@ng_Holmes

ngholmes@cornell.edu

cperl.lassp.cornell.edu

RETHINKING INTRODUCTORY PHYSICS LAB COURSES

AAPT New Faculty Workshop,
November 3rd 2017

NATASHA G. HOLMES

CORNELL PHYSICS EDUCATION RESEARCH LAB

LABORATORY OF ATOMIC & SOLID STATE PHYSICS
PHYSICS DEPARTMENT, CORNELL UNIVERSITY

Complete this sentence:

MY INTRODUCTORY PHYSICS LABS WERE…

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.

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

…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

Forgettable and haven't used them in my own teaching practice.

Awful

Something to get through in compliance with the norms of schooling

formulaic.

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

cookbook.

confusing and not relatable

pretty cookbookish

..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

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

Hofstein & Lunetta (1982; 2004)

DO LABS TARGET…

A.
Understanding scientific concepts

B.
Interest and motivation

C.
Practical skills and problem solving abilities

D.
Scientific habits of mind

E.
Understanding the nature of science and measurement

Hofstein & Lunetta (1982; 2004)

LABS TARGET…

Understanding scientific concepts

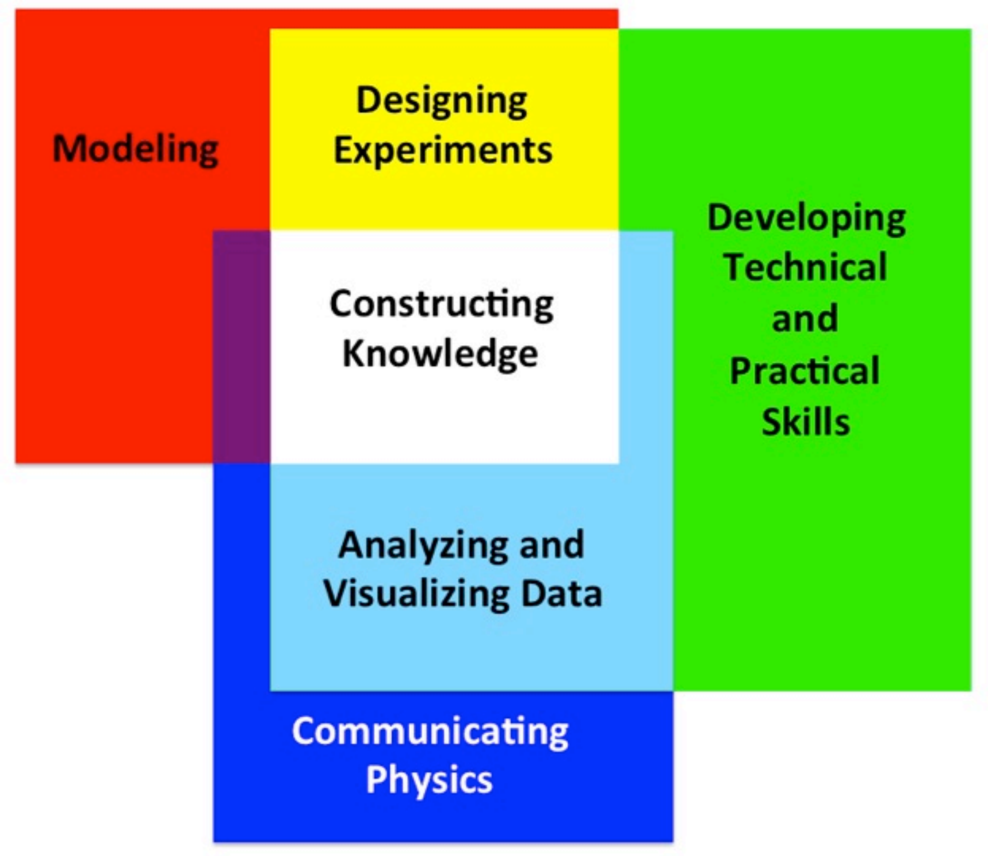
Interest and motivation

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

Hofstein & Lunetta (1982; 2004)

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

STUDYING THE IMPACT OF LABS ON REINFORCING COURSE CONTENT

Research question

- Does taking a lab, designed to reinforce course material, improve student understanding of course material?

Conditions

- Students taking and students not taking the associated lab course (optional)

Assessment

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

Holmes, Olsen, Thomas, & Wieman (2017) *Phys. Rev. PER*

Holmes & Wieman (2016) *Am. J. Phys.*

DEALING WITH SELECTION EFFECT

Students who take the lab ≠ Students who do not take the lab

LAB RATIO

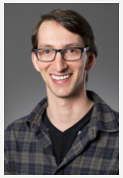
$$\frac{\text{Score on lab-reinforced questions}}{\text{Score on non-lab-reinforced questions}}$$

(All content covered in lecture/discussion, some further reinforced in labs)

HYPOTHESIS

$$\left(\frac{\text{Score on lab-reinforced questions}}{\text{Score on non-lab-reinforced questions}}\right)_{\text{Lab students}} > \left(\frac{\text{Score on lab-reinforced questions}}{\text{Score on non-lab-reinforced questions}}\right)_{\text{No-Lab students}}$$

MULTI-INSTITUTION STUDY


Jack Olsen (UW)


Jim Thomas (UNM)


Carl Wieman (Stanford)

Institution 1:

- Small, private, elite research-based institution in California

Institution 2:

- Large, public research-based institution in Northwestern US

Institution 3:

- Medium, public research-based institution in southwestern US

Holmes, Olsen, Thomas, & Wieman (2017) Phys. Rev. PER

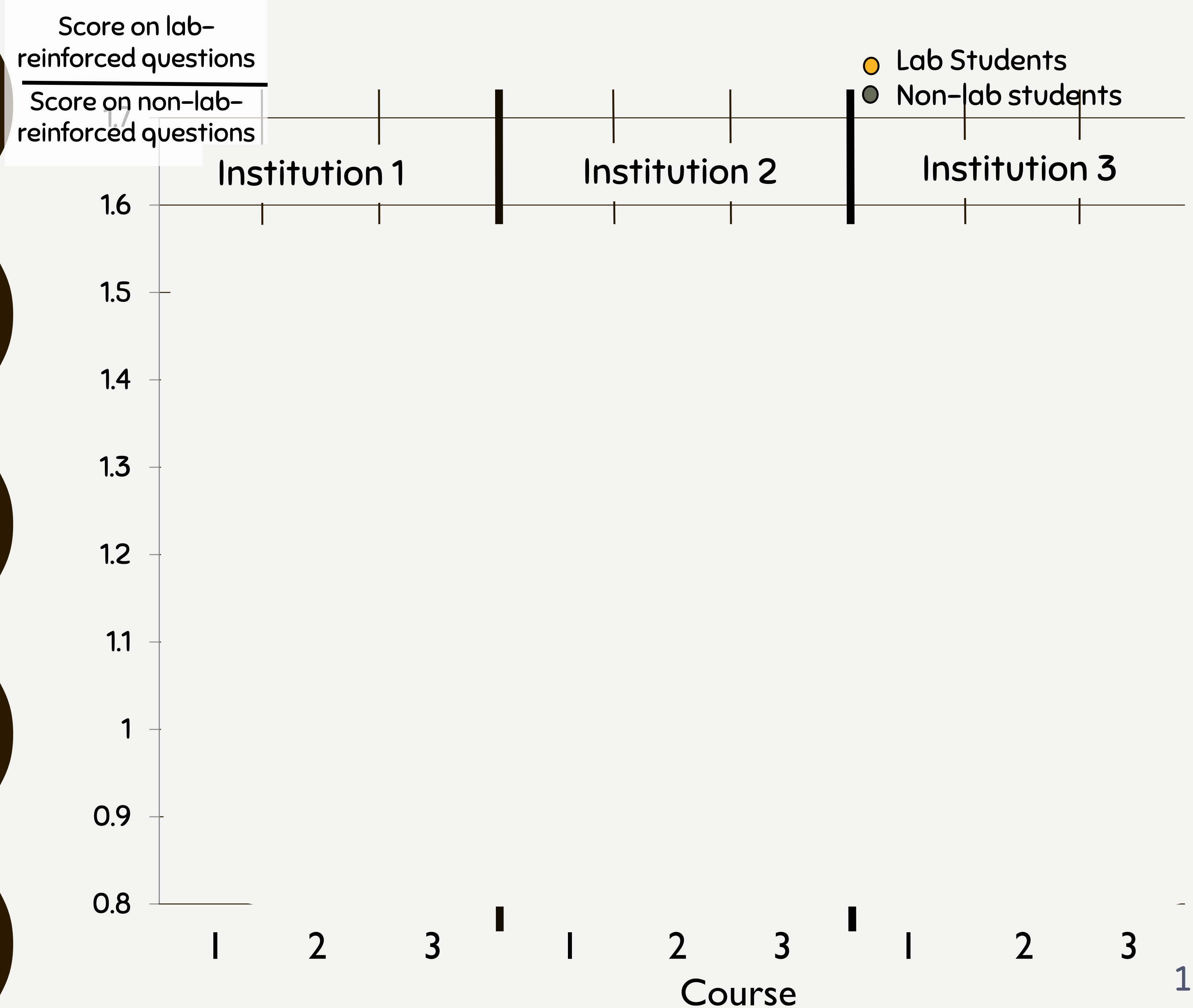
MULTI-INSTITUTION STUDY

Differences:

- 3 very different populations of students
- Varied instructional approaches
- Mechanics and E&M courses
- Different instructors

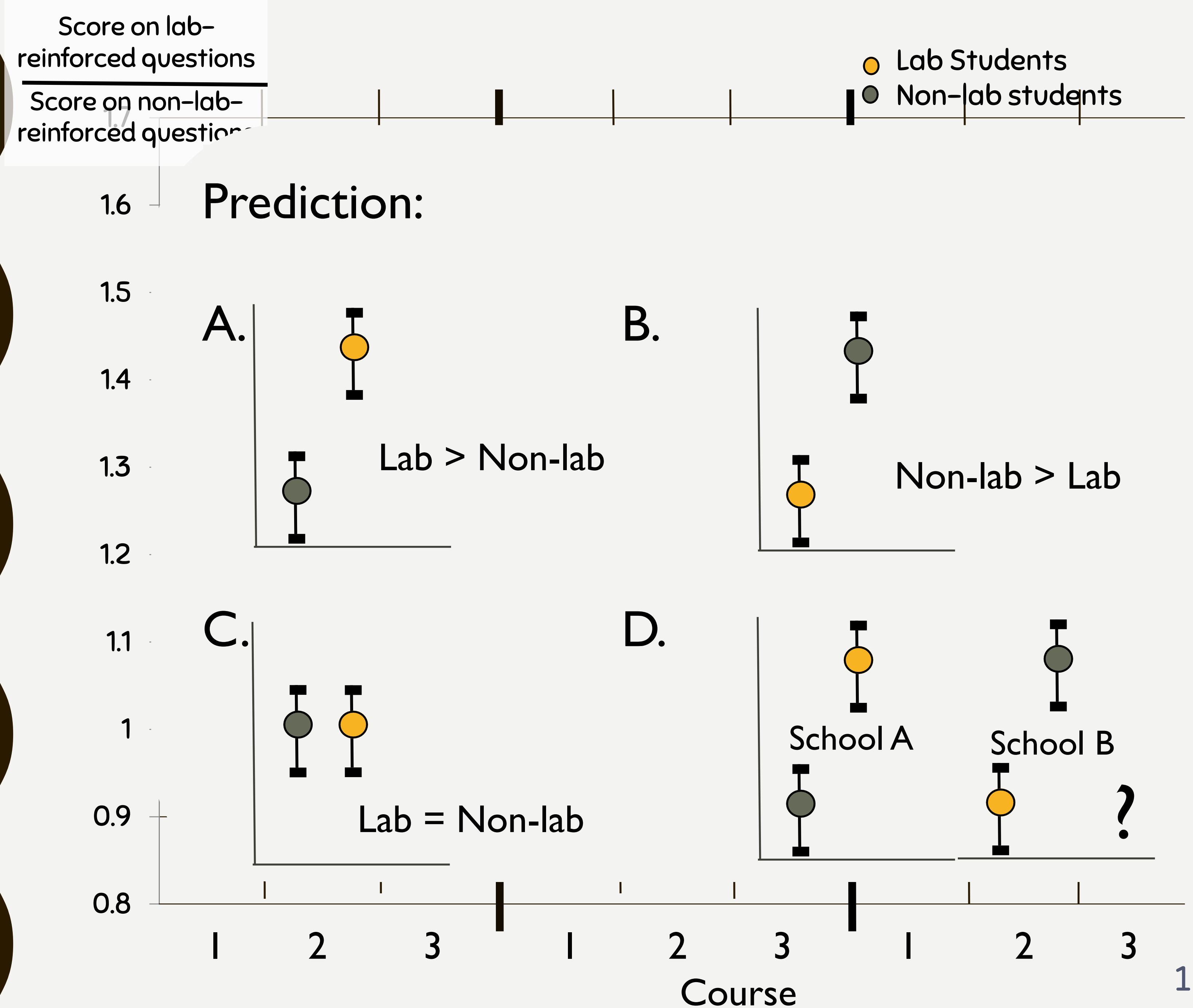
Similarities:

- 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

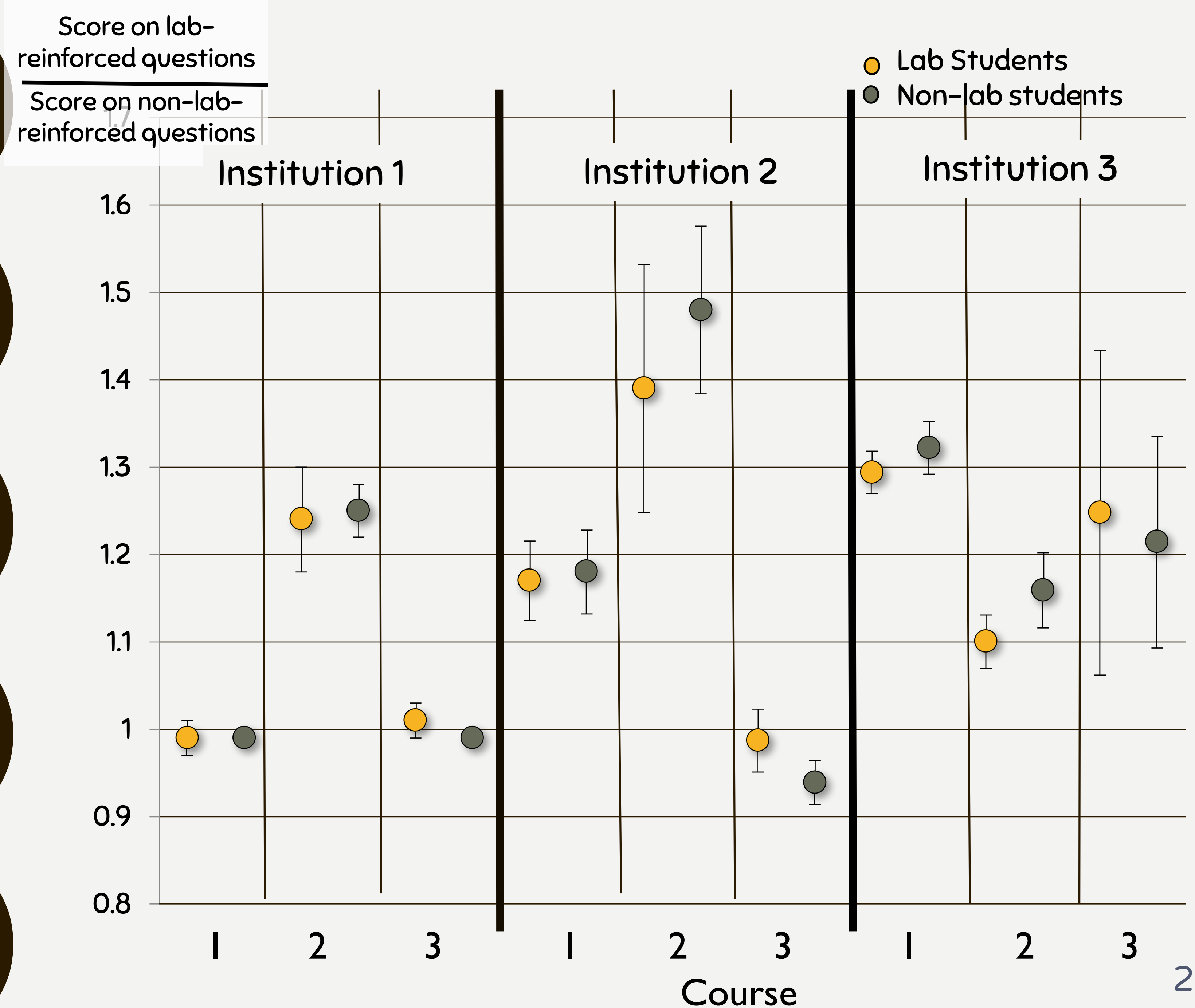


Holmes, Olsen, Thomas, & Wieman (2017)

Prediction:



Holmes, Olsen, Thomas, & Wieman (2017)



Holmes, Olsen, Thomas, & Wieman (2017)

LABS ARE NOT PROVIDING MEASURABLE ADDED-VALUE TO LEARNING COURSE CONTENT

WHY?

Who's doing the work?

- Labs are inherently active
- Students are *doing* work

Who’s doing the intellectual work?

QUICK NOTES:

- Interactive lecture demonstrations!
  - Predict-observe-explain methods are very effective and more efficient (15 minutes?)
    - e.g. Miller, et al. "Role of physics lecture demonstrations in conceptual learning," Phys. Rev. ST-PER (2013).
- Simulations (PhET)!
  - As good (Better?) than hands-on and can be done cheaply, at home, etc.
    - e.g. Finkelstein, et al. "When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment." Phys Rev ST-PER (2005)

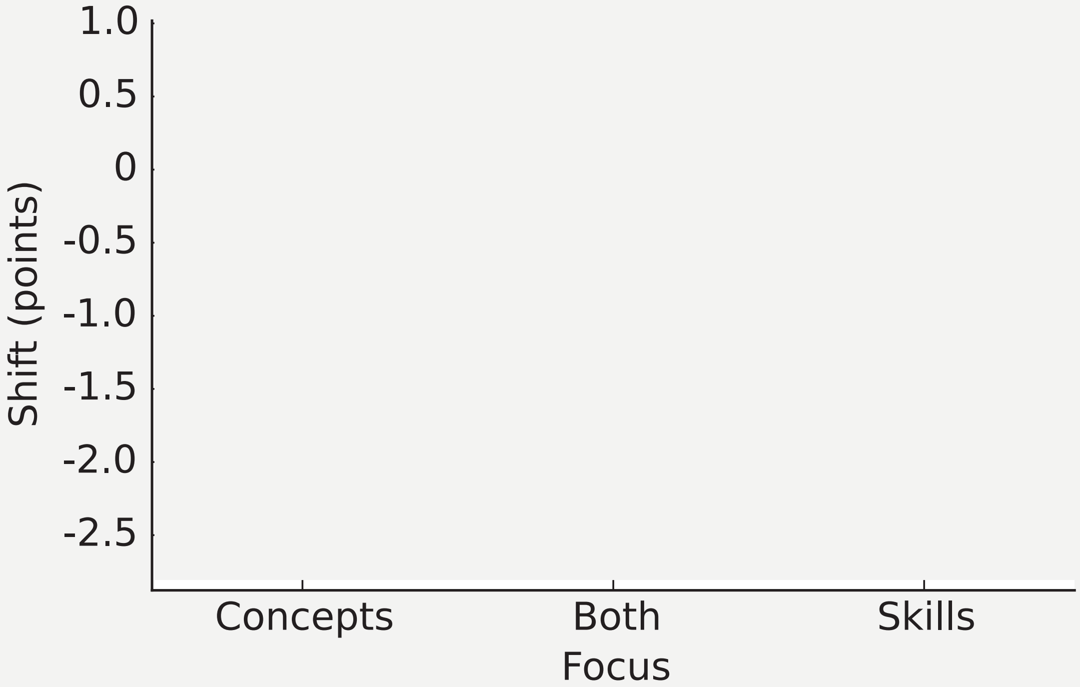
STUDENT ATTITUDES TOWARDS EXPERIMENTAL PHYSICS

Colorado Learning Attitudes about Science Survey for Experimental Physics

- Zwickl et al. (2014) *Phys Rev ST – PER*

Do students agree with statements about experimental physics? Scores aligned with expert responses

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



STUDENT ATTITUDES TOWARDS EXPERIMENTAL PHYSICS

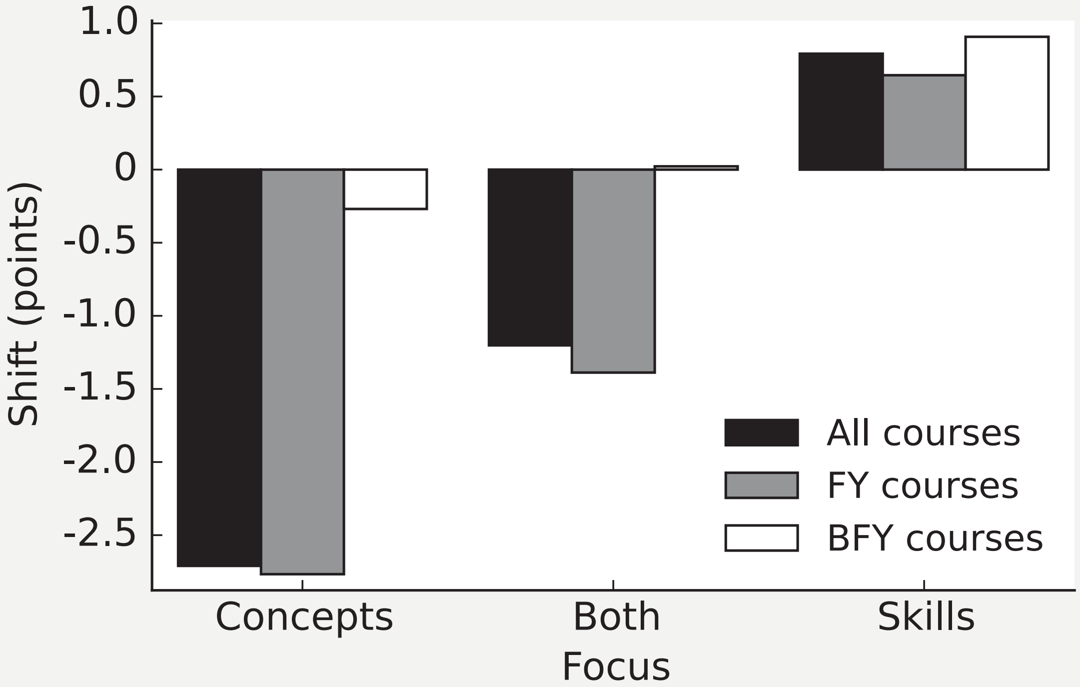
Positive shift means attitudes & belief become more expert-like

Wilcox & Lewandowski (2017) Phys. Rev. PER **13**, 010108

STUDENT ATTITUDES TOWARDS EXPERIMENTAL PHYSICS

Positive shift means attitudes & belief become more expert-like

Wilcox & Lewandowski (2017) Phys. Rev. PER **13**, 010108



LABS THAT AIM TO REINFORCE CONCEPTS DECREASE STUDENT ATTITUDES TOWARDS EXPERIMENTAL PHYSICS

Positive shift means attitudes & belief become more expert-like

Wilcox & Lewandowski (2017) Phys. Rev. PER **13**, 010108

LABS TARGET

Hofstein & Lunetta
(1983; 2004)

Understanding scientific concepts

Interest and motivation

Practical skills and problem solving abilities

Scientific habits of mind

Understanding the nature of science and measurement

DESIGN A NEW PENDULUM LAB: GOALS

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Think-pair:

- Pick two learning goals for doing this lab related to experimentation
- A learning goal is "By the end of this experiment students should be able to…"
  - e.g. Quantify uncertainty in repeated trials using standard deviation
  - NOT Show that pendulum doesn't depend on angle or mass – that's a physics content goals

DESIGN A NEW PENDULUM LAB: GOALS

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Think-pair:

- Pick two learning goals for doing this lab

Tasks:

- How would you structure the lab so students can actively learn that/those objective(s)?
- What are the issues that arise?

LET'S BRAINSTORM: PENDULUM LAB

Traditional

Measure T for given L and find g?

Measure L and calculate T?

Lay out all the instructions, number of trials, etc.

Full open-ended

Here's a pendulum, choose a research question and design an experiment.

Here's a room full of lab equipment, choose a research question and design an experiment.

?

EX: COMPARE PERIOD OF PENDULUM FROM DIFFERENT AMPLITUDES

Objectives:

- Identify sources of statistical uncertainty, instrumental precision, and systematic effects
- Decide what and how much data are to be gathered to produce reliable measurements given the set of concerns above
- Define and calculate the mean, standard deviation, the standard uncertainty in the mean, and the difference between means in units of uncertainty
- Propose and carry out follow-up investigations or revisions in light of the data and model

EX: COMPARE PERIOD OF PENDULUM FROM DIFFERENT AMPLITUDES

Objectives:

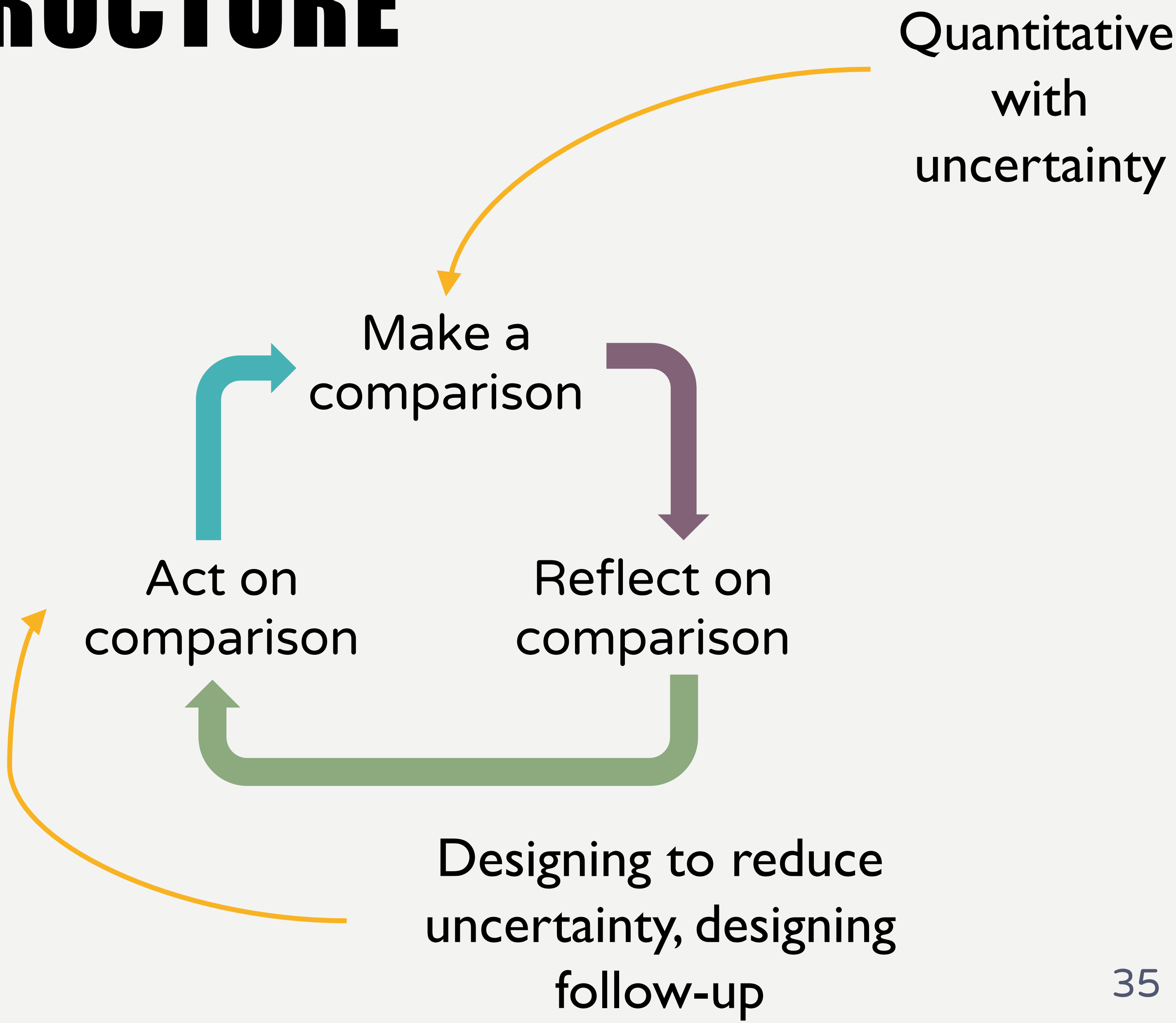
- Identify sources of statistical uncertainty, i precision, and systematic effects
- Decide what and how much data are to b to produce reliable measurements given the set of concerns above
- Define and calculate the mean, standard deviati standard uncertainty in the mean, and the differ between means in units of uncert
- Propose and carry out follow-up s or revisions in light of the data and

Understanding the nature of science and measurement

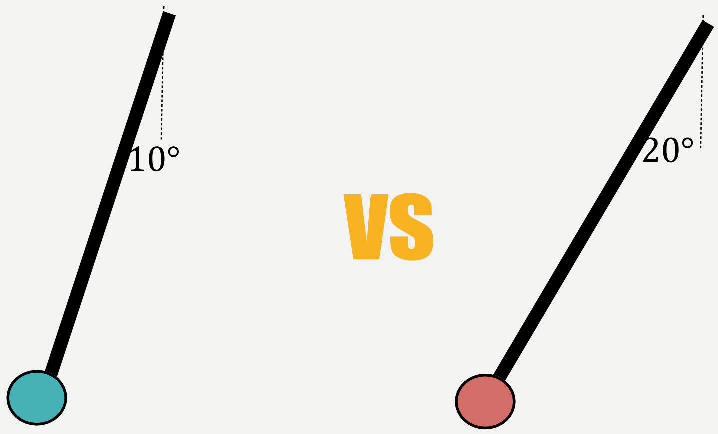
Practical skills and problem solving abilities

Scientific habits of mind

STRUCTURE

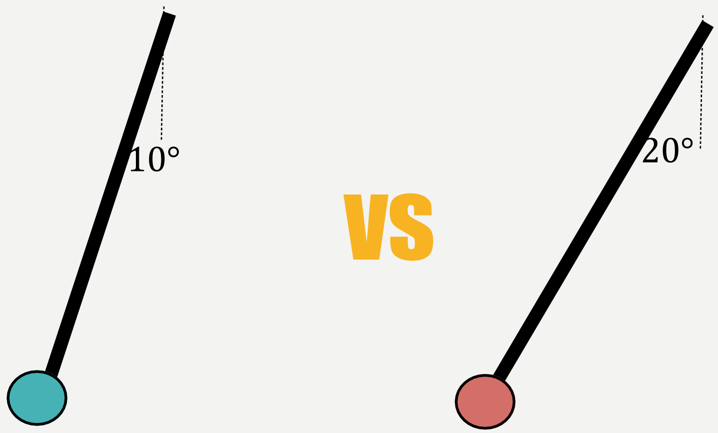

Quantitative, with uncertainty
Make a comparison
Reflect on comparison
Act on comparison
Designing to reduce uncertainty, designing follow-up

COMPARE PERIOD OF PENDULUM FROM DIFFERENT AMPLITUDES



Holmes & Bonn (2015) The Physics Teacher

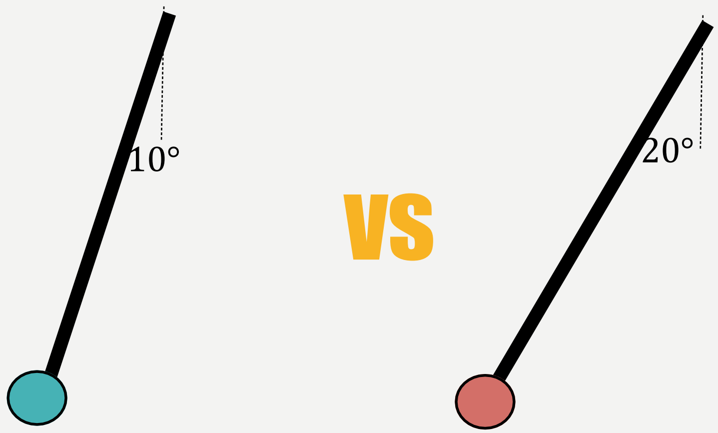
COMPARE PERIOD OF PENDULUM FROM DIFFERENT AMPLITUDES



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

Holmes & Bonn (2015) The Physics Teacher

COMPARE PERIOD OF PENDULUM FROM DIFFERENT AMPLITUDES



Diff $\sim 0.2\sigma$

T= 1.84 ± 0.08 s   T= 1.81 ± 0.08 s

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

Holmes & Bonn (2015) The Physics Teacher

What might a difference of 0.2σ mean?

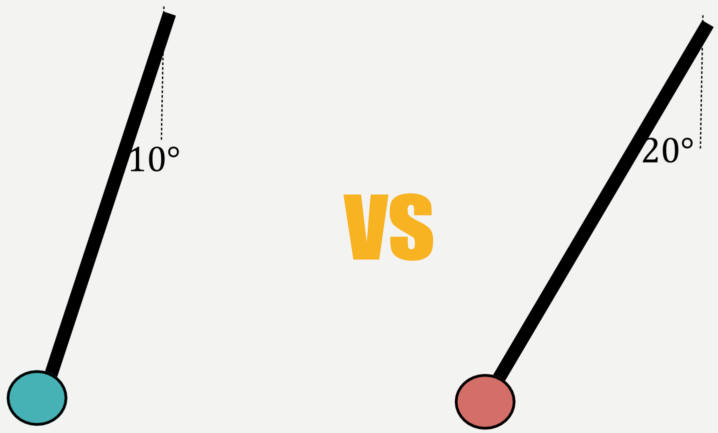
$$t' = \frac{T_{10°} - T_{20°}}{Uncertainty}$$

Small difference means values are close

AND/OR

uncertainty is large

DECIDE WHAT TO DO NEXT



$t' \sim 0.2\sigma$

T= 1.84 ± 0.08 s   T= 1.81 ± 0.08 s

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

Holmes & Bonn (2015) The Physics Teacher

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 DO THEY *WANT* TO DO NEXT?

Instructions tell them to find a way to reduce their uncertainty, implement it, and then evaluate whether it helped.

A.
B.
C. Use a photogate instead of a stopwatch
D. Measure another angle
E. Write it up, list their sources of error, then go home

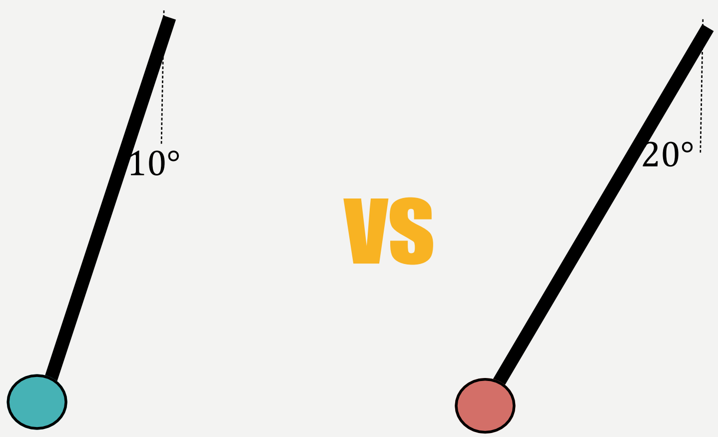
WHAT COULD THEY DO NEXT?

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 DID 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 DID THEY DO NEXT?



$t' \sim 3.7\sigma$

T= 1.830 ± 0.004 s T= 1.851 ± 0.004 s

- Measure time, t, for 20 periods
- Divide by 20 to get period, repeat average, standard error…

Holmes & Bonn (2015) The Physics Teacher

the opposite of the expected happened:

$$t_{improv} > 3 \Rightarrow \text{measured values are } \underline{\text{different}}$$

Conclusion:

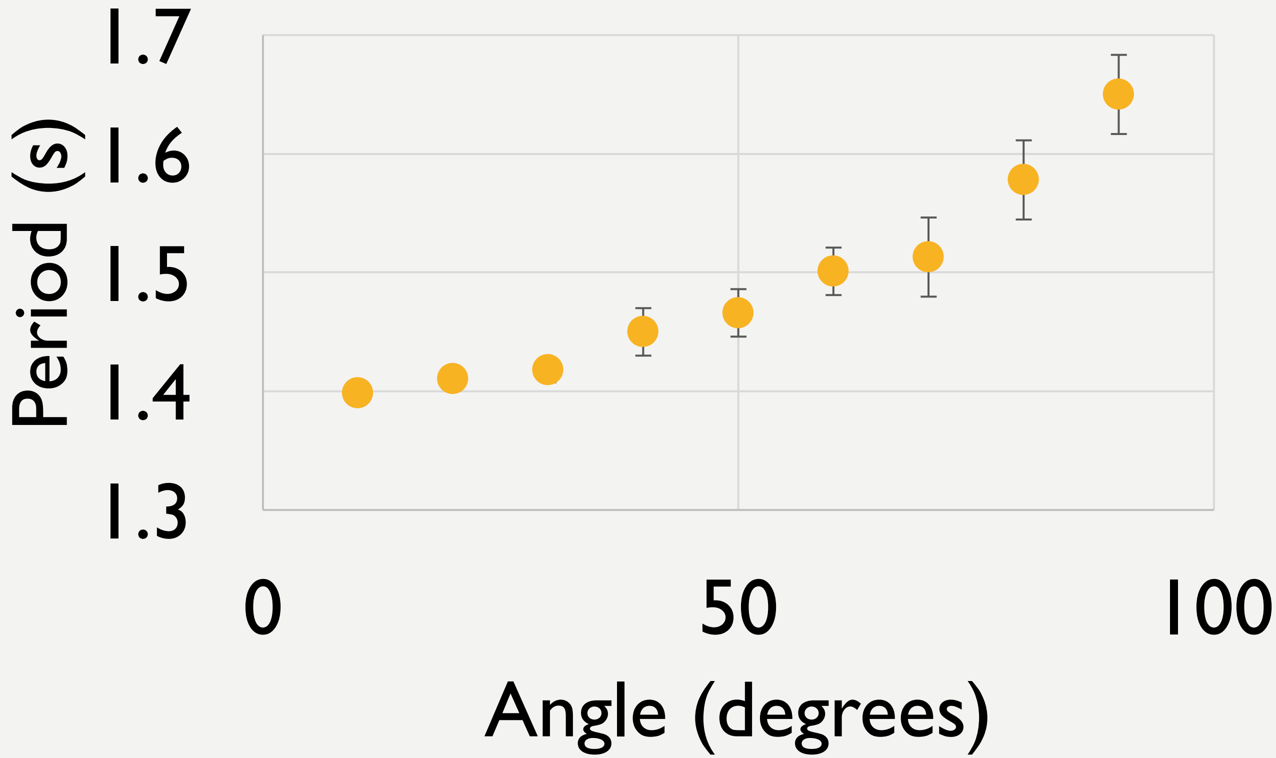
the period of a pendulum does depend on the angle with the vertical in the initial position.

the algebraically derived formula for $T \approx 2\pi\sqrt{\frac{l}{g}}$ 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.

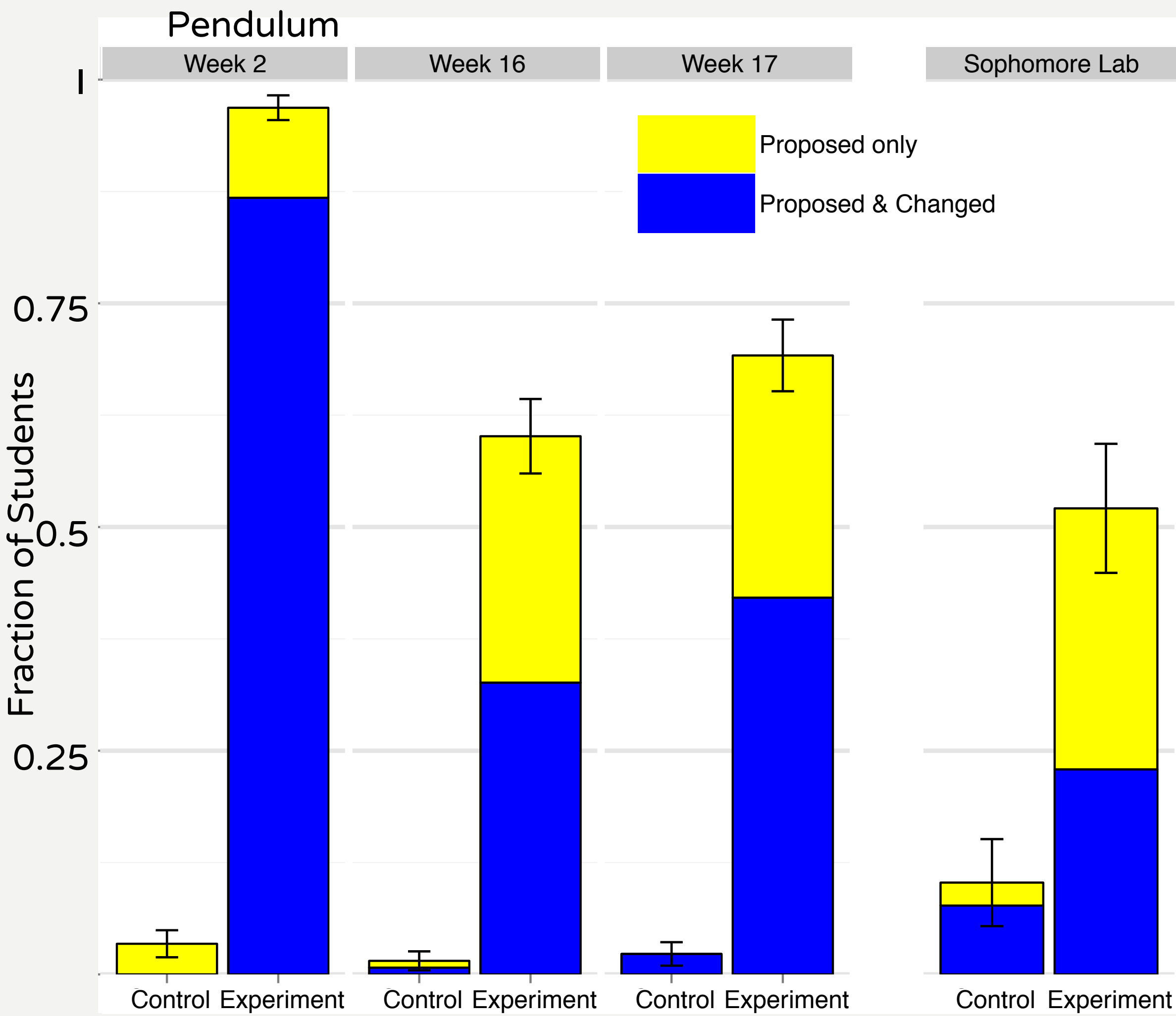
If you can make a precise enough measurement, you can show that the theoretical derivation of the equation of motion for a pendulum is just a 'good approximation' and reality is slightly more complicated.

PERIOD AS A FUNCTION OF ANGLE



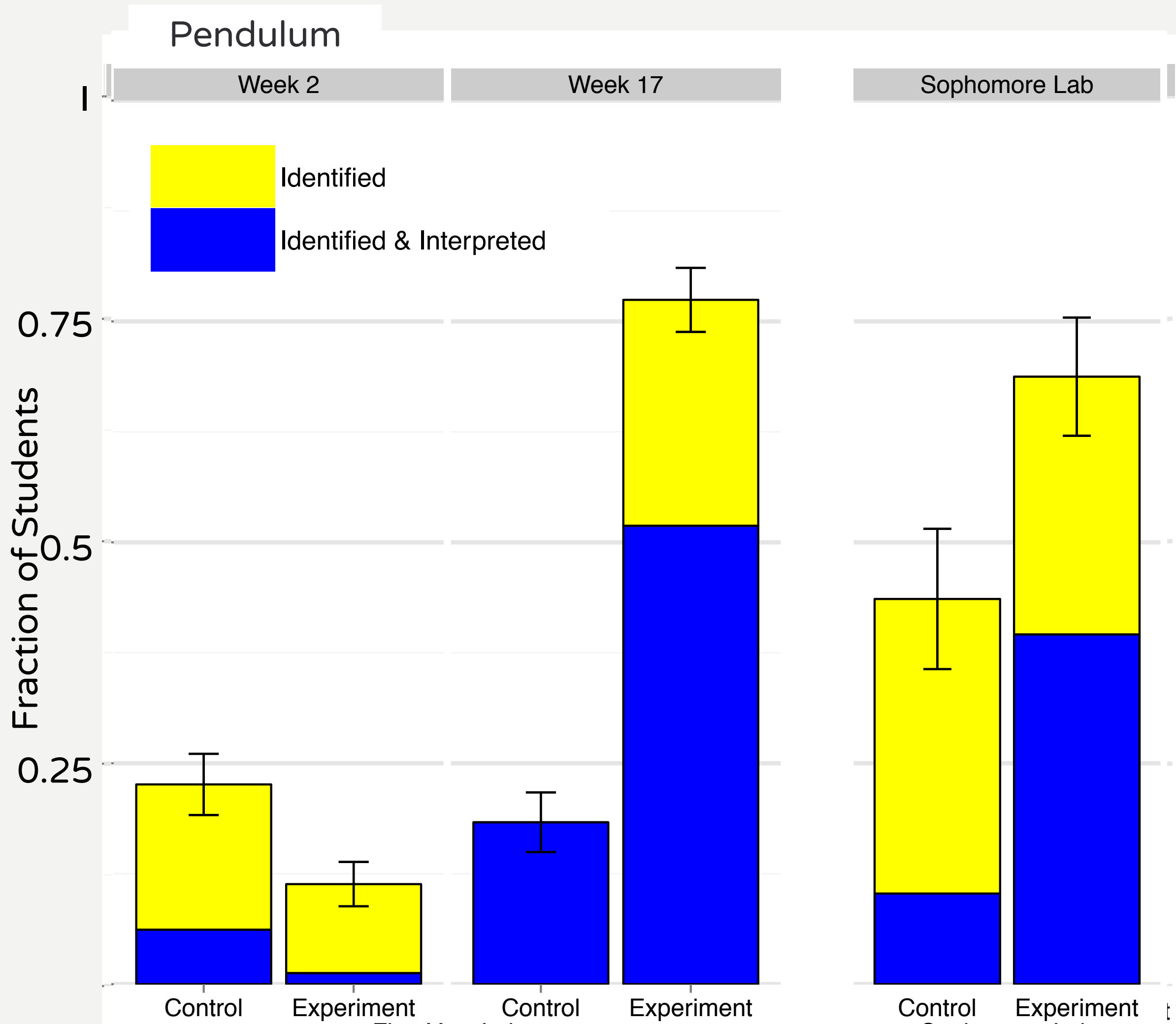
Holmes, Wieman & Bonn (2015) *PNAS*

OTHER EVIDENCE OF IMPACTS…



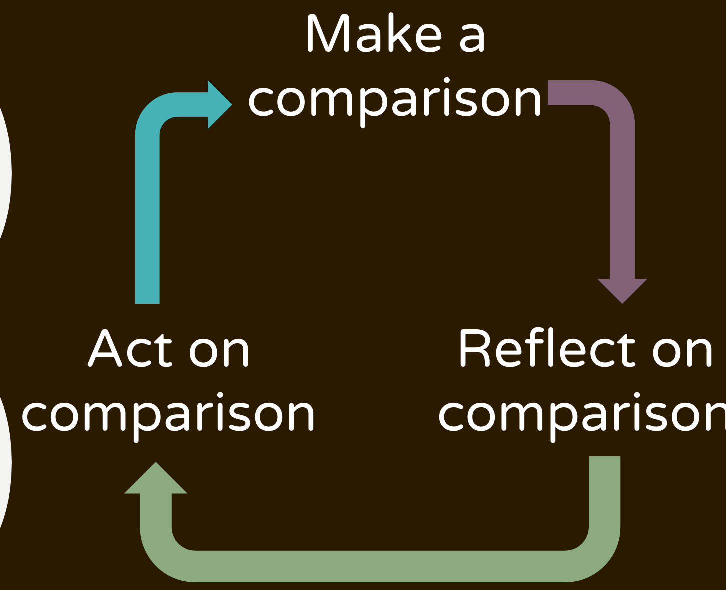
Holmes, Wieman & Bonn (2015) *PNAS*

OTHER EVIDENCE OF IMPACTS…



WHY ITERATIVE CYCLES WORK

- Comparisons help students make sense of results
- Agency 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)...

POSSIBLE FIRST STEPS:

- Change the goals to focus on process rather than product
- Spread labs over multiple sessions
- Give students agency

POSSIBLE FIRST STEPS:

- Change the goals to focus on process rather than product
  - Use things where they don't necessarily know the answer (e.g. pendulum angle dependence, or a value that they can't "look up")
  - Grade on the behaviors you want, make them submit things that represent the behaviors you want
- Spread labs over multiple sessions
  - Less worry about "content" coverage
- Give students agency:
  - Reduce structure and remove with guiding questions
  - Does NOT mean open up the space entirely – can still structure, scaffold, and constrain
  - Again: Use experiments where students don't know the answer
  - Fade structure over time

Holmes & Wieman (2016) Phys. Rev. PER

CONTROL: DRAG LAB

"In most physics problems we make certain assumptions. Sometimes these are justified, other times they are not. This week we will look at the effects of drag.

The free-fall model assumes that when we drop an object the only force acting upon it is its own weight, and hence the object will accelerate downwards at the familiar 9.8 m/s^2. In reality, the object will have to push air out of its path, and by Newton's Third Law, since it is pushing down on the air, the air below is pushing back upwards on the object. From a simplistic point of view, the faster an object is falling the more air it will have to push out of the way, and hence the greater upwards force it will experience.

There are two models for this force, called the drag force. In some cases the drag force is linear with the velocity of the falling object ($F_D = -bv$), in others it is proportional to the square of the velocity ($F_D = -bv^2$). In either case, the drag force will oppose the direction of motion, so for an object that is dropping straight down the drag force will be opposite the weight. If an object is going fast enough, the drag force will balance out the weight, and the object will stop accelerating, and will this have a constant velocity (mathematically this isn't strictly true, the object's velocity will asymptotically approach this velocity). This is known as the terminal velocity.

In today's lab we'll use motion detectors and coffee filters. Set up your motion detector so that it is over the floor rather than over the table. Collect position data while dropping one single coffee filter. Determine the terminal velocity from the motion detector data. Repeat with a pair of filters stuck together, and continue to take data until you've dropped a mass consisting of seven or eight coffee filters."

INTERVENTION: DRAG LAB

"Describe how you think the coffee filters motion will evolve as they fall towards the floor and explain your reasoning. Discuss your ideas with other groups. This process is called 'modeling' the motion. A few things to think about as you build up your model:

- What are the forces acting on the coffee filters?
- Are there any assumptions or approximations you can make to simplify the model?

In class, you were presented with two competing models that characterize the motion of the falling coffee filters. Design an experiment to test which model best characterizes the motion of the coffee filters. Things to think about in your design:

- What are the relevant variables to control and which ones do you need to explore?
- What are some logistical issues associated with the data collection that may cause unnecessary variability (either random or systematic) or mistakes?
- How can you control or measure these?
- What ways can you graph your data and which ones will help you figure out which model better describes your data?

Discuss your design with other groups and modify as you see fit."

EXAMPLE: UPPER-DIVISION OPTICS LAB

Limitations:

- Safety + expensive equipment (lasers)
- Lots of content knowledge required
- Lots of practical, equipment knowledge required

Solution:

- Week 1: Use structured lab
- Week 2: Students design and carry out their own extension:
  - new variables, improvements to design, extend range…

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?
- a) RC b) LR:
  - Voltage as a function of time – demonstrate exponential decay
  - Time constant proportional to a) R? b) 1/R?

WAYS TO ASSESS

- PLIC: closed-response assessment of students’ critical thinking skills in context of intro physics labs
    - cperl.lassp.cornell.edu/PLIC
- 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

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