Techniques for Teaching Critical Thinking in a first-year physics laboratory

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Context:

- Phys 107/109/Science One Physics Lab
- 135 students each year during 2012/13 & 2013/14
- Learning Goals
  - 40+ goals about making measurements, modeling data, statistics and data, and higher-level skills
  - See: www.phas.ubc.ca/~phys109/LearningGoals.html

Intervention: Main Points

t-scores:

- based on Student's t-value – used for comparing data sets or measurements
  - t<1 – Measurements agree OR uncertainties too large
  - t>3 – Measurements unlikely to agree [or uncertainties too small]

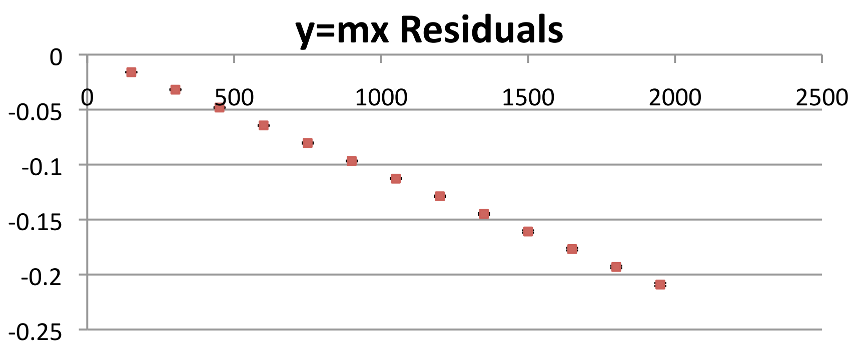
$$t = \frac{X - Y}{\sqrt{\delta_X^2 + \delta_Y^2}}$$

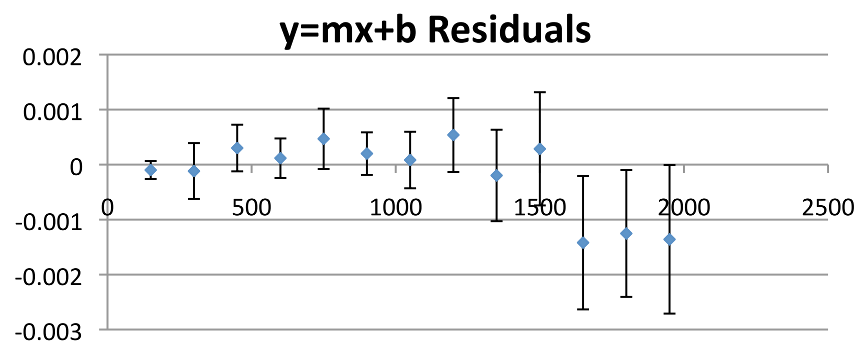
- Experiments needed to work, physically, so that comparisons were meaningful:
  - Disagreements with theory needed to be explained, modeled, or resolved
  - Each experiment involved a comparison and a chance to improve or change the model or measurement
  - Comparisons never made to 'expert' values – only to values measured in the lab

Intervention: Main Points

Residuals Plots:

- Model ($f(x_i)$) – Data (y_i) plotted as a function of x_i
- Should be randomly scattered with magnitude of scatter around the size of uncertainties





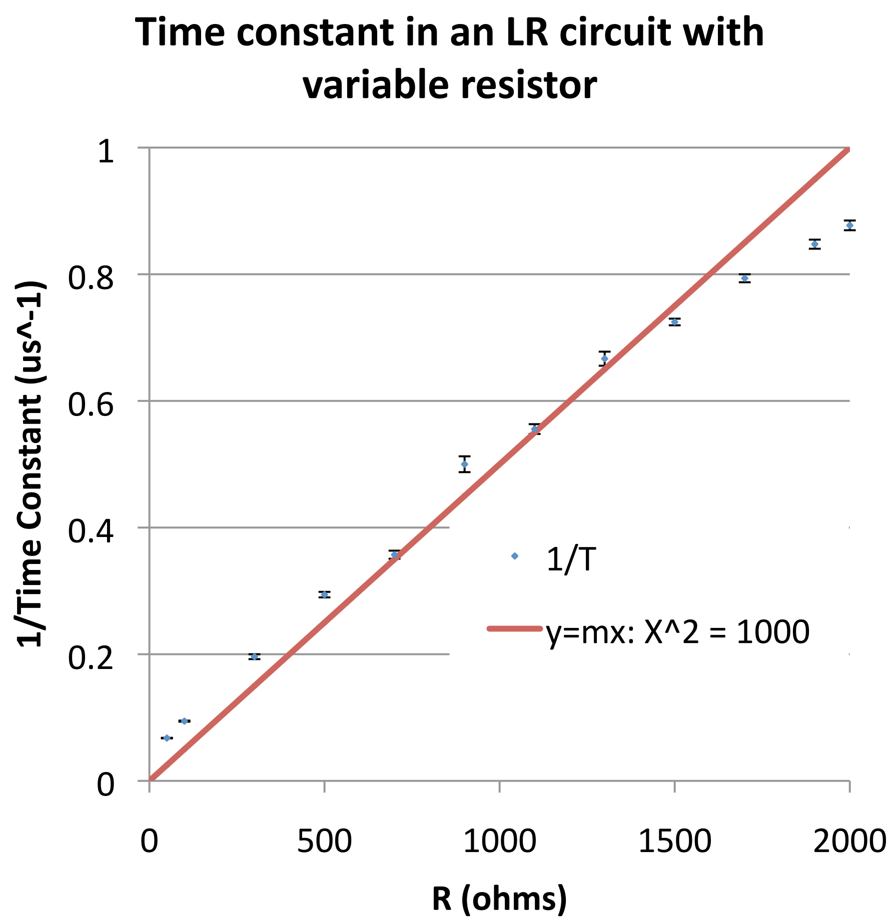
- Better supports weighted least-squares fitting where:

$$\chi^2 = \frac{1}{N}\sum_{i=1}^{N}\frac{\left(y_i - f(x_i)\right)^2}{\delta_{y_i}^2}$$ is minimized.

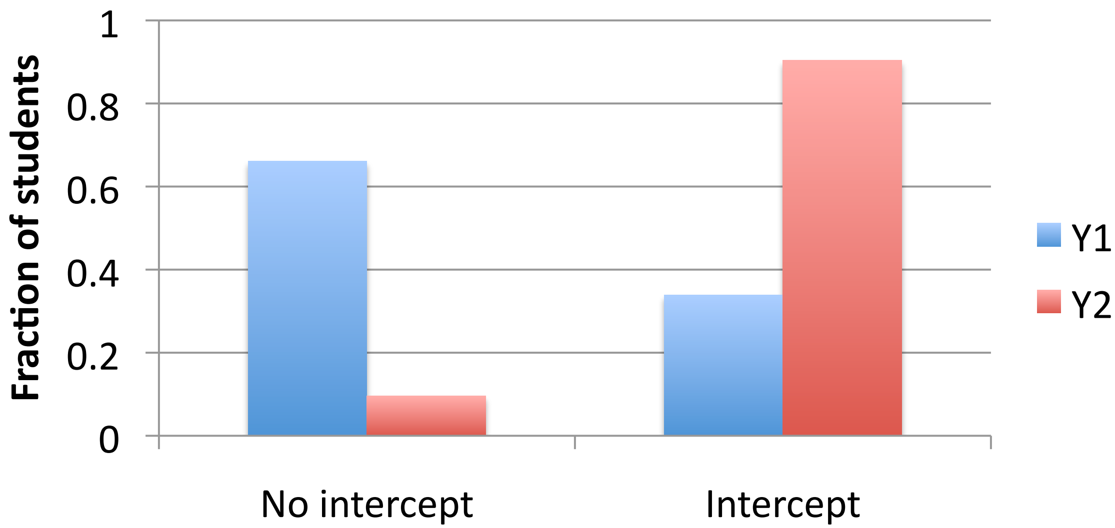
  - $\chi^2<1$ – Data fits model OR uncertainties too large
  - $\chi^2>3$ – Data does not fit model well [or uncertainties too small]

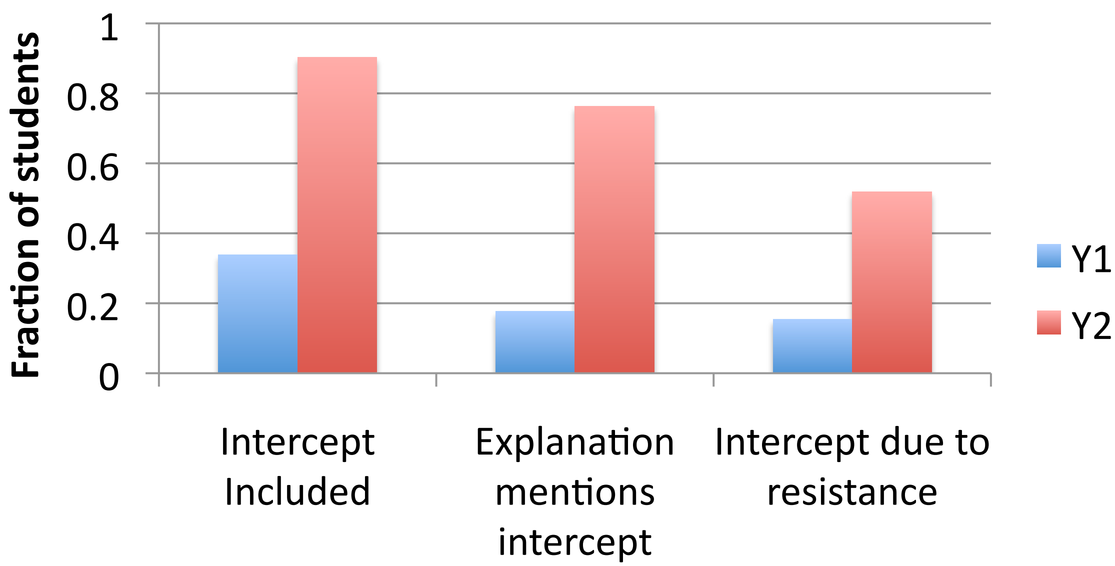
LR Circuits Lab

- Students are asked to verify the given model that the time constant in an LR circuit is: $\tau=L/R$
- They are asked to plot 1/tau vs R, which should, theoretically, give a straight line through the origin
- But it doesn't – due to extra resistance elsewhere in the circuit
- This is a student's fit to their data from last year (done by hand) – forcing y=mx instead of using y=mx+b.



More students thoughtfully adapt model to fit their data in Y2





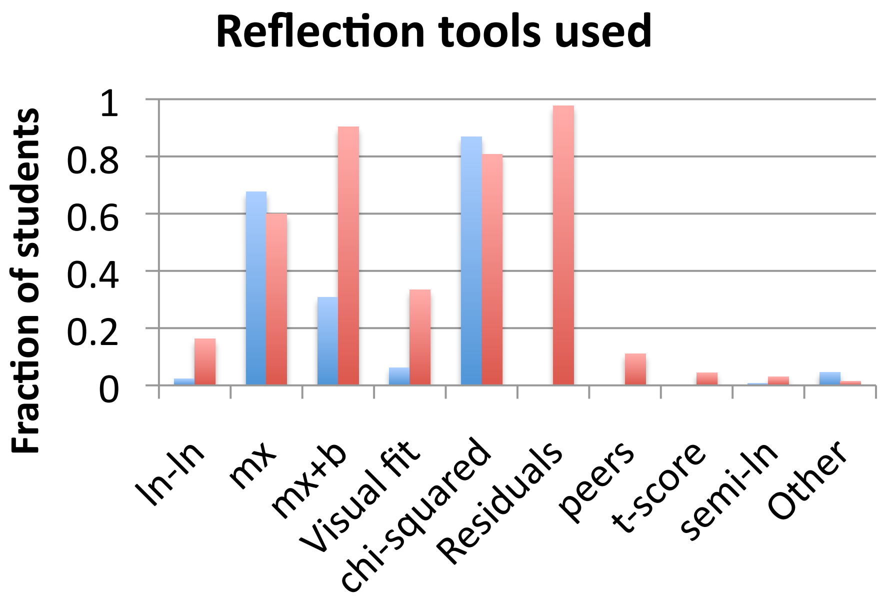
NH: Why did you include an intercept?

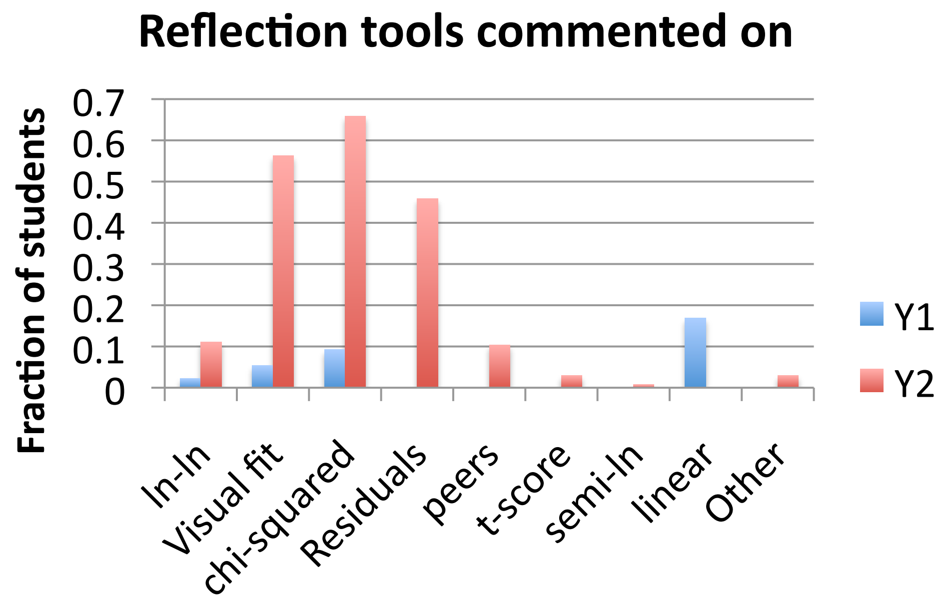
Student: Because, the one without the intercept, it just didn't fit that well, so we realized, there has to be something wrong with it.

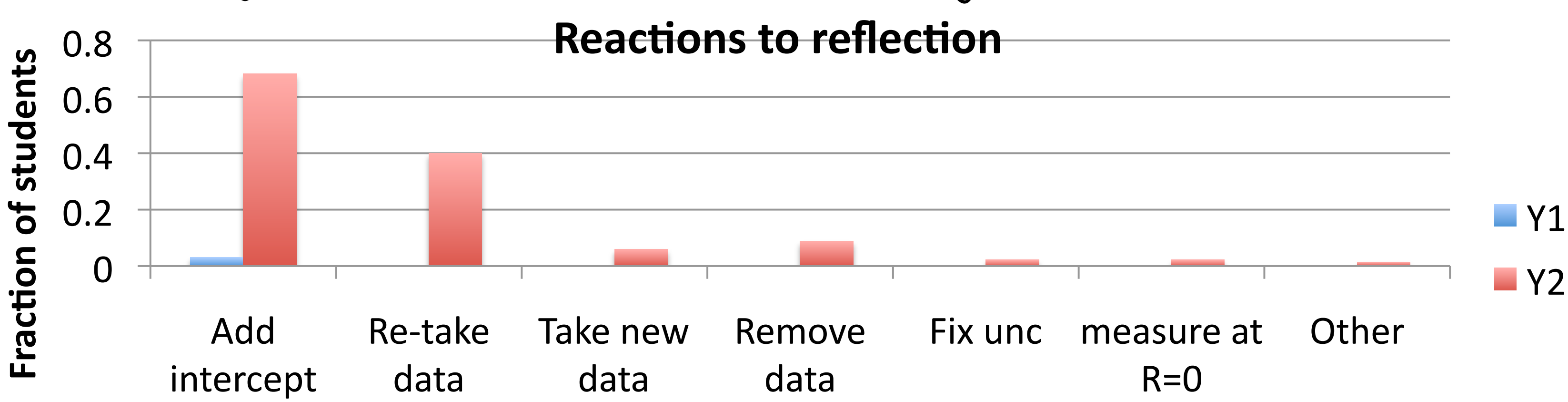
NH: How did you know that it didn't fit well?

Student: Well, this one, you can tell, that it just really doesn't fit well and I think, if you do the residuals, it's a line, and it crosses, so you know that it should have an intercept.

Students use more reflection tool and react based on reflection

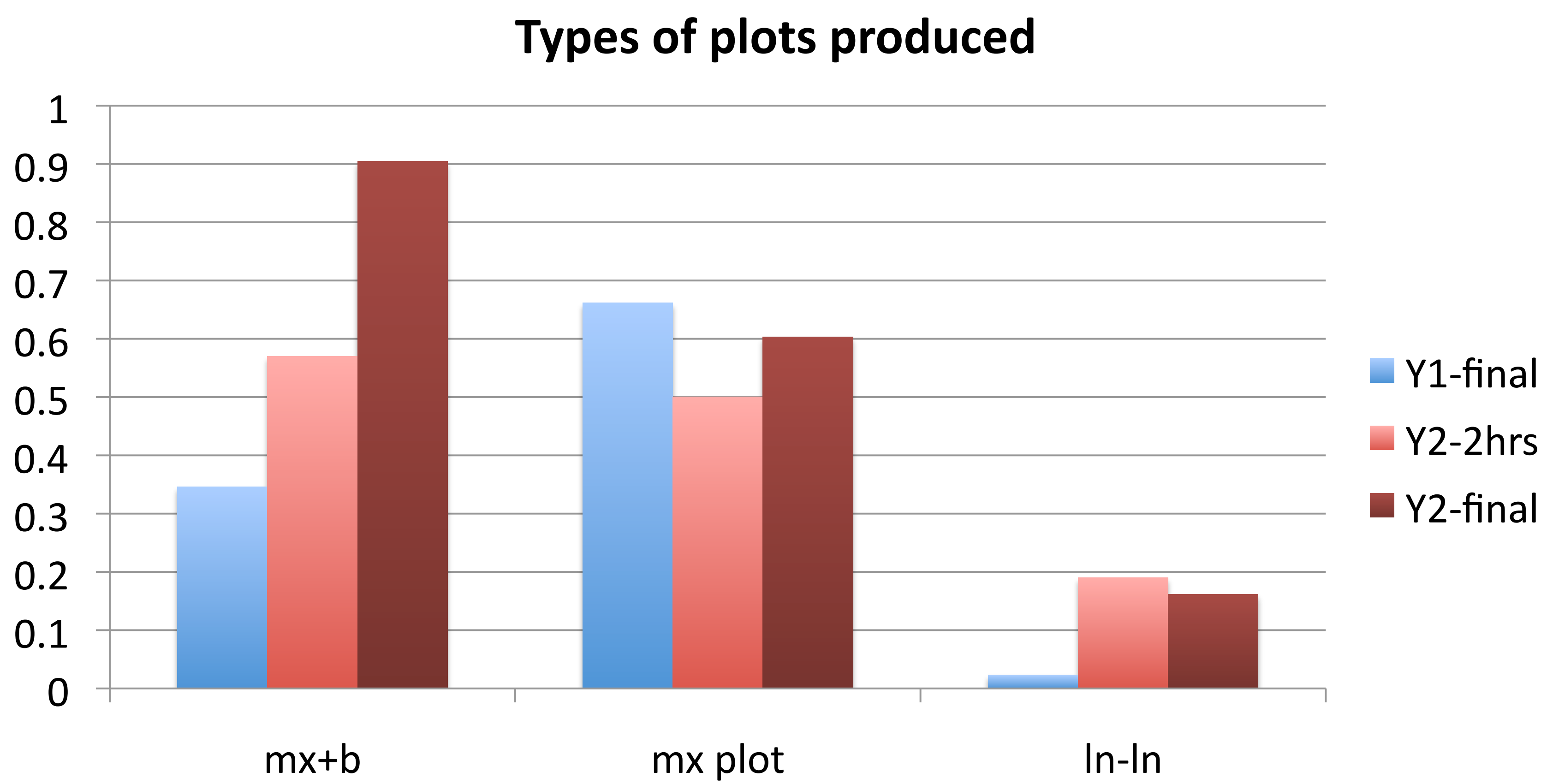






Time on Task

In Y1, students had an invention activity before the experiment, so had less time to do the experiment. We checked where students were at this year at the 2-hr mark, and they were still ahead of the Y1 students.



Concise Data Processing Assessment

	Y1	Y2	
Average pre-score	3.59 ± 0.16	3.21 ± 0.14	
Average post-score	3.45 ± 0.18	4.02 ± 0.19	
Average gain	-0.14 ± 0.17	0.81 ± 0.18	$t(236) = 3.86$, $p = 0.0001$
Average normalized gain	-0.066 ± 0.04	0.10 ± 0.03	$t(236) = 3.79$, $p = 0.0002$

J. Day and D. Bonn, "Development of the Concise Data Processing Assessment," *Phys. Rev. ST Phys. Educ. Res.*, 7(1), 010114 (2011).

Achievement Goals and Motivation Orientation

	Y1	Y2	
Mastery Approach	3.72 ± 0.11	4.07 ± 0.07	$t(197.85) = -2.70$, $p = 0.007$
Performance Approach	3.33 ± 0.95	3.49 ± 0.08	$t(234) = -1.37$, $p = 0.172$
Performance Avoidance	3.43 ± 0.10	3.33 ± 0.09	$t(233) = 0.782$, $p = 0.435$

Sample survey questions:

- Mastery Approach: I am striving to understand the content of this course as thoroughly as possible.
- Performance Approach: My goal is to perform better than the other students.
- Performance Avoidance: My aim is to avoid doing worse than other students.

No difference in orientations at the beginning of the year.

See, e.g. Elliot & McGregor (2001). A 2x2 achievement goal framework. *Journal of Personality and Social Psychology*, 80(3):501–519.

Summary of improvements

What?	Why?
More students more willing to modify theoretical model based on their own data	•Experiences where models didn't work •More trust in their data from experiences improving their data – many more students re-took data this time
More students writing about their thought process and tactics for improving the model and draw conclusions	•TAs provided better quality feedback on students' written work since marking fewer books •Took more care in written material in books since mark shared with partner
More students thinking critically about their data to improve the model and draw conclusions	•Rewarding students for high-quality data •Experiences where model and data could be improved gave impetus for improving

Summary of improvements

What?	Why?
More students pulling on multiple strategies and comparing them to evaluate model	•Each lab involved a comparison •More experience with each strategy •Experience with different uses of each strategy
Students' motivation decreased less over the year than last year.	•More authentic experiences •Less "hoop jumping"
Content learning increased	•More deliberate practice through authentic experiences

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Interview tidbits

“When I’m reading about something or solving physics problems or just reading about physics concepts, the idea of me being a physicist in that sense is very far fetched…it helped me think about a bunch of data that I have in front of me, that looks like chaos, in a more scientific way…

It [the lab] integrates everything so much more and it helps me see myself as a scientist way more than all my other classes, because those are just putting information… giving me information, rather.. It helps me actually reach in and realize, ‘oh, this makes sense! I can actually do this too,’ rather than just memorize a textbook.”

Interview tidbits

"I found physics lab really really useful for our [Science One] Term 2 projects."

"I think that we were encouraged to find better ways to measure stuff very often. Take more data."

"From the labs, we got a sense of what sensible values should be."

"The lab teaches us not just the skills, but the behaviours. Like, taking good data – that can be applied to any scientific field… The statistical techniques that we learn in the physics lab, as well as the carefulness that you learn in the lab is going to get carried on to do research in upper years."

"In physics, there's lots of simplifications and approximations and things that we can ignore, when we do the experiments ourselves we can see why physicists would do that."

Interview tidbits

A goal was "to be a good scientist on our own... Because the difference between a lab and a class is that in a lab, you're having to make your own measurements, whereas in a class or a midterm, they just give you values and say, 'ok, compute this.' I guess it really is more applied and you have to think more about it."

"It's good, 'cuz we get to actually practice, like, real science rather than just filling out [forms] and finding answers… We get to scrutinize and criticize what we're actually getting and trying to understand what the measurement itself is, is more important than getting the right answer in the very end."