"Choose your own adventure" labs for introductory physics

Dan Roth

Olympic College, Bremerton, WA

Overview

Engineering Physics

- Olympic College is a two-year college
- Most of the students in my classes are working towards transferring to an engineering school
- Everything covered in this presentation is for Engineering Physics (Phys 25x), our calculus-based sequence.
- All students have been *through* Calc III
  - Series, functions of two variables and their graphs, contour diagrams, vector algebra, dot and cross products, multivariable functions, partial differentiation

The usual story

- Two hours, once per week
- "Flavor of the week"
  - New lab each week on a different topic
- Fairly prescriptive

The problems

- Students don't learn much
  - Research has raised questions about how effectively traditional lab activities contribute to student understanding of the course content
  - In my experience, they don't necessarily even learn how to follow directions...
- Students do not gain meaningful understanding of measurement uncertainty
- Students do not get practice designing valid experimental procedures

N. G. Holmes and C. E. Wieman, Phys. Today **71**, 1 (2018)

C. Wieman and N. G. Holmes, Am. J. Phys. **83**, 11 (2015)

A. Arons, Phys. Teach. **31**, 5 (1993) ... and many more. The Arons paper alone cites about half a dozen papers that have trouble substantiating the effectiveness of introductory physics labs.

Incremental changes

Some of the things I've done leading up to the big redesign:

- Prune the directions so that students need to think more critically about what they are doing, instead of blindly following a recipe
- Increase student choice
  - Eg. instead of "hang 50 g from the spring," use "hang a small amount of mass, between 25 g and 75 g from the spring"
  - The specific amount doesn't really matter; this phrasing is intended to get the students to think a bit more thoroughly about what they're doing, and to take good notes
- Explicitly ask students to evaluate sources of experimental error in the lab report

However, I was still unsatisfied.

Choose your own adventure

- Multiple weeks
  - Students go through a process of designing then revising an experiment
  - After the first week, their data is fairly crude; they figure this out, analyze sources of error, and revise the experiment
  - They have the opportunity to actually follow through and carry out the revised procedure
- Broad scope
  - Students are not told explicitly how to find what they're looking for
  - E.g. "Determine a mathematical relationship between the period and amplitude of a pendulum."
- Students come up with their own experiments
  - Think about experimental uncertainty and what it means to design a "good" experiment

Lab handout format

Before lab revisions

1. Background
2. Materials list
3. Procedure
4. Data tables (pre-made)
5. Analysis tables (pre-made)
6. Post-lab questions

CYOA labs

1. Background
2. Tools
3. Task(s)
4. Follow-up/discussion questions

Handout details

1. Background
   - Similar as before, but more a bit more brief
   - I like to keep it to less than one page
2. Tools
   - Not a list of materials
   - Gives a general sense of what is available
   - I'll usually add some note about how a particular piece of equipment may be useful, since the students are not as intimately familiar with all the nuances of our equipment
3. Task(s)
   - A statement of what they need to accomplish or determine
   - Sometimes there are multiple tasks
4. Follow-up/discussion questions
   - A few specific questions to help students link different aspects of the lab together
   - Not on every lab—sometimes the tasks alone are straightforward enough

Density & Stats: Week 1

Measurement uncertainty

- Students are already familiar with density, and how to calculate it
- Given a cork stopper and a rubber stopper
- Determine density by two methods
  - Everyone lands on direct measurement and water displacement for volume
  - Uncertainty determined from propagation of error:

$$(\delta\rho)^2 = \left(\frac{\partial\rho}{\partial V}\delta V\right)^2 + \left(\frac{\partial\rho}{\partial m}\delta m\right)^2$$

  - Specific form depends on how volume is determined

Density & Stats, week 2

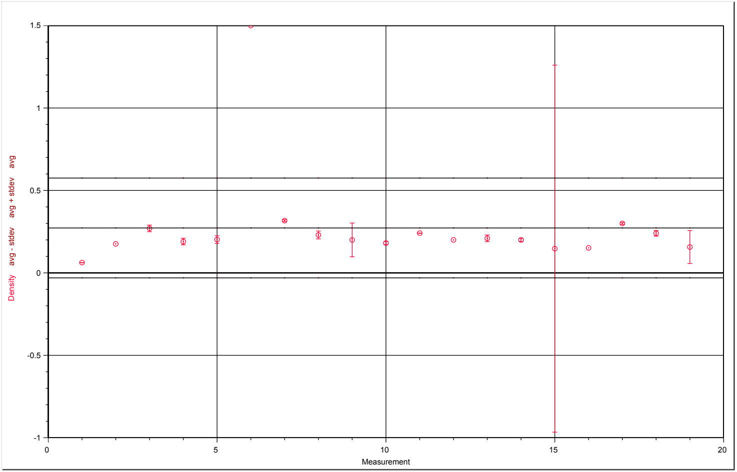
Statistics

- I collect the class data a before the next lab meeting
- Data compiled into semi-anonymous table
- I do not edit for obvious (to me) errors
- Students analyze the mean and standard deviation
  - One set of data must be done by hand—lots of repetitive calculations, but important to understand the "black box"
- Students also do a visual comparison, with error bars
  - Visualize what error bars really mean; get a sense of how to compare data with uncertainty

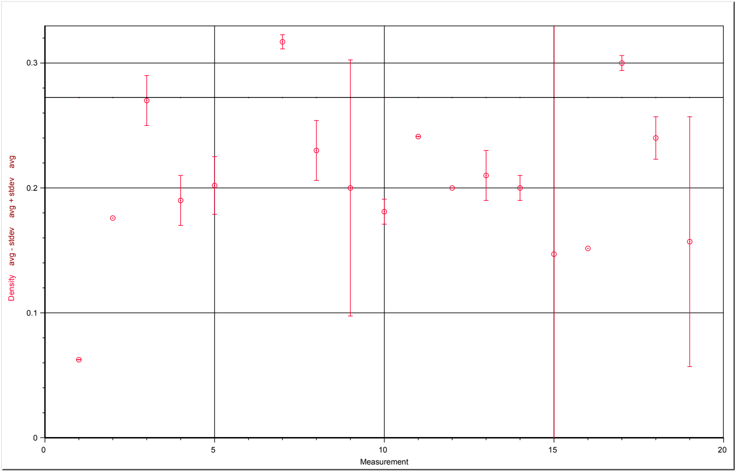
Sample data

	Measurement 1			Measurement 2		
Group	Density	Uncertainty	Units	Density	Uncertainty	Units
1	62.5	1.75×10^{-6}	kg/m^3	241.15	1.1×10^{-8}	kg/m^3
2	175.9093	not reported	kg/m^3	200	not reported	kg/m^3
3	0.27	0.02	g/mL	0.21	0.02	g/mL
4	0.19	0.02	g/cm^3	0.2	0.01	g/cm^3
5	0.20	0.0231	g/cm^3	0.147	1.113	g/cm^3
6	1.5	not reported	g/mL	151.6	not reported	kg/m^3
	145	not reported	kg/m^3	(Gr. 6 reported two values from method 1)		
7	0.317	0.00567	g/cm^3	0.3	0.006	g/cm^3
8	230	24	kg/m^3	240	17	kg/m^3
9	200	0.1025	g/mL	(Not reported)		
10	0.181	0.01	g/mm^3	0.157	0.1	g/mL

Sample graph—zoom in



Sample graph—zoom in



First week of a project

- Introduce the big picture for the lab
- Go over the main pieces of equipment available
  - Give some idea on how to use specific things
  - Call attention to specific ways they're used
  - Go over operational principles for some things (e.g. discuss how the motion detectors work)
- Take questions—though I don't give very detailed answers.
  - "That's certainly something to think about while you're coming up with your preliminary experiment!"
- Set them loose! Pay attention to how they are designing the experiments
  - If the project is only two weeks, I'll help point groups in the right direction if I see them heading wildly off track.

Following weeks

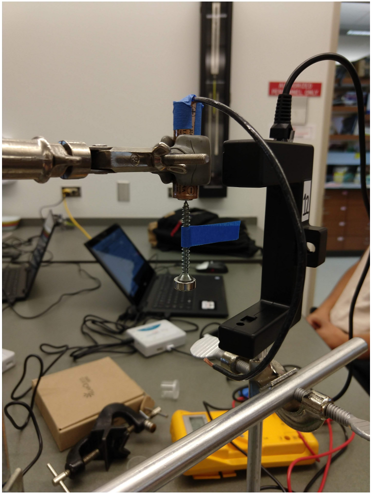
- Brief introduction: just remind students what they're working on
- Call attention to common pitfalls I observed in first week
- Give some sense of direction for the students who are still a bit lost

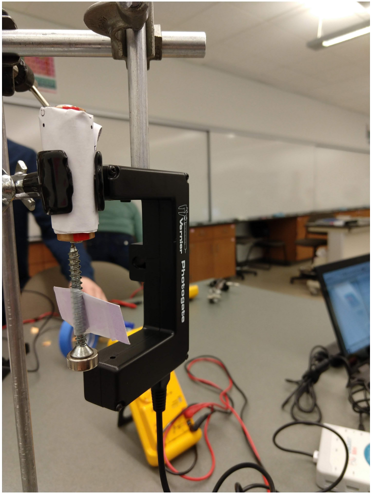
My observations

- Students think about data more—outliers, uncertainty, etc.
- Students take more ownership of the data
  - Before: bare minimum amount of data, just print off graphs instead of saving
  - CYOA: More thoughtful about data that is taken, save data for more analysis and manipulation outside of lab time
- Lab reports are more thorough and thoughtful
  - E.g. instead of just paraphrasing what is written in the lab handout, students give a thoughtful explanation of the “purpose” of the lab
  - Much more attention to sources of experimental error and reliability of results
- I spend less time grading lab reports
- Students get creative

Student-created setups

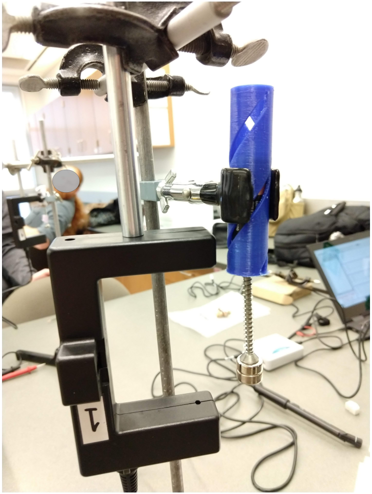
Homopolar motor lab

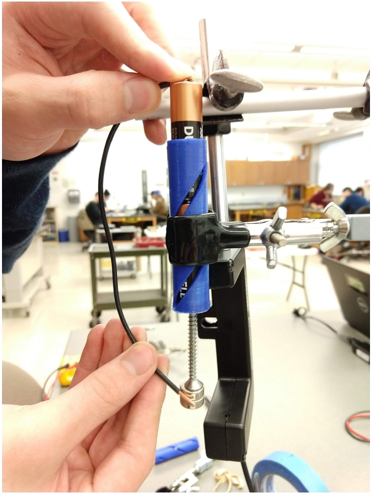




Student-created setups

Homopolar motor lab



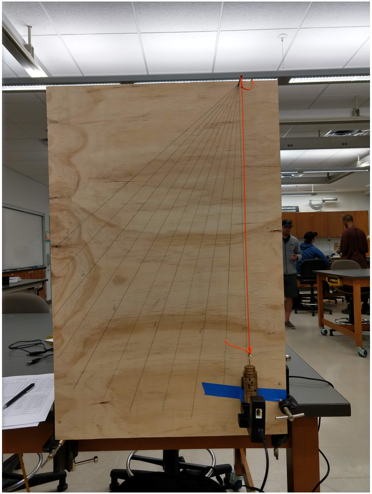


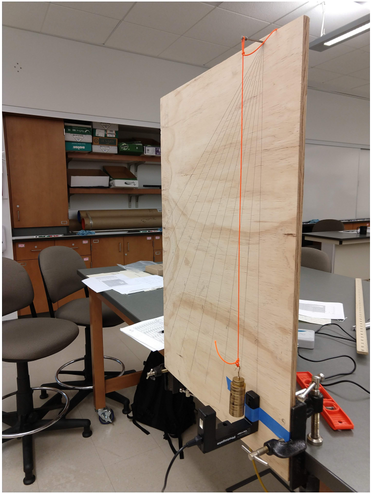
Student-created setups

Pendulum lab

Student-created setups

Pendulum lab





Students' responses

From course evaluations

"Refined my ability to design an experiment"

I refined my ability to design an experiment; although I had previous experience in designing experiments, this lab allowed me to focus more on the error analysis and data processing and how to minimize minute errors in the procedure.

"Come up with our own steps"

I liked the fact that we were allowed to come up with our own steps for accomplishing a goal rather than having set instructions given to us.

Students' responses

From course evaluations

"I took pride in the lab reports"

I have developed more on the skill of thinking like an engineer. I really liked the aspect of not being given a way to do the lab and having the free range to choose what I thought was best to find the data needed [. . .] With past labs, I always felt like I was just doing what I was told and then that was it. I never really had to think about it and apply what I am learning in class. I would just try cramming out a lab report each week. Instead with these labs, I took pride in the lab reports because my partner and I had figured out all that work [. . .] The water property lab really allowed for everyone to have different experiments to find the same thing.

Where to go from here

- Revise existing labs; write new ones
- Apply to the algebra-based sequence
  - Already started. Main challenge: cannot use propagation of error. Instead, I have the students take many data points, and take the average and standard deviation.
  - Secondary challenge: students tend to have less science experience, so designing valid experiments is more challenging. I give more guidance in the lab handouts.
- Spend more class time dealing with uncertainty
  - Involve it in in-class examples and demonstrations
  - Lecture topic early in the quarter (before first lab)?

Thanks!

- Email: `droth@olympic.edu`
- I'm happy to share! I have some printouts with me this weekend, and a flash drive with everything I've done so far

Questions?