Rethinking introductory physics lab courses

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Natasha G. Holmes
Cornell Physics Education Research Lab
Laboratory of Atomic & Solid State Physics Physics Department, Cornell University

@ng_Holmes
ngholmes@cornell.edu
cperl.lassp.cornell.edu
Cornell Physics Education Research Lab

N.G. Holmes (PI)

Students & Postdocs
Saaj Chattopadhyay (Undergraduate)
Katherine Quinn (Grad student)
Tim Rehm (Undergraduate)
Emily Smith (Postdoc)
Cole Walsh (Grad student)

Collaborators

Stanford University
Carl Wieman
Isabella Rios
Adam Stanford-Moore
Ruqayya Toorawa

University of British Columbia
Doug Bonn
Joss Ives
James Day
Dhaneesh Khumar
Sarah Gilbert
Ido Roll
Resources

Many materials shared online at
sqilabs.phas.ubc.ca
Currently developing new labs that will be shared at
cperl.lassp.cornell.edu
Contact me if you want some examples:
ngholmes@cornell.edu
Complete this sentence:

My introductory physics labs were...
Frustrating but fun. We had no textbook for the course, and learned every concept through experiments. Almost made me change my major!

where I realized I am not an idiot and I am capable of physics.

..instrumental in my love for physics and particularly experimentation, data fitting, and visualization.

lab equipment troubleshooting sessions.

where I learned to use excel to record/analyze loads of data pretty quickly ('twas '02). Getting math models from graphs was awesome
Eminently forgettable … I don’t think I remember a single one.forgettable, for the most part.

Forgettable and haven't used them in my own teaching practice.
Outdated! The thing that sticks out most in my mind is a problem about rewinding a cassette tape.

...boring, unconnected to lectures. Electronics TA made fun of me bc I didn’t already know how capacitors worked. Didn’t electronics as a kid.

Not aligned with the course and used older equipment than my high school.

Awful

confusing and not relatable
Something to get through in compliance with the norms of schooling, and mostly a boring repeat of high school physics with worse teachers.

Pressurised. Felt like too much to 'get through' to get things working and the 'correct answer'.

..spent with a lab-mate who was willing to cook the data in order to finish ASAP so that the prof would let us leave an hour or two earlier.

pretty cookbookish, felt very disconnected from the physics we were learning in the courses.
Guiding questions

What should students be learning?

What instructional approaches improve student learning?

What are students learning?

Modified from Science Education Initiative “three-pronged approach” for course transformation
What should students be learning?

What are students learning?

What instructional approaches improve student learning?

What are you trying to measure?

How are you going to measure it?

What variables are you going to change?

Modified from Science Education Initiative “three-pronged approach” for course transformation
What are the goals of physics lab courses?

- **Think**: List some goals of intro physics labs
- **Pair**: Discuss them with your neighbor
- **Share**: Discuss with the group
Labs target...

- Understanding scientific concepts
- Interest and motivation
- Practical skills and problem solving abilities
- Scientific habits of mind
- Understanding the nature of science and measurement
AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum

Report prepared by a Subcommittee of the AAPT Committee on Laboratories
Endorsed by the AAPT Executive Board
November 10, 2014
Many Lab courses target...

- Understanding scientific concepts
- Interest and motivation
- Practical skills and problem solving abilities
- Scientific habits of mind
- Understanding the nature of science and measurement

Hofstein & Lunetta (1982; 2004)
Studying the impact of labs on reinforcing course content

What are you trying to measure?

What variables are you going to change?

Taking the lab vs not taking the lab

Final exam (lab-related and non-lab-related questions)

Course content

How are you going to measure it?

Holmes, Olsen, Thomas, & Wieman (2017) *Phys. Rev. PER*
Students who take the lab ≠ Students who do not take the lab

Must account for selection effects

Holmes, Olsen, Thomas, & Wieman (2017) *Phys. Rev. PER*
All content covered in lecture/discussion, some further reinforced in labs

Score on non-lab-reinforced questions

Score on lab-reinforced questions
Hypothesis

Lab students

Score on lab-reinforced questions

Score on non-lab-reinforced questions

No-Lab students

Score on lab-reinforced questions

Score on non-lab-reinforced questions
Multi-institution study

Features:
- 3 very different populations of students
- Varied instructional approaches
- All three shared the goal to reinforce material in the rest of the course

Labs were designed to achieve that aim (e.g. making predictions, comparing results to predictions, etc.), generally quite prescribed.
Prediction

Lab students

Score on lab-reinforced questions
Score on non-lab-reinforced questions

No-Lab students

Score on lab-reinforced questions
Score on non-lab-reinforced questions

A. Ratio will be greater for lab students
B. Ratio will be greater for no-lab students
C. Ratio will be the same for both groups
Score on lab-reinforced questions
Score on non-lab-reinforced questions

Institution 1 | Institution 2 | Institution 3
---|---|---

Course 1 | Course 1 | Course 1
Course 2 | Course 2 | Course 2
Course 3 | Course 3 | Course 3

Final exams
Groups also not distinguishable when looking across midterm exams or only at conceptual questions.
Labs are not providing measurable added-value to learning course content.
Student attitudes towards experimental physics

The Colorado Learning Attitudes about Science Survey for Experimental Physics

e.g.
• When doing an experiment, I try to understand how the experimental set up works.
• When doing a physics experiment, I don't think much about sources of systematic error.

Scores aligned with expert responses

Labs that aim to reinforce concepts decrease student attitudes towards experimental physics.

Positive shift means attitudes & belief become more expert-like.
Why?

Prather: Who’s doing the work?

• Labs inherently interactive and active
• Students are doing work
• But what work?
• Who’s doing the intellectual work?
What should students be learning???

What instructional approaches improve student learning?

What are students learning?
Labs target...

- Understanding scientific concepts
- Interest and motivation
- Practical skills and problem solving abilities
- Scientific habits of mind
- Understanding the nature of science and measurement
Quantitative critical thinking

The process through which you make decisions and decide what to believe

Especially related to “believing” evidence, data, models, etc.
Quantitative critical thinking

Make a comparison

Act on comparison

Reflect on comparison
Compare period of pendulum at different amplitudes

- Measure time for single period, $T$
- Repeat 10 times, find average, standard error
Compare period of pendulum at different amplitudes

- T = 1.84 ± 0.08 s
- T = 1.81 ± 0.08 s

10° vs 20°
Quantitative critical thinking

Make a comparison

Act on comparison

Reflect on comparison?
Compare period of pendulum at different amplitudes

$T = 1.84 \pm 0.08 \text{ s}$

$W S$

$T = 1.81 \pm 0.08 \text{ s}$

$T_{10} - T_{20} \approx 0.2\sigma$
What might a difference of $\sim 0.2\sigma$ mean?
What might a difference of $\sim 0.2\sigma$ mean?

A. The measured periods agree
B. The measured periods don’t agree
C. The uncertainty is too large
D. The uncertainty is too small
E. Other
Small difference means values are close
AND/OR
uncertainty is large
Quantitative critical thinking

Make a comparison

Act on comparison

Reflect on comparison
What should they do next?

\[ T = 1.84 \pm 0.08 \text{ s} \]
\[ T = 1.81 \pm 0.08 \text{ s} \]

- Measure time for single period, \( T \)
- Repeat 10 times, find average, standard error

**Diff** 
\( \sim 0.2\sigma \)
What do they want to do next?

A. Increase the number of trials
B. Measure more swings per trial
C. Use a photogate instead of a stopwatch
D. Measure another angle
E. Write it up, list their sources of error, then go home
What should they do next?

A. Increase the number of trials
B. Measure more swings per trial
C. Use a photogate instead of a stopwatch
D. Measure another angle
E. Write it up, list their sources of error, then go home
What should they do next?

\[ T = 1.830 \pm 0.004 \text{ s} \quad T = 1.851 \pm 0.004 \text{ s} \]

\[ \text{Diff} \sim 3.7 \sigma \]

- Measure time, \( t \), for 20 periods
- Divide by 20 to get period, repeat, average, etc.
The opposite of the expected happened:

\[ \theta_{\text{max}} > 3 \Rightarrow \text{measured values are different} \]

**Conclusion:**

The period of a pendulum does depend on the angle with the vertical in the initial position.

The algebraically derived formula for \( T = 2\pi \sqrt{\frac{L}{g}} \) of a pendulum is only valid for small angles.

Considering the results of this experiment, 20° is obviously not "small" enough since the angle has an effect on the period \( T \) and should be somehow represented in the formula.

If you can make a precise enough measurement, you can show that the theoretical derivation of the equation of motion for a pendulum is just a good approximation and reality is slightly more complicated.
Period as a function of angle
Measurements are indistinguishable
Conclude and go home.
Design way to reduce uncertainty

Measurements are distinguishable
Conclude and go home.
Check for mistakes
Design new experiment
Check / revise model
Design way to reduce uncertainty

$Diff = \frac{A - B}{\sqrt{\delta_A^2 + \delta_B^2}}$

Small value
Large value
\[ \chi^2 = \frac{1}{N} \sum \frac{(f(x_i) - y_i)^2}{\delta y_i^2} \]

Small value

- Measurements are indistinguishable from model
  - Conclude and go home.
  - Design way to reduce uncertainty

Large value

- Measurements are distinguishable from model
  - Conclude and go home.
  - Check for mistakes
  - Design new experiment
  - Check / revise model
  - Design way to reduce uncertainty
Why iterative cycles work

- Autonomy and freedom to make decisions (and mistakes)
- Feedback and support to learn from decisions
- Opportunities and time to revise and improve
- Situations where physics isn’t ‘perfect’ (deal with disagreements)

Gick & Holyoak (1980, 1983); Bransford et al. (1989); Ericsson et al. (1993); Bransford & Schwartz (1999); Kapur (2008)…
General features

**Time to iterate and improve**
- Span labs across multiple weeks

**Provide autonomy/agency**
- Remove structure and explicit directions and replace with guiding questions
- Fade the structure over time

**Shift focus to process instead of product**
- Remove value on verifying existing theories
- Provide grade incentive for experimentation behaviors (e.g. evidence of iteration, justification for design choices, interpretations based on data)

Holmes & Wieman (2016) Phys. Rev. PER
Other examples

- **Drag:**
  - Is drag force on coffee filters proportional to terminal velocity \( (v) \) or terminal velocity squared \( (v^2) \)?

- **Bouncing ball:**
  - Where/how is energy lost as a ball bounces vertically?

- **Light intensity:**
  - Does light intensity drop off exponentially or as a power law with: a) distance from the source, b) translucent filters placed in front?

- ...
Ways to assess

- PLIC: closed-response assessment of students’ critical thinking skills in context of intro physics labs
- E–CLASS: survey of students’ attitudes and beliefs about experimental physics
- CDPA: multiple choice test of student understanding of data analysis
- Physics Measurement Questionnaire: open-response assessment of student understanding of uncertainty and measurement
Want to use the PLIC?
Contact me
(ngholmes@cornell.edu)

Also looking for responses from experts!
Summary

- Labs offer opportunity to teach critical thinking and experimentation skills (with suggested limits to how well they teach physics concepts)
- SQILabs use deliberate practice with cycles of comparisons and making decisions to develop students’ critical thinking skills
- Other pedagogies and things to check out:
  - Investigative Science Learning Environments (studio/workshop, Rutgers)
  - iOLab (pocket device students can take home, UIUC)
  - Teaching measurement and uncertainty the GUM way (Cape Town)
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Sarah Gilbert Ido Roll