Michigan AAPT Fall Meeting
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Supporting the integration of computation into physics courses

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Legacy
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Adam Fritsch (FAST)
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Kristy Griswold
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Bridget Humphries
Maddie Klinkoski
Sam Luba
Sonny Ly
Claire Morrison
Keenan Noyes
Zach Nusbaum
Anna Turnbull

AAU
NSF
HHMI
HOWARD HUGHES MEDICAL INSTITUTE
PICUP
SCIENCE + SOCIETY @ STATE

Reasons you might consider computation:

Computational modeling can enhance (and perhaps improve) instruction

Experience with computational modeling is expected of our graduates

Computational modeling is how modern science is done

Classroom use with computational modeling can provide authentic science experiences

Developing the 21st century scientific workforce

Ivie & Stowe, 2002

Gaps in undergraduate program:

- Using scientific software
- Using computational modeling

Chonacky & Winch, 2008

Few departments teaching computational modeling

Lack of resources & expertise

Where does it go?

Caballero, Chonacky, Hilborn, & Merner, ~~2017~~ 2018

Comprehensive AIP-hosted survey

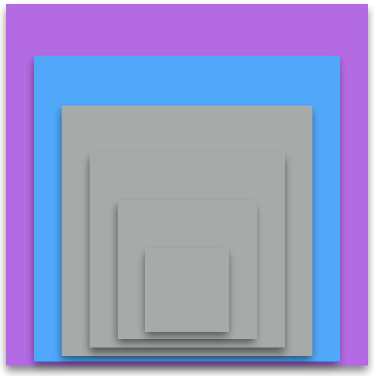
All departments; random faculty

The American Association of Physics Teachers urges that every physics and astronomy department provide its majors and potential majors with appropriate instruction in computational physics.

Approved by the AAPT Executive Board at the Spring 2011 meeting.

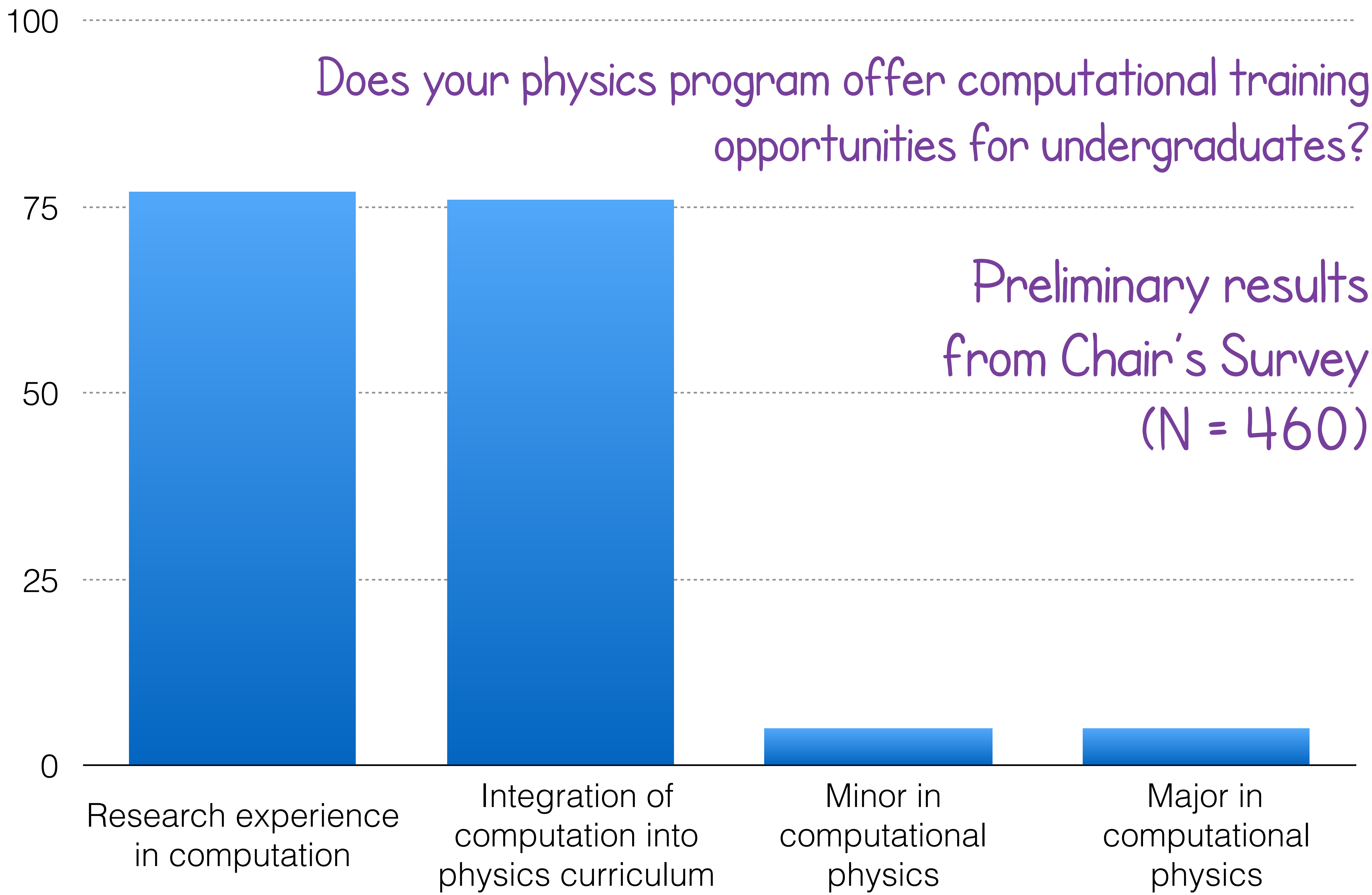
Surveying the state and implications of computational physics instruction

- 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



w/ N. Chonacky, R. Hilborn, & L. Merner
DUE-1431776 & DUE-1432363

Surveying the state and implications of computational physics instruction



Surveying the state and implications of computational physics instruction

Expected Outcomes:

- Implementation models that interested departments and programs can replicate
- Factors that characterize successful/failed implementations
- Identify departments to study in more detail

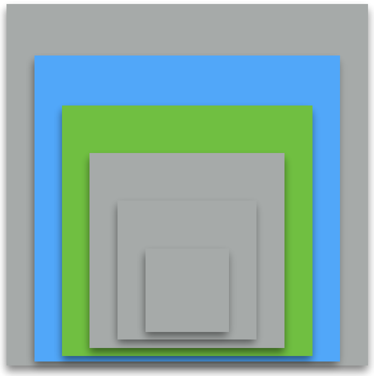
PICUP

w/ N. Chonacky, R. Hilborn, & L. Merner

DUE-1431776 & DUE-1432363

Integrating Computation into Undergraduate Physics

- Develop, support, and grow a community of faculty working to integrate computation into their courses
- Co-develop exercises for a wide variety of courses across platforms and implementations
- Study how faculty move into this community

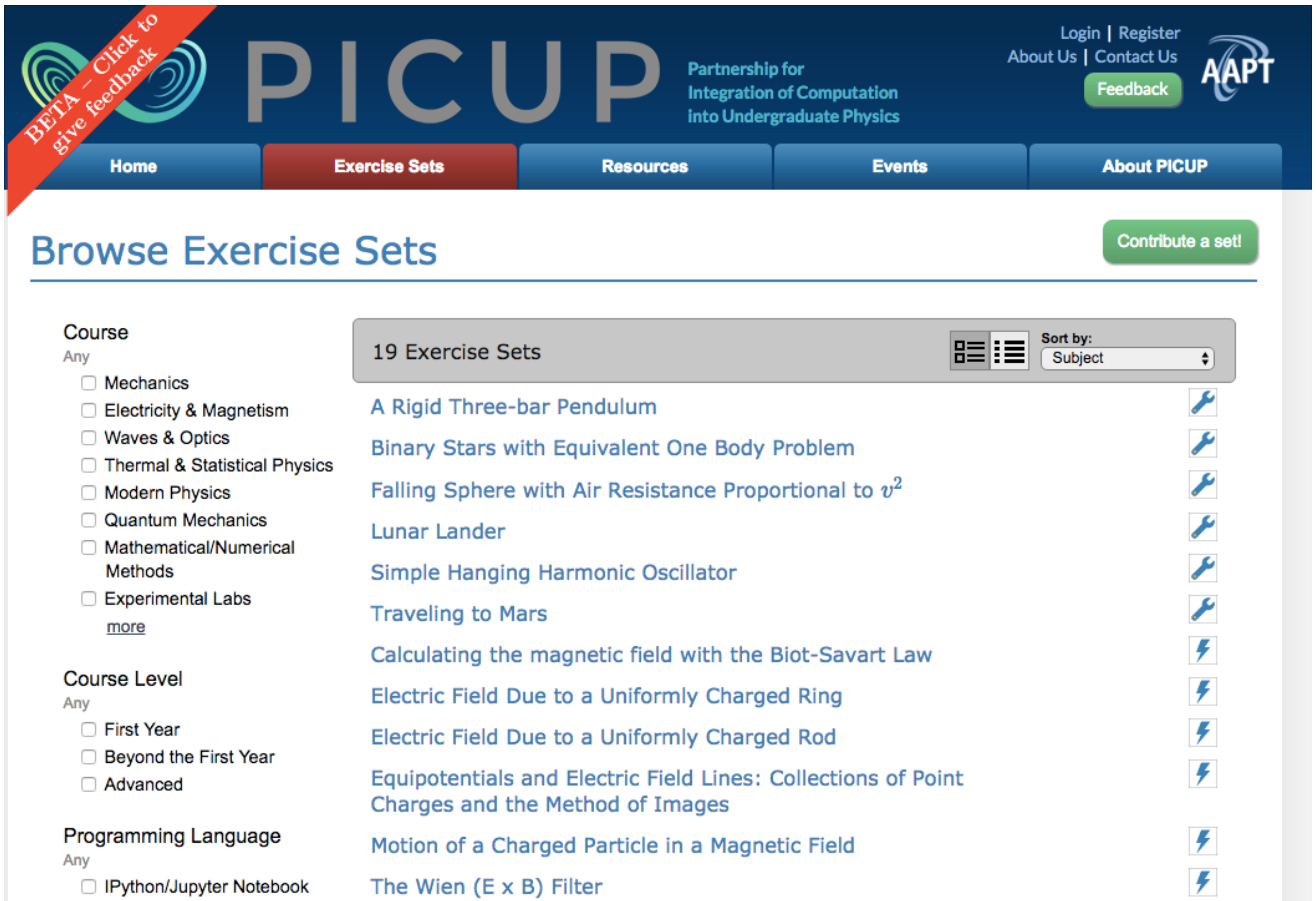


w/ K. Roos, M. Lopez del Puerto,
L. Engelhardt, R. Hilborn, & P. Irving
DUE-1524128, DUE-1525525, DUE-1525062,
DUE-1524493, & DUE-1524963

Integrating Computation into Undergraduate Physics

Summer Residential Workshop

Integrating Computation into Undergraduate Physics



compadre.org/picup brought to you by the tireless efforts of B. Mason & L. Barbato

Studying faculty movement into the community

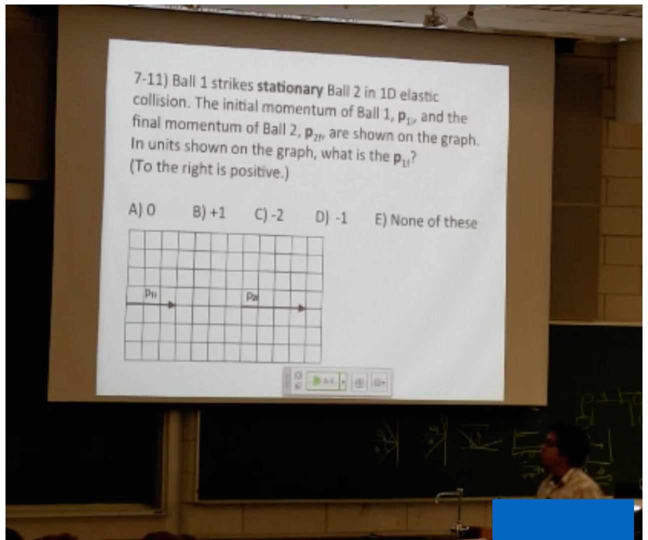
Expected Outcomes:

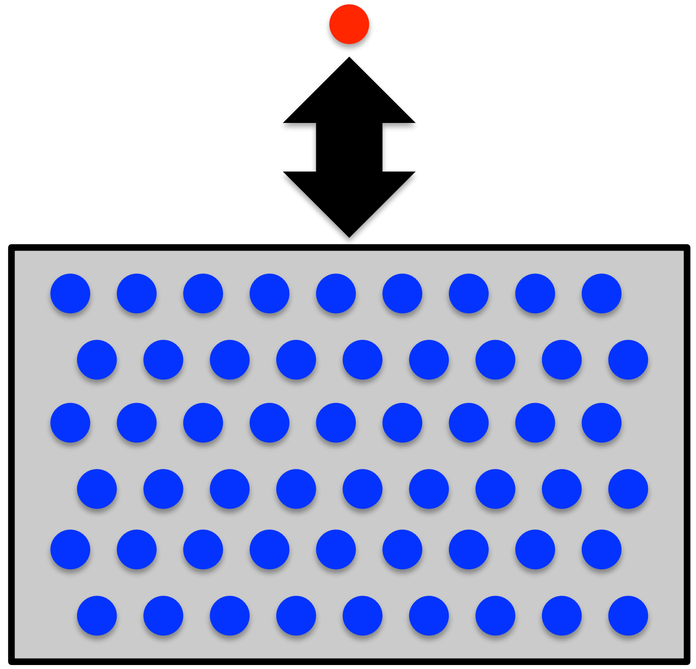
- Specific practices and norms of the computational physics education community
- Factors that influence how new members take up and modify those practices and norms
- Structural and community supports needed to bring new members into the community

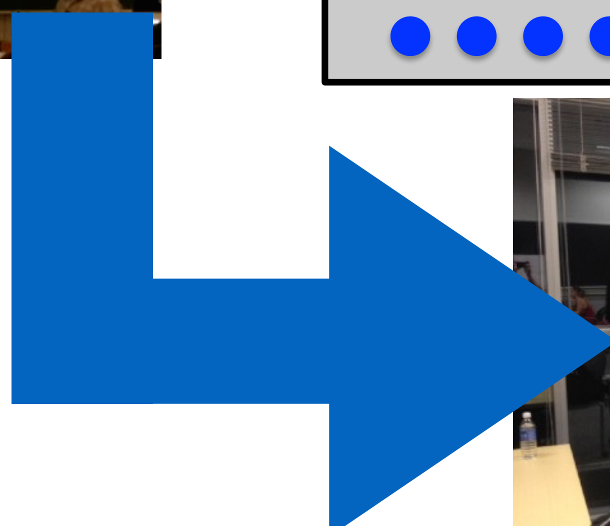
PICUP

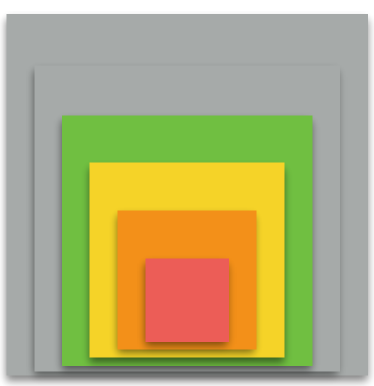
w/ P. Irving
DUE-1524128

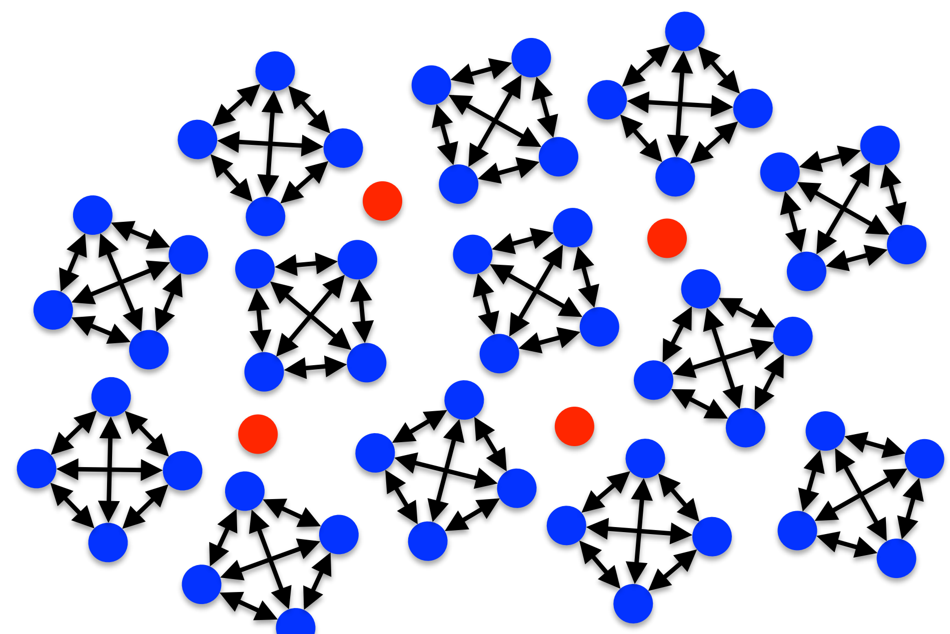
Projects and Practices in Physics (P^3)











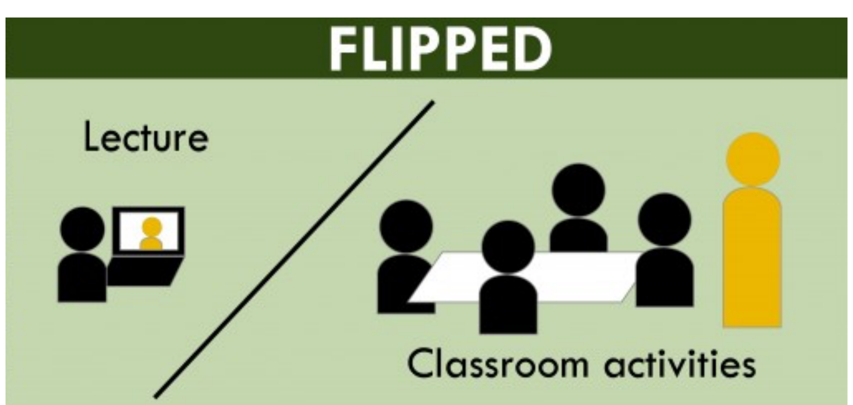
pcubed.pa.msu.edu

http://arxiv.org/abs/1607.04455

w/ P. Irving & M. Obsniuk

A Typical Week

- Monday: Pre-class reading/HW (conceptual clicker-style)
- Tuesday: In-class project (analytical)
- Thursday: In-class project (analytical/ computational)
- Sunday: Post-class HW (standard end-of-chapter + conceptual)



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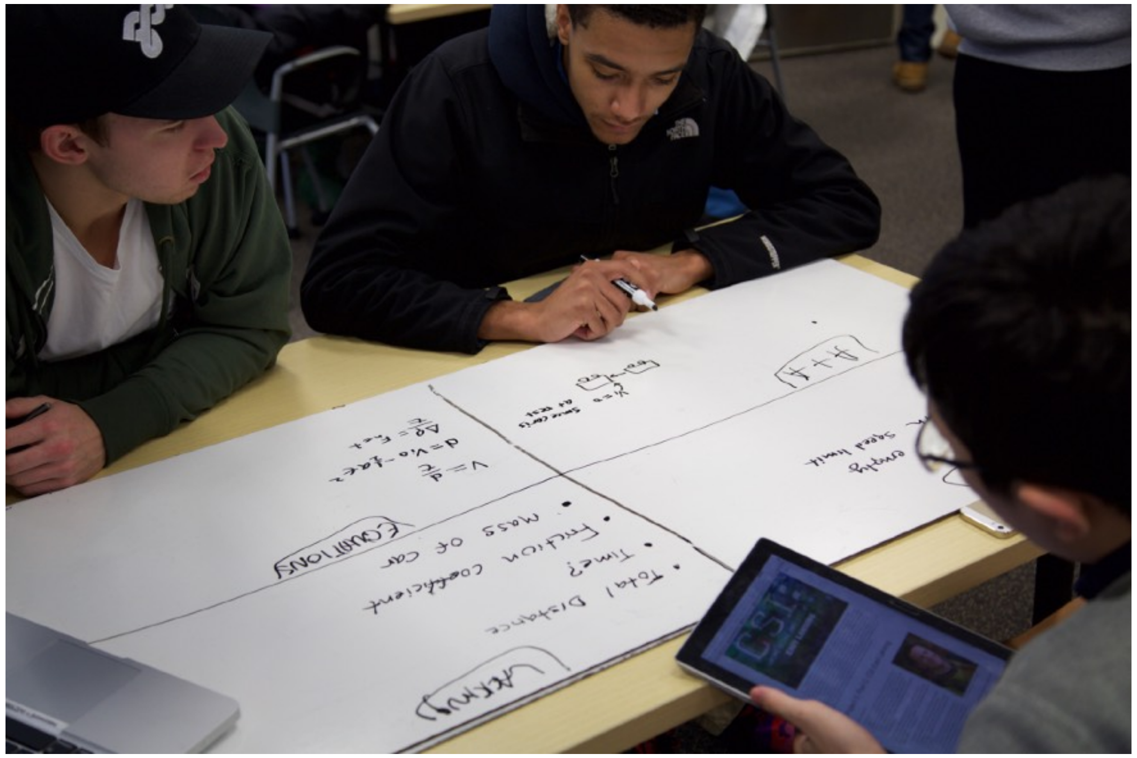

Total Distance
Time?
Friction coefficient
mass of car
Equations
Lacking


Facts
Lacking

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)
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
```

"Open-source" Materials*

The Concept of Iterative Prediction

"Iterate" means to "repeat." In physics, it often means to perform the same calculation repeatedly using information produced by the previous calculation. You might think of this as taking the output of a calculation and using it as the input for the new calculation.

To predict motion iteratively is to apply the momentum update and position update formula over small time steps, using their own predictions and the inputs for the next calculation. The steps for iteratively prediction motion are as follows:

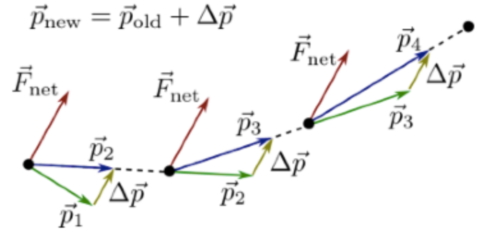
- Calculate the (vector) forces acting on the system.
- Update the momentum of the system: $\vec{p}_f = \vec{p}_i + \vec{F}_{net}\Delta t$.
- Update the position of the system: $\vec{r}_f = \vec{r}_i + \vec{v}_{avg}\Delta t$.
- Repeat

This process can be used for any system with any type of force. The accuracy of your predictions depend on the length of the time step. By using this method, you assume that the net force and average velocity are roughly constant over the time interval (for each time interval). If you are interested in more details, this method is similar to Euler-Cromer symplectic integration.

Applying Iterative Prediction

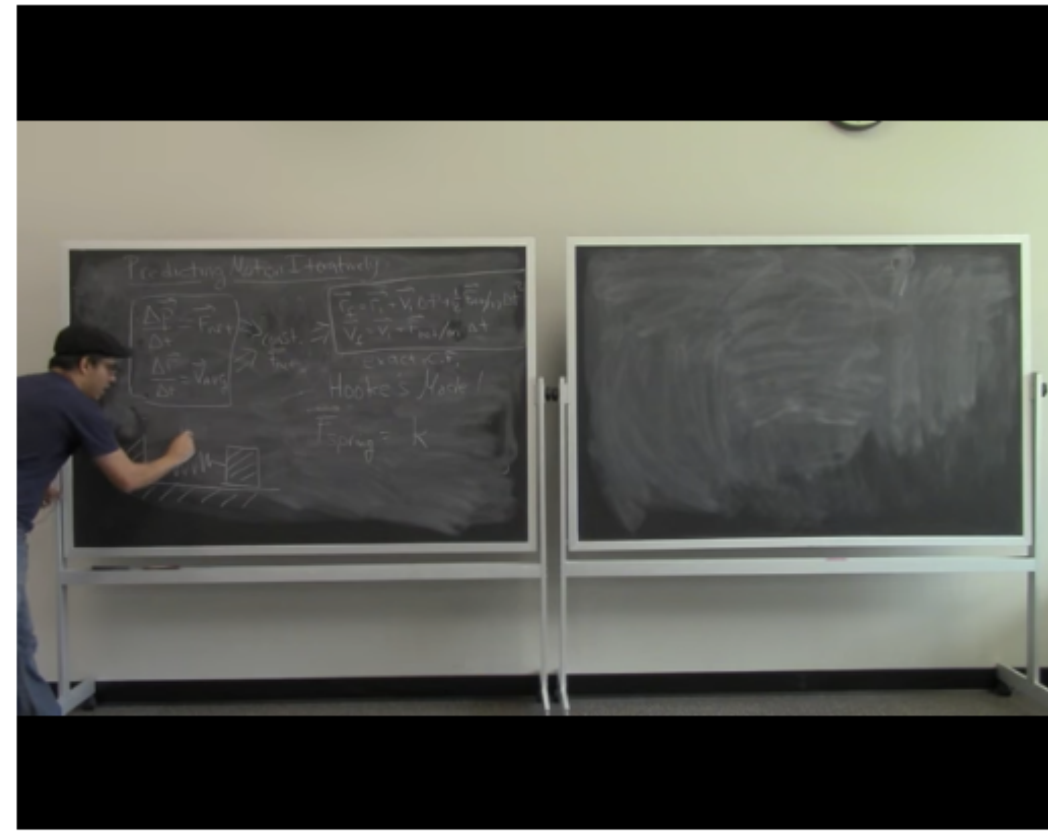
To reiterate, this method is not limited to non-constant forces and can be used to predict the motion in situations where a constant force model can be applied. A visual representation of such an iterative prediction over 3 steps is shown below. In each step, the momentum changes and, thus, the new momentum is calculated. This new momentum is used to determine the new location of the ball. The process is executed again with an updated prediction.

$$\Delta\vec{p} = \vec{F}_{\rm net}\Delta t$$
$$\vec{p}_{\rm new} = \vec{p}_{\rm old} + \Delta\vec{p}$$



If you were to connect the straight lines in this picture, you would see a trajectory that looks more like moving through a curved trajectory. The time step here is quite long for the motion, but using a shorter time step, the line segments are shorter and more closely produce a curved trajectory.

Lecture Video



Project 3: Part B: Geostationary orbit

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: Part B
Keep them in the same directory.
Project 3 Code (satellite.py)
PhysUtil Module

pcubed.pa.msu.edu

*E&M materials this summer/fall

Weekly Feedback

- Students are provided with weekly formative feedback on:
  - their individual understanding
  - their group's understanding
  - their role in facilitating/focusing the group's efforts

Irving, Sawtelle, Caballero 2015 PERC
Irving et. al, TPT (in preparation)

Weekly Feedback

<u>"Liam's" Feedback:</u>

tendency to jump quickly into a plan of action without evaluating whether it is the right plan

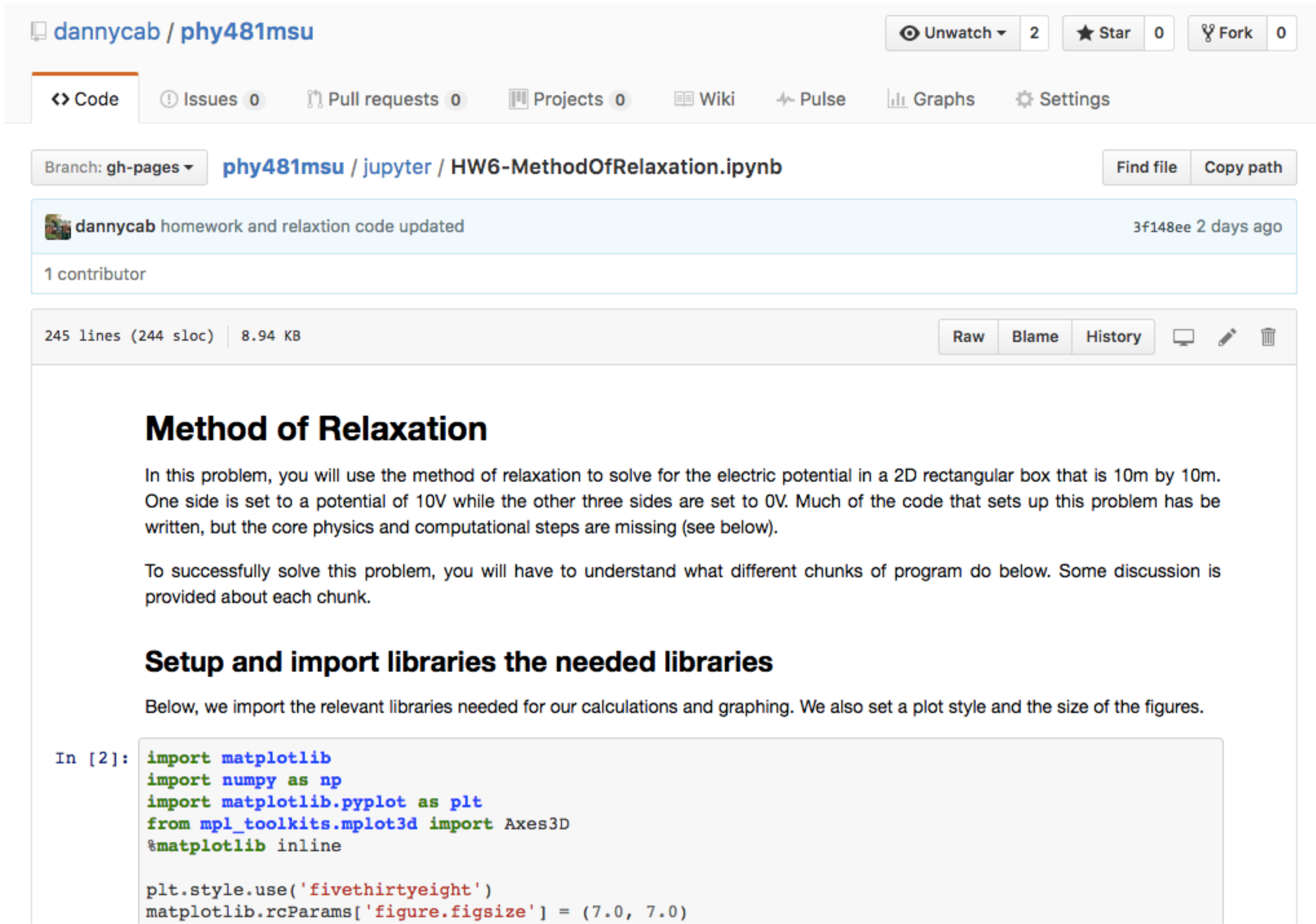
like to see you take on a more guiding role

expect you to encourage another group member to take the lead when working with Python.

Irving, Sawtelle, Caballero 2015 PERC
Irving et. al, TPT (in preparation)

Liam given “just-in-time” feedback

Upper-Level Physics, too!



https://dannycab.github.io/phy481msu/

Punchline: Physics Education Research 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

Partnerships with "traditional" faculty are incredibly important to this work.

Thank you!
Questions?

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