@ng_Holmes
ngholmes@cornell.edu
cperl.lassp.cornell.edu

RETHINKING INTRODUCTORY PHYSICS LAB COURSES

AAPT New Faculty Workshop,
June 26, 2018

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

LEARNING OUTCOMES:

By the end of this session, you should be able to:

- List goals you have for students in your lab courses
- Describe some techniques and strategies for teaching those goals
- Adapt your own lab activities to incorporate those techniques and strategies

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

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

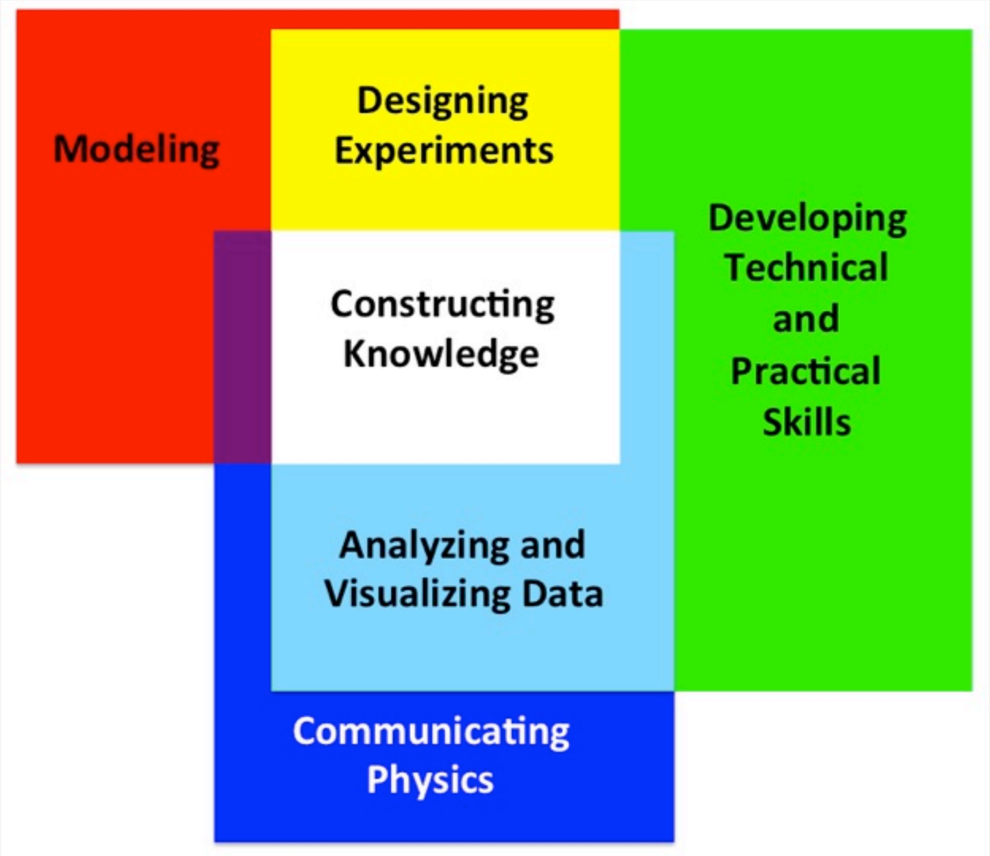
Hofstein & Lunetta (1982; 2004)

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

Hofstein & Lunetta (1982; 2004)

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

Understanding scientific concepts

Interest and motivation

Practical skills and problem solving abilities

Scientific habits of mind

Understanding the nature of science and measurement

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

Holmes, Wieman, & Bonn (2015)
Holmes & Bonn (2018)

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

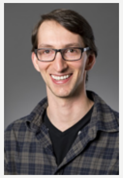
$$\frac{\text{Score on lab-reinforced questions}}{\text{Score on non-lab-reinforced questions}}$$

(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

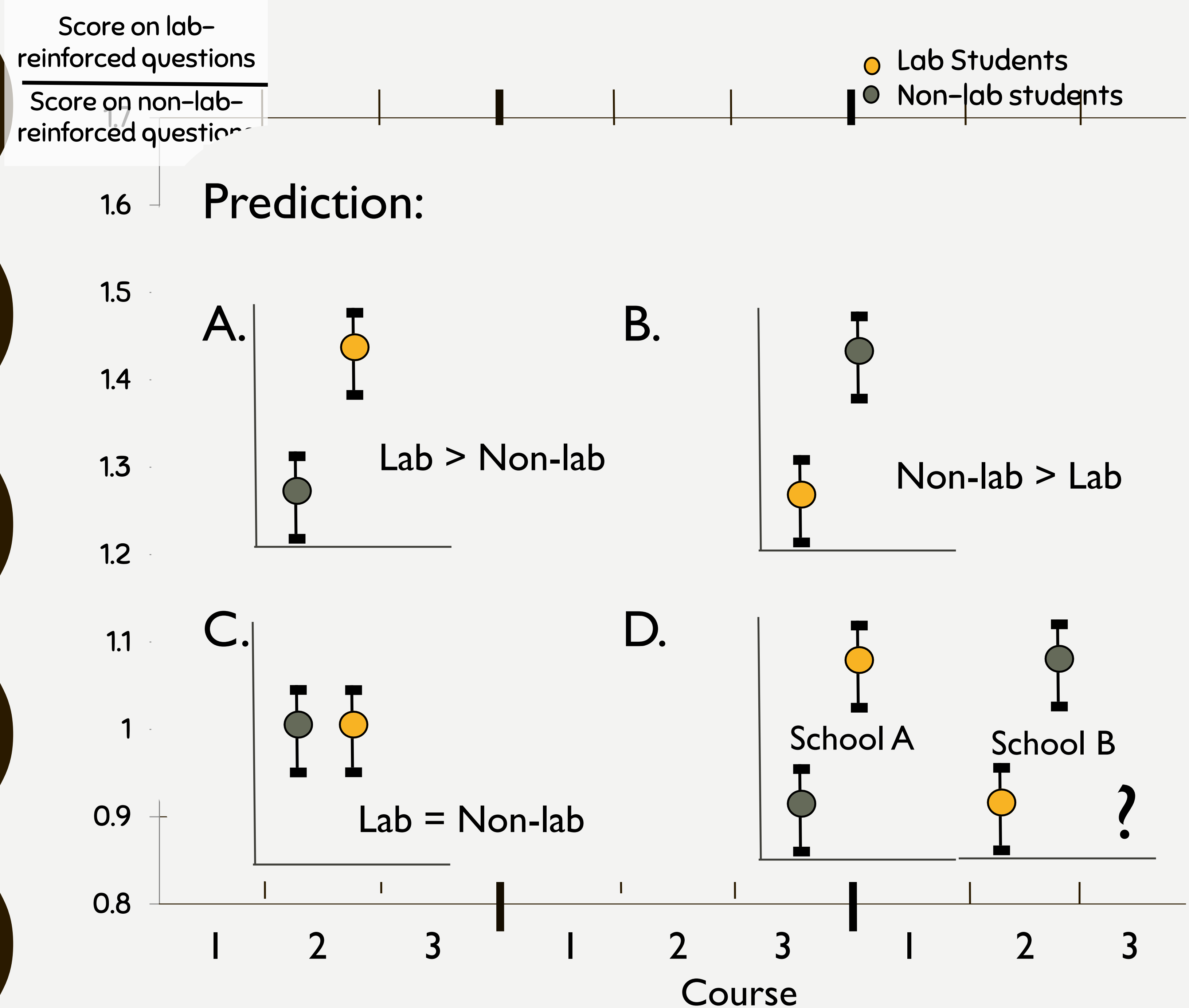
MULTI-INSTITUTION STUDY

Differences:

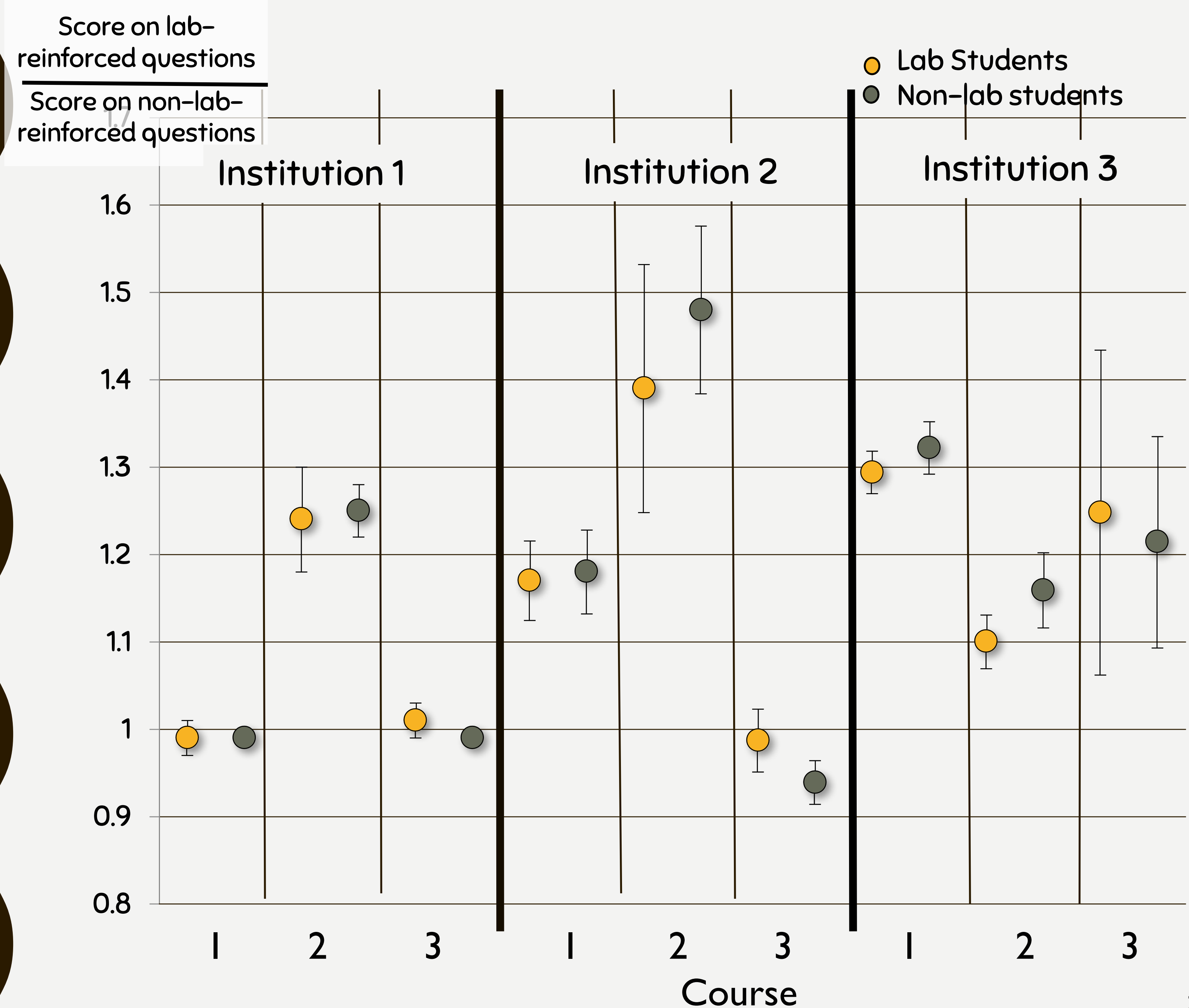
- 3 very different populations of students
- Varied instructional approaches
- Mechanics and E&M courses
- Different instructors

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)



Holmes, Olsen, Thomas, & Wieman (2017)

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. 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. 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*

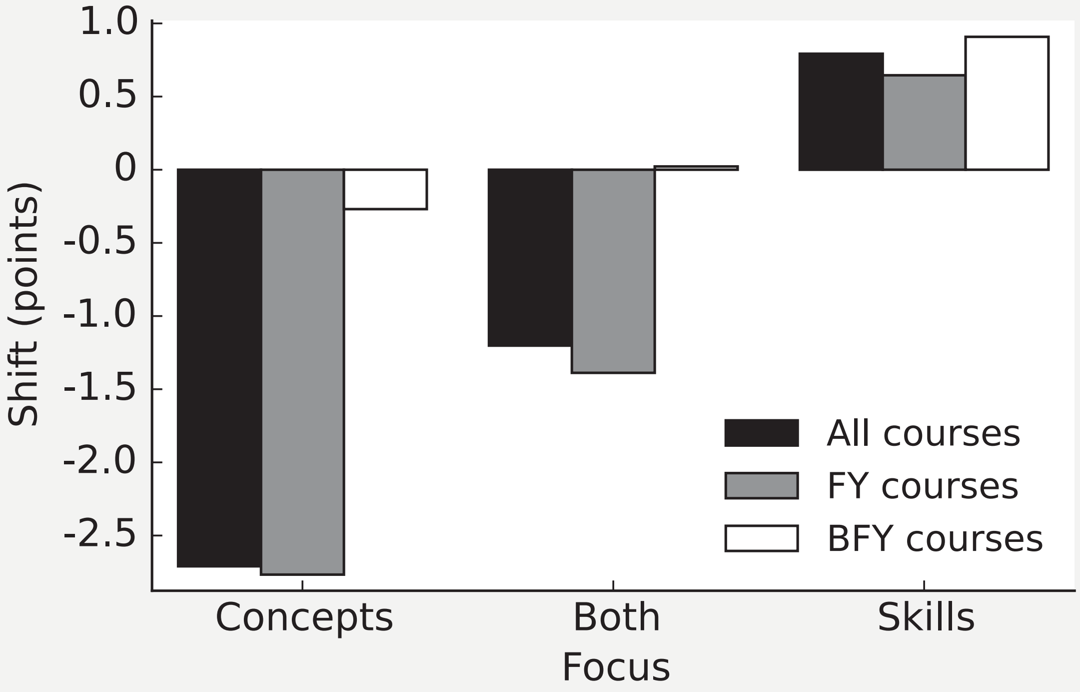
Do students agree with statements about experimental physics? Scores aligned with expert responses

- 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



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

15. To better investigate the model, what should the Group 2 students do next?

16. Why should they do this?

I HATE labs. Theoretical only.

THE EXTREME CASE

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

LEARNING GOALS AT CORNELL:

By the end of the three-course intro lab sequence, students should be able to:

1. Collect data and revise the experimental procedure iteratively, reflectively, and responsively,
2. Evaluate the process and outcomes of an experiment quantitatively and qualitatively,
3. Extend the scope of an investigation whether or not results come out as expected,
4. Communicate the process and outcomes of an experiment, and
5. Conduct an experiment collaboratively and ethically.

DESIGN A NEW PENDULUM LAB: GOALS

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

Think:

- Pick one learning goal from the list above
- Narrow it down to one or two more specific outcomes (skills)
- Use the language "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 goal

DESIGN A NEW PENDULUM LAB: ACTIVITY

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

Think-Pair:

- How would you structure the lab so students can actively achieve that outcome?
- What are the issues that arise?

DESIGN A NEW PENDULUM LAB: ACTIVITY

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

Share:

- What was your goal?
- What was your lab activity?
- How does the lab activity achieve the goal?
- What are the issues that arise?

A NOTE ON STRUCTURE

Traditional

- Measure T for given L and find g
- Measure L, predict and measure 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.

↔ ? ↔

OUR PENDULUM LAB

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

OUR PENDULUM LAB

Objectives:

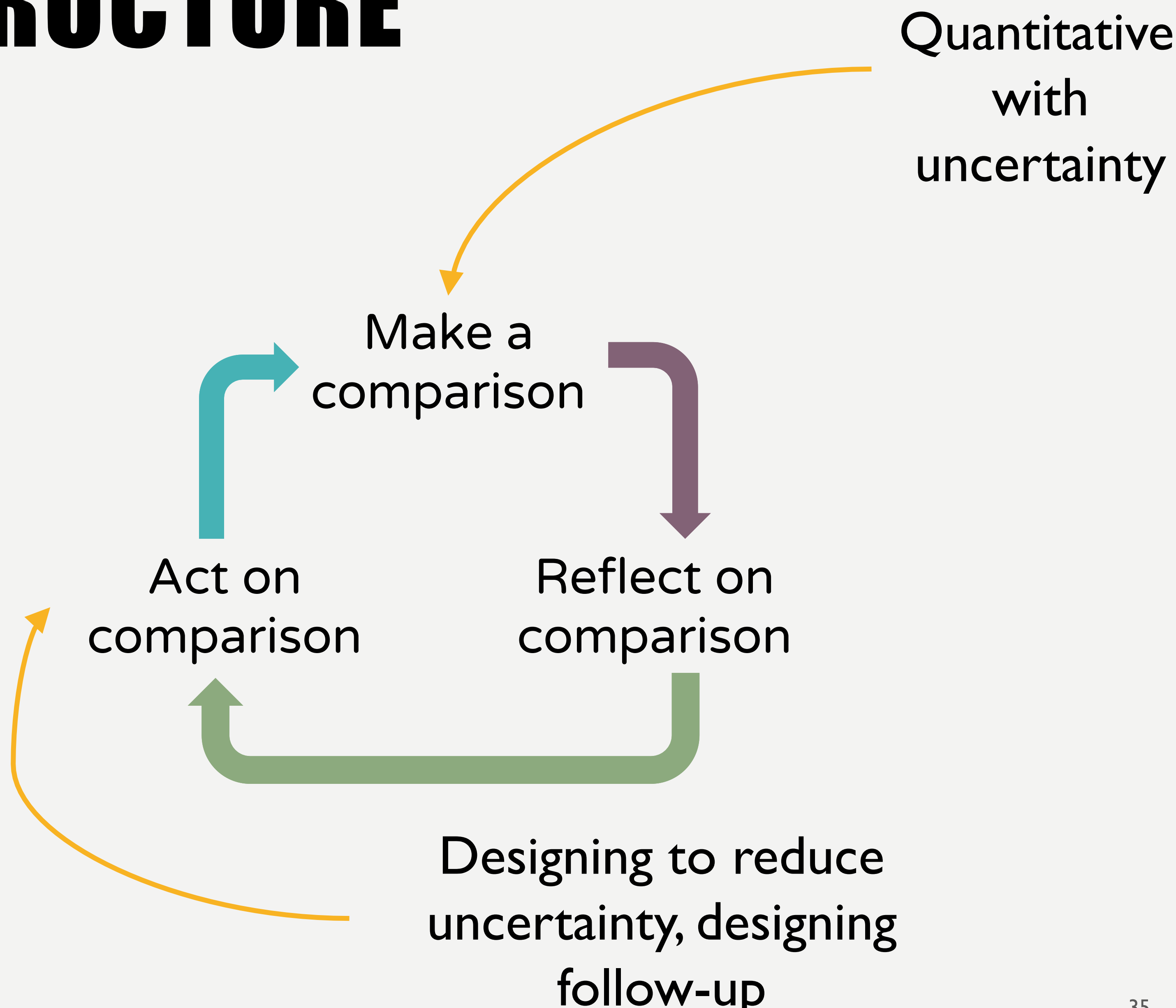
- **Identify sources of statistical uncertai**[n...] instrumental precision, and systematic effec[ts]
- **Decide what and how much data** are t[o be] gathered to produce reliable measurements given the set of concerns above
- **Define and calculate** the mean, stand[ard] deviation, the standard uncertainty in th[e mean] and the difference between means in un[its of] uncertainty
- **Propose and carry out foll**[ow-up] **investigations** or revisions in [...] data and model

Understanding the nature of science and measurement

Practical skills and problem solving abilities

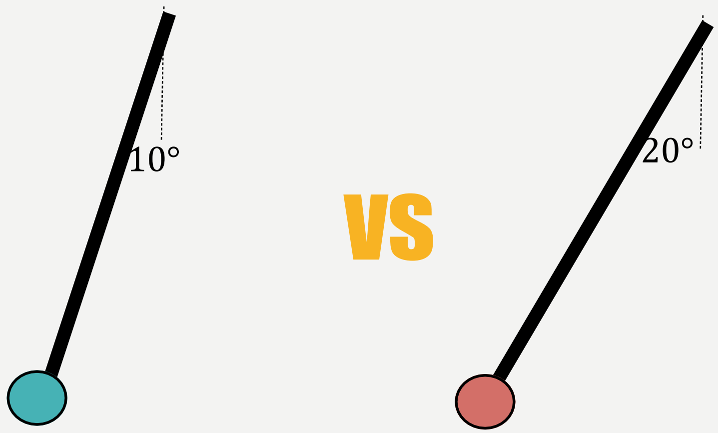
Scientific habits of mind

STRUCTURE


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

LAB QUESTION:

Does the period of a pendulum differ when released from different amplitudes (10° and 20°)?



Diff $\sim 0.2\sigma$

Case study:

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

WHAT DO THEY *WANT* TO DO NEXT?

1. Increase the number of trials
2. Measure more swings per trial
3. Use a photogate instead of a stopwatch
4. Measure another angle
5. Write it up, list their sources of error, then go home

WHAT DO THEY *WANT* TO DO NEXT?

How do we deal with this?

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

D. Measure another angle

E. Write it up, list their sources of error, then go home

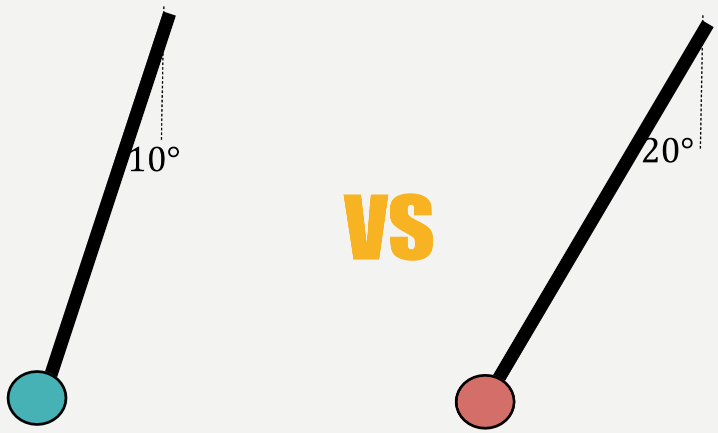
WHAT *COULD* THEY DO NEXT?

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?



$t' \sim 3.7\sigma$

Case study:

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:

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

Conclusion:

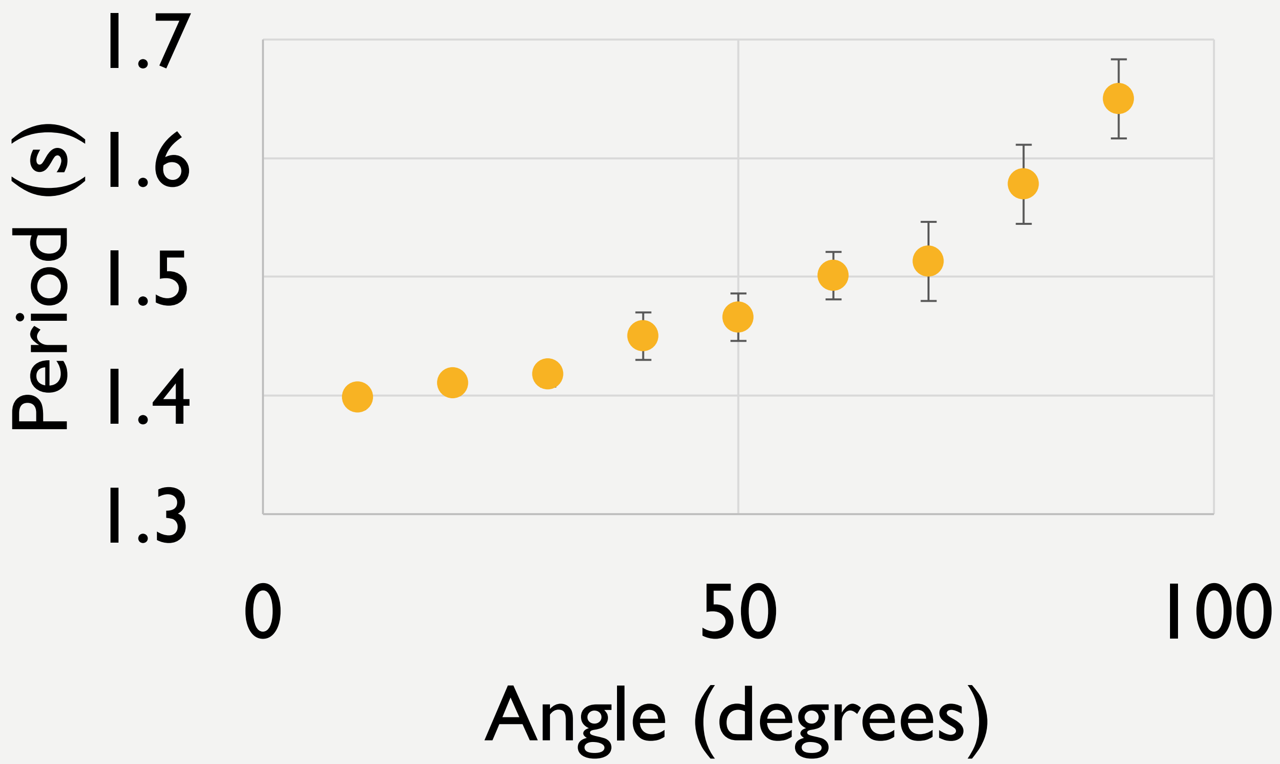
the period of a pendulum does depend on the angle with the vertical in the initial position.

the algebraically derived formula for $T \approx 2\pi\sqrt{\frac{l}{g}}$ of a pendulum is only valid for small angles.

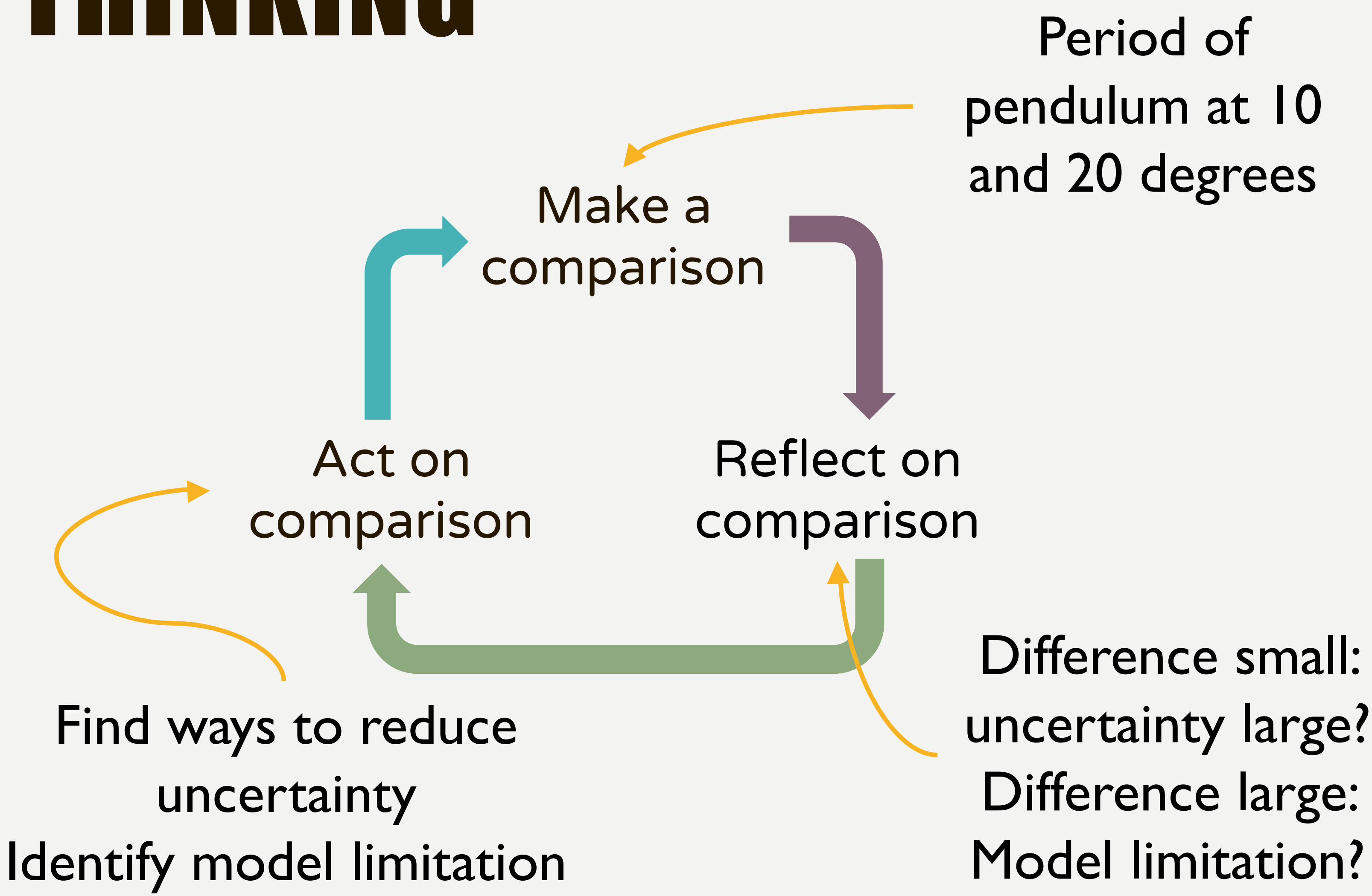
Considering the results of this experiment, 20° is obviously not 'small' enough since the angle has an effect on the period T and should be somehow ~~mea~~ represented in the formula.

If you can make a precise enough measurement, you can show that the theoritical 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

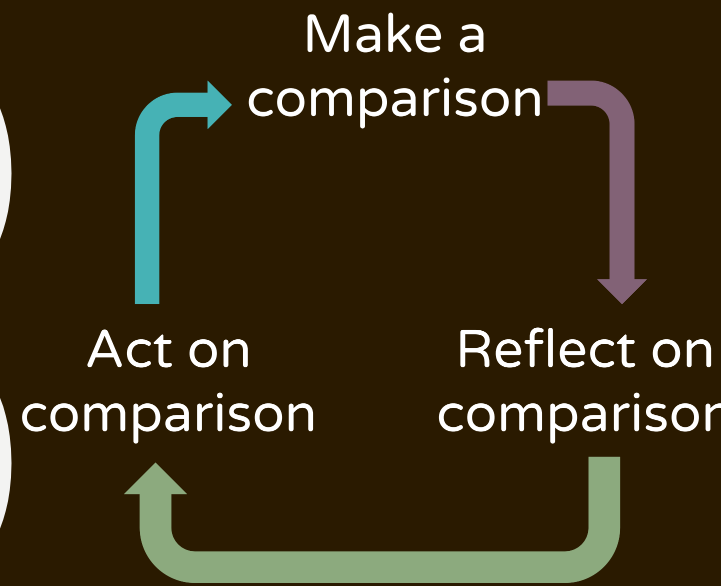


QUANTITATIVE CRITICAL THINKING



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

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
  - tinyurl.com/ECLASS-physics

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
  - tinyurl.com/ECLASS-physics
- CDPA: multiple choice test of student understanding of data analysis
- Physics Measurement Questionnaire: open-response assessment of student understanding of uncertainty and measurement

POSSIBLE ~~PITFALLS~~ CHALLENGES?

- Shifting focus to process is hard
  - "Coverage"
  - Want them to get to the right answer
- Giving students control is scary
  - "Controlled chaos"
- Others you can think of?

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…

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