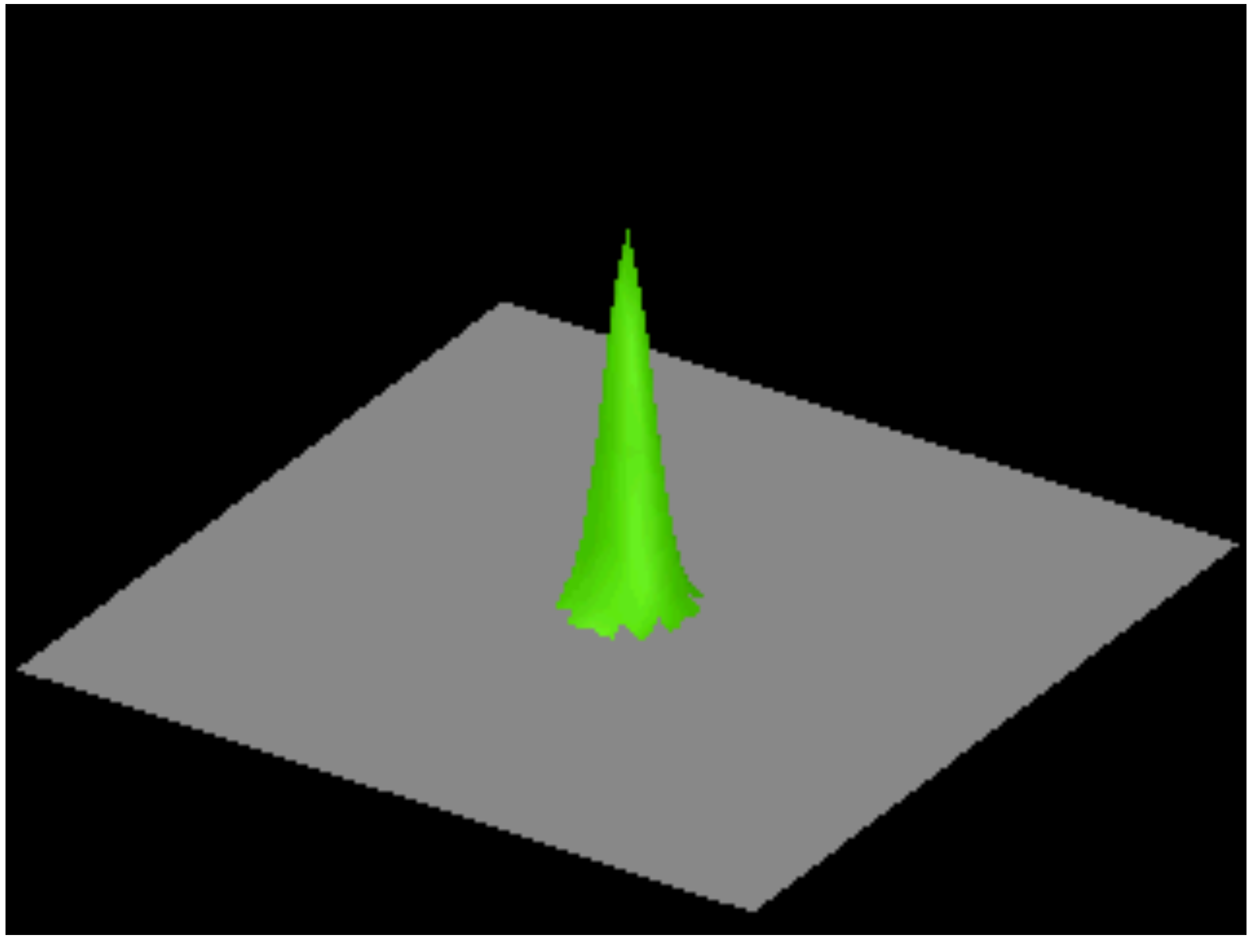
$\ldots(x_2)$ $\rho \equiv Nq/V$

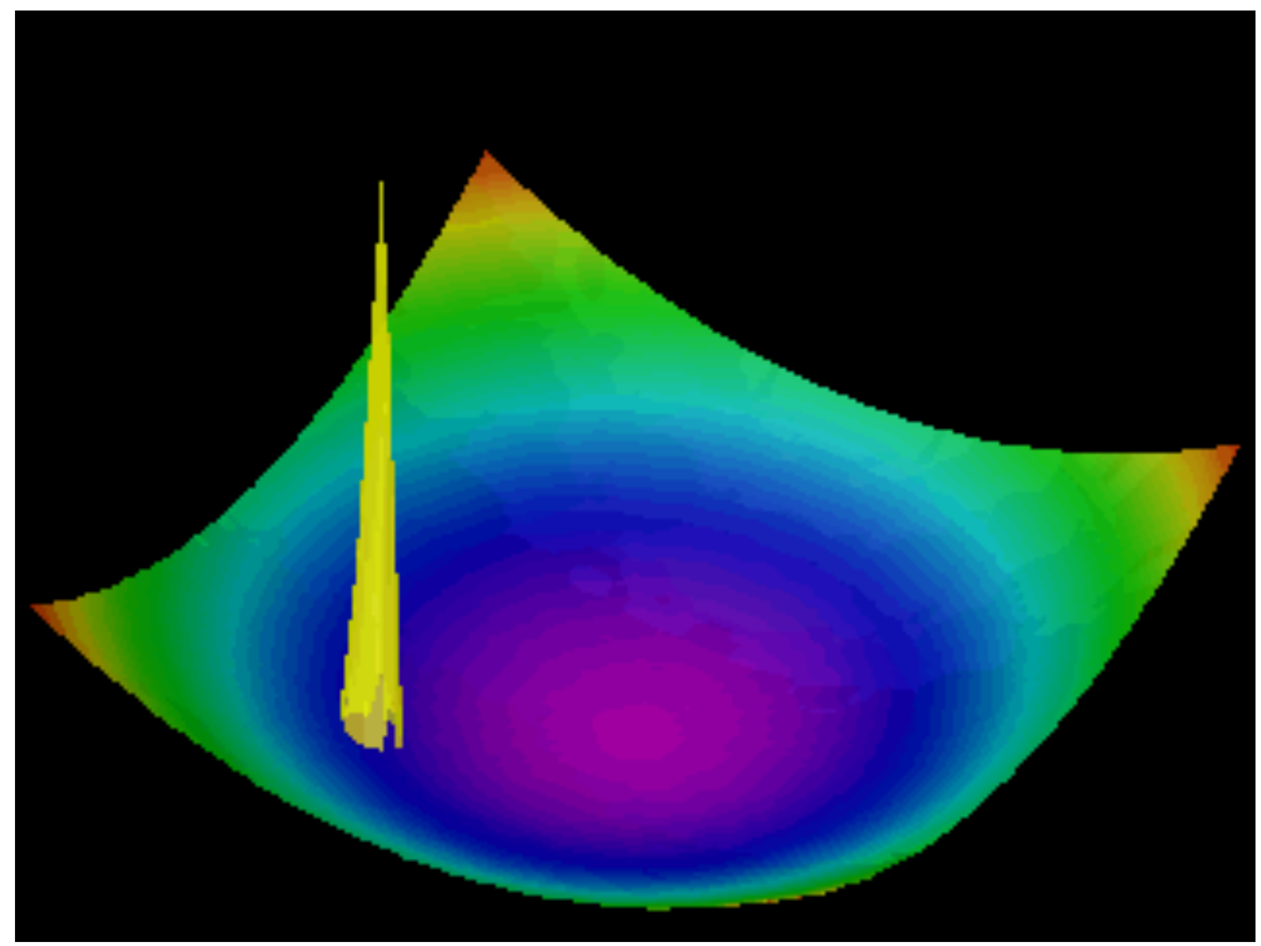
$\ldots\psi_2(x_2) \pm \psi_2(x_1)\psi_1(x_2)]$ $E_{tot} = \hbar^2(3\pi^2 Nq)^{5/3}V^{-2/3}$

ket: toestandsvector in Hilbertruimte : colomvector *
bra: " "duale " : rowvector

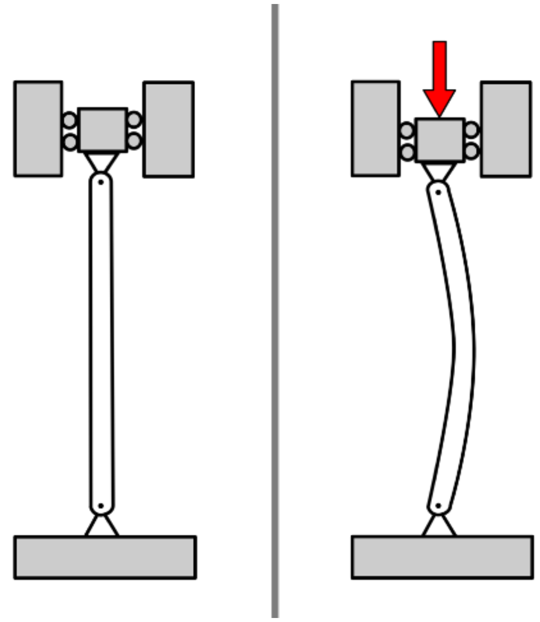
var. princ.: pick $\psi(x)$, determine A, determine $\langle H\rangle \rightarrow$

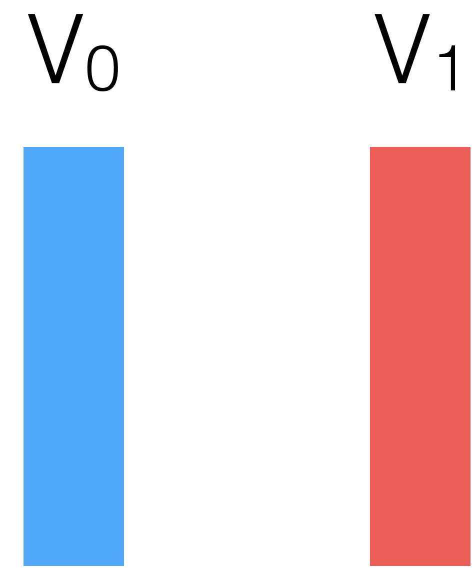
$\psi(x) = A\ldots$
$1 = |A|^2\int\ldots$
$\int^b|\psi\ldots$



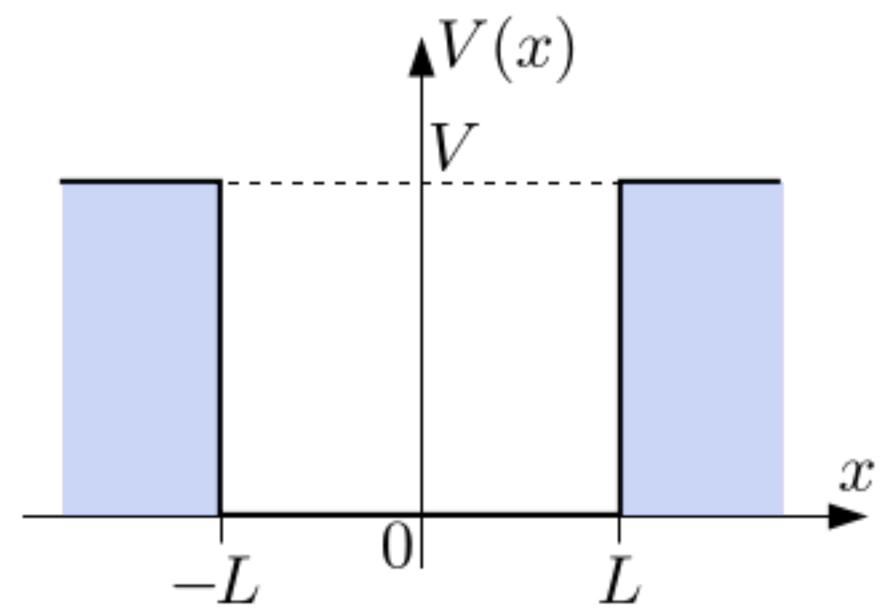


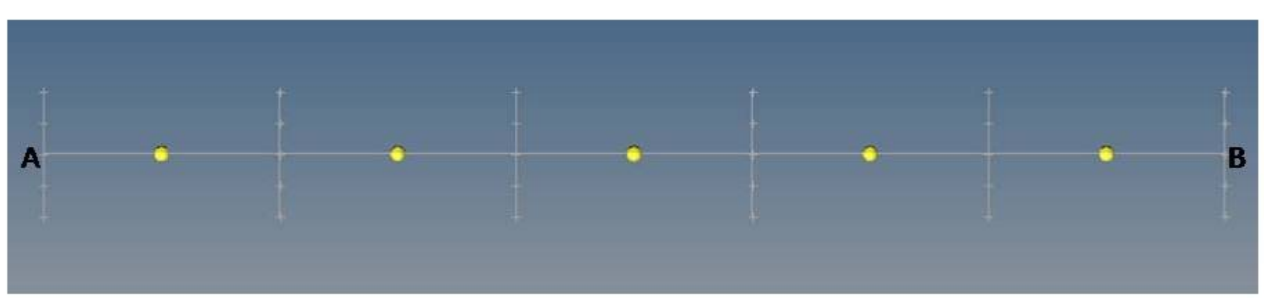
Michielson and De Raedt, 2012



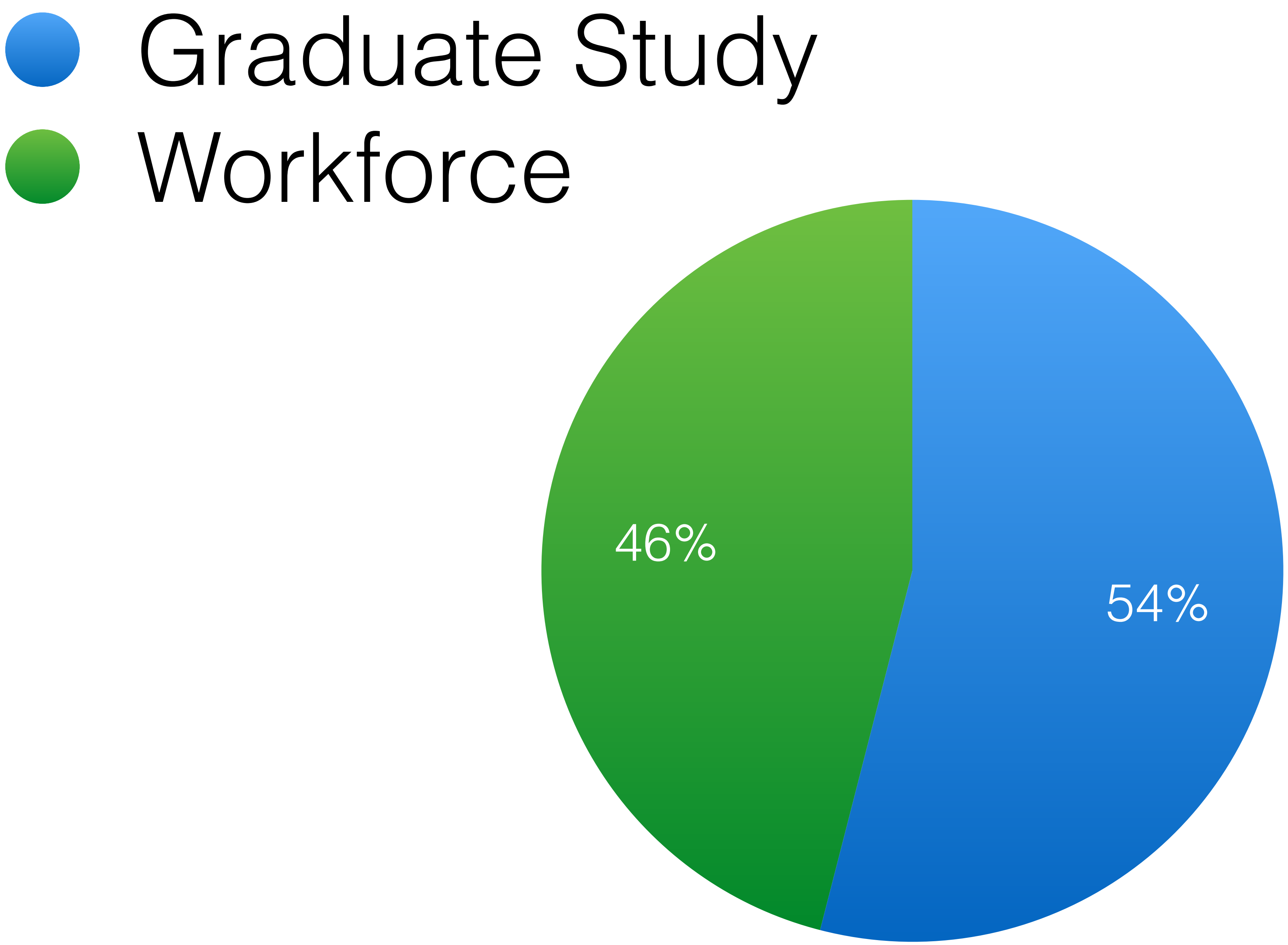


$$A\frac{d^2u(x)}{dx^2} = -Bu(x)$$



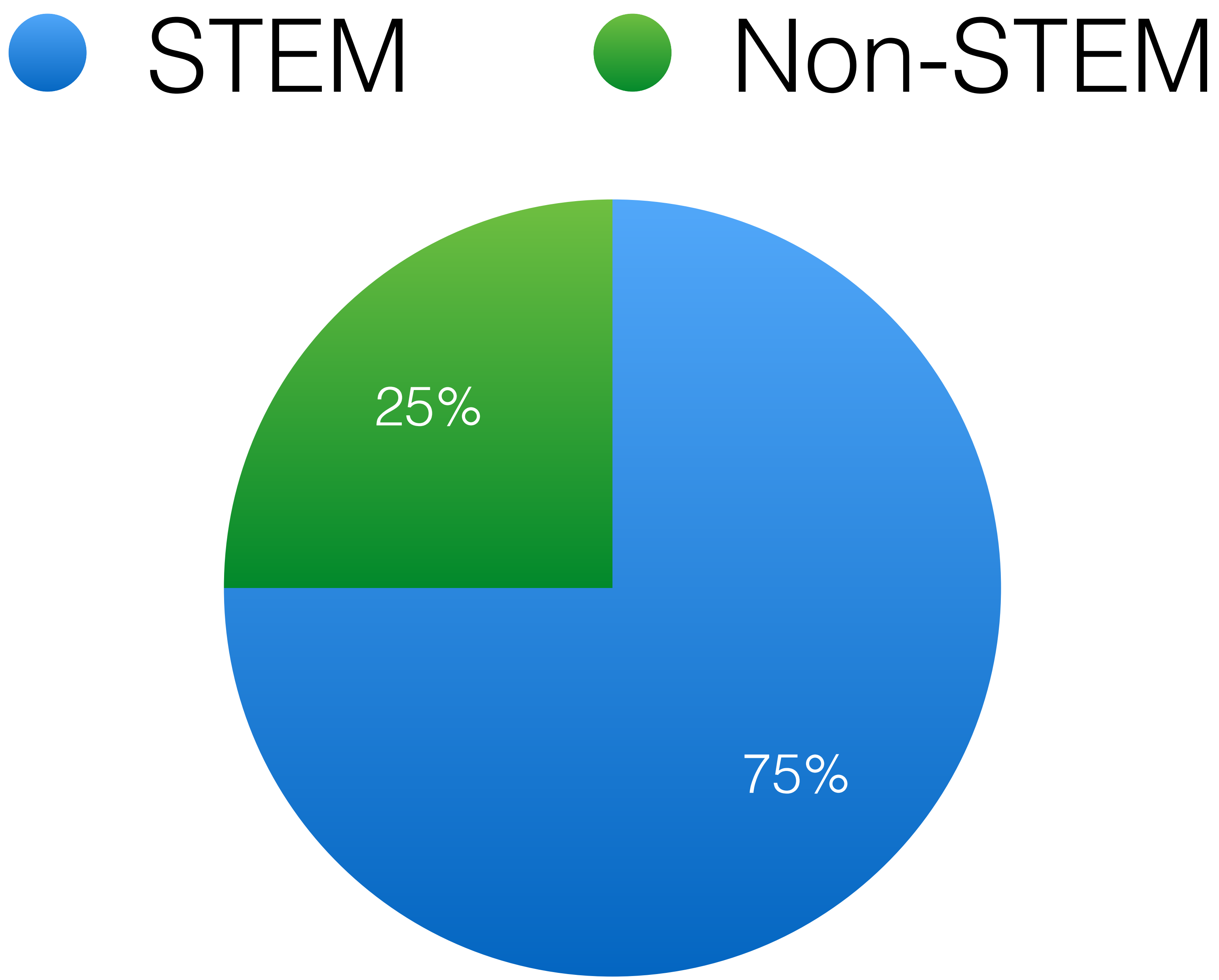


Where do Bachelor's grads in physics go?



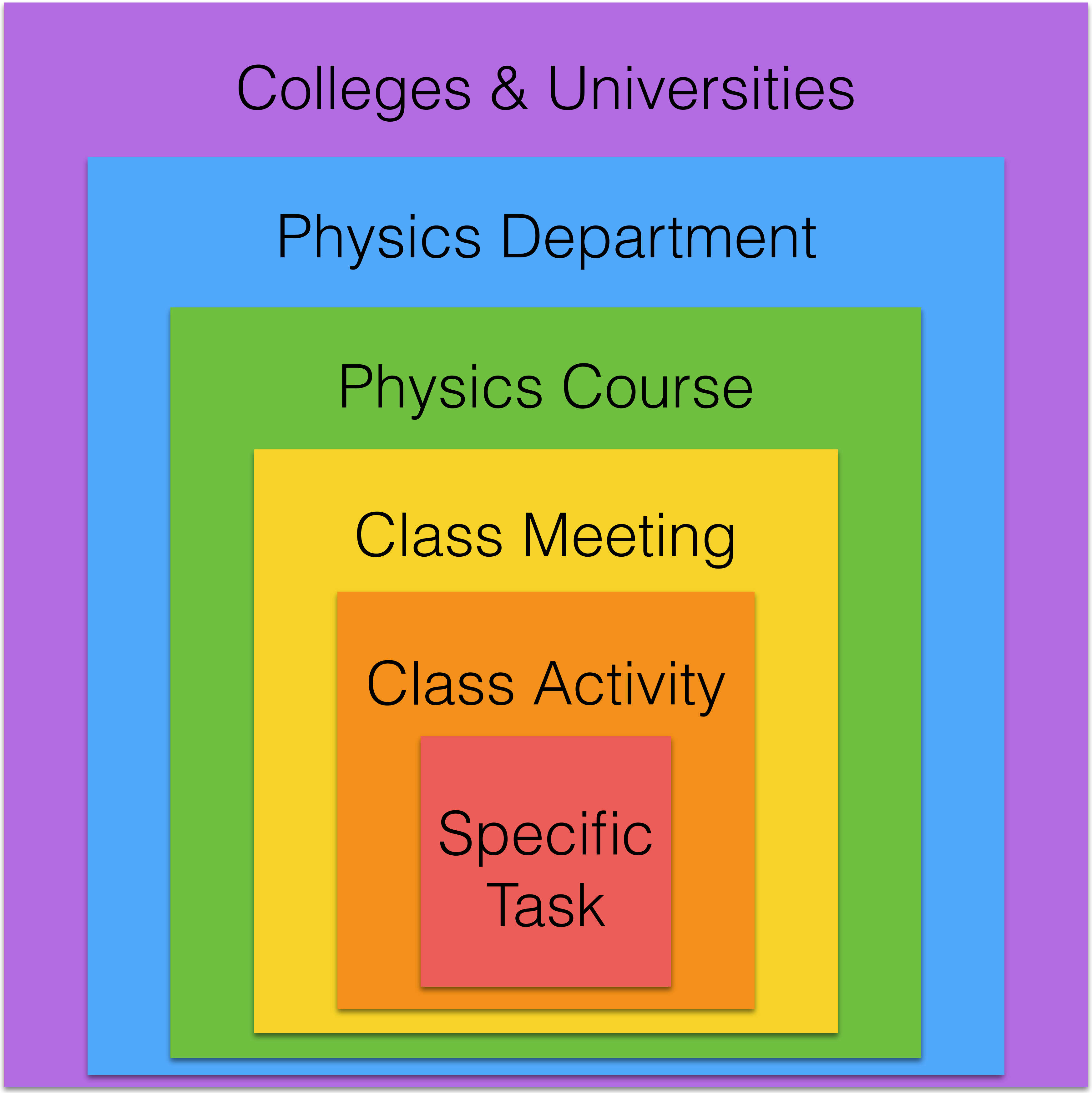
2013 & 2014 Graduates, AIP

What are Bachelor's graduates doing?



2013 & 2014 Graduates, AIP

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


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

What do we study?

Sample Research Questions at decreasing "scales":

- What is the national landscape surrounding computational integration in physics courses?
- How do faculty come into the community of those teaching with computation?
- How are courses designed to incorporate computation given departmental resources and constraints?
- What kind of understanding of computation do students develop in classical mechanics?
- What knowledge and strategies do students use when constructing a shooting method model for energy eigenstates?
- How do students understand a specific line of code (e.g., `VN[i,j]=(V[i-1,j]+V[i+1,j]+beta**2*(V[i,j-1]+V[i,j+1]))/denom`)?

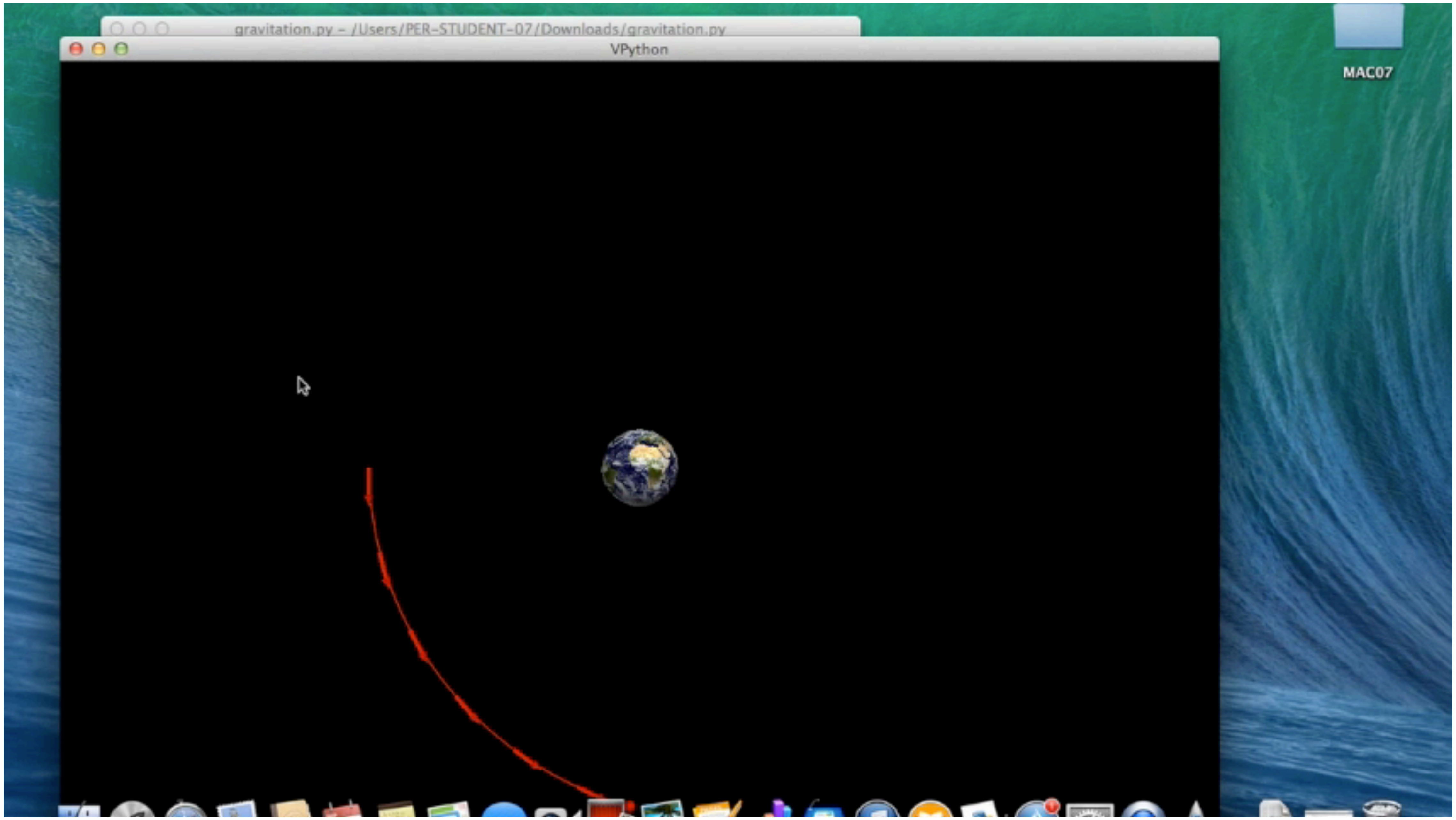

Georgia Institute
of Technology
Atlanta, GA

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.

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
```

How proficient are they?

New Model: Central Force

- Assign initial conditions
- Compute force
- Update velocity

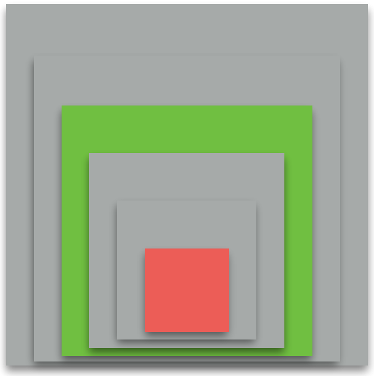
approx. 1300 students

```
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)

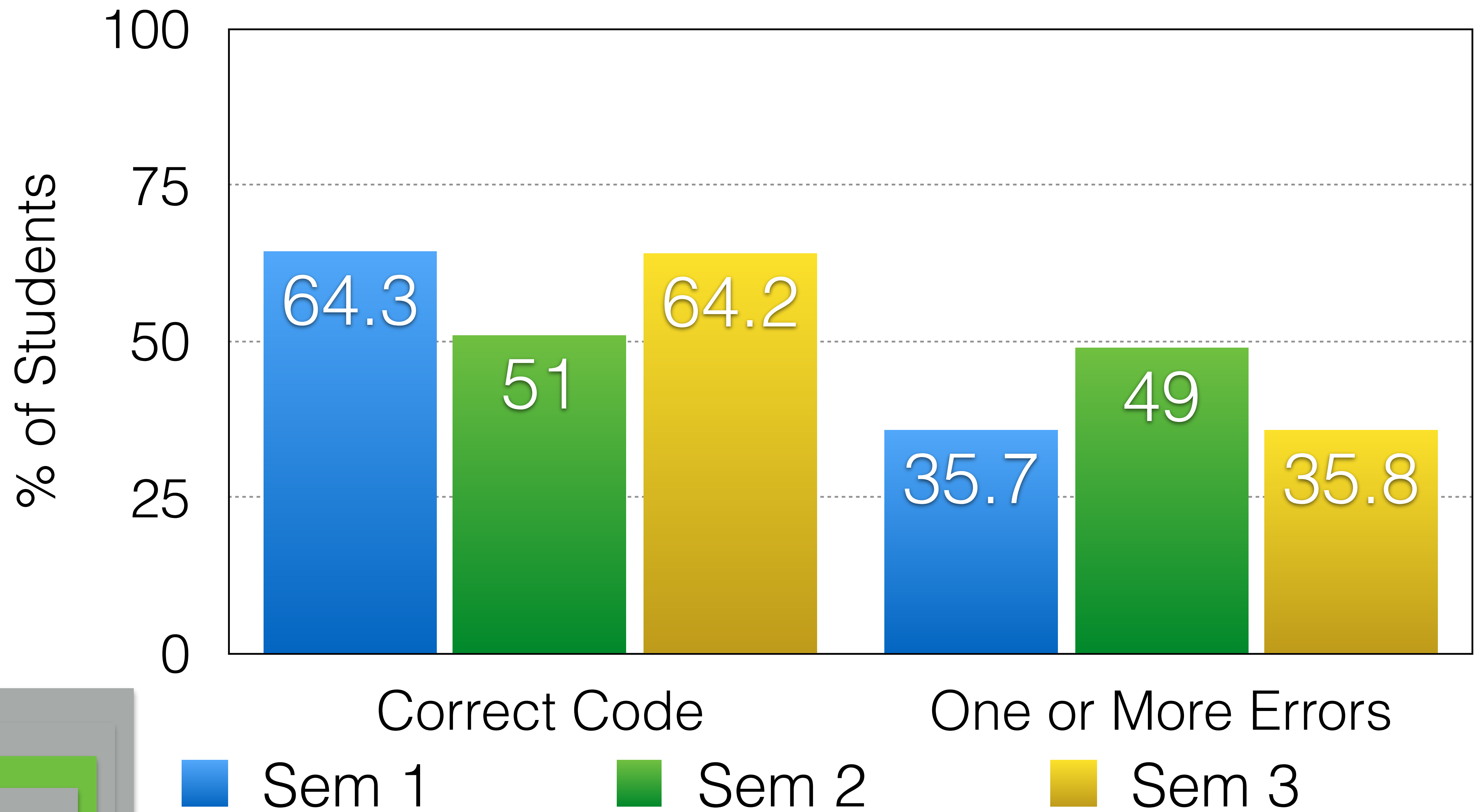
Force Calculation (contextualize)

Newton's Second Law (implement)



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

How’d they do?

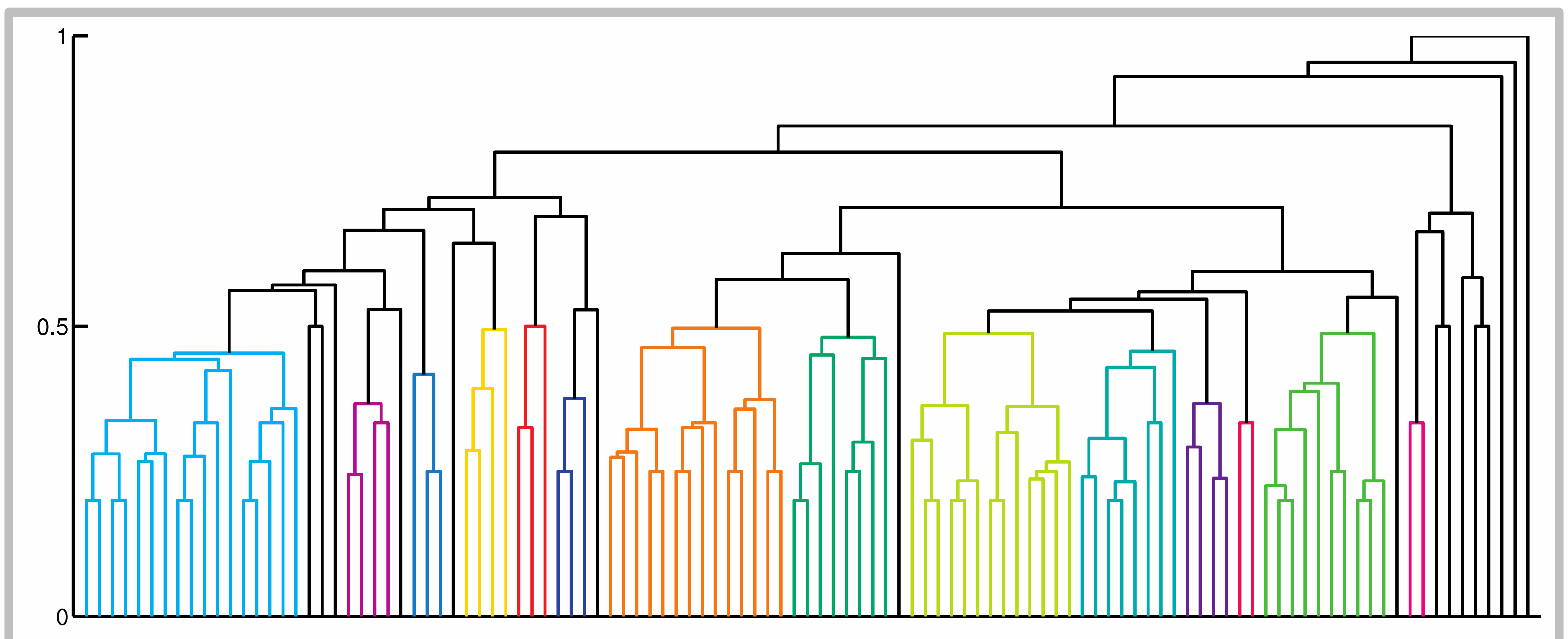


Caballero, Kohlmyer, Schatz, PRST-PER 8, 020106 (2012)

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)

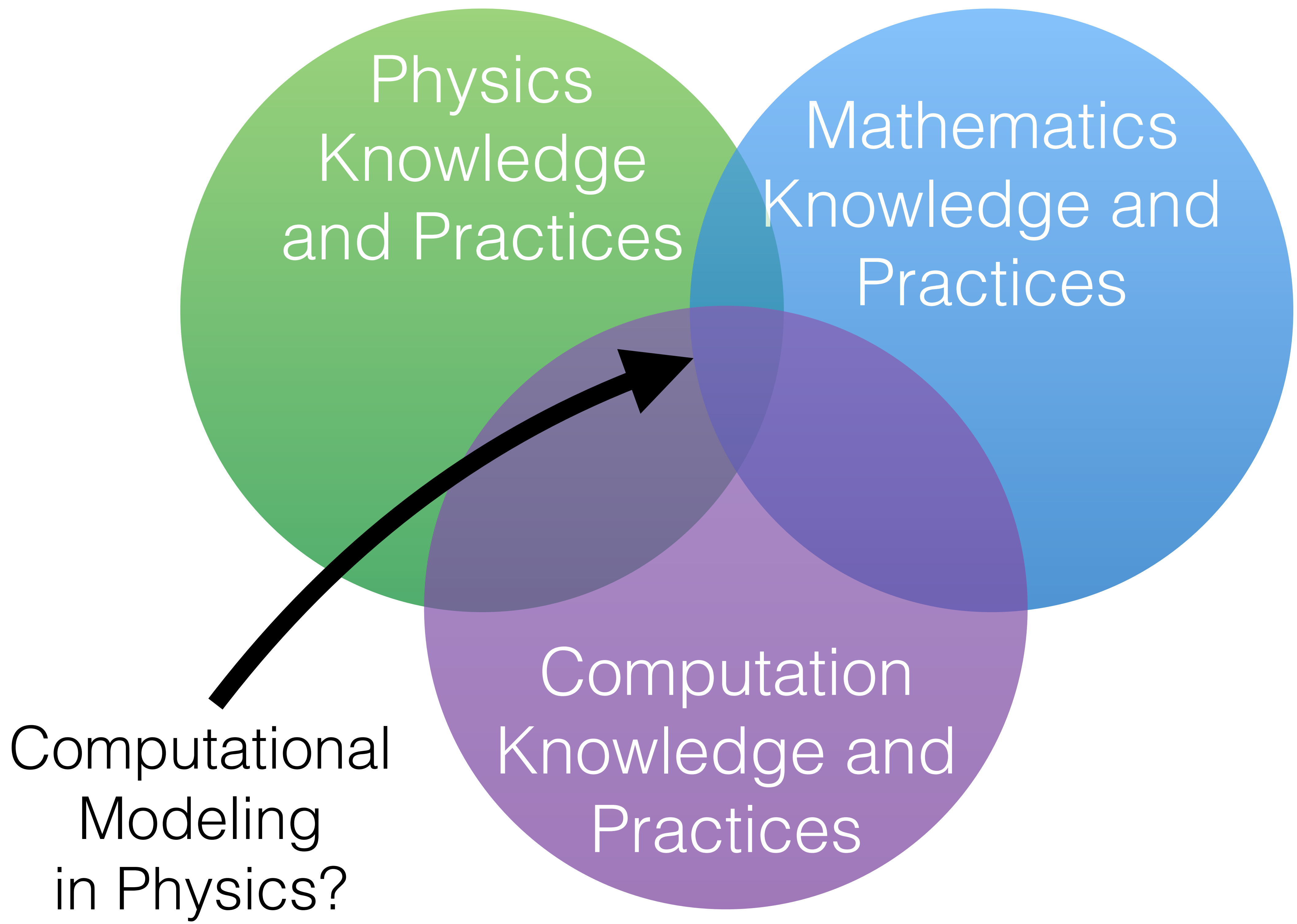
Dominant Errors are Not Syntactic*

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

*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?


Boulder, CO

East Lansing, MI

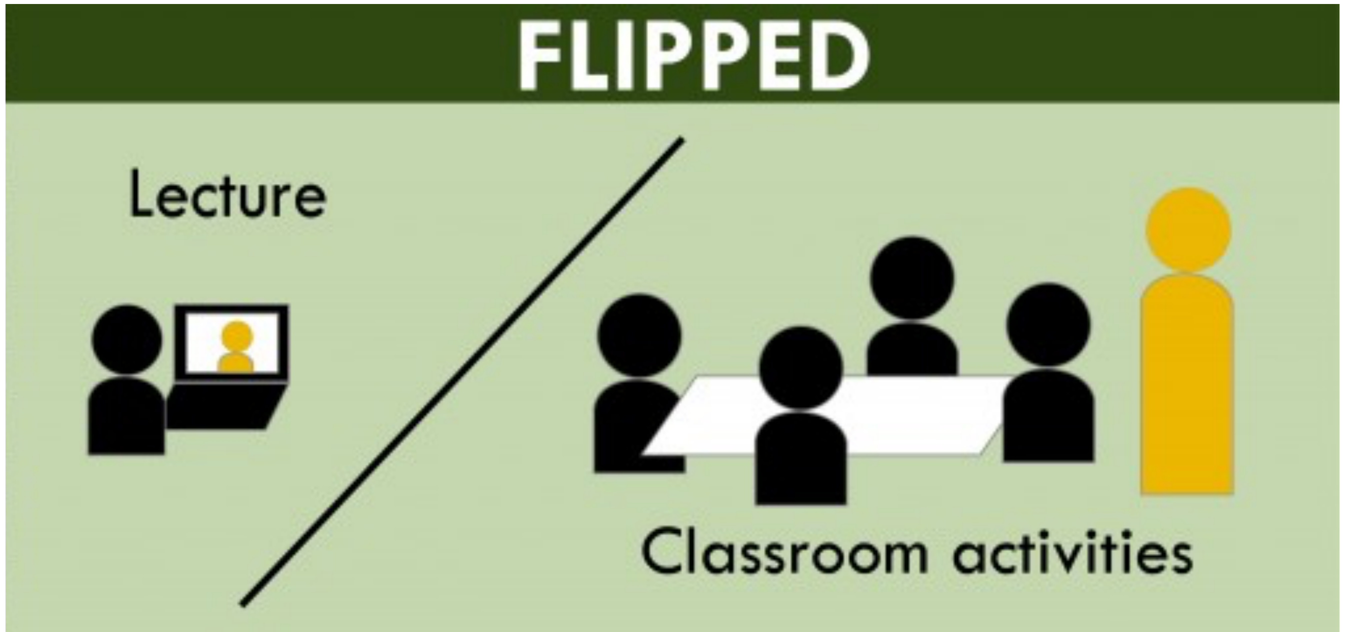

East Lansing, MI


Porcupine Mountains, UP, MI

How might students approach computational problems?

w/ Obsniuk & Irving

Interactive Computational Instruction in Physics



+

=

pcubed.pa.msu.edu
Irving, Obsniuk, & Caballero, EJP (2017)

Projects & Practices in Physics

a community-based learning environment

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.

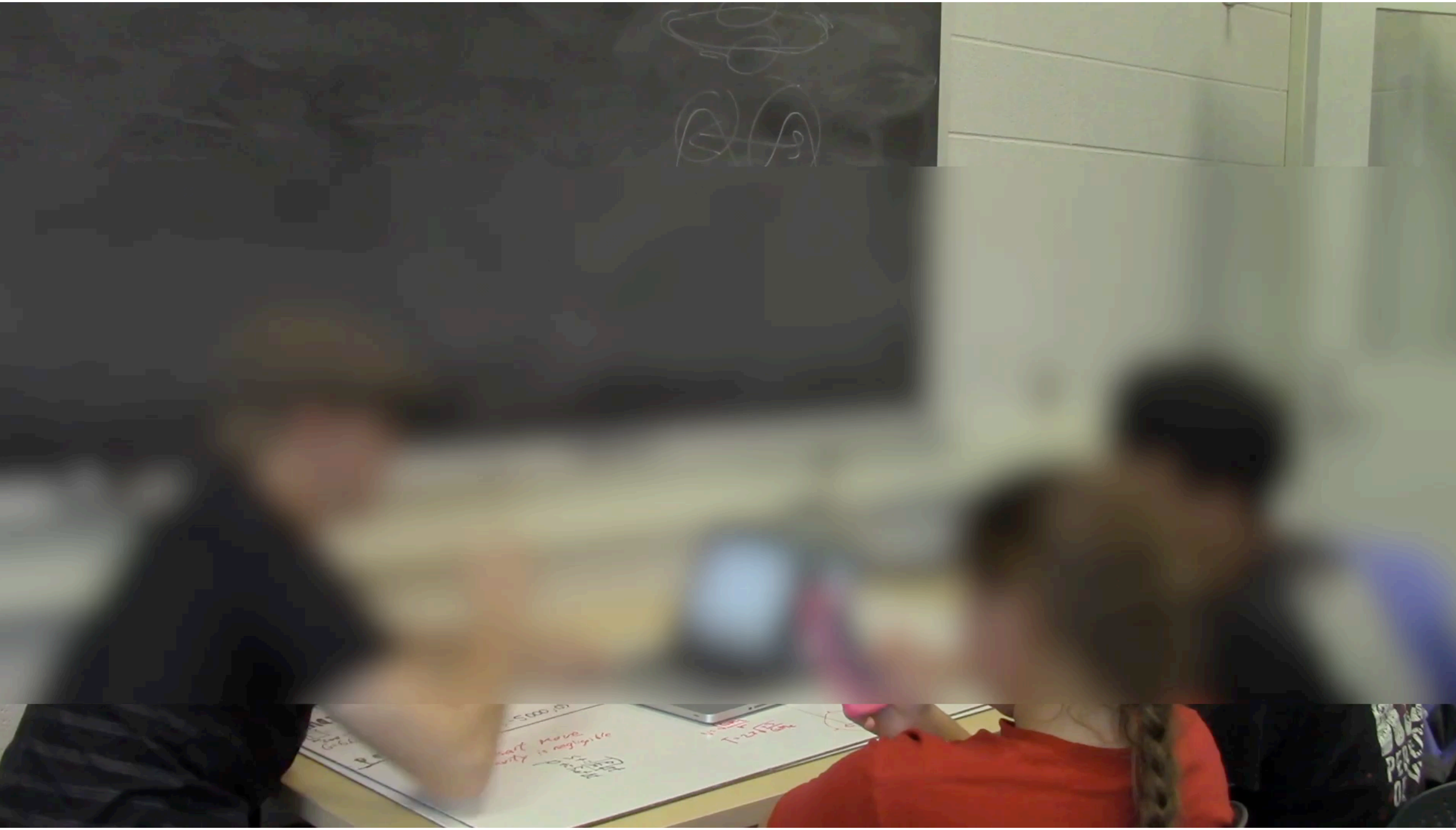
Code for Project 3:
geosync.py
PhysUtil Module

What do students do when the code doesn't work?!

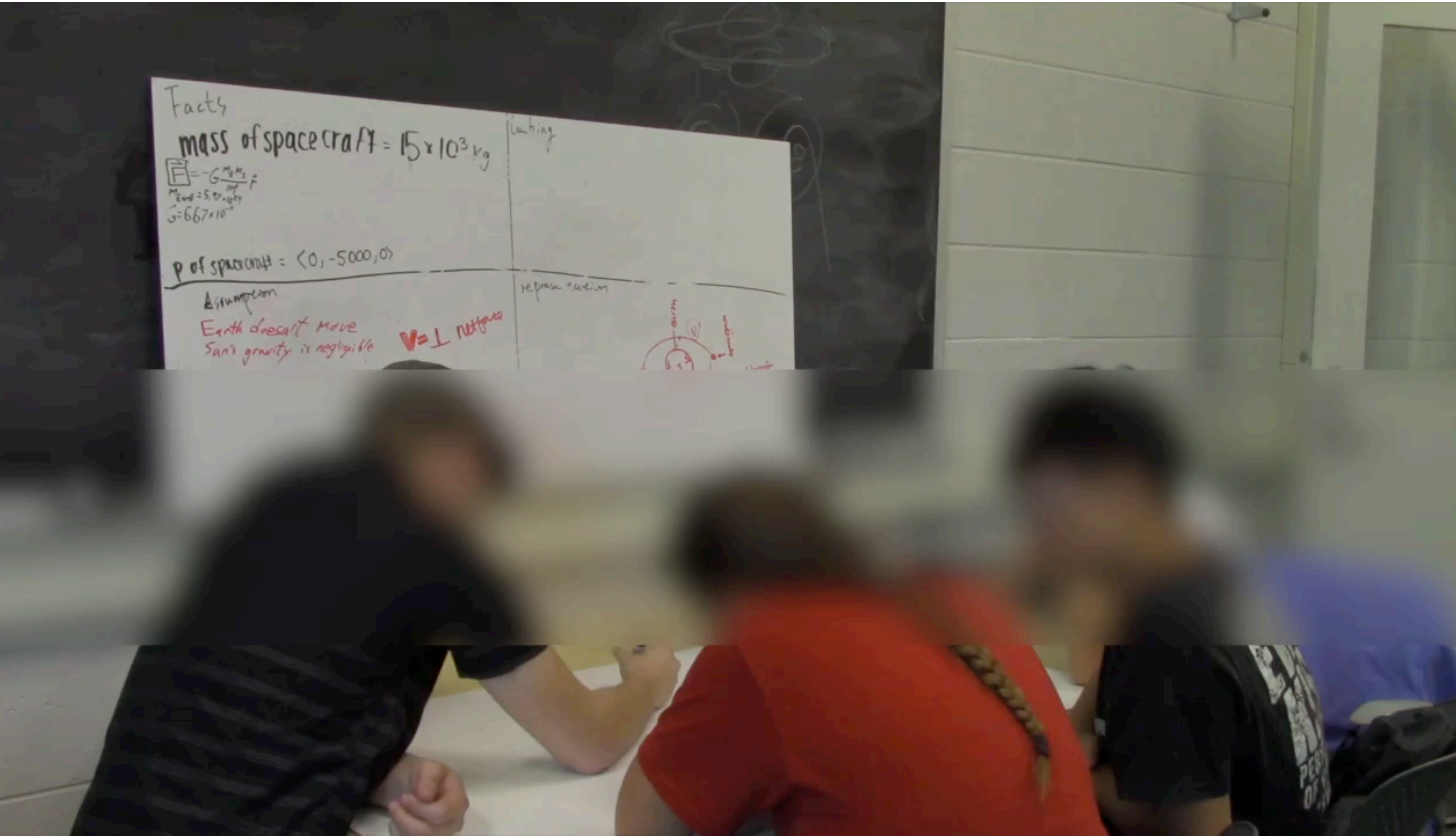
w/ Obsniuk & Irving

AFTER

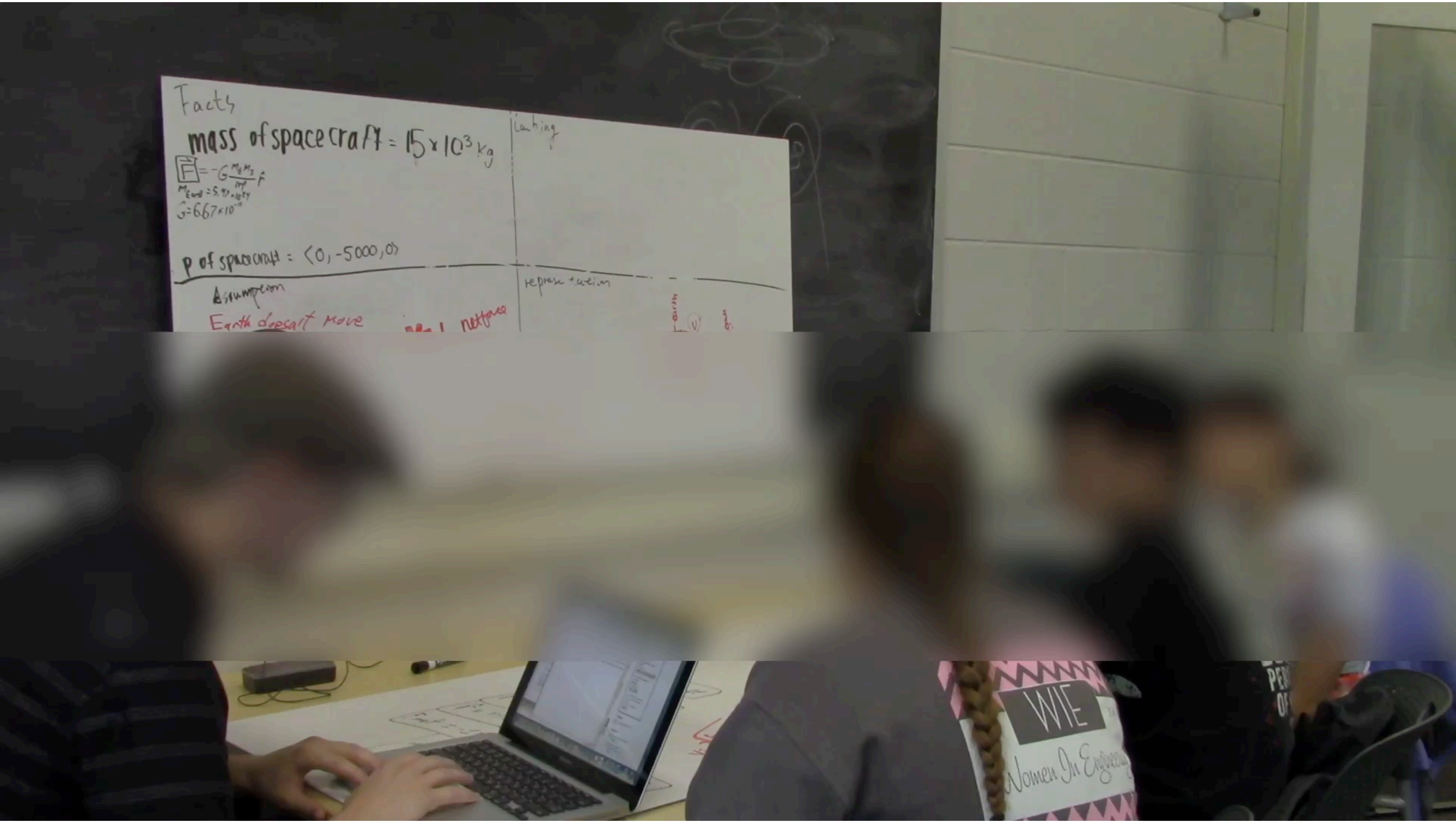
```
from __future__ import division
from visual import *
from visual.graph import *
from physutil import *

# 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."

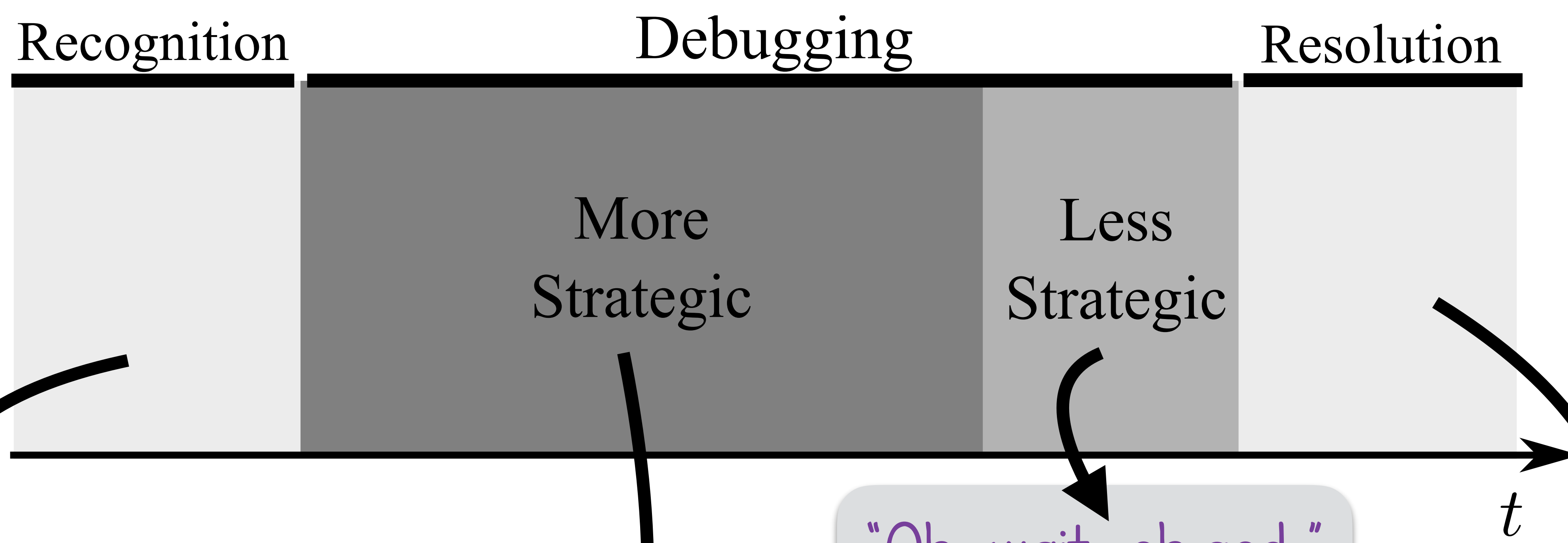


The group begins "debugging."



"Debugging" leads the group to doing physics.

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?"

"Oh, wait…oh god."

"Did you change it?"

"Maybe, that's the problem. That we don't have the initial momentum correct."

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
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# Objects
Earth = sphere(pos=vector(0,0,0), radius=6.4e6, material=materials.BlueMarble)
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        FnetMotionMap.update(t, Fnet)

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

        t = t +deltat
```

```
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?

w/ Obsniuk & Irving

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`

Obsniuk, PhD Thesis (in progress)

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

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

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.*

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

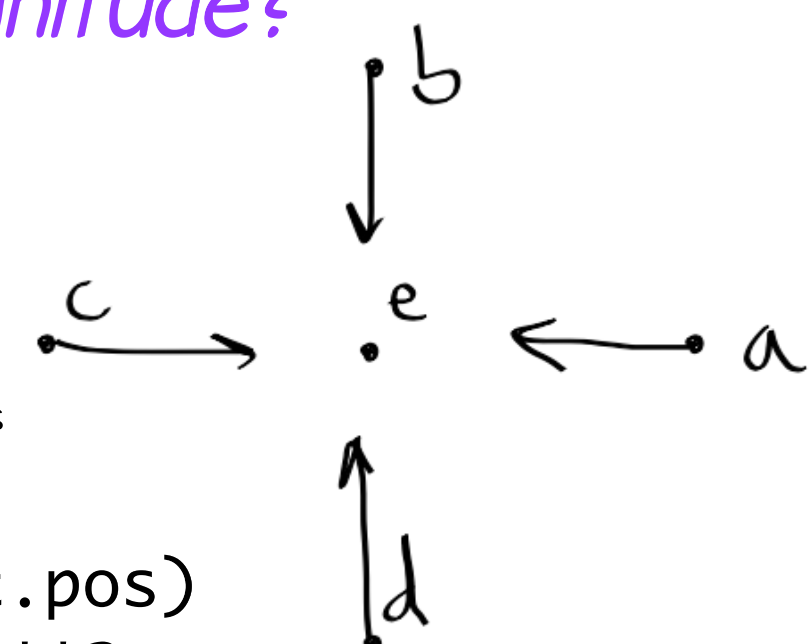
$$F_{grav} = G\frac{M_{Earth}m_{sat}}{R^2}$$

Obsniuk, PhD Thesis (in progress)

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?*



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

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

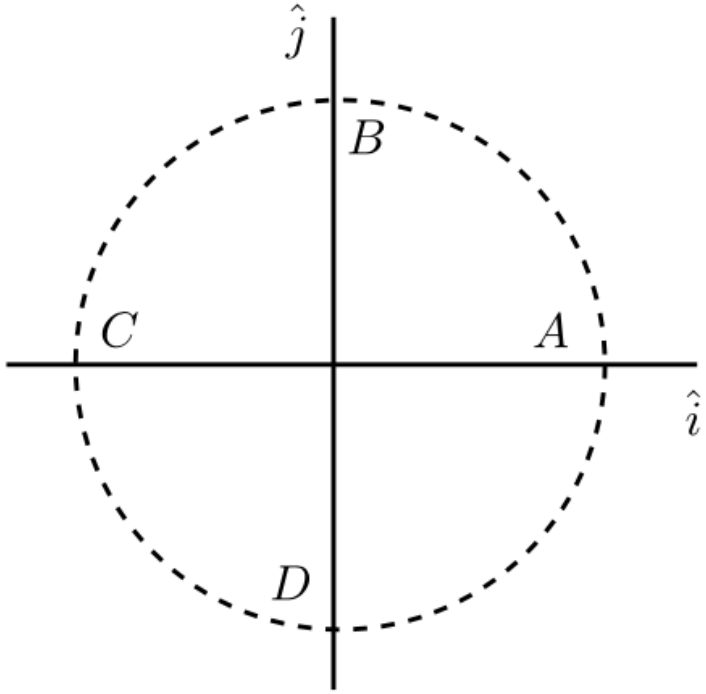
```
dir = sat.pos/mag(sat.pos)
Fnet = -G*m1*m2*dir/R**2
```

Obsniuk, PhD Thesis (in progress)

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:

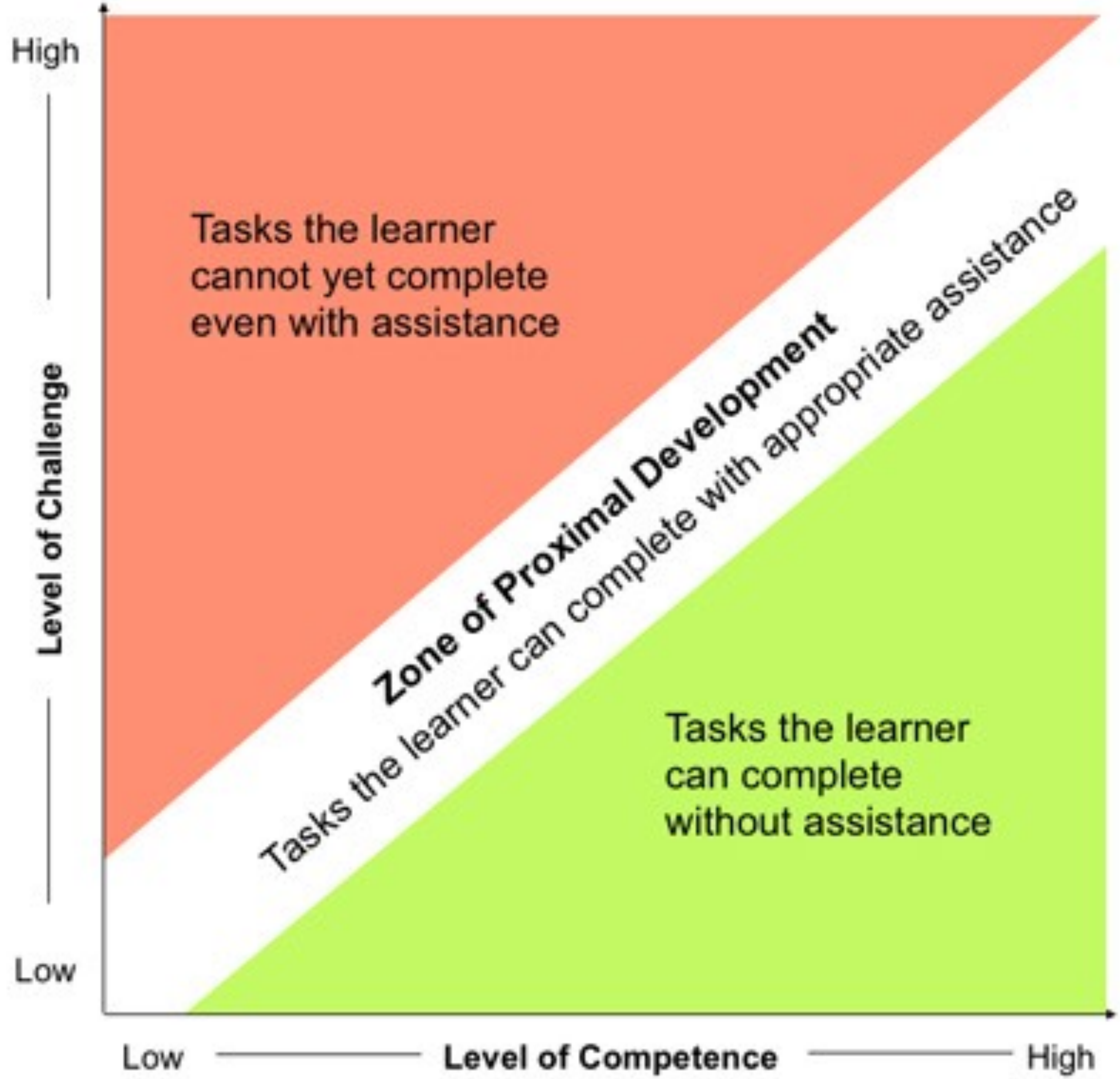
$\hat{r} = \langle \square, \square, \square \rangle$

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

At C:

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

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



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

How are students taught computation?

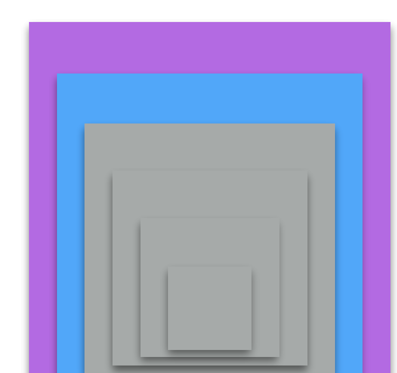
w/ Chonacky, Hilborn, & Merner

Surveying the state and implications of computational physics instruction

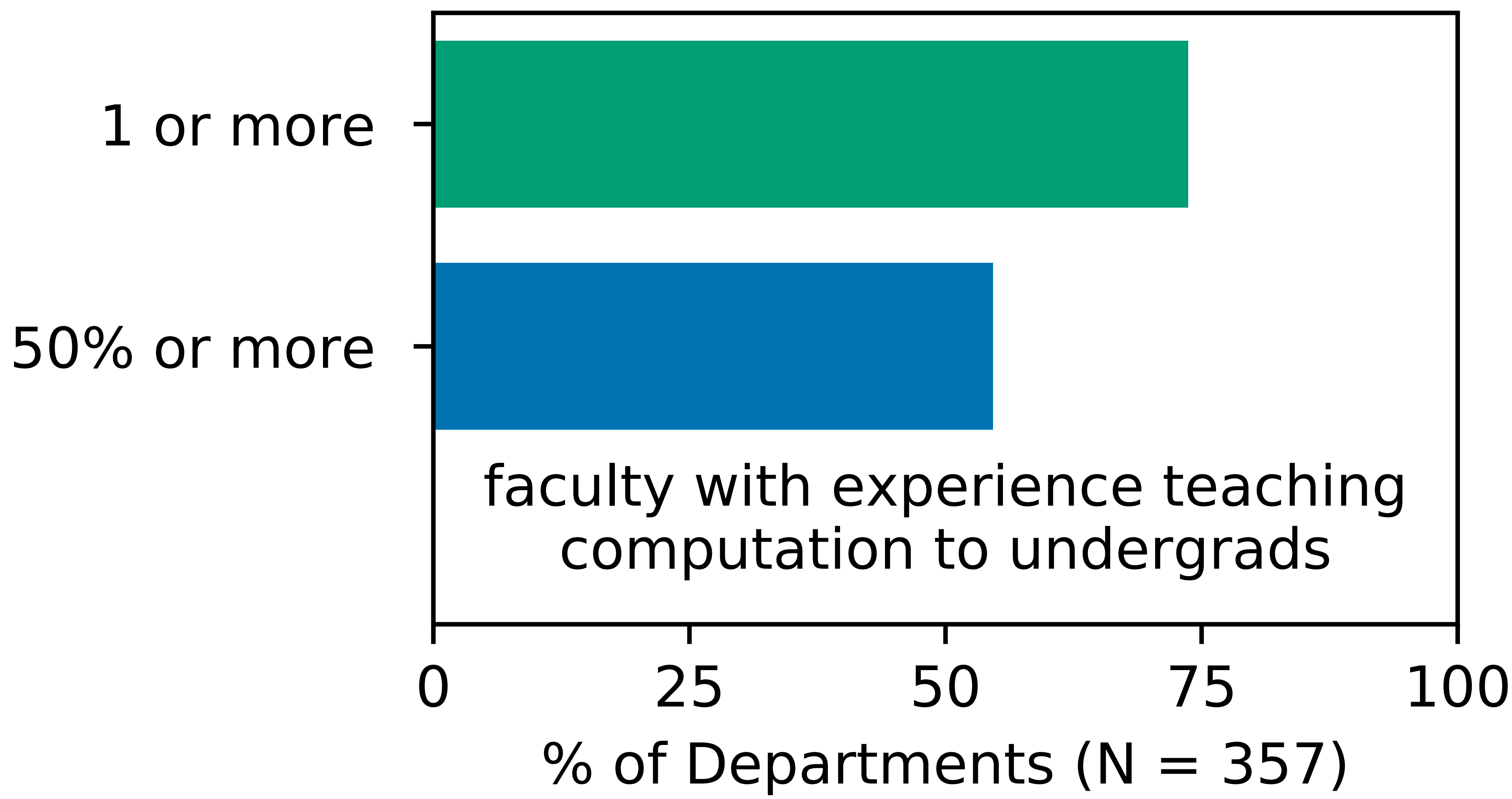
- Distribute a survey of faculty to investigate the current state of computational physics instruction
- Draw implications for efforts to bolster computational instruction
- Track changes to the state over time

- Sample: 357 departments; 1296 faculty

NSF PICUP

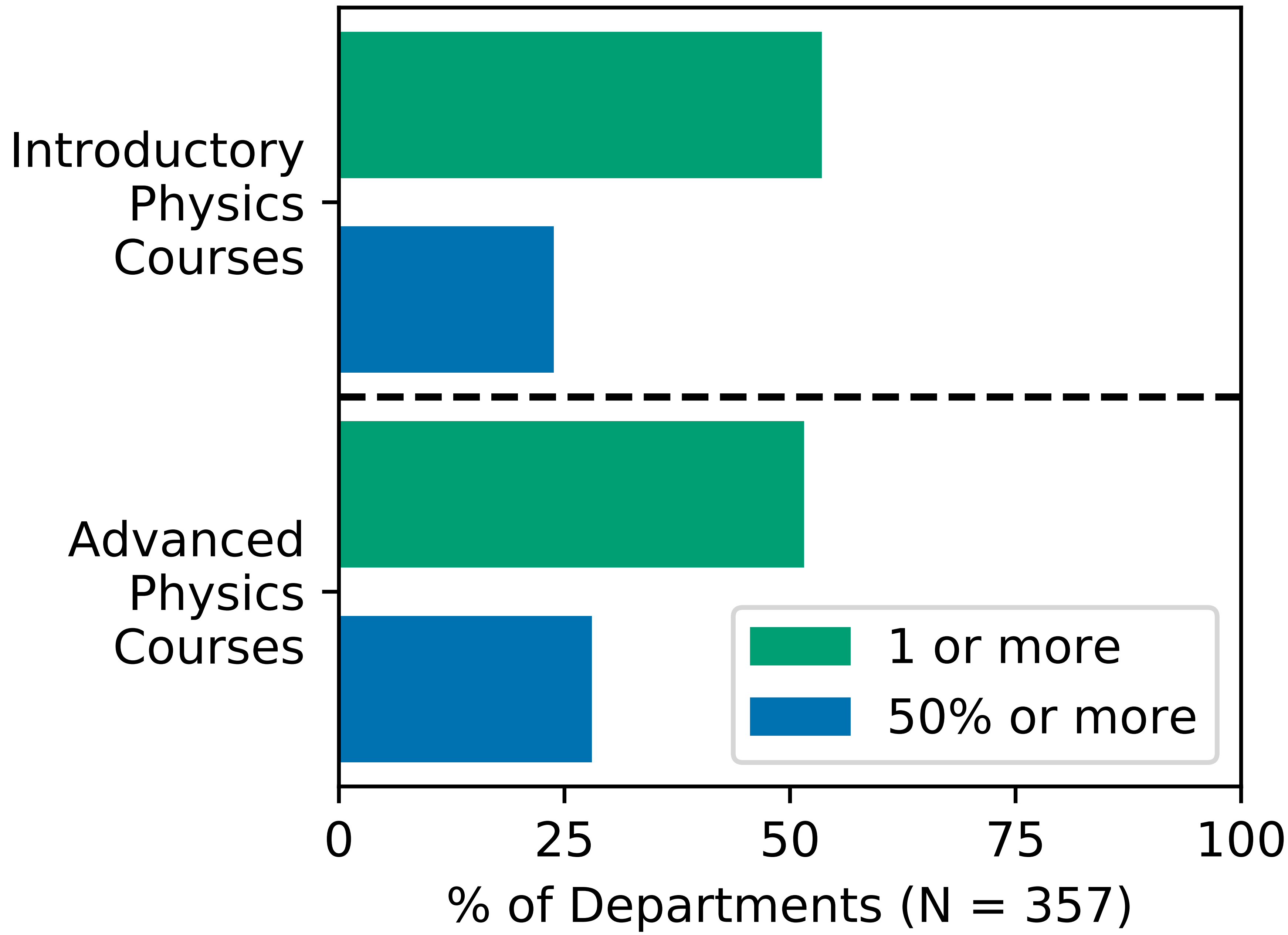


Do you have experience teaching computation?



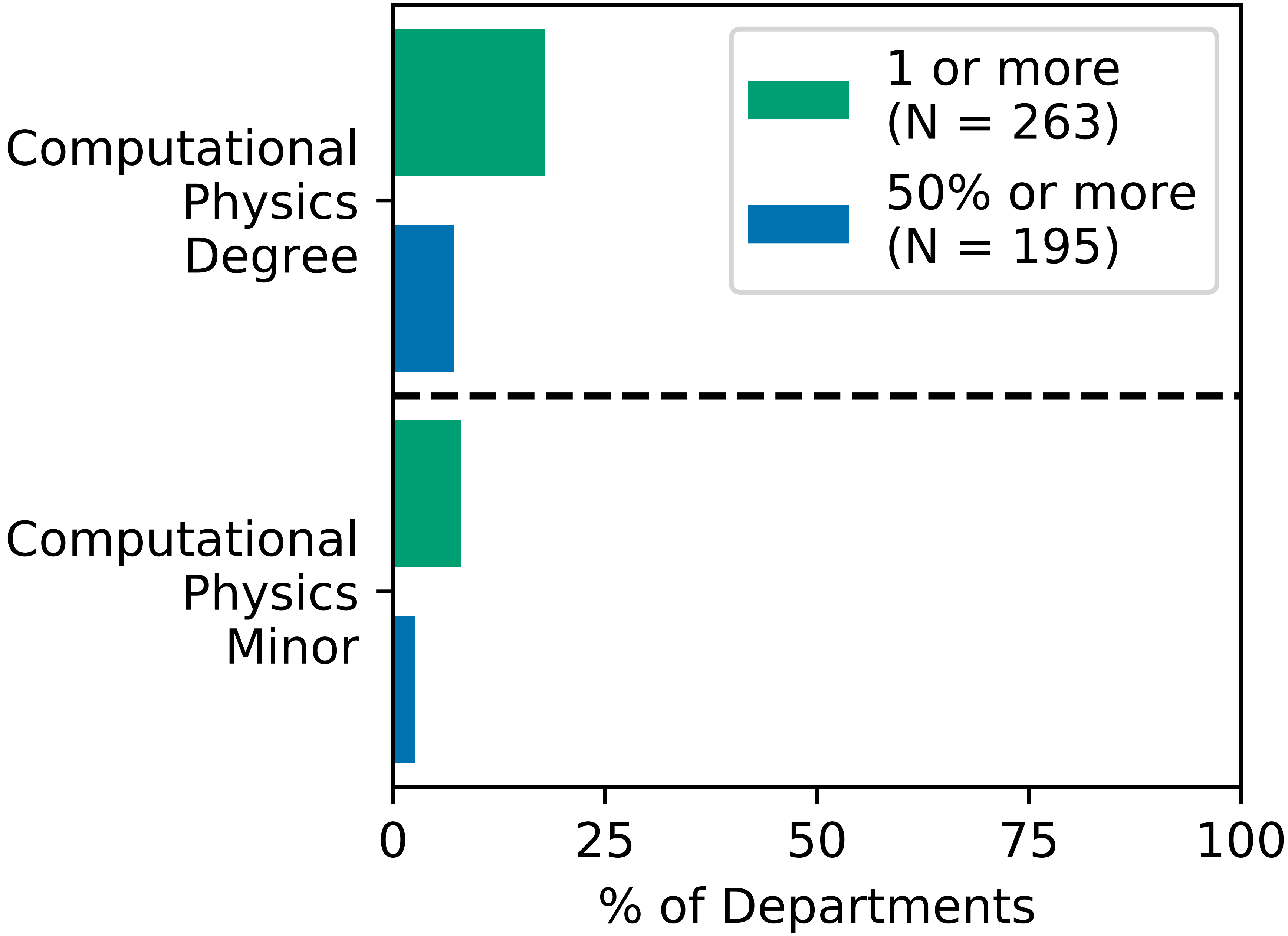
Caballero, https://arxiv.org/abs/1712.07701

In which courses is computation taught?



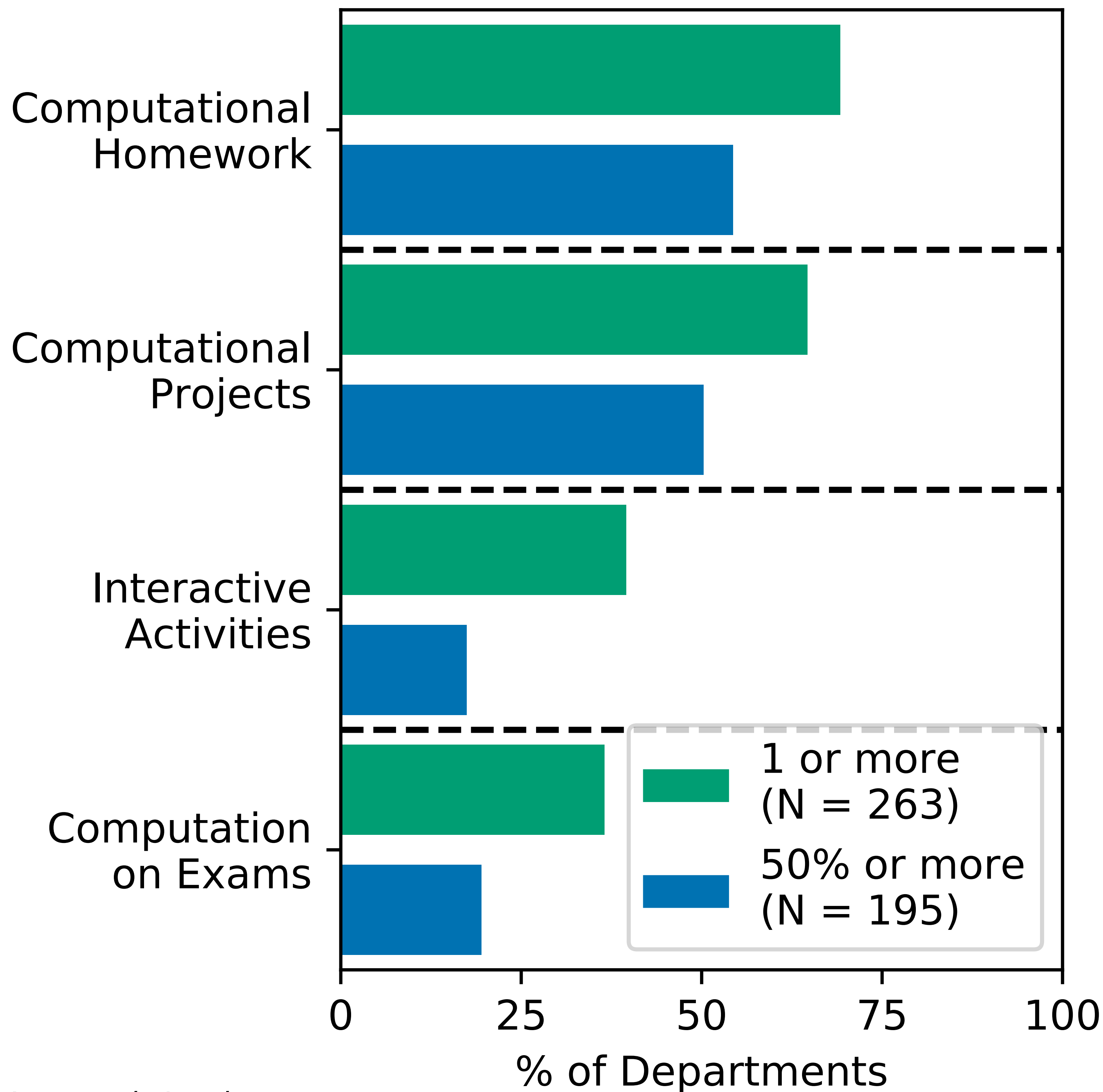
Caballero, https://arxiv.org/abs/1712.07701

Prevalence of formal programs



Caballero, https://arxiv.org/abs/1712.07701

Prevalence of Instruction



Caballero, https://arxiv.org/abs/1712.07701

Take-Aways

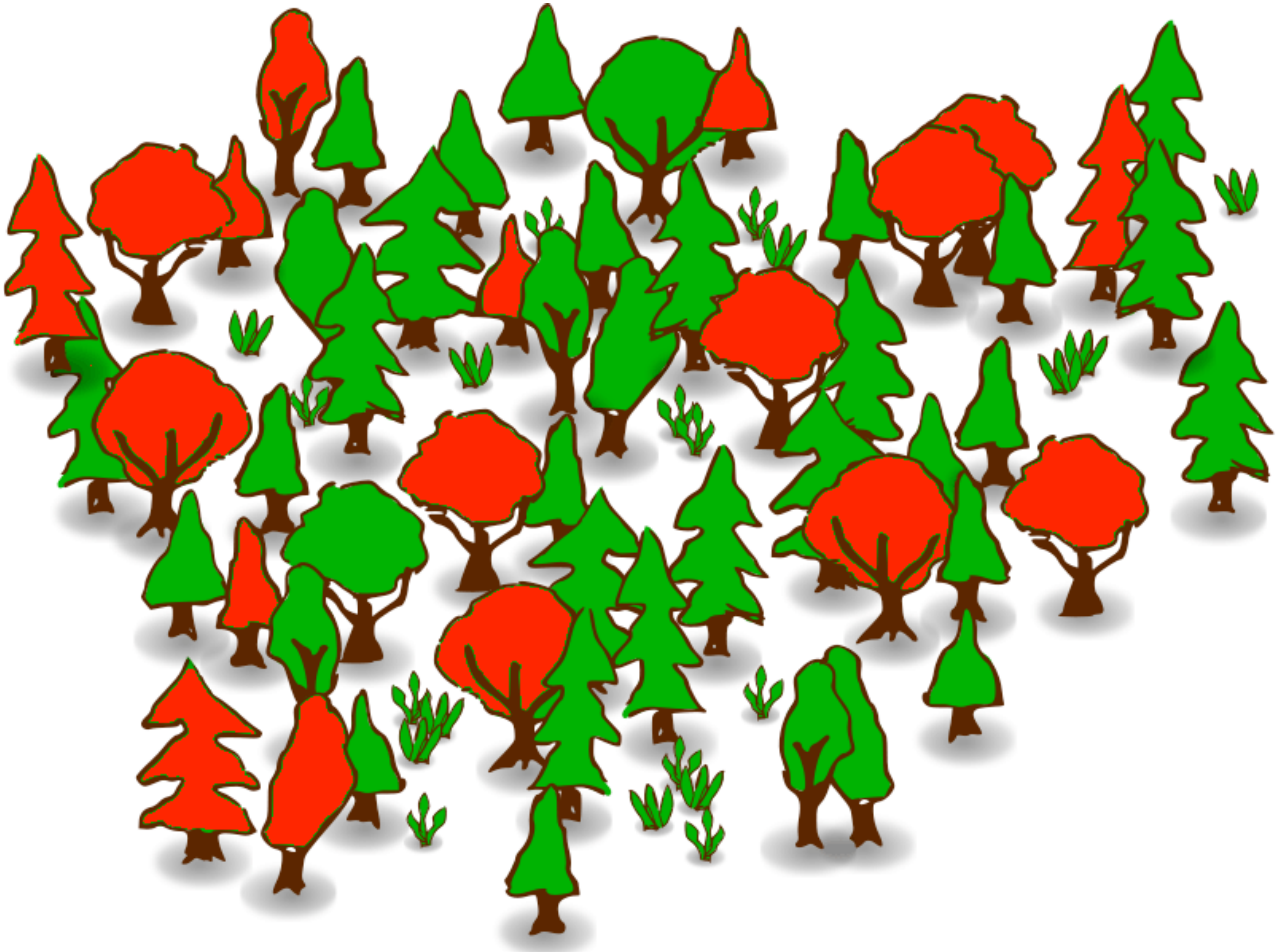
- A majority of faculty report having experience teaching undergraduate students computation
- Computational instruction is more prevalent than in the past[1]
- We are lacking formal computational physics programs
- There is a need to explore interactive methods and assessment techniques for computation

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

Can we learn something more from this data?

w/ Young, Allen, Aiken

Let's get weird...



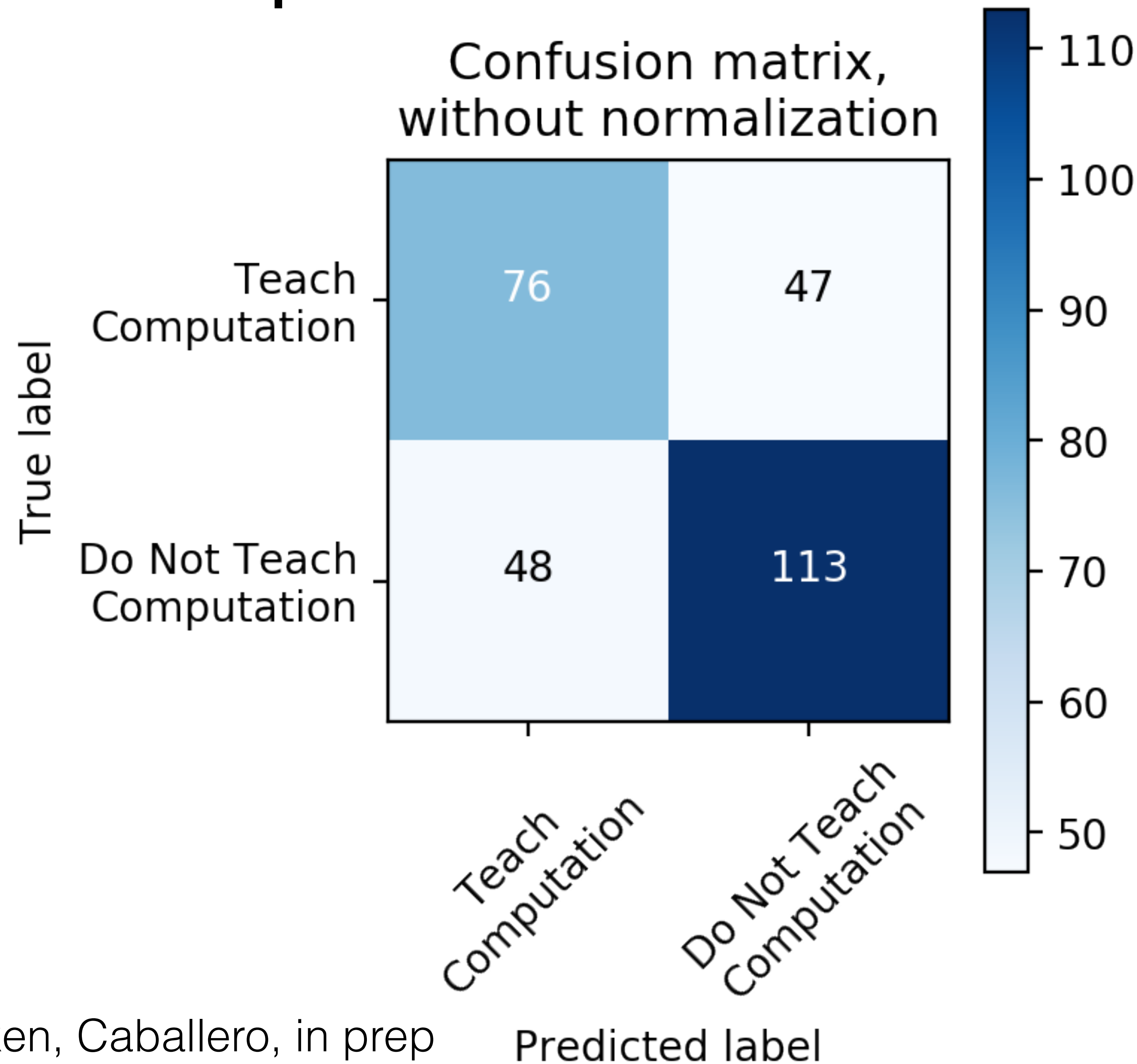
Breiman, Leo. "Random forests." Machine learning 45.1 (2001): 5-32.

Do you have experience teaching computation?

Yes

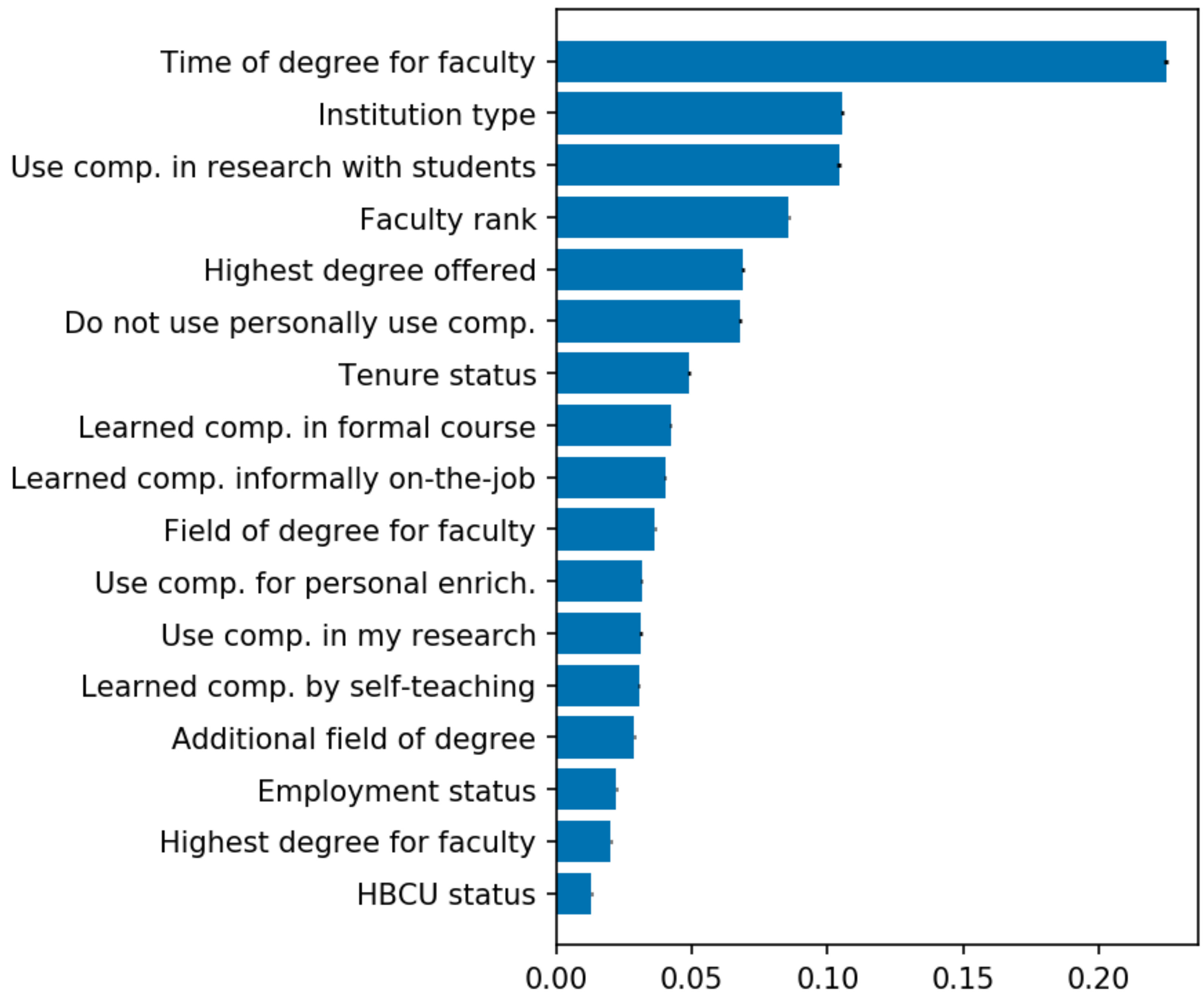
No

Validation against sequestered data



Young, Allen, Aiken, Caballero, in prep

Important Features



Young, Allen, Aiken, Caballero, in prep

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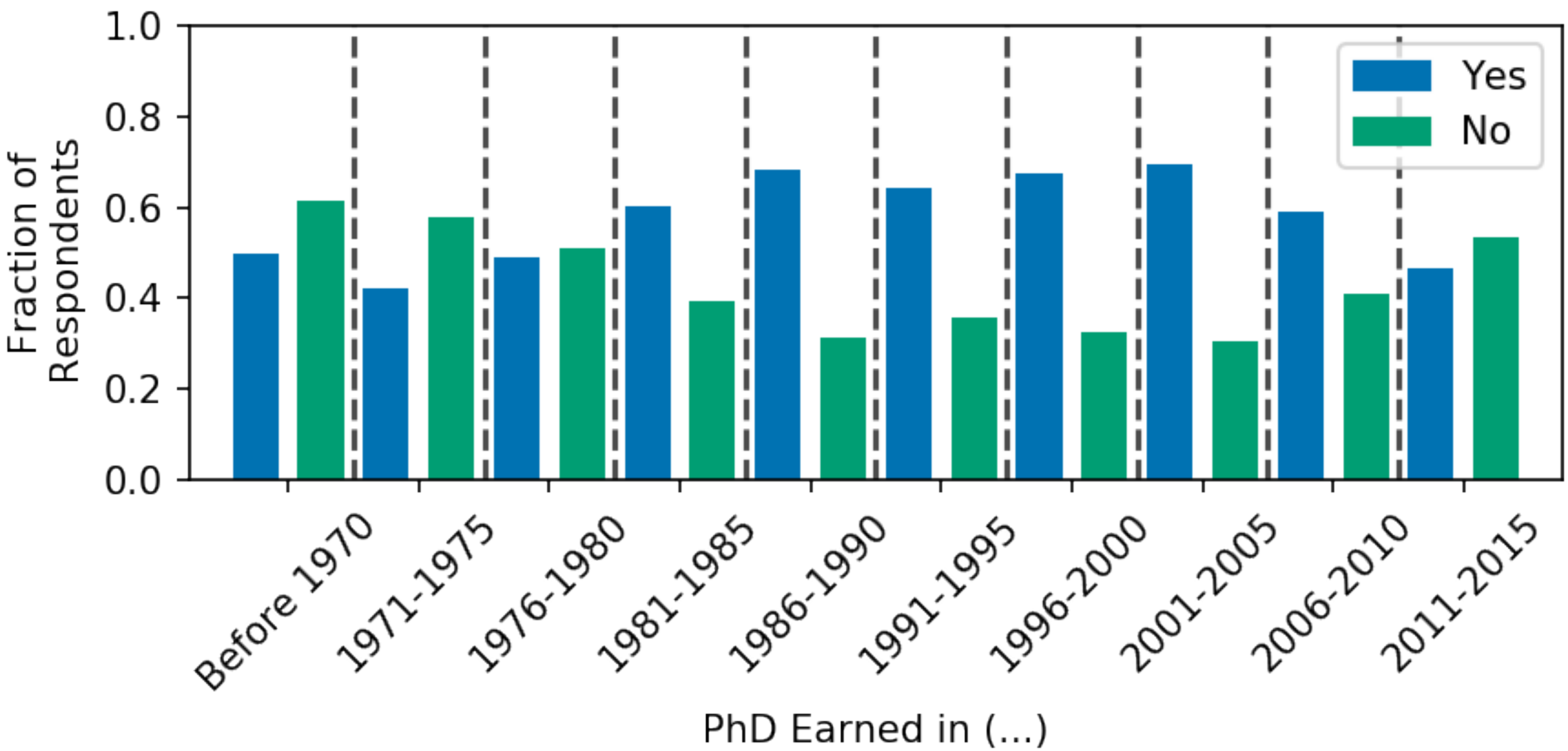

Young, Allen, Aiken, Caballero, in prep

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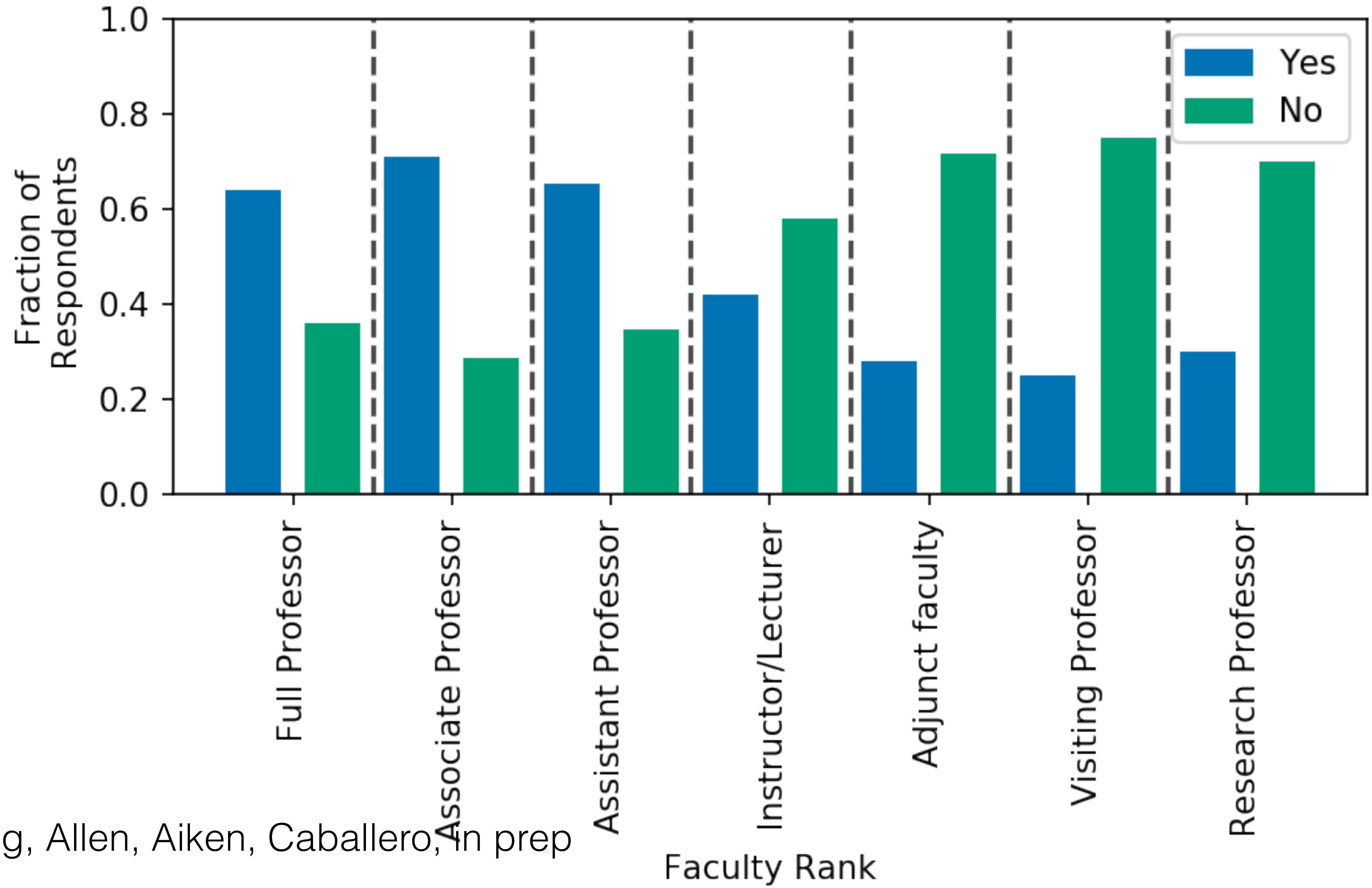

Young, Allen, Aiken, Caballero, in prep

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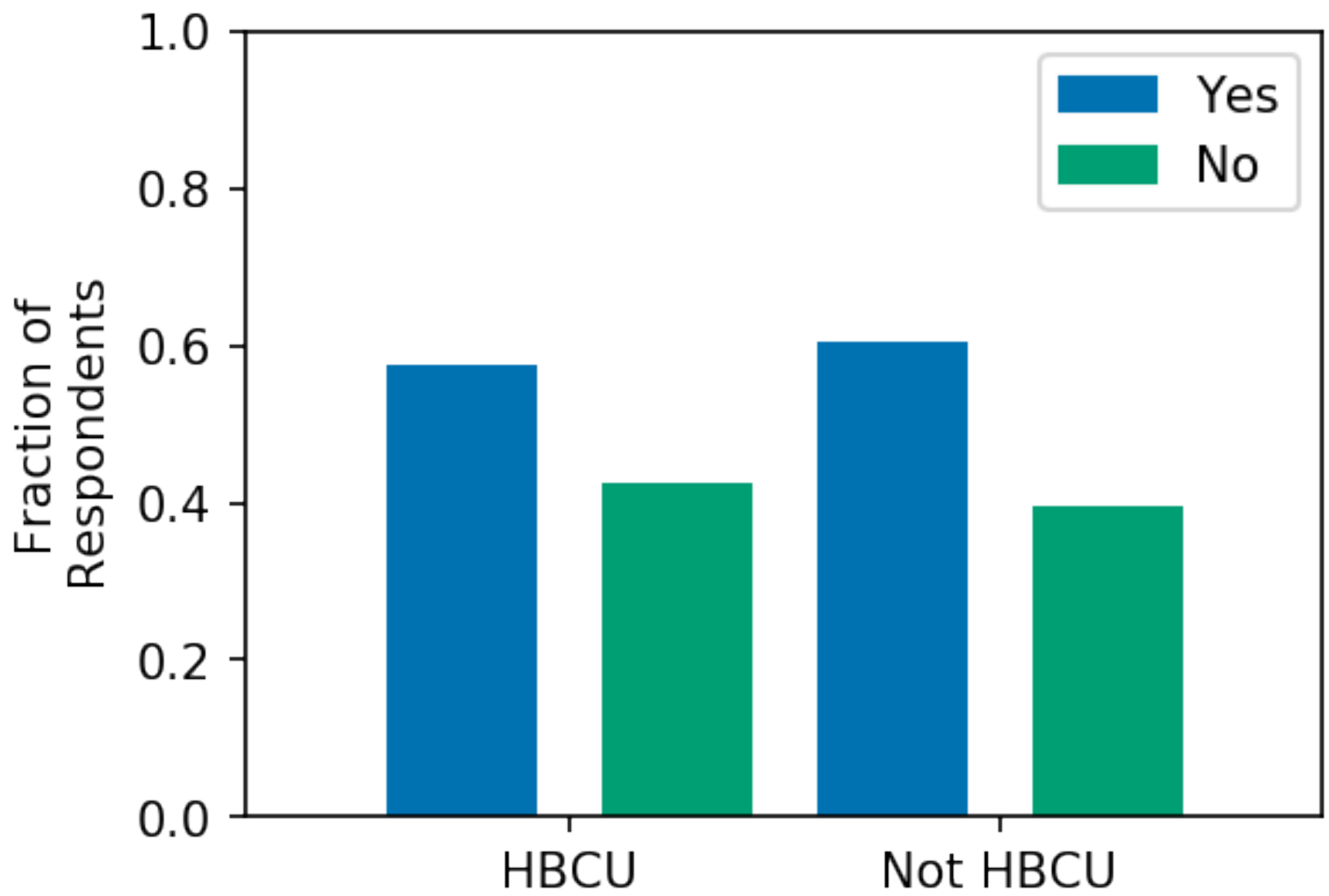

Young, Allen, Aiken, Caballero, in prep

Concerns

- More false classifications when data is biased
  - Solution: Bootstrap when training
- Most important features tend to have more “degrees of freedom”
  - Solution: Alter training algorithm
- Results tied to specific algorithm?
  - Solution: Apply several ML techniques

Other Projects

- How do students debug a program with a visually wrong result? (Oleynik, MSU undergrad)
- How do bioscience students approach modeling predator-prey relationships with computation? (Sand, UiO PhD student)
- What are instructors ideas and approaches to teaching computation in an introductory classroom? (Pawlak, MSU PhD student)
- How do instructor’s ideas relate to their enacted teaching practice when teaching computation in intro physics? (Leary, MSU undergrad)
- What features are predictive of the ways faculty teach computation? (Allen, MSU undergrad)
- What features are predictive of the degree to which faculty teach computation? (Young, MSU PhD student)
- How can computation be used to understand students’ paths in science? (Aiken, UiO PhD student)
- How do faculty come into the community of computational physics teachers? (w/ Irving, MSU faculty)

MICHIGAN STATE UNIVERSITY

The MSU Department of Physics and Astronomy voted unanimously in favor of all majors to learn computational physics.*

–April 11, 2017

*Computational science pre-req for major (immediate)
+ integration of computation in mandatory courses (next 5 yrs.)

PER can help support and facilitate the coming computational revolution

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

Thank you!
Questions?

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gopicup.org

PICUP

UNIVERSITAS OSLOENSIS MDCCCXI

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