On developing an open access first year physics textbook and other free things

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4 June 2019

On over-complicating my life to teach a first year physics course…

…but hopefully it's useful!

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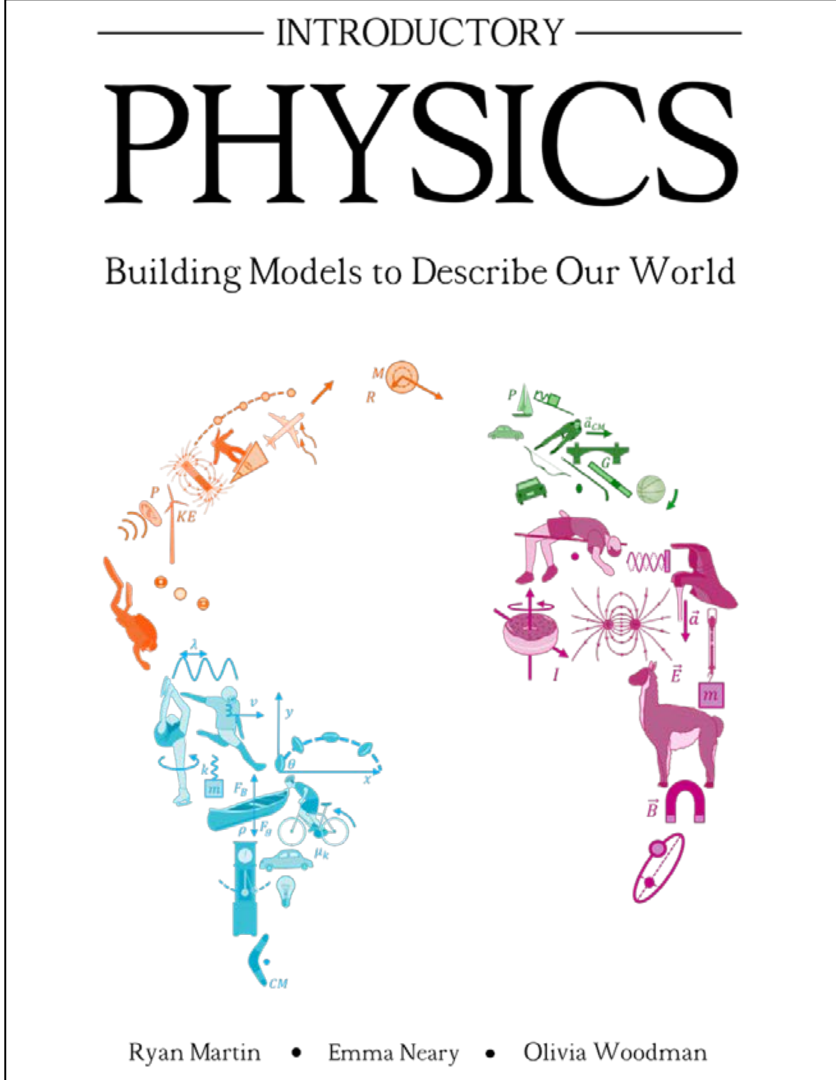
Outline

- Motivation for developing open access educational resources (OER) in the context of an introductory physics course.
- Working with students to:
  - Develop a textbook
  - Develop software for the lectures
  - Develop software for the labs
- Some evidence of success from the labs



Motivation: Education should be…

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- Free

In the common sense (cost nothing), but also in the true sense, freedom.

From the Free Software Foundation:

“*Free software” means software that respects users' freedom and community. Roughly, it means that the users have the freedom to* ***run, copy, distribute, study, change and improve*** *the software. Thus, “free software” is a matter of liberty, not price. To understand the concept, you should think of “free” as in “free speech,” not as in “free beer”.*”

Motivation: Education should be…

- Free
- Effective

Educational materials and instruction should be evidence-based and make use of good pedagogy

Motivation and goals

- Teaching first year calculus-based intro physics course at Queen's (PHYS 104/106):
  - The main course to recruit into our physics major program
- Goals:
  - Effective evidence-based lecture instruction (flipped classroom, etc.)
  - Effective development of skills as a physicist and scientist (build models/design experiments)
  - Increase diversity in our students

The solution… …does not exist

- What does exist:
  - Textbooks that cost $$$, no good free alternative adapted for active learning → Develop a **new open access textbook**
  - Active-learning tools such as iClicker, Learning Catalytics, online polling software, are either not free or clunky, or not designed for education, or all of the above → Develop clean **polling software designed with pedagogy in mind**
  - Strong evidence that "traditional labs do not help" → Think about **laboratory instruction**

The textbook

- Adapted for the **flipped class room**:
  - Minimize the length of the narrative (e.g. no "info boxes")
  - Integrate questions and activities to engage with the material

5.8 Thinking about the material

Reflect and research

1. What was the name of the publication in which Newton's published his three laws, and when was it published?
2. When did Galileo come up with his principle of inertia?
3. When you skate on ice, there is kinetic friction between your skates and the ice. Does the coefficient of kinetic friction depend on the temperature of the ice? If yes, what is the optimal temperature for skating with the least amount of friction?

To try at home

1. Place two books stacked on each other on the palm of one hand held horizontally. Use your other hand to press down (and forward) on the top book and try to move the bottom book. No matter how hard you push down (to increase the force of friction between the two books), you cannot make the bottom one move. How come?

To try in the lab

1. Propose an experiment to determine whether gravitational and inertial mass are equal.
2. Propose an experiment to measure the coefficients of static and kinetic friction between a block and a surface.

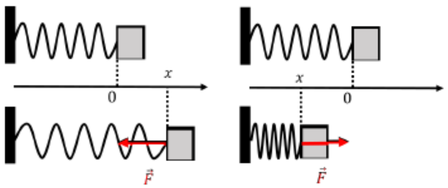


Figure 5.6: A spring is attached to a fixed wall on its left and to a movable block on its right. The x axis is chosen to describe the position of the end of the spring where the block is attached and the origin corresponds to the point where the spring is not extended or compressed (the top row). The x axis is chosen so that positive values of x correspond to the spring being extended. On the bottom left, the spring is extended by a distance x (the position of the block has positive x), and the force from the spring on the block is in the negative x direction. On the bottom right, the spring is compressed (the position of the block has negative x), and the force from the spring is in the positive x direction.

Checkpoint 5-5

In Figure 5.6, we chose the positive x axis to correspond to positions where the spring is extended and verified that Hooke's Law ($\vec F = -kx\hat x$) holds. If we had chosen the positive direction to correspond to compression (positive x to the left), would Hooke's Law still correctly describe the direction of the force exerted by the spring on the block?

A) Yes.
B) No.

Inertial forces

Inertial forces are exerted on an object when the forces on the object are modelled in a non-inertial frame of reference. For example, in the frame of reference of an accelerating elevator, or that of a car going around a curve, one can use Newton's Three Laws to model motion, if an additional inertial force is included. In a frame of reference that has an acceleration given by $\vec a$, an inertial force $-m\vec a$ is exerted on an object. This is the nature of the outwards force that is felt when your car goes around a curve, or the perception of being weightless in an elevator that has a large downwards acceleration. We will discuss inertial forces in more detail in section 5.2.1.

"Applied" forces

"Applied" forces is just a general "catch-all" term for specifying forces that are not described above. For example, the force applied by a person onto an object is often referred to as an applied force.

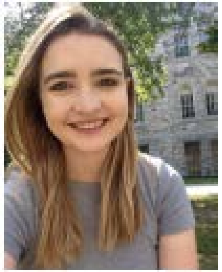
5.3 Mass and inertia

Mass is a property of an object that quantifies how much matter the object contains. In SI units, mass is measured in kilograms. One kilogram is defined to be the mass of a cylinder

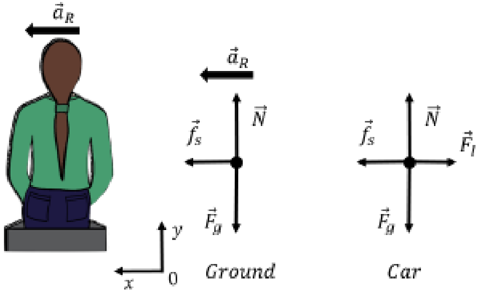
The textbook

- Adapted for the flipped class room
- **Written with students**:
  - Student "thought boxes" to provide a different perspective of challenging topics.
  - Review of material, contributions to questions, artwork, activity design, etc

Emma



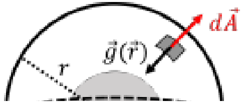
Olivia



Olivia's Thoughts

If you want to know if a surface is closed, ask yourself if you could put water inside the surface and not be worried about it spilling out. For example, if you put water in a sphere or a cube , the water would not spill out even if you shook it around, so they are closed surfaces. A flat square is an open surface because there is no "inside" to even put the water in. A bowl is an open surface because, though you can put water in it, the water could spill out.

We will go into more detail about Gauss' Law when we cover electromagnetism, but it is worth seeing how to use it in a simple scenario. Figure 9.9 shows a spherical body of mass M and radius R for which we would like to determine the value of the gravitational field at a distance r from the centre of the body.



Credits

This textbook, and especially the many questions in the Question Library would not have been possible without the many contributions from students, teaching assistants and other professors. Below is a list of the people that have contributed material that have made this textbook and Question Library possible.

Adam McCaw
Ali Pirhadi
Alexis Brossard
Amy Van Nest
Ceaira Heimstra
Damara Gagnier
Daniel Barake
Daniel Tazbaz
David Cutler
Emily Darling
Emily Mendelson
Emily Wener
Emma Lanciault
Genevieve Fawcett
Gregory Love
Haoyuan Wang
Jack Fitzgerald
James Godfrey
Jenna Vanker
Jesse Fu
Jesse Simmons
Jessica Grennan
Joanna Fu
Jonathan Abott
Josh Rinaldo
Kate Fenwick
Madison Facchini
Marie Vidal
Matt Routliffe
Maya Gibb
Nicholas Everton
Nick Brown
Nicole Gaul
Noah Rowe
Olivia Bouaban
Patrick Singal
Qiqi Zhang
Quentin Sanders
Robin Joshi
Ryan Underwood
Sam Connolly
Sara Stephens
Shona Birkett
Stephanie Ciccone
Talia Castillo
Tamy Puniani
Thomas Faour
Troy Allen
Wei Zhuolin
Yumian Chen
Zifeng Chen
Zoe Macmillan

The textbook

- Adapted for the flipped class room
- Written with students
- **Emphasizes the scientific method** and **building models**:
  - Emphasize that we **build models** to **describe** what is observed, not explain.
  - Emphasize that **science is just a bunch of rules to follow**, anyone can learn to apply them with practice. Physics is not about intuition of how the world works.

Emma's Thoughts

What's the difference between a model and a theory?
"Model" and "Theory" are sometimes used interchangeably among scientists. In physics, it is particularly important to distinguish between these two terms. A model provides an immediate understanding of something based on a theory.

For example, if you would like to model the launch of your toy rocket into space, you might run a computer simulation of the launch based on various theories of propulsion that you have learned. In this case, the model is the computer simulation, which describes what will happen to the rocket. This model depends on various theories that have been extensively tested such as Newton's Laws of motion, Fluid dynamics, etc.

- "Model": Your homemade rocket computer simulation
- "Theory": Newton's Laws of motion, Fluid dynamics

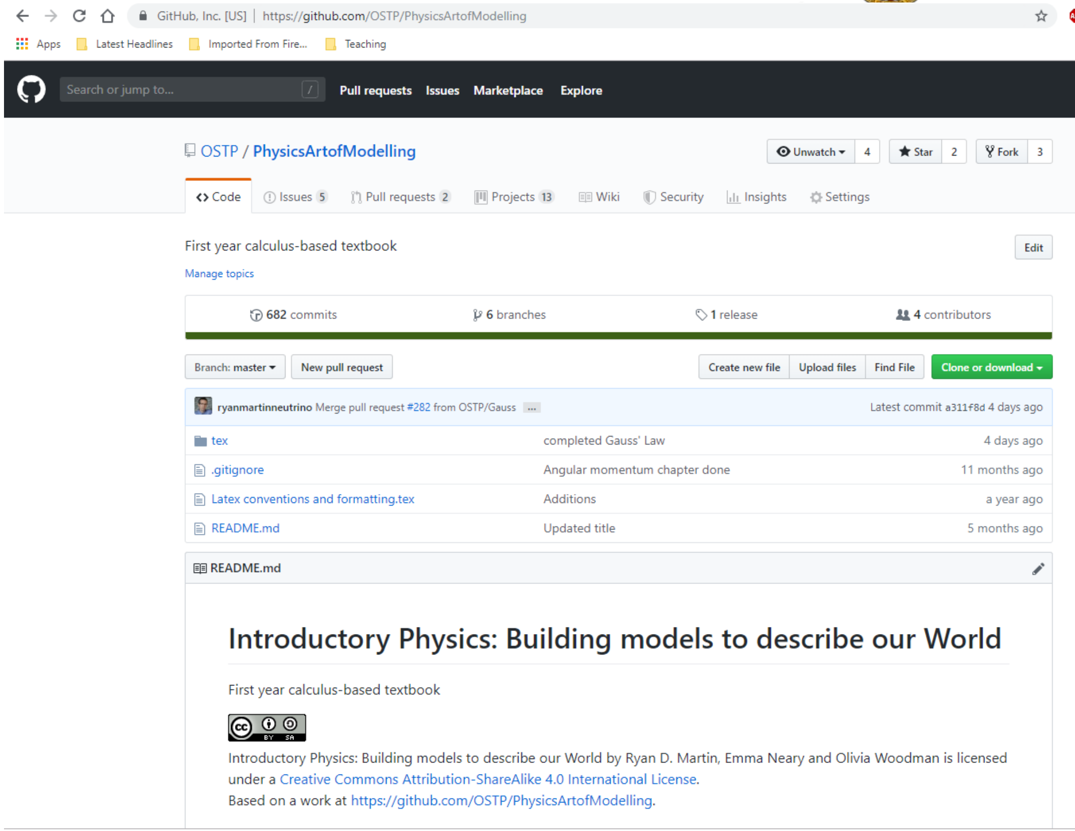
With this analogy, we can quickly see that the "model" and "theory" are not interchangeable. If they were, we would be saying that all of Newton's Laws of Motion depend on the success of your piddly toy rocket computer simulation!

1.3 Fighting intuition

It is important to remember to fight one's intuition when applying the scientific method. Certain theories, such as Quantum Mechanics, are very counter-intuitive. For example, in Quantum Mechanics, an object can be described as being in two locations at the same time. In the Theory of Special Relativity, it is possible for two people to disagree on whether two events occurred at the same time. These particular prediction from these theories have not been invalidated by any experiment.

The textbook

- Adapted for the flipped class room
- Emphasizes the scientific method and building models
- Written with students
- “**Living**” textbook:
  - Use a format that makes it easy to update, improve, contribute, and correct.
  - Hosted on github!



The textbook

- Adapted for the flipped class room
- Emphasizes the scientific method and building models
- Written with students:
- "Living"textbook
- Integrates a **experimental physics curriculum**:
  - Because that's half the discipline!!!
  - Chapters on experimental physics, python programming, scientific writing, data analysis
  - Examples of experimental proposals and reports, as well as how to review both
  - Suggested experiments to perform in the lab

C.1 The process of science and the need for scientific writing

Conducting experiments that test a scientific theory is integral to the advancement of science and to the refining of scientific theories. In practice, scientists do not have a lab full of

To try in the lab

1. Propose an experiment to determine whether gravitational and inertial mass are equal.
2. Propose an experiment to measure the coefficients of static and kinetic friction between a block and a surface.

2.3.4 Comparing model and measurement - discussing a result

In order to advance science, we make measurements and compare them to a theory or model prediction. We thus need a precise and consistent way to compare measurements with each other and with predictions. Suppose that we have measured a value for Chloë's constant $k = (0.44 \pm 0.09)\,\mathrm{s\,m^{-\frac{1}{2}}}$. Of course, Chloë's theory does not predict a value for k, only that fall time is proportional to the square root of the distance fallen. Isaac Newton's Universal

Type of measurement	How to determine central value and uncertainty
Repeated measurements	Mean and standard deviation
Single measurement with a graduated scale (e.g. ruler, digital scale, analogue meter)	Closest value and half of the smallest division
Counted quantity	Counted value and square root of the value

Table 2.5: Different types of measurements and how to assign central values uncertainties.

code does the following:

- *assigns* the value of 2 to the variable a
- *assigns* the values of 2*a to the variable b
- prints out the value of the variable b

Python Code D.1: Declaring variables in Python

```python
#This is a comment, and is ignored by Python
a = 2
b = 2*a
print(b)
```

Output D.1:

```
4
```

Emma's Thoughts

"Precision", "Accuracy" and "Uncertainty" - what's the difference?

Have you ever started writing a lab report and wondered whether or not you should describe your measurement in terms of "accuracy" or "precision"? What about describing

The textbook

- Adapted for the flipped class room
- Emphasizes the scientific method and building models
- Written with students
- “Living”textbook
- Integrates a experimental physics curriculum
- Provide **many practice problems** and problems to be used for assignments:
  - Well written out examples in the narrative, 2 sample problems with solution at end of chapter
  - Question Library, separate document, with many problems, and (neatly written) solutions, students can see answers, but not solutions
  - Questions contributed from students

11 Rotational energy and momentum

11.1 Multiple Choice

204. A figure skater is spinning with her arms extended. As she brings her arms in close to her body, she begins spinning faster because

◯ Her arms do work on her body, and thus increases her kinetic energy.

◯ Her moment of inertia decreases, which increases her angular momentum.

◯ Her moment of inertia decreases, which increases her angular velocity. **(Correct)**

◯ It only looks like she’s spinning faster because she is more compact.

205. Two identical solid spheres roll down two different inclined planes A and B. Both A and B have the same height, but different angles of inclination. If you release the balls at the

Example 11-3

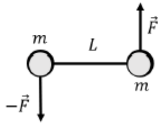


Figure 11.14: A dumbbell made of two small identical masses separated by a distance L.

Two small point masses, m, are connected by a mass-less rod of length L to form a dumbbell, as illustrated in Figure 11.14. A net force of magnitude F is exerted on each mass, in opposite directions, as illustrated in the Figure.

a) What is the linear acceleration of the centre of mass of the dumbbell?
b) What is the angular acceleration of the dumbbell relative to an axis that goes through its centre of mass and is perpendicular to the page?
c) What is the angular acceleration of the dumbbell relative to an axis that goes through one of the masses and is perpendicular to the page?

Solution

11.10 Sample problems and solutions

11.10.1 Problems

Problem 11-1: Calculate the moment of inertia of a uniform disk of mass M and radius R, rotated about an axis that goes through its centre and is perpendicular to the disk. (Solution)

Problem 11-2:

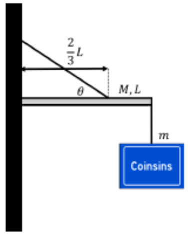


Figure 11.25: A sign is suspended on a horizontal bar of mass M and length L.

A sign holder is built by attaching a bar of mass M and length L to a wall using a hinge that allows the bar to rotate in the vertical plane. The sign of mass m is attached to the end of the bar that is opposite fo the wall. The bar is held up by a rope that is attached to the wall on one end and to the bar on the other end, two thirds of the length of the bar from the wall, as illustrated in Figure 11.25. The rope makes an angle θ with respect to the horizontal bar. Find the tension in the rope and the magnitude of the force exerted by the hinge onto the bar. (Solution)

The textbook: Development and first use

- Open and Affordable Course Materials Working Group at Queen's issued RFP to develop open access textbooks, obtained grant + departmental support
- Hired two students in summer 2018 and completed chapters up to electromagnetism
- Used in PHYS 104/106 into the second term, then switched to the Openstax: University Physics series to cover electromagnetism.
- Unique opportunity to compare our new textbook with the best existing free offering (Openstax)

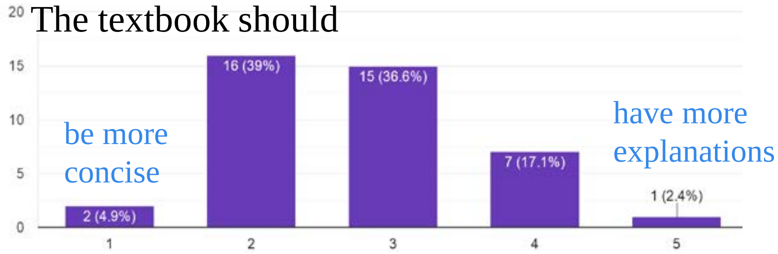
Surveyed students (41 out 150 students, ½ not majoring/minoring)

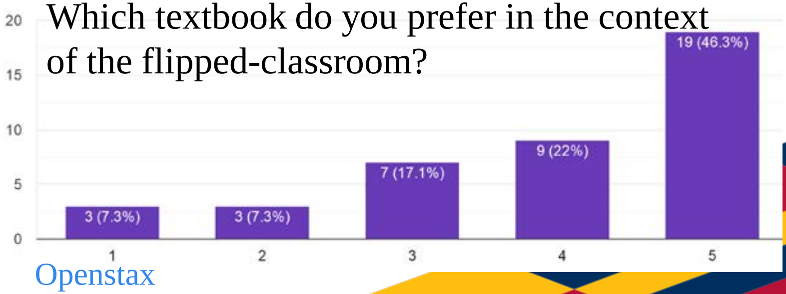
“Olivia/Emma's thoughts were by far the most helpful part of the textbook as they put the information into terms that I could understand, I definitely think that having more of them would have helped me understand the material. (…)”

“I found the textbook way easier to understand than the openstax one because the explanations were formatted more like a conversation than a scientific definition”

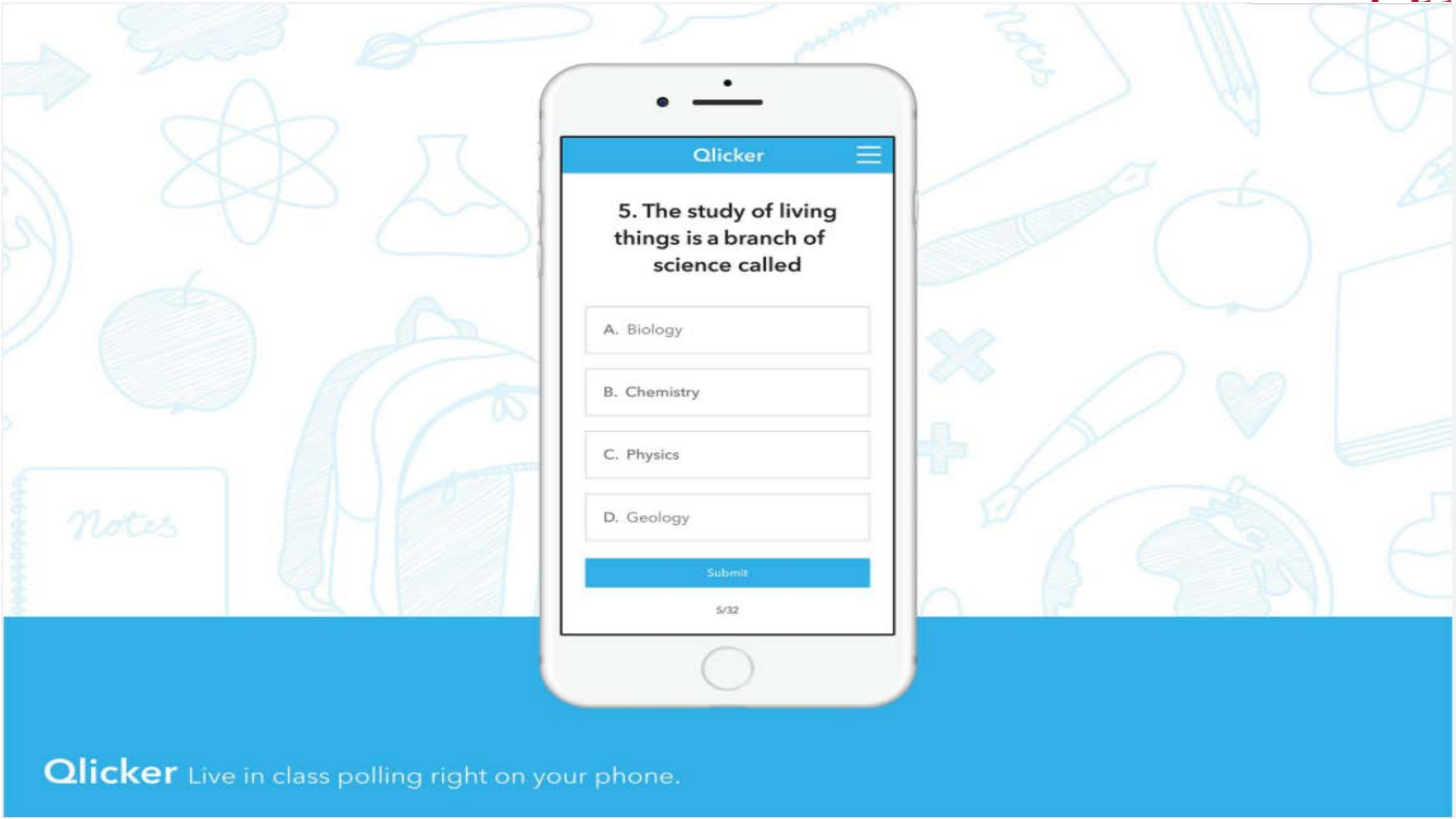
“The Openstax textbook is too long and provides you with a lot of unnecessary info. I found the first semester textbook to provide me with the exact amount of knowledge I needed and explained in a way that was easy to understand. I also preferred the structuring of the first semester textbook with the way the main content was written out made it easy to follow.”

“Overall the textbook project is brilliant and I consider myself very fortunate to have come in a year where I was able to use at least half of it for physics 104!”





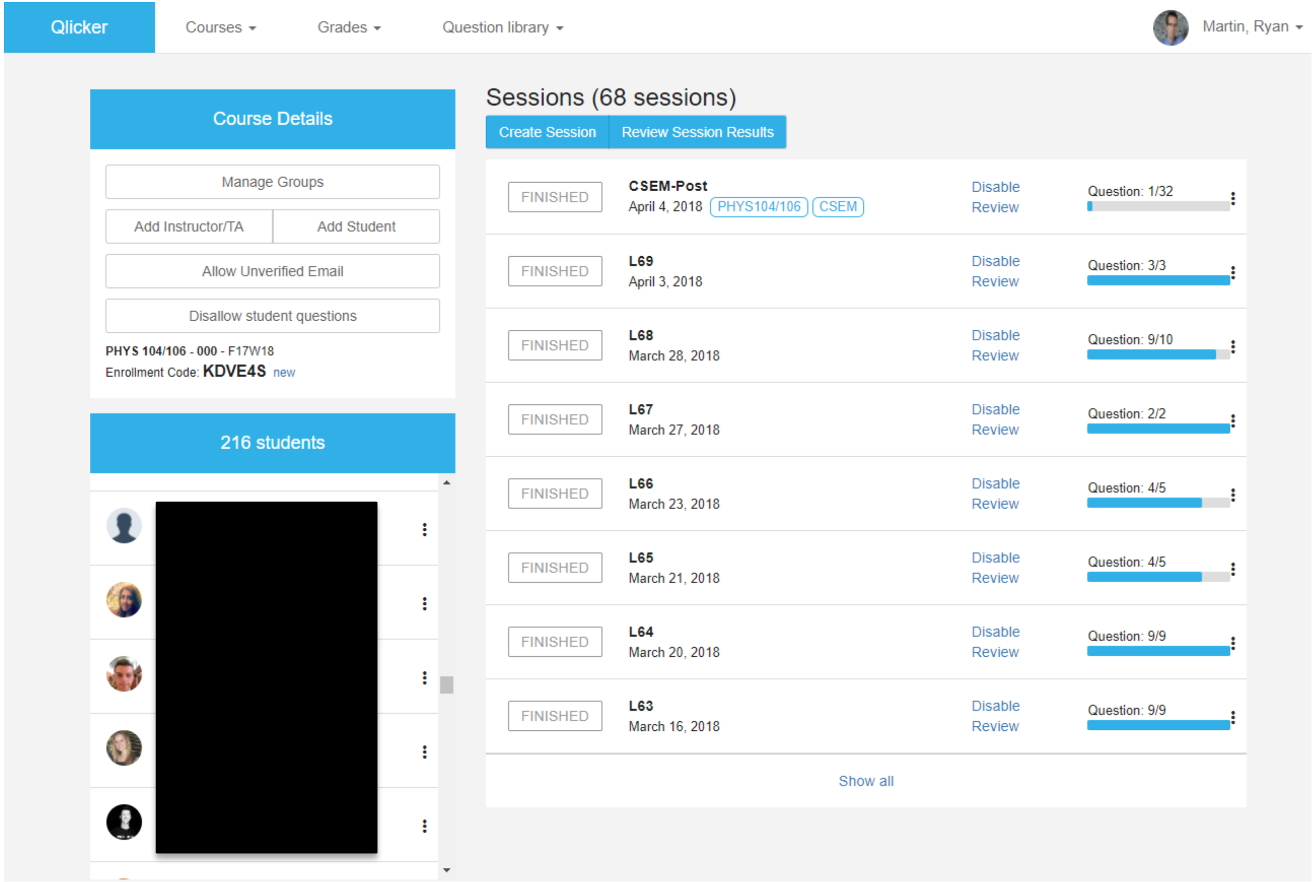
The software for the lectures: Qlicker



Qlicker: overview and features

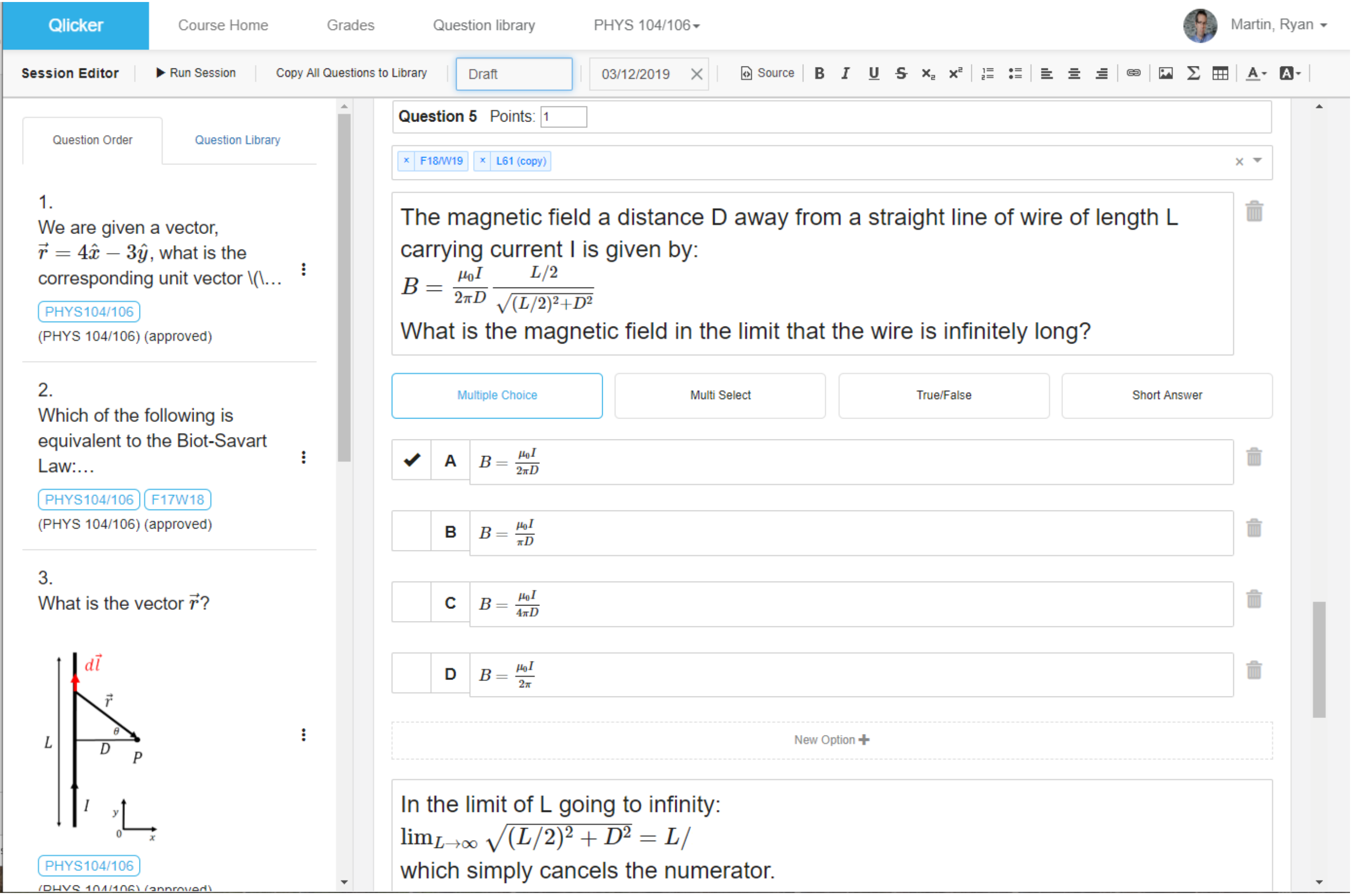
- **Free** and open source (of course!)
- Web application: any web-connected device with a **browser** can be used
- **Clean and easy** to use interface with **Latex integration** for mathematical expressions
- Multiple **question types**:
  - MC, MS, T/F, Long answer (including upload a picture), Numerical
- An easy to search **library of questions** for use by profs and/or students
- Ability for **students to contribute questions** to a course (and for TAs to review and approve those questions)
- Ability for **students to review and practice** questions
- Ability to handle **at home quizzes**/tests, including ability to grade manually (e.g. long answers).
- Grade book, students can review grades, prof can **export grades** as CSV
- Anyone with some computer know-how can run their own qlicker server

Screen shots: Prof course page



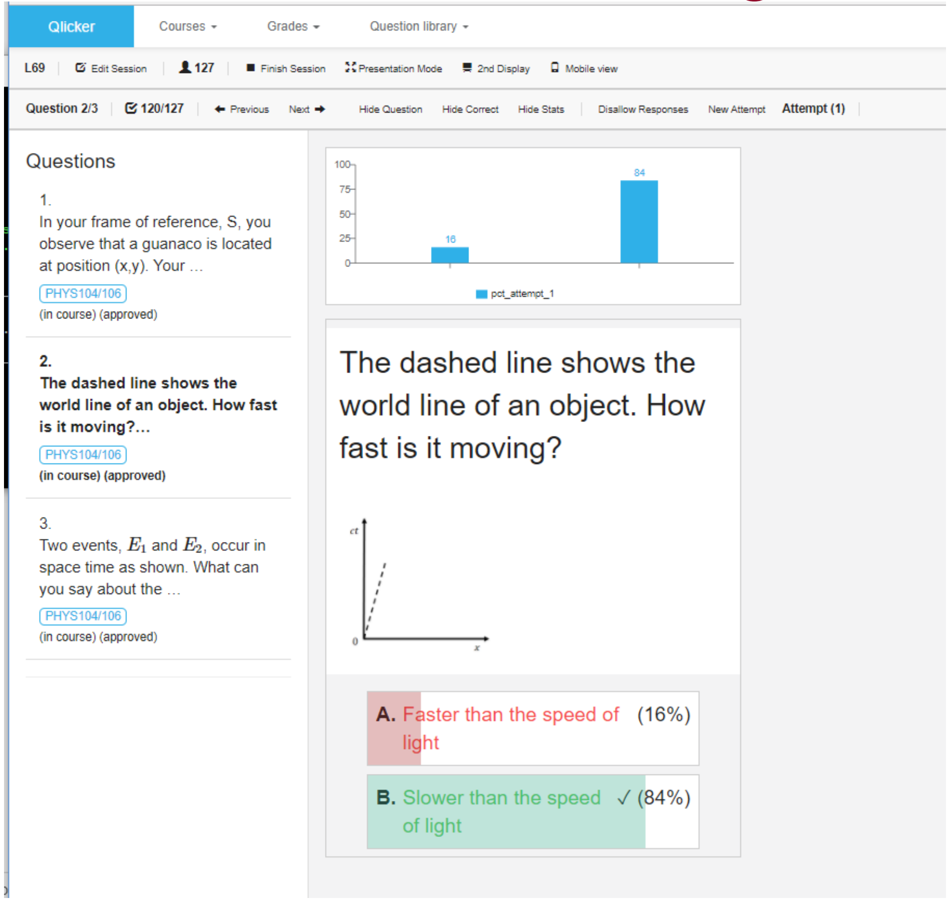
- List of clickable students with pictures
- List of sessions (e.g. in class or at home quizzes)
- Manage course membership
- Students can be grouped
- Create/copy/delete sessions

Screenshot: Designing a session



- Access to library of questions
- Include Latex
- Drag and drop pictures
- Write a **full solution** for students to use during review or supplement explanation

Screenshot: Running a session



Various ways for prof to run a session:

- Use split screen
- Use mobile device
- Show interface directly

During a session:

- Can have multiple attempts
- Can show students statistics
- Can show students correct answer

Qlicker: Development and use

- F16W17: 3 students developed a prototype as a project for CISC 498.
- Summer 2017: further development by student supported by Physics (part time).
- Summer 2017: Obtained Centre for Teaching and Learning enhancement grant and department matching.
- F17W18: Supported student to maintain Qlicker for a pilot test in PHYS 104/106 (~200 students).
- F17W18: Implemented many updates during the year to improve the interface.
- Summer 2018: Implemented more updates based on feedback
- F18W19: **Used in several classes across campus**.
- Summer 2019: **Expanding pilot project** with ITS support.

How I used Qlicker in PHYS 104/106

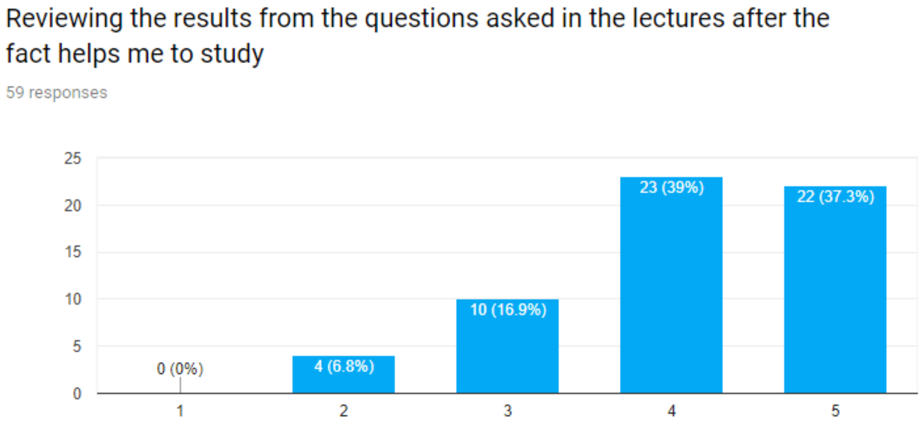
- Flipped classroom, students complete a reading assignment every week:
  - MC question quiz
  - Submit an original question through Qlicker that tests the material
    → many of the MC questions on exams were from students!
- Lectures each have ~5-10 Qlicker questions to answer, including some "long answer" questions to be completed as a group.
  - 5% participation grade, full grades for one lecture if at least 50% of questions answered
  - No control/penalty to avoid people answering from home, etc, (if they answer the questions from home during the lecture, they're at least following the lecture a little!)

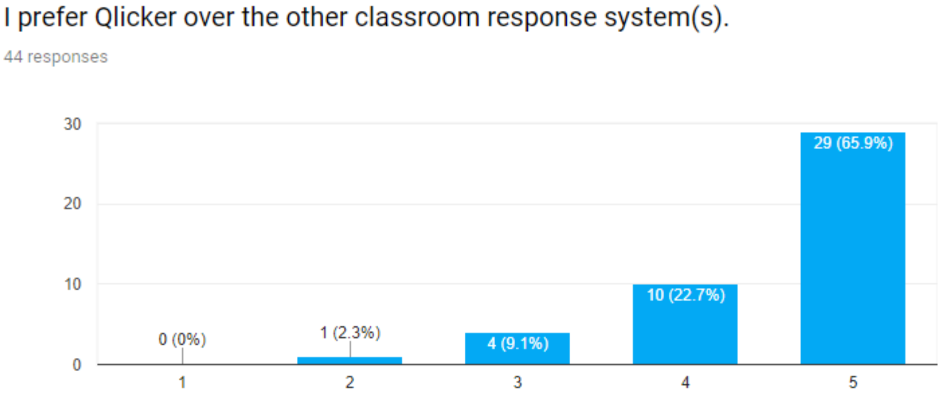
What the students thought (in 2017-2018)

"I think Qlicker is an easy and accessible learning tool for active learning during lectures. It's hassle free and also I can see how I'm doing in terms of my class and what concepts I need review. It also encourages me to pay more attention to the lecture material. I've had other difficulties in Learning Catalytics such as problems logging in, joining sessions, and reviewing my own sessions. It's also very expensive for my financial standing. Qlicker is also so much prettier and a happier blue."

"(…) Really do think letting us come up with a question each week helped a lot though."

"I do not see why other courses would not use qlicker- it is accessible, very easy to use, and really helps with my studying to determine areas of weakness."





The software for the labs: QExpy

- Want to develop computer literacy in our physics students as early as possible (first year!)
- Chose python + Jupyter notebooks
- Goals:
  - Students using python
  - Students can correctly propagate uncertainties
  - Students can plot and fit data
  - Students can write simple programs
- Developed the Qexpy python3 module (anyone can install with pip) with students. See CAP 2018 talk.
- SoftwareX paper to be published soon

In [3]:

```
import qexpy as q
#Define two measurements, x and y
x = q.Measurement(5,1) #5 +/- 1
y = q.Measurement(10,0.2) # 10 +/- 0.2
#A quantity that depends on these
z = (x+y)/(x-y)
#Choose sig figs to show:
q.set_sigfigs(2)
print("z = ",z)
```

```
z =  -3.00 +/- 0.80
```

$$\sigma_F^2 = \left(\frac{\partial F}{\partial x}\sigma_x\right)^2 + \left(\frac{\partial F}{\partial y}\sigma_y\right)^2 + 2\frac{\partial F}{\partial x}\frac{\partial F}{\partial y}\sigma_{xy}$$

or Monte Carlo…

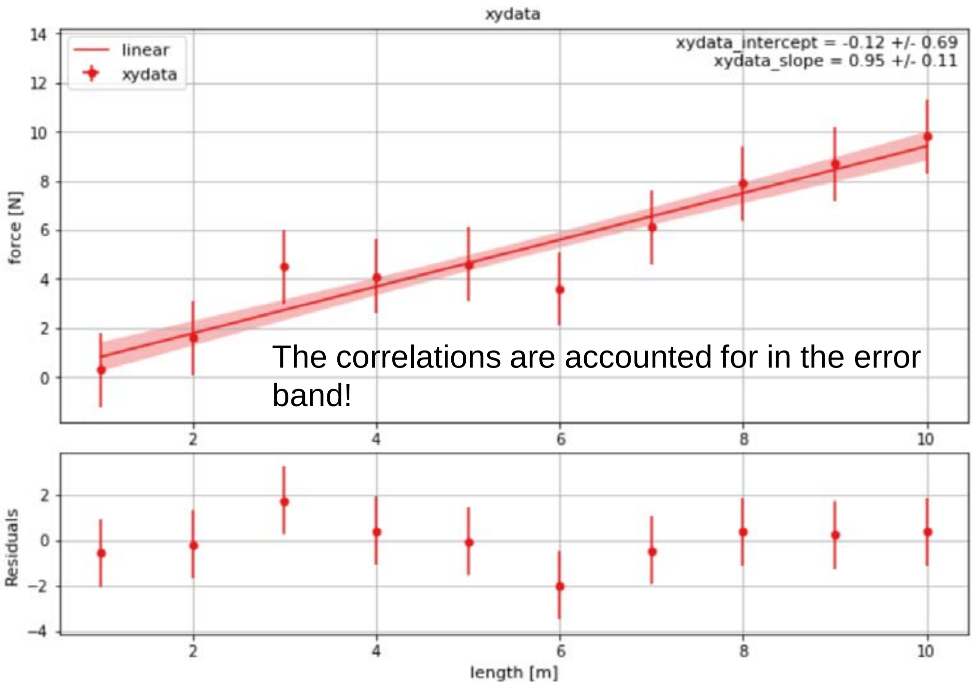
Example linear fit in QExpy

```
In [11]: #Define a plot object
fig1 = q.MakePlot(xdata = [1, 2, 3, 4, 5, 6, 7, 8, 9, 10],
                  ydata = [0.3, 1.6, 4.5, 4.1, 4.6, 3.6, 6.1, 7.9, 8.7, 9.8],
                  yerr = 1.5,
                  xname = 'length', xunits='m',
                  yname = 'force', yunits='N',
                  data_name = 'xydata')
#Fit to a linear function
results = fig1.fit("linear")
#Add residuals sub plot
fig1.add_residuals()
fig1.show()
```

```
-----------------Fit results-------------------
Fit of  xydata  to  linear
Fit parameters:
xydata_linear_fit0_fitpars_intercept = -0.12 +/- 0.69,
xydata_linear_fit0_fitpars_slope = 0.95 +/- 0.11

Correlation matrix:
[[ 1.    -0.886]
 [-0.886  1.   ]]

chi2/ndof = 3.62/7
---------------End fit results----------------
```



The correlations are accounted for in the error band!

Putting this altogether in PHYS 104/106

A (crazy) week in the life of a 104/106 student:

- **Sunday**: Complete Reading Assignment (read a chapter, answer some questions, provide feedback, submit their own question)
- **Monday**: Attend Lab-torial (90min of group work on weekly assignment, 90min on lab activity). In class quiz every second week!
- **Tue/Wed/Fri**: Attend 50min lecture, sit in groups, answer many questions in lecture, peer instruction (570 questions in a year!)
- **Wed evening**: Drop-in session (ug help on assignments)
- **Friday**: Challenging assignment due (6 difficult questions)
- **Sunday**: Assimilation Quiz, and repeat!

Labs in 104/106

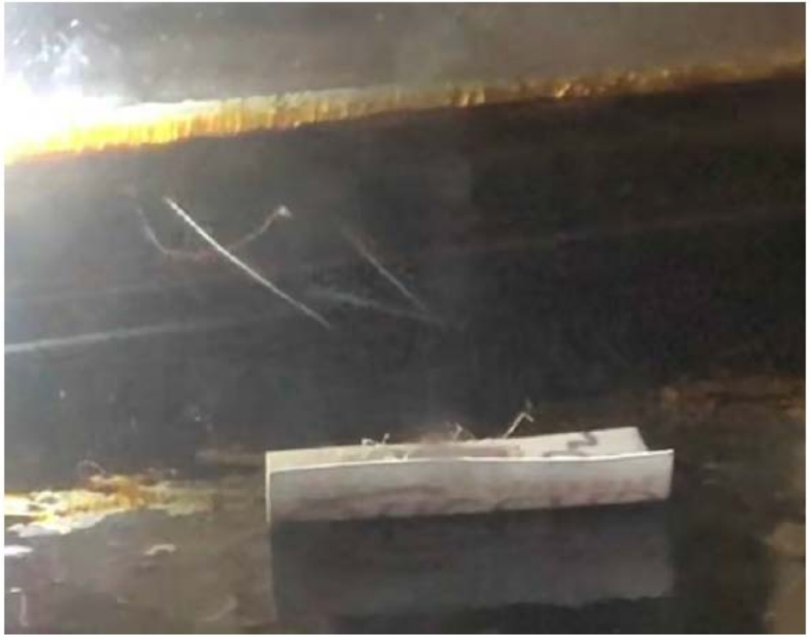
- Goals:
  - Develop skills as a physicist
  - **Not re-inforce physics concepts from lectures**
  - Attain a level to produce a “good” open inquiry lab (aka design labs)
  - (Typical physics student: “I hate labs”) ← not this!
- Implementation:
  - Choose one of two labs (agency)
  - Open-ended for the most part (no procedure given – guided/open inquiry)
  - Emphasis on scientific method, and developing proposals in particular
  - Groups of 3-5, change midyear. Initial groups were designed based on answers from a questionnaire that asked about:
    - Prior physics experience
    - Prior math experience
    - Prior programming experience
    - Oral and written communication
    - Past leadership experience

Structuring inquiry in the labs

- L1 (confirmation inquiry):
  - Intro to Jupyter notebooks (open, edit, etc.)
  - Intro to Qexpy (propagate an uncertainty)
  - Measure g with uncertainty by dropping a ball
- L2 (structured inquiry):
  - Given a partially complete lab “report” to fill in, which includes most of the procedure
- L3 (guided inquiry):
  - Develop a proposal for an experiment to measure how fast you can throw a ball (or model how far you can jump)
  - Proposal is reviewed by a different group
  - Proposal is carried out by that same different group
- LX (some confirmation and guided inquiry to develop new skills):
  - Suggested experiments from the textbook
  - Worksheet to develop python proficiency
  - Mini-experiments to learn to use scope, build circuits, etc
- L19-L24:
  - **Open-ended design lab**
  - Document with ~30 ideas provided to students, as well as encouragement to explore their own ideas
  - Physics not necessarily covered in the course.

Some evidence of success – What students did in a 6(really 4) week design lab

- **Students built 3 cloud chambers from scratch, used to measure strength of a radioactive source, estimate energy of alphas.**
- Modelled the Doppler effect from a buzzer spinning around on a string in a horizontal circle.
- Modelled a gravity assist
- Examined how water droplets coalesce on water surface with standing waves → students looking to publish this work!
- Investigated how water can move up trees, how a sponge sucks water upwards



Some evidence of success – What students did in a 6(really 4) week design lab

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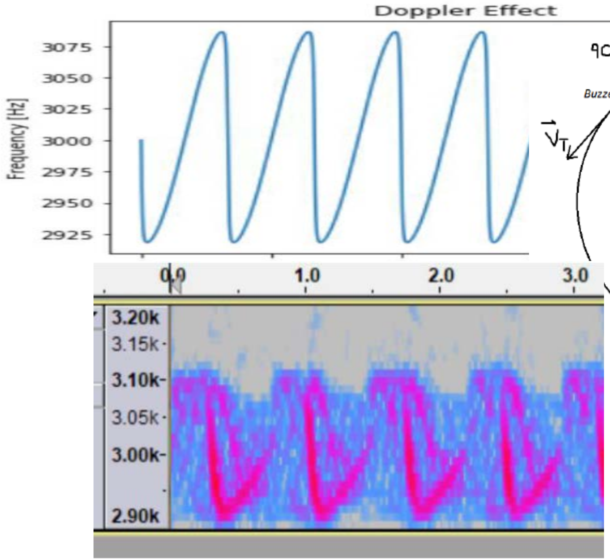

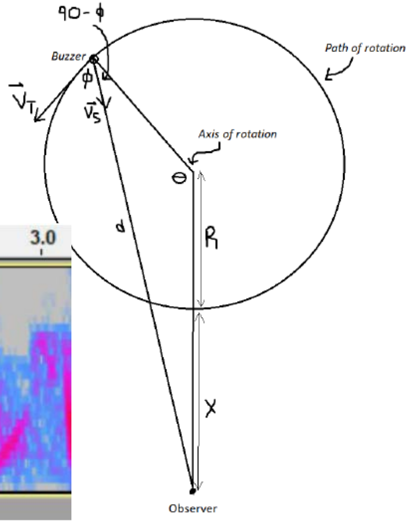

Figure 1: Circular motion of buzzer relative to observer

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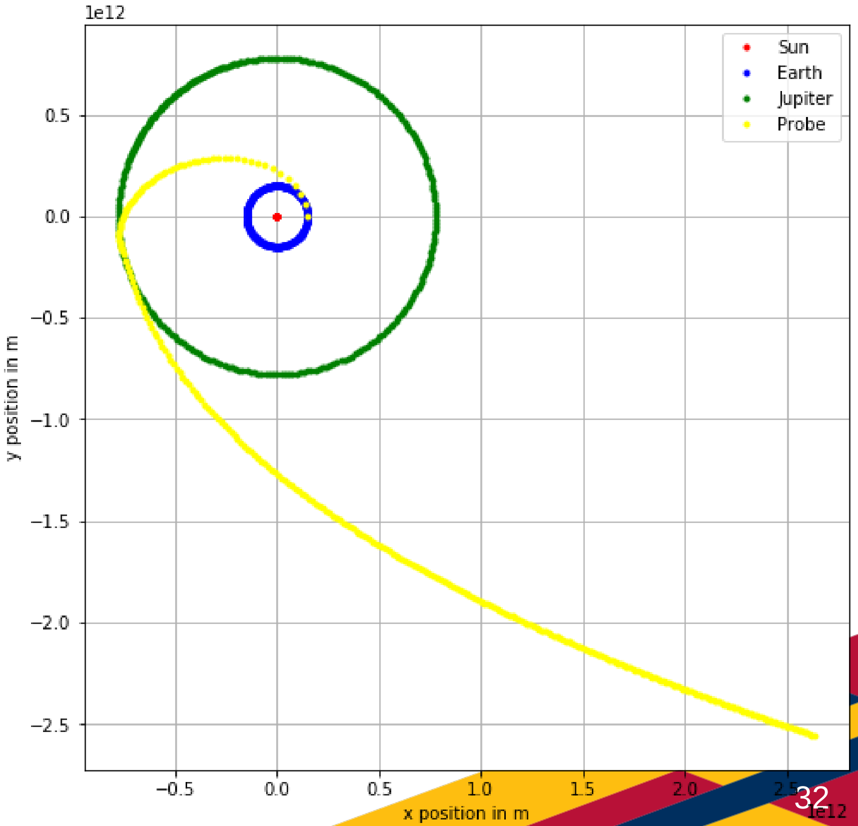

Conclusions

- Education really should be free; response from students when we go through the effort of developing free resources is… priceless
- We tried to develop a textbook that is:
  - Designed for active learning
  - Does not ignore that half (most?!) of physics is experimental
  - Has strong input from students
  - Open source
- Involving students in the development of resources has been very beneficial. Also, an opportunity to train students in useful skills!
- Have received excellent feedback from students on the textbook and Qlicker, because they're free, but also because they were co-developed with students.
- We are happy to make any/all of this work available, we hope that it will be useful (and that you'll contribute!)
- I think we are on the right track for re-designing our first year labs

Resources

- Textbook:

https://github.com/OSTP/PhysicsArtofModelling

- Qlicker:

https://github.com/qlicker/qlicker

- Qexpy:

https://github.com/Queens-Physics/qexpy