University of Toronto,
February 9th, 2018

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RETHINKING INTRODUCTORY PHYSICS LAB COURSES

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LASSP & PHYSICS, CORNELL UNIVERSITY

CORNELL PHYSICS EDUCATION RESEARCH LAB

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Collaborator: Carl Wieman

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Michelle Kelley

Jack Madden

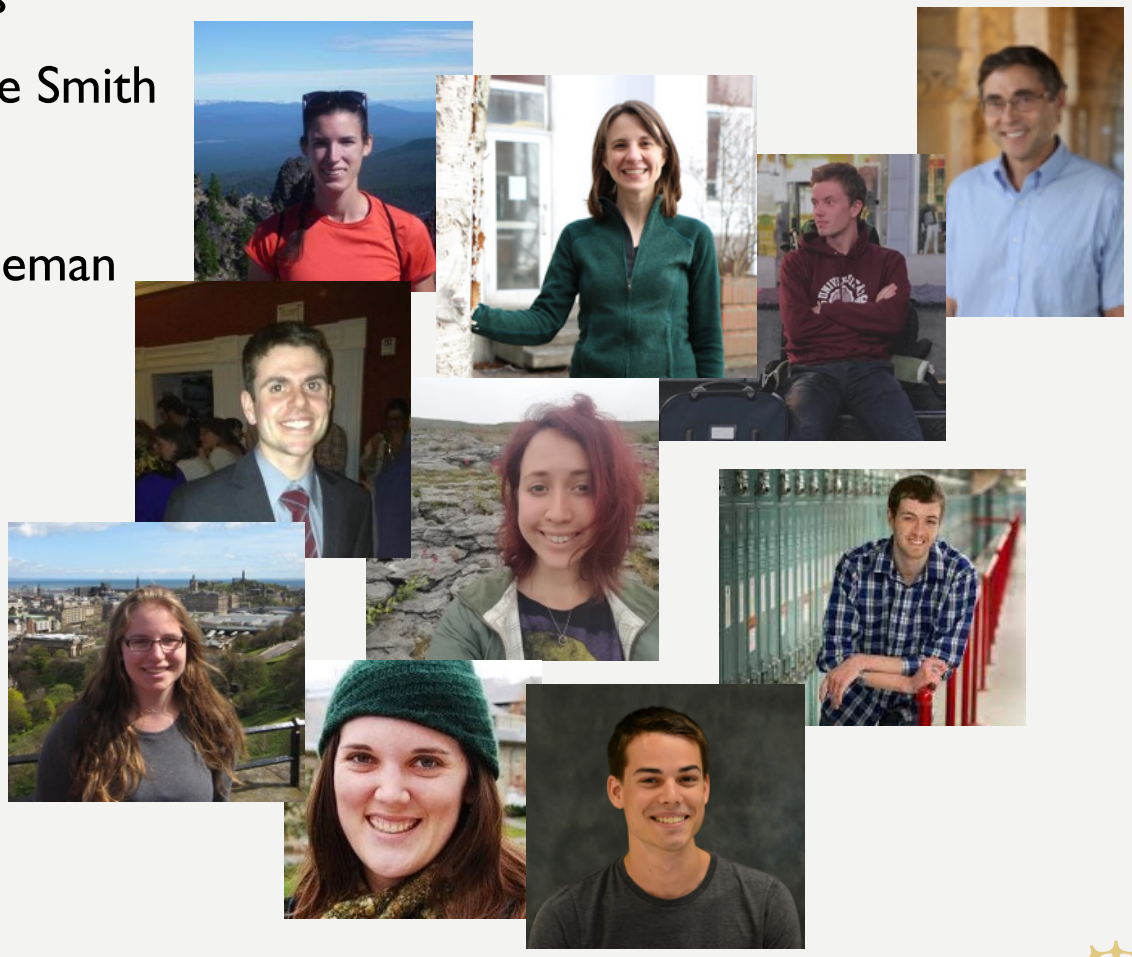
Kathryn McGill

Katherine Quinn

Martin Stein

Ryan Tapping

Cole Walsh



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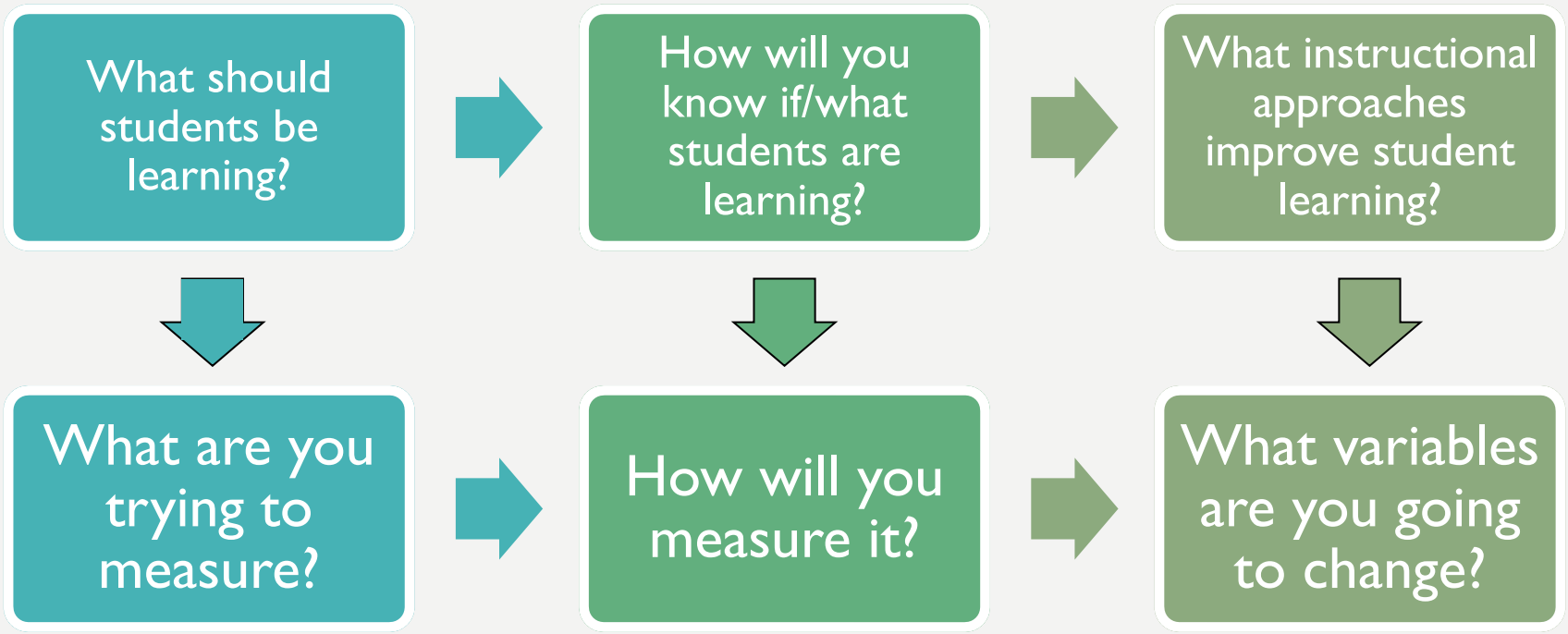
GUIDING QUESTIONS

What should students be learning?

How will you know if/what students are learning?

What instructional approaches improve student learning?

GUIDING QUESTIONS



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 GOALS

1. Understanding scientific concepts

2. Interest and motivation

3. Practical skills and problem solving abilities

4. Scientific habits of mind

5. Understanding the nature of science and measurement

LABS GOALS

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

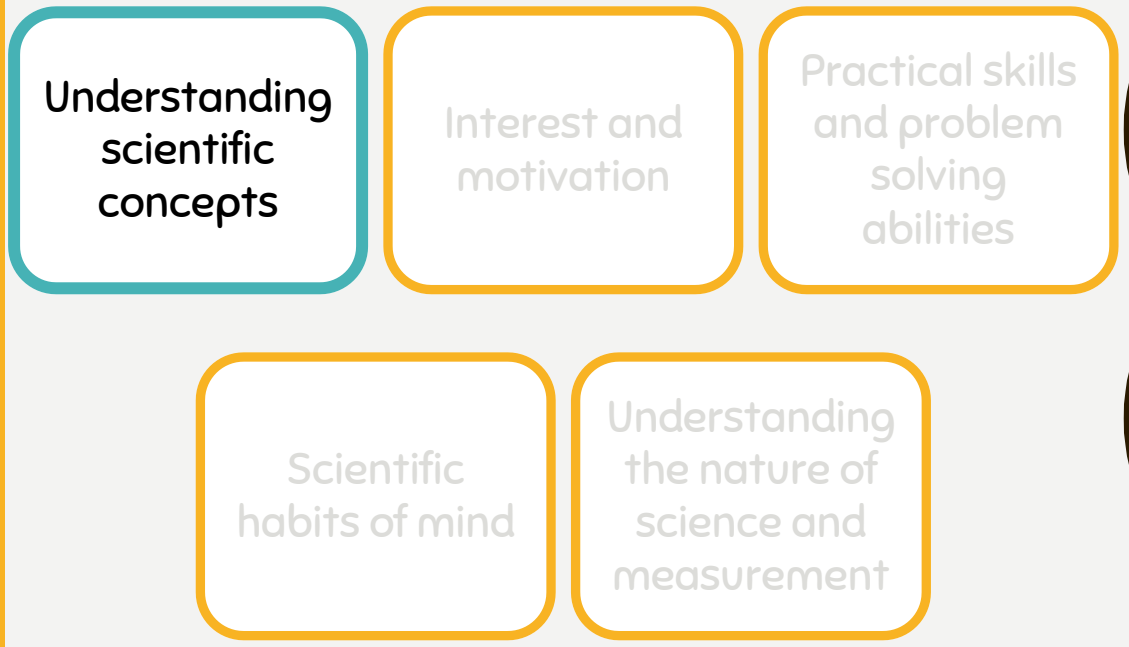
BUT

there has not been much published research on the effectiveness of laboratory curricula

Hofstein A, Lunetta VN (1982) *Rev Educ Res* 52(2):201–217.
Hofstein A, Lunetta VN (2004) *Sci Educ* 88(1):28–54.
Singer SR, Hilton ML, Schweingruber HA eds. (2005)
Singer SR, Nielsen NR, Schweingruber HA eds. (2012)
Docktor JL, Mestre JP, *Phys Rev ST- PER* 10(2):20119. (2014)

MANY LABS TARGET

Hofstein & Lunetta (1983; 2004)



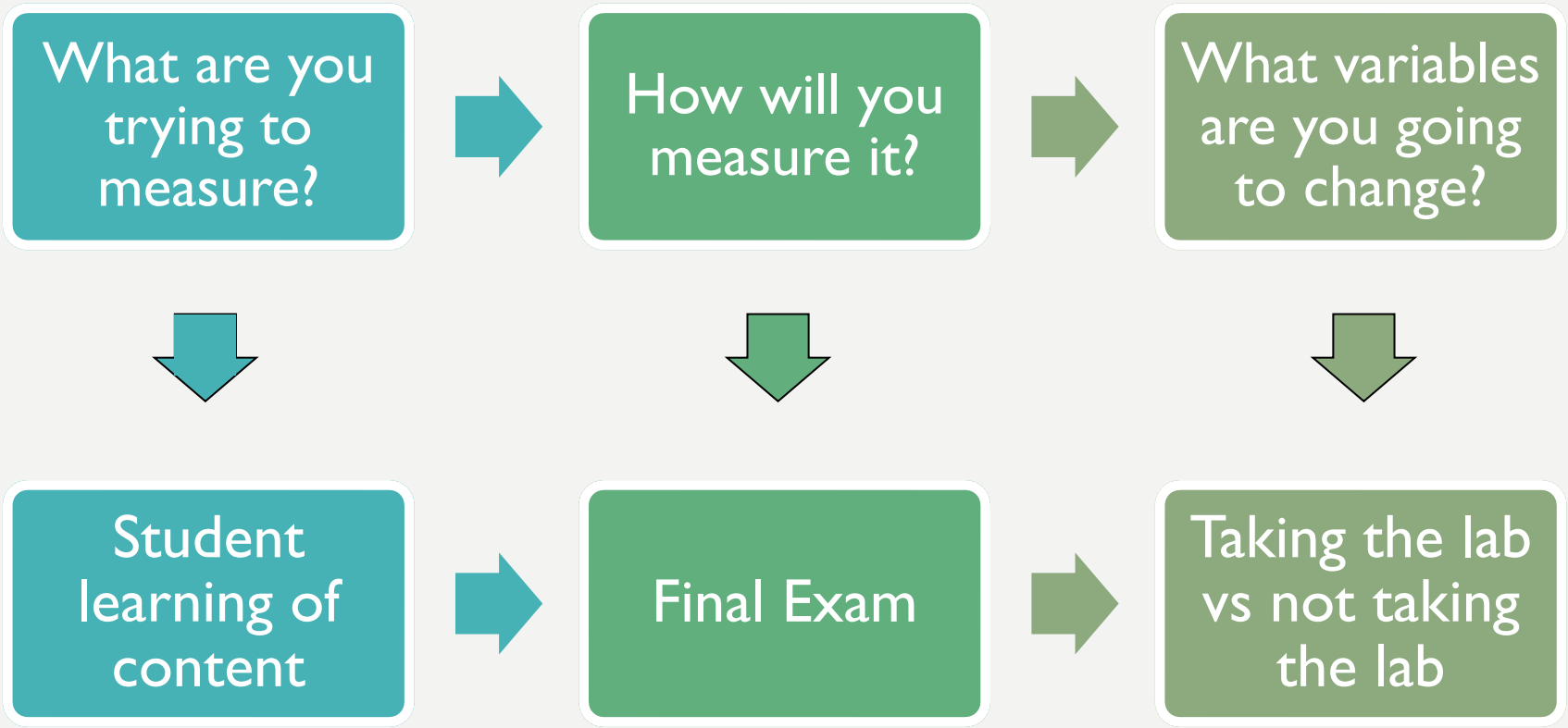
STUDYING THE IMPACT OF LABS ON REINFORCING COURSE CONTENT

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.*

GUIDING QUESTIONS



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

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

Lab students

No-Lab students

MULTI-INSTITUTION, MULTI-COURSE 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

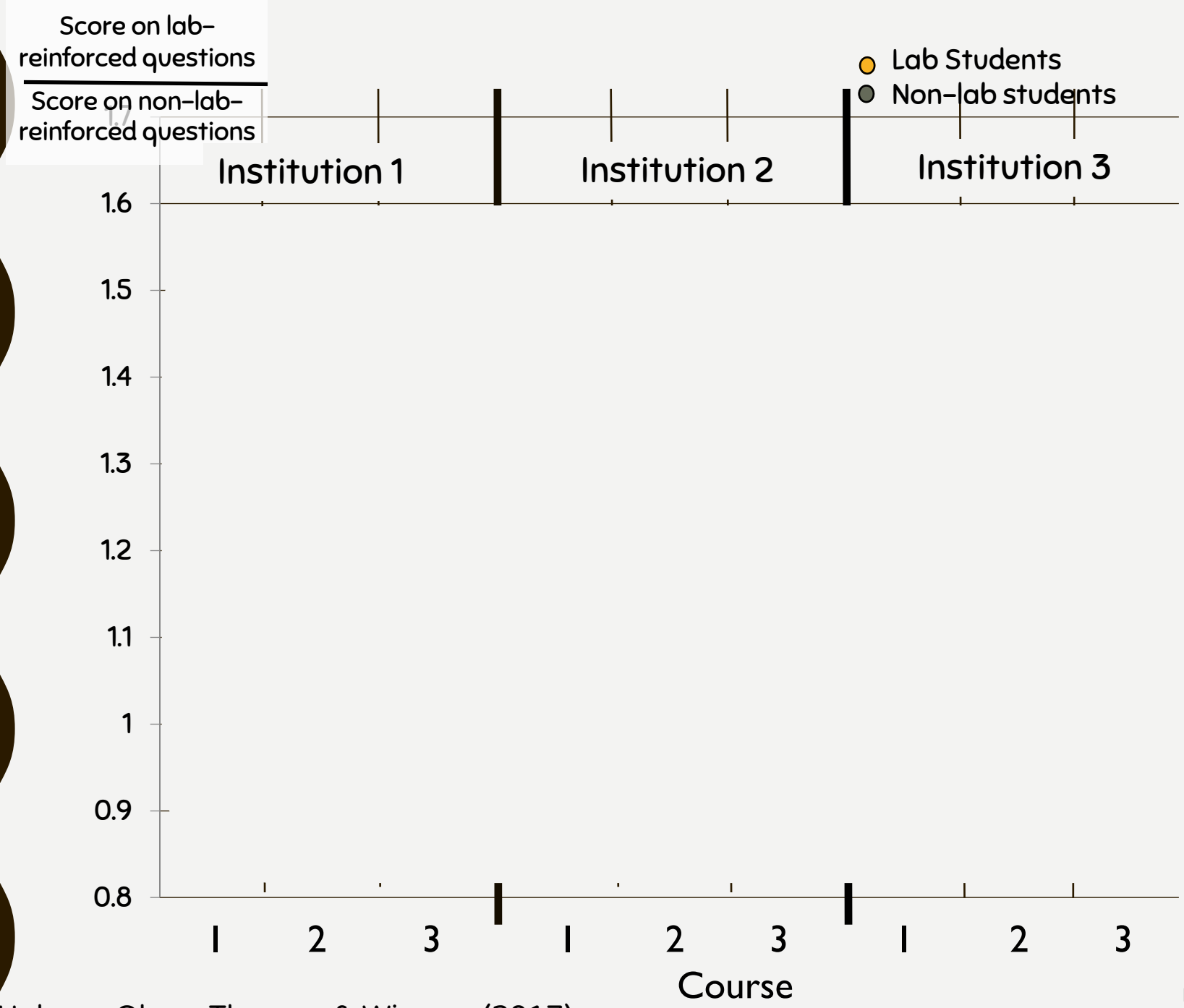
MULTI-INSTITUTION, MULTI-COURSE STUDY

Differences:

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

Similarities:

- All 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



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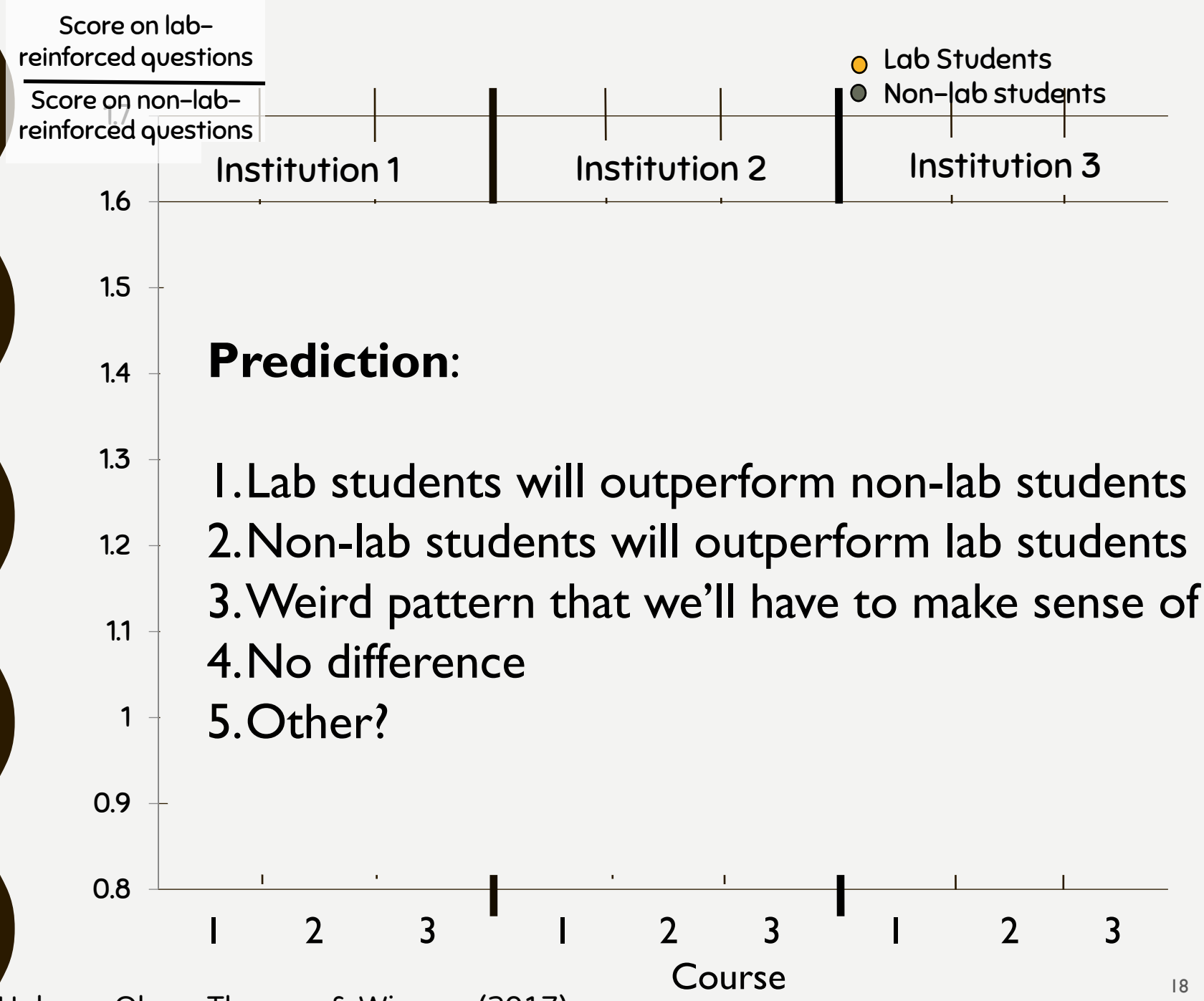
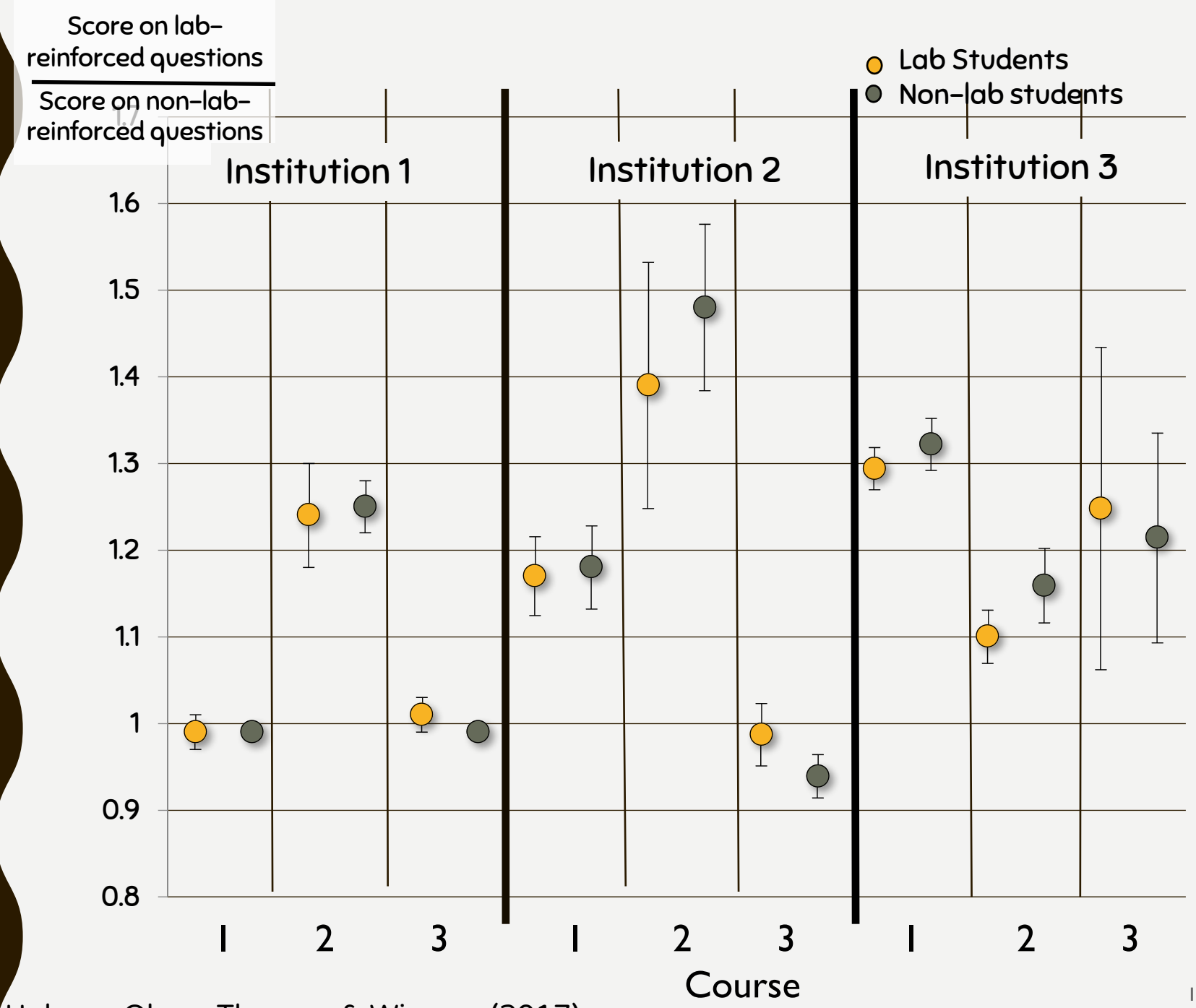


Prediction:

1. Lab students will outperform non-lab students
2. Non-lab students will outperform lab students
3. Weird pattern that we'll have to make sense of
4. No difference
5. Other?

Holmes, Olsen, Thomas, & Wieman (2017)



Holmes, Olsen, Thomas, & Wieman (2017)

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

MORE EFFICIENT (MANY CAVEATS):

Interactive Lecture Demos!

- Predict-observe-explain methods are very effective and more efficient (15 minutes?)
  - Miller, et al. Phys. Rev. ST-PER (2013).

Simulations!

- Better than hands-on and can be done cheaply, at home, etc.
  - Finkelstein, et al. Phys Rev ST-PER (2005)

STUDENT ATTITUDES TOWARDS EXPERIMENTAL PHYSICS

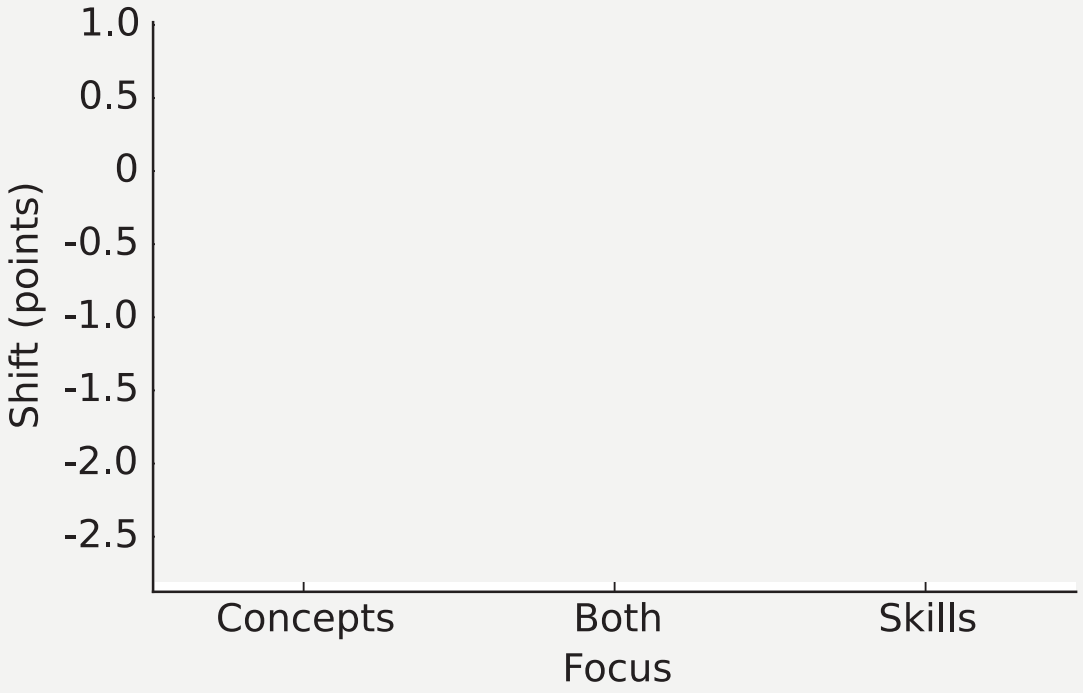
Colorado Learning Attitudes about Science Survey for Experimental Physics

- 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

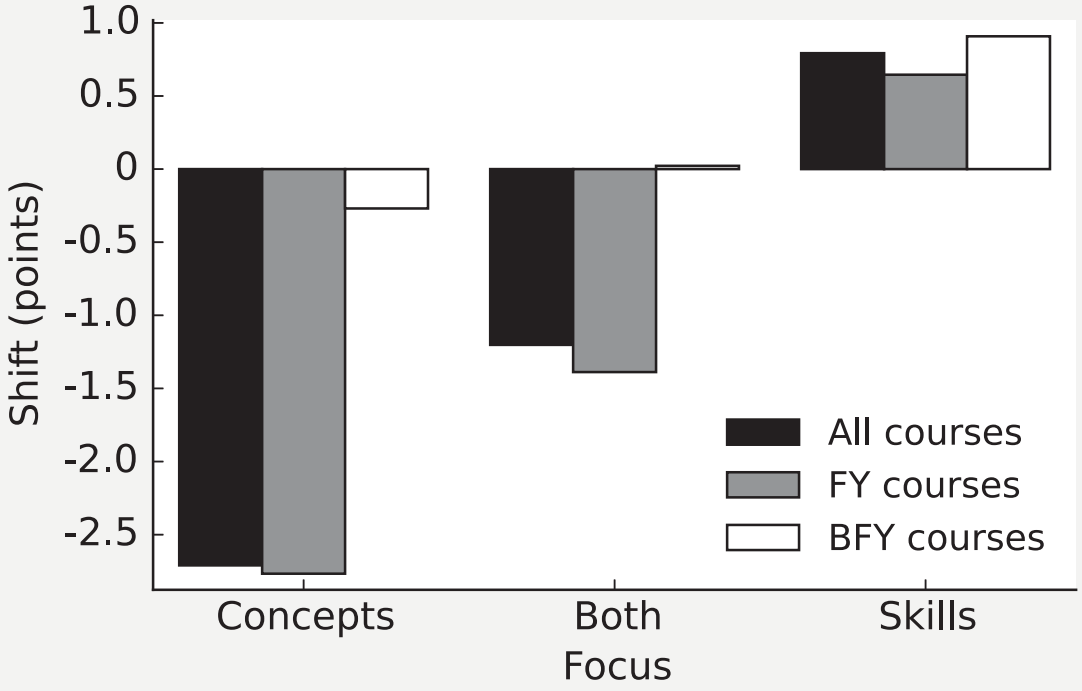
STUDENT ATTITUDES TOWARDS EXPERIMENTAL PHYSICS



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?

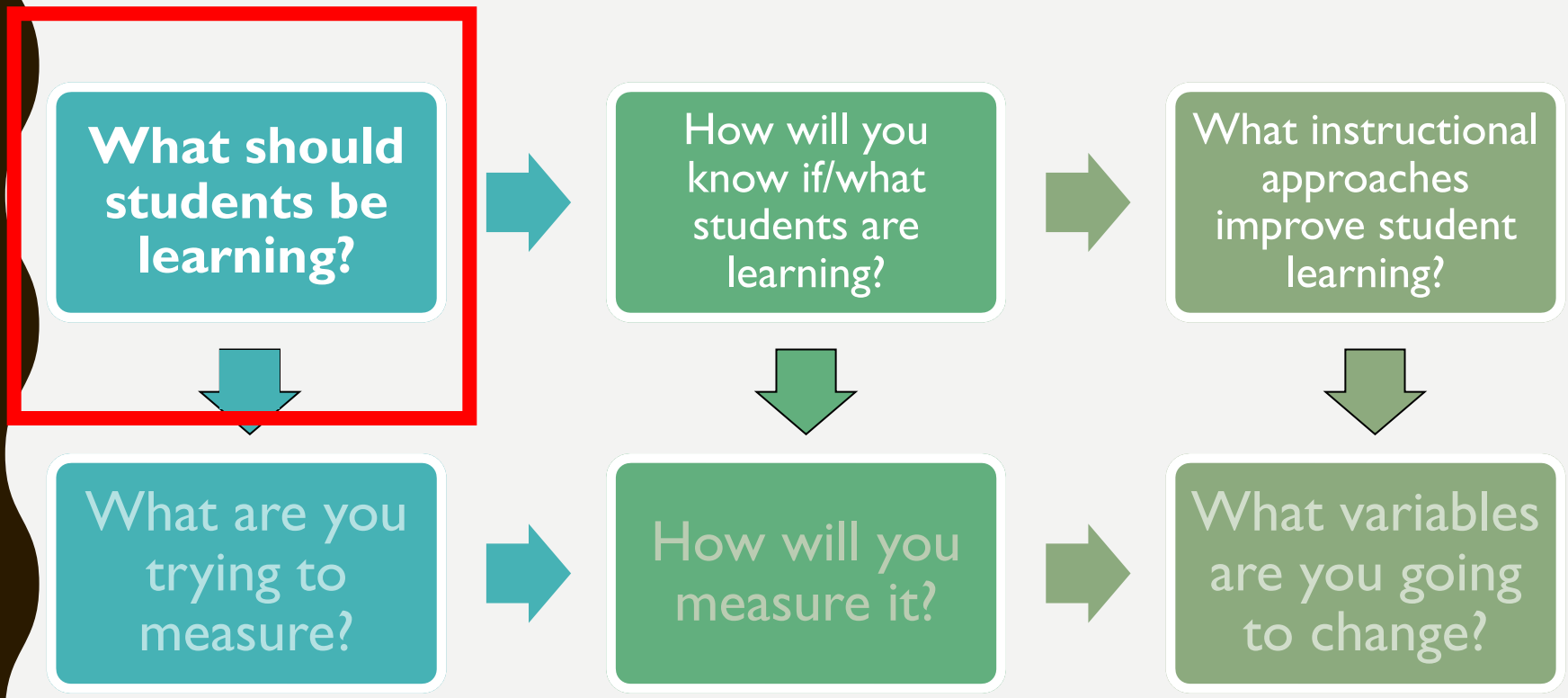
16. Why should they do this?

I 

labs. Theoretical only.

THE EXTREME CASE

GUIDING QUESTIONS



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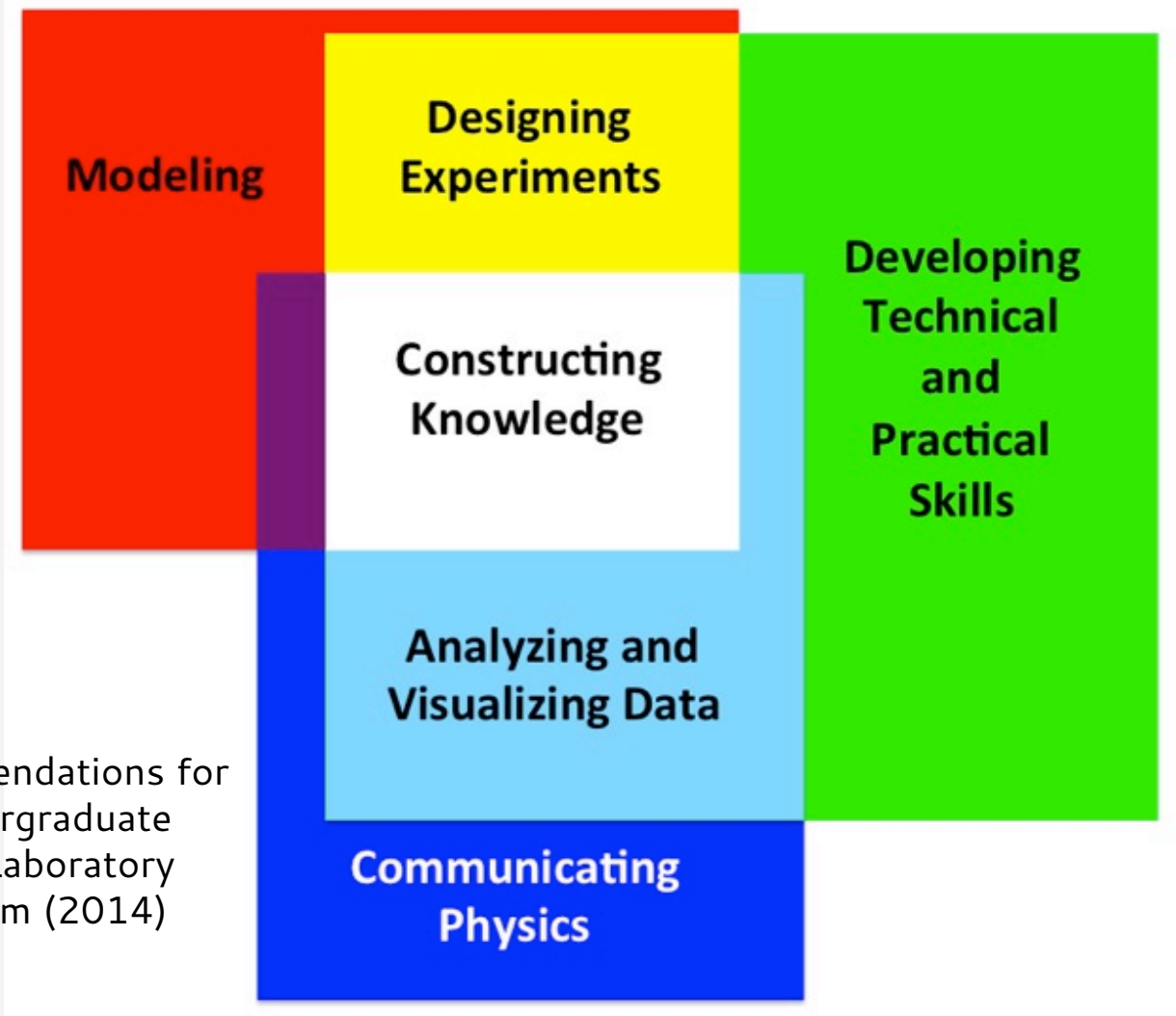


AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum (2014)

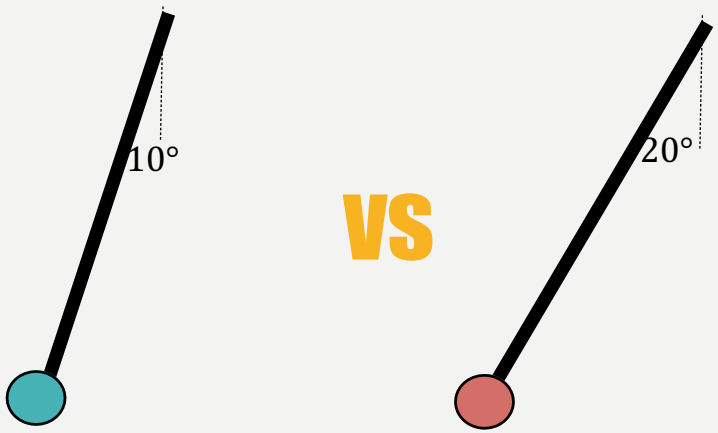
QUANTITATIVE CRITICAL THINKING

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

Especially related to "believing" evidence, data, models, etc.

LAB QUESTION:

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



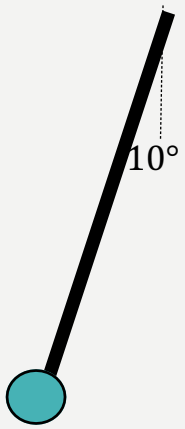
$$T = 2\pi\sqrt{\frac{L}{g}}$$

Holmes & Bonn (2015) The Physics Teacher

LAB QUESTION:

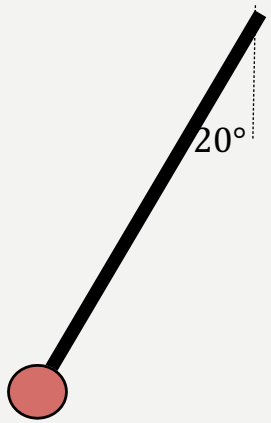
Does the period of a pendulum differ when released from different amplitudes (10° and 20°)?

Case study:



T= 1.84 ± 0.08 s

VS



T= 1.81 ± 0.08 s

Diff $\sim 0.2\sigma$

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

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

Holmes & Bonn (2015) The Physics Teacher

What might a difference of 0.2σ mean?

1) The periods agree
2) The periods don't agree
3) The uncertainty is too large
4) The uncertainty is too small
5) Other

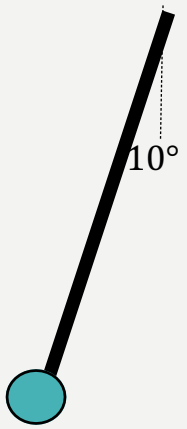
What might a difference of 0.2σ mean?

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

Small difference means values are close
AND/OR
uncertainty is large

WHAT SHOULD THEY DO NEXT?

Case study:



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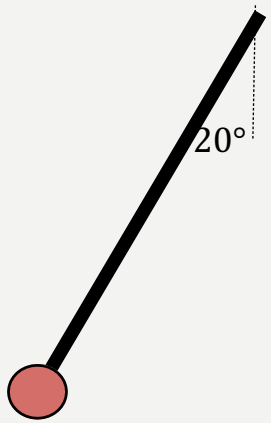


T= 1.81 ± 0.08 s

$t' \sim 0.2\sigma$

- 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?

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 *COULD* THEY DO NEXT?

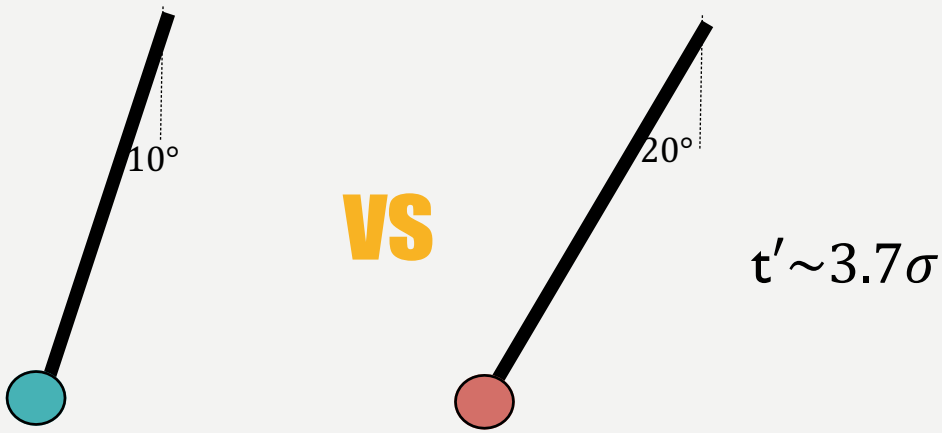
1. Increase the number of trials
2. Measure more swings per trial
3. Use a photogate instead of a stopwatch
4. Measure another angle
5. Write it up, list their sources of error, then go home

WHAT DID THEY 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 DID THEY DO NEXT?

Case study:



$t' \sim 3.7\sigma$

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:

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

Conclusion:

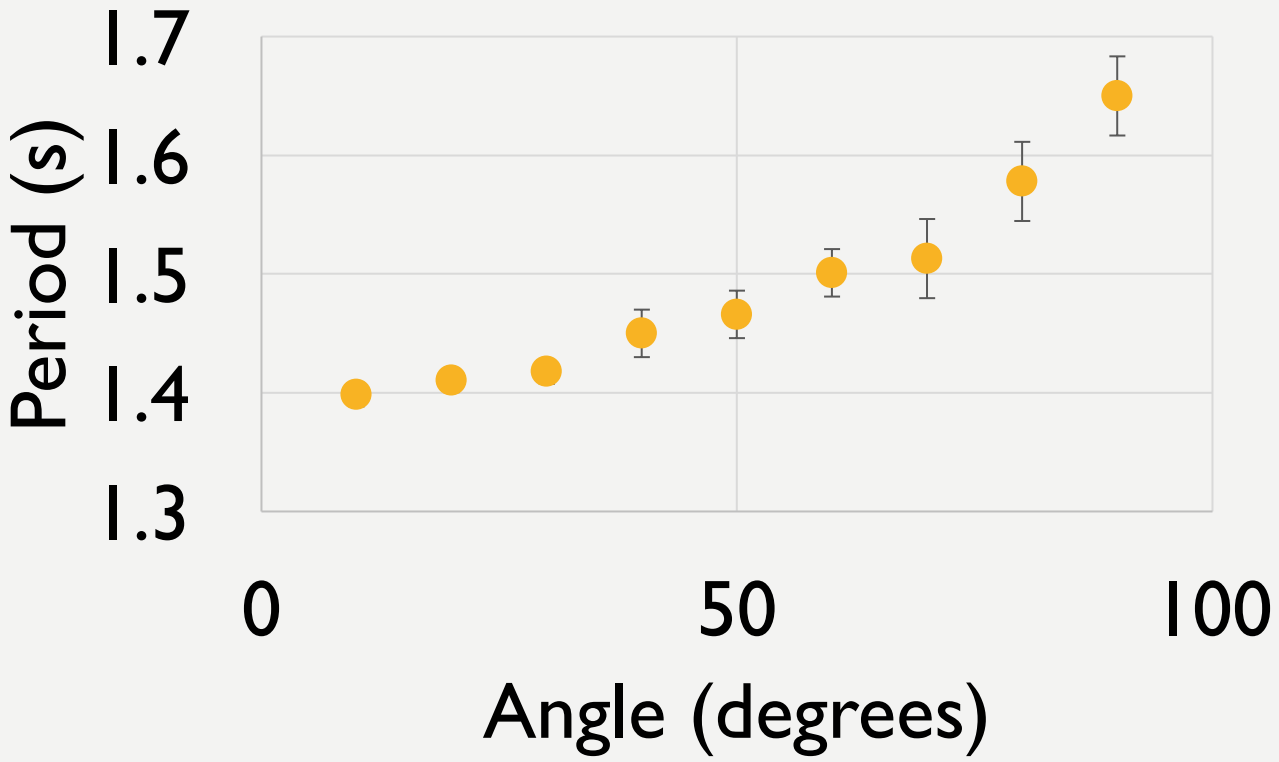
The period of a pendulum does depend on the angle with the vertical in the initial position.

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 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



WHAT JUST HAPPENED?

CRITICAL THINKING

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

Especially related to "believing" evidence, data, models, etc.

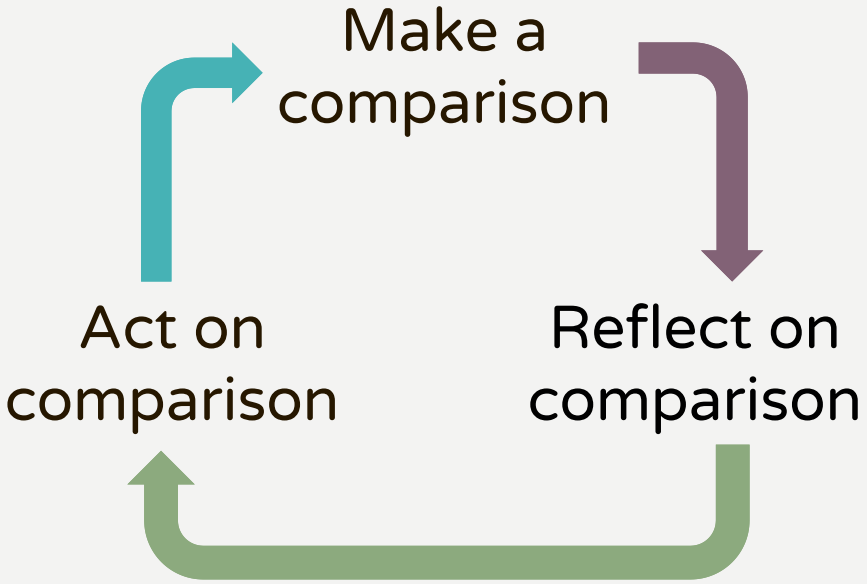
DEFINITION

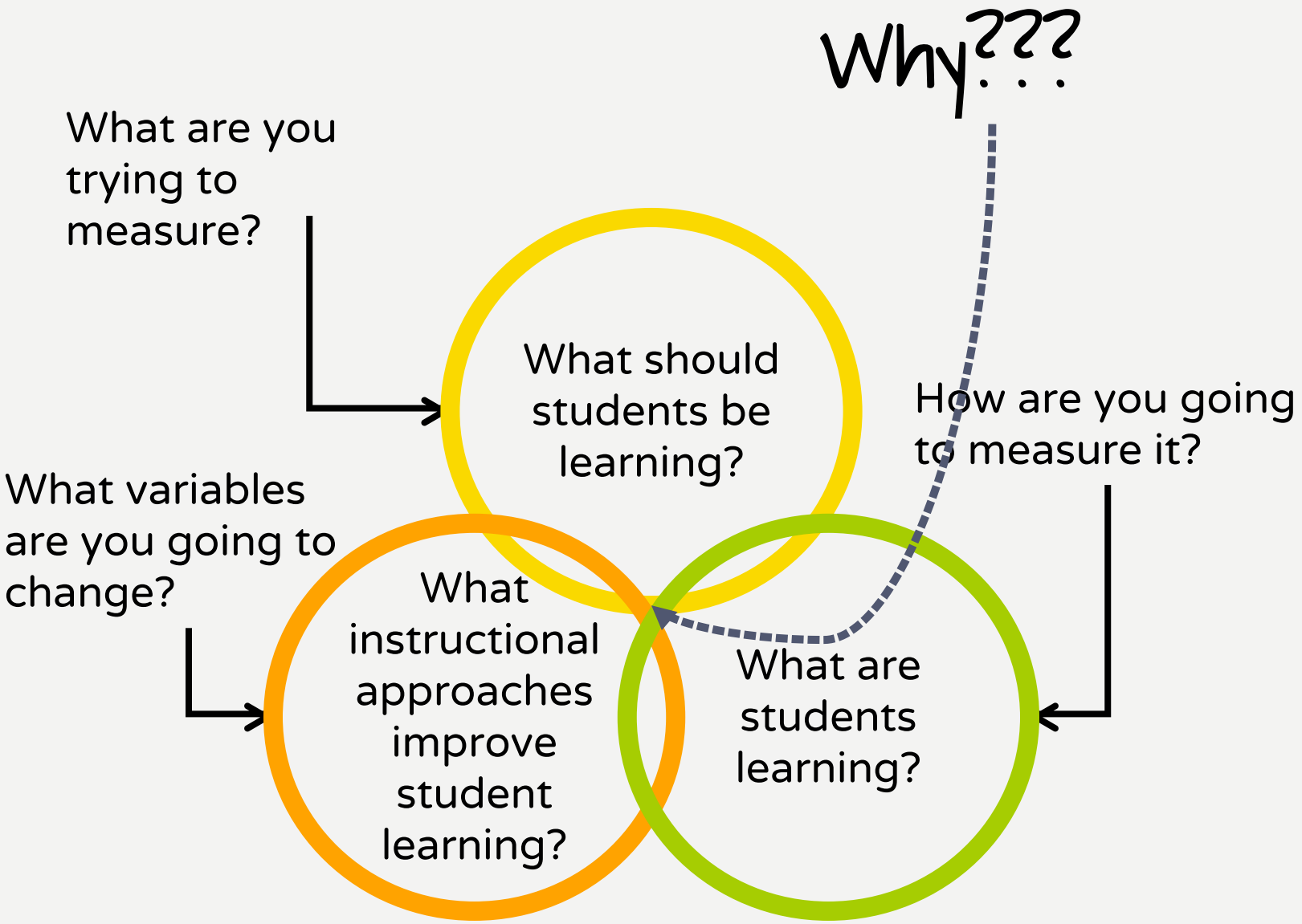
How did they decide what to believe?

Think-Pair-Share

(Think *literally* for now…)

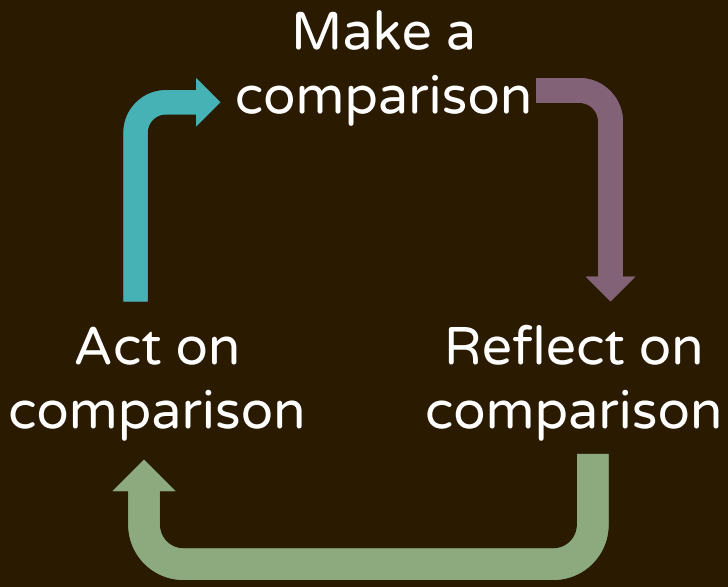
QUANTITATIVE CRITICAL THINKING




Why???
What are you trying to measure?
What should students be learning?
How are you going to measure it?
What variables are you going to change?
What instructional approaches improve student learning?
What are students learning?

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)...

CAN WE GET ALL STUDENTS DOING THIS?

ASSESSING COMPARISON CYCLES INSTRUCTION

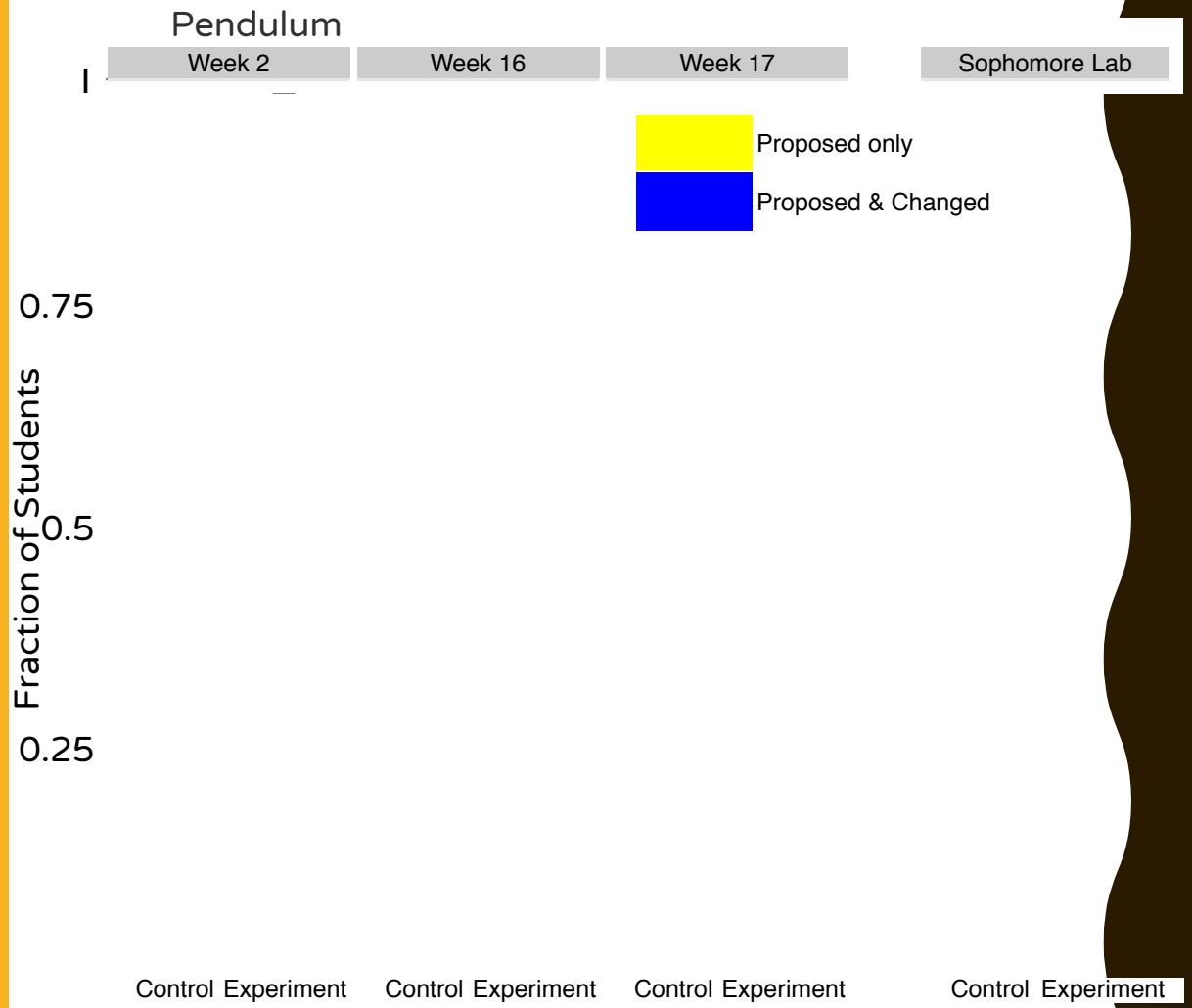

Doug Bonn (UBC)


Carl Wieman (Stanford)

	Control Group	Experimental Group
N	~150	~140
Time	Weekly 3-hour labs over two semester	
Experiments	Same set of mechanics and E&M activities	
Products	Written lab book notes	
Instructions to iterate/ improve	None	Faded out over the course

Holmes, Wieman & Bonn (2015) *PNAS*

ITERATING TO IMPROVE DATA



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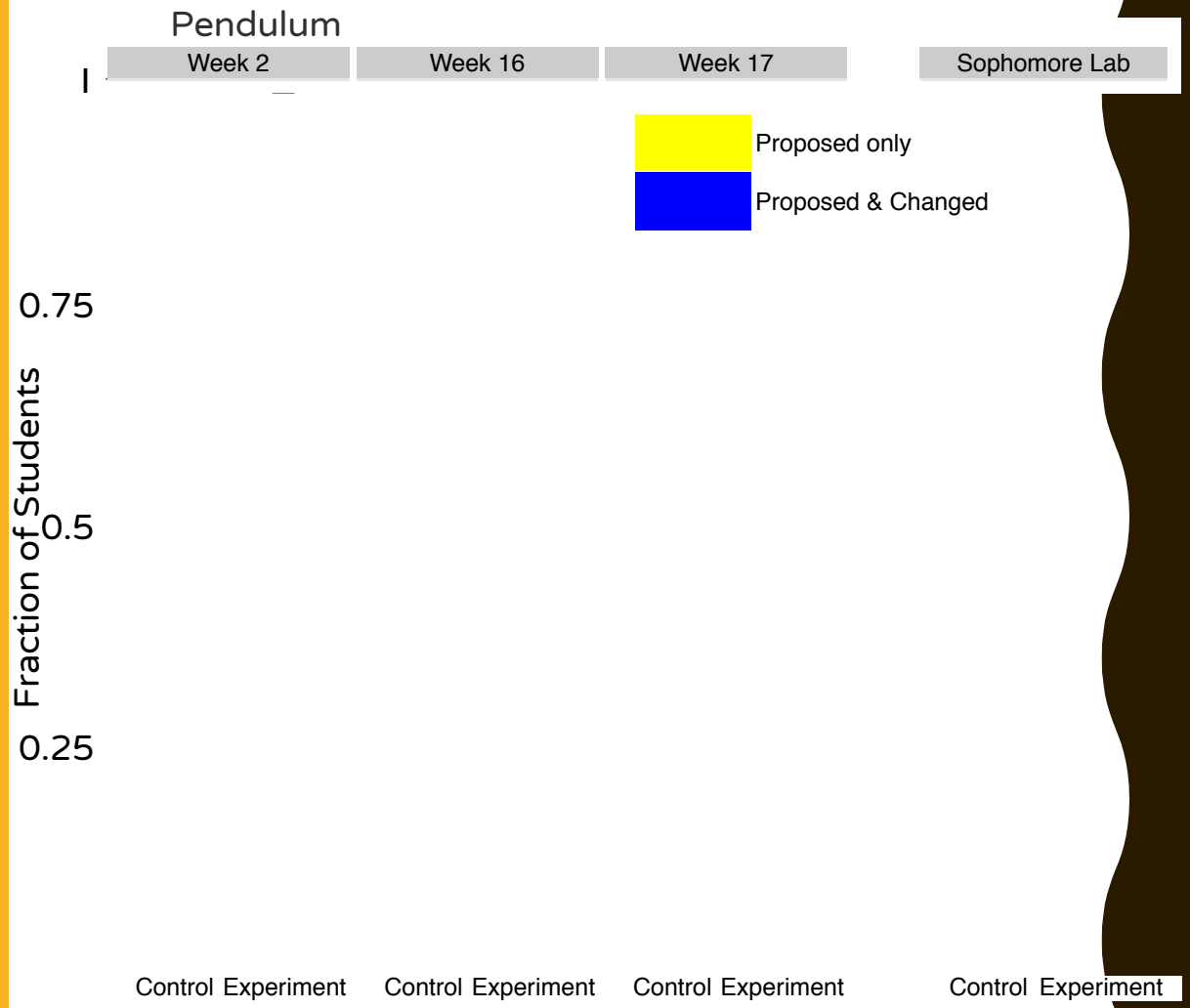

What fraction of students in a control group do you expect to iterate without being told to?

1. Less than 25%
2. Between 25% and 50%
3. Between 50% and 75%
4. More than 75%

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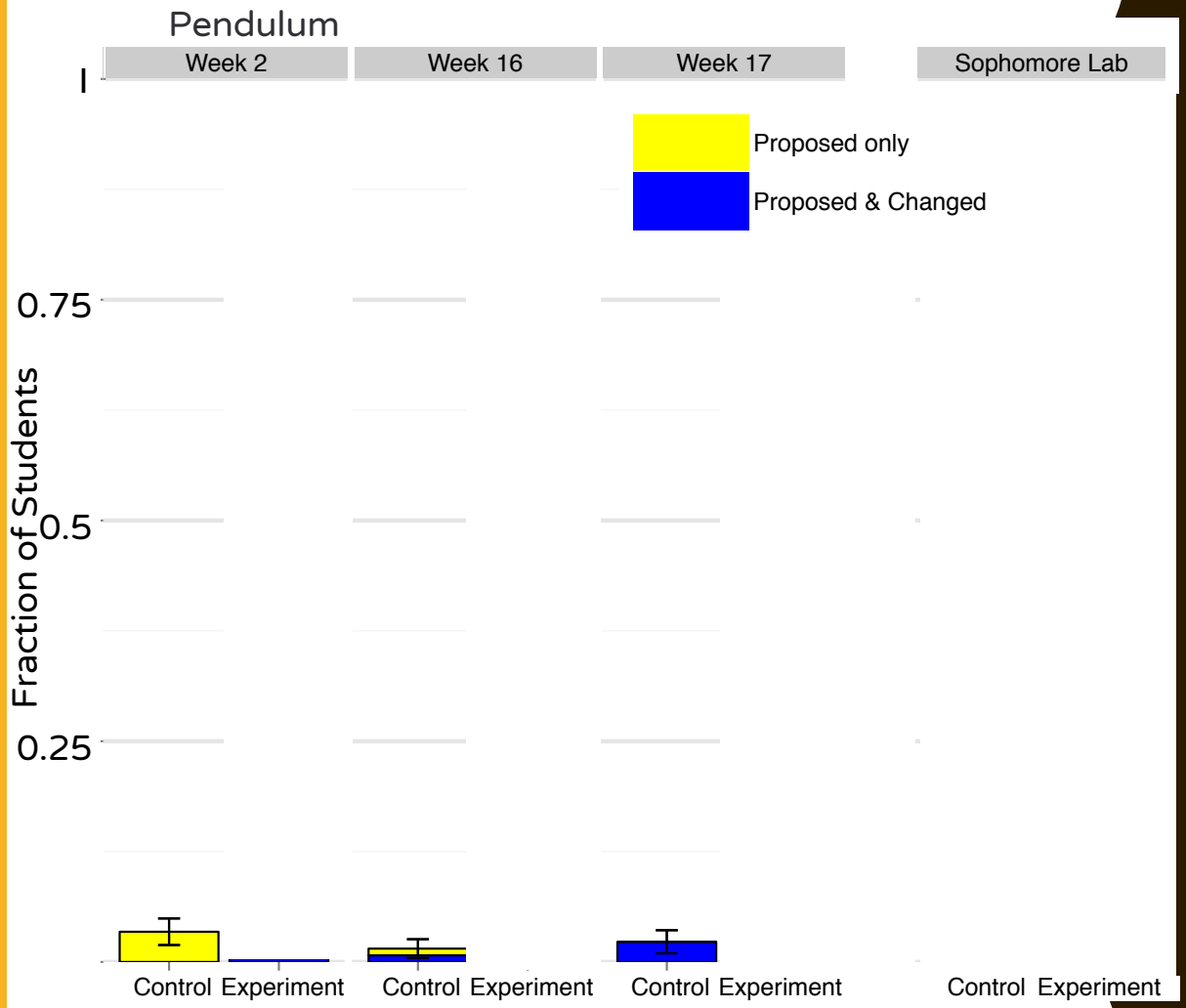

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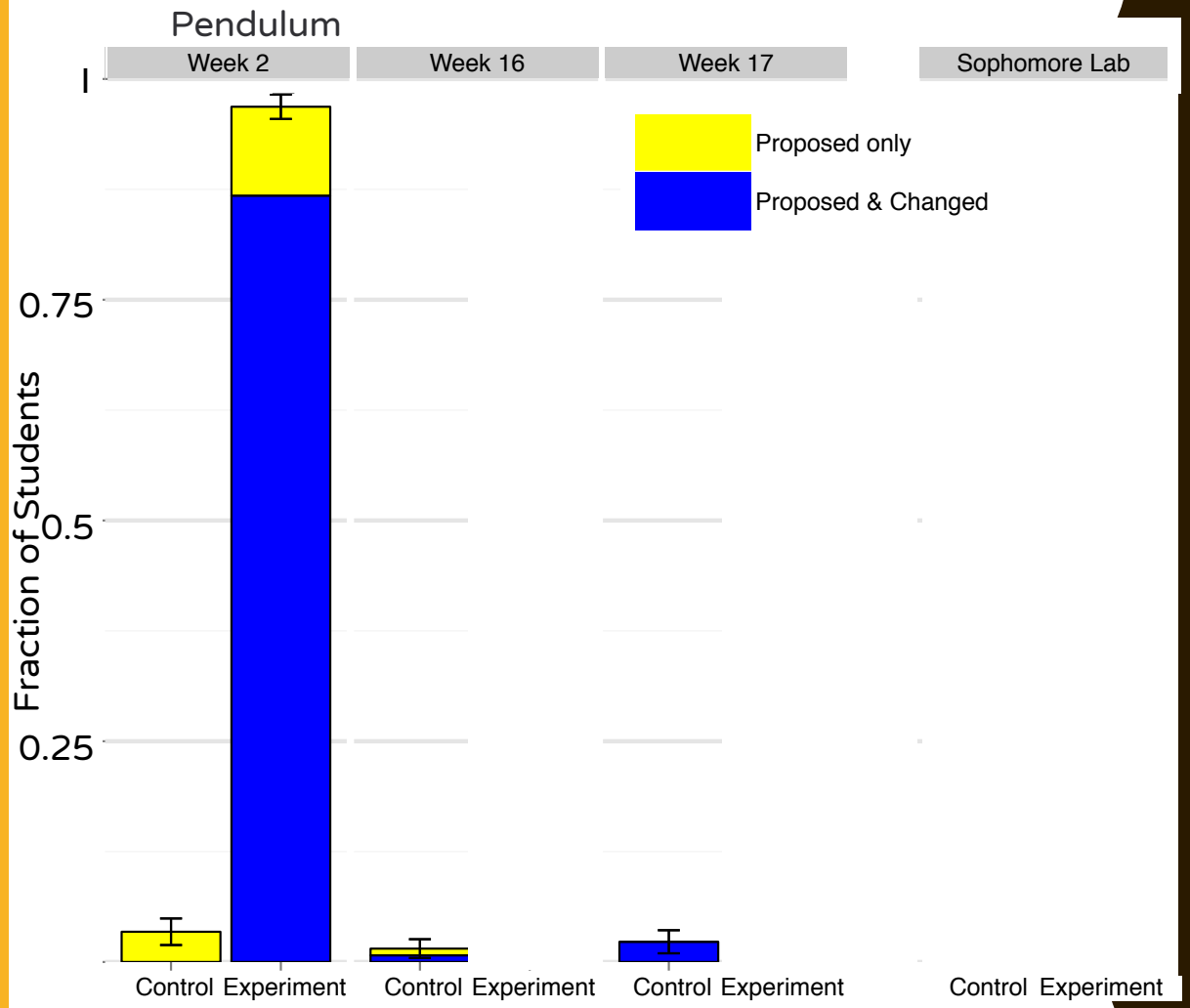

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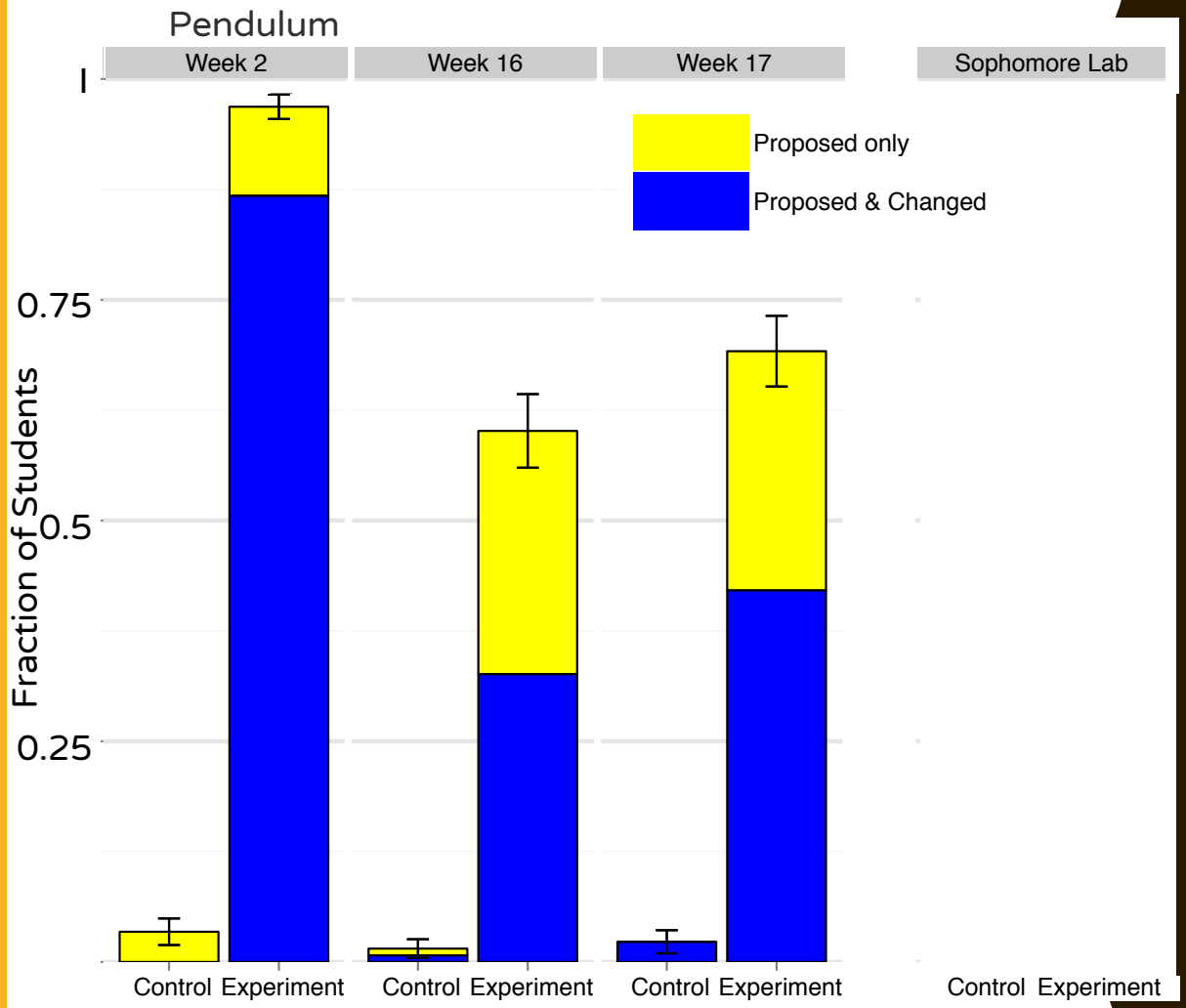

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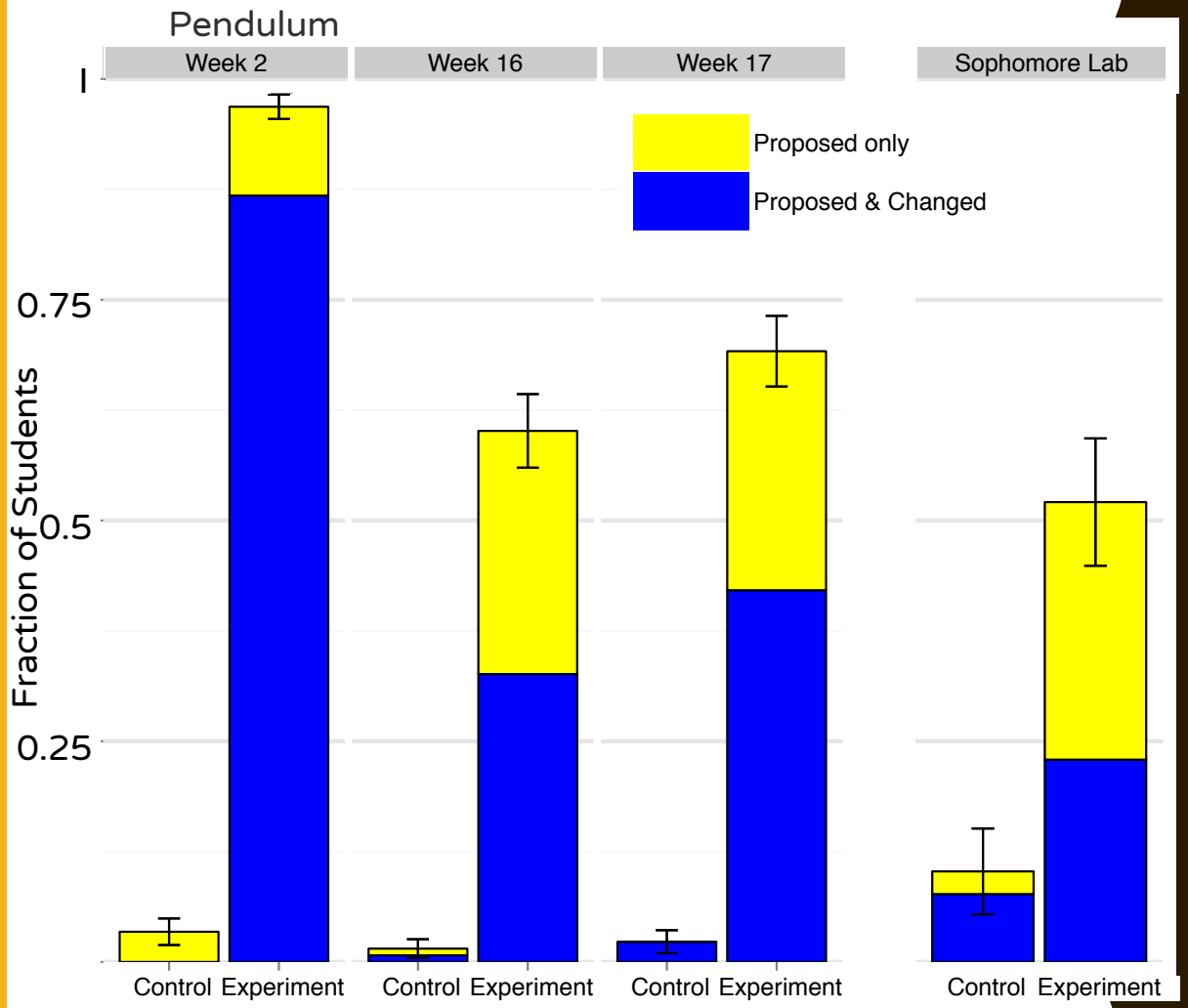

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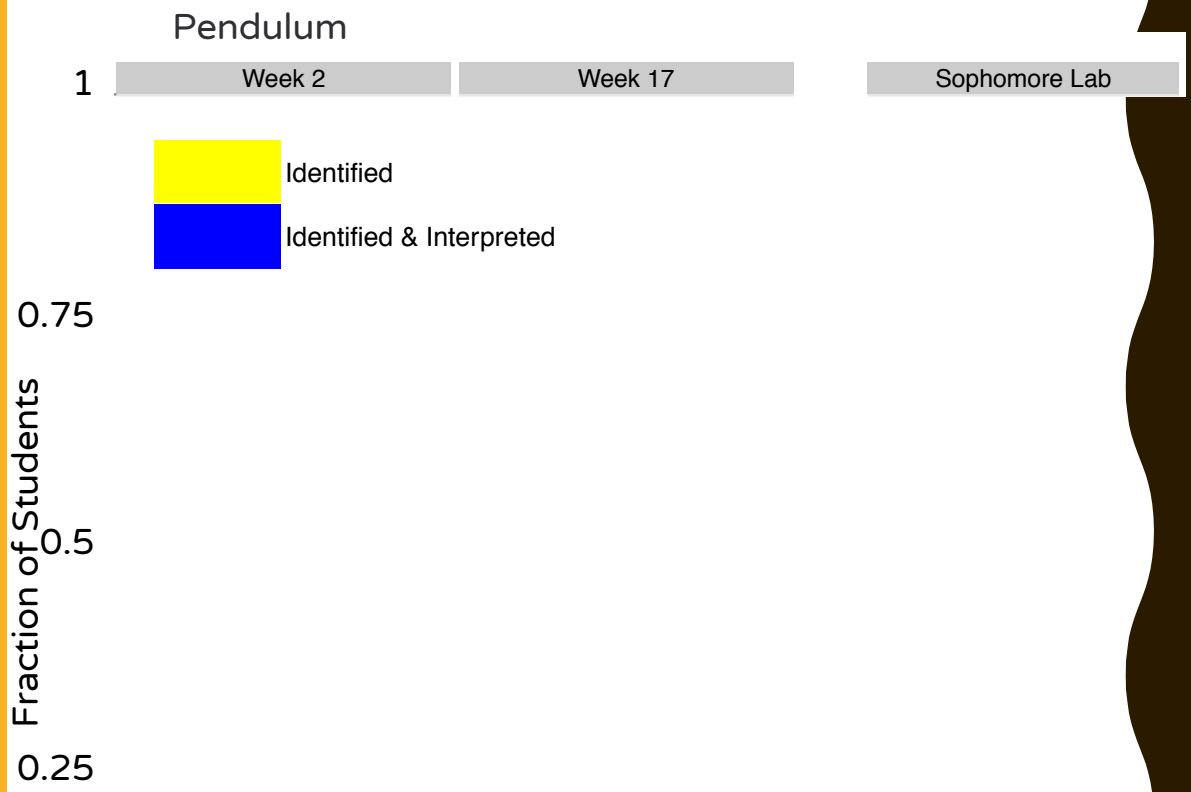

EVALUATING MODEL ISSUES

What fraction of students in the intervention group do you expect to identify and/or interpret model issues in Week 1?

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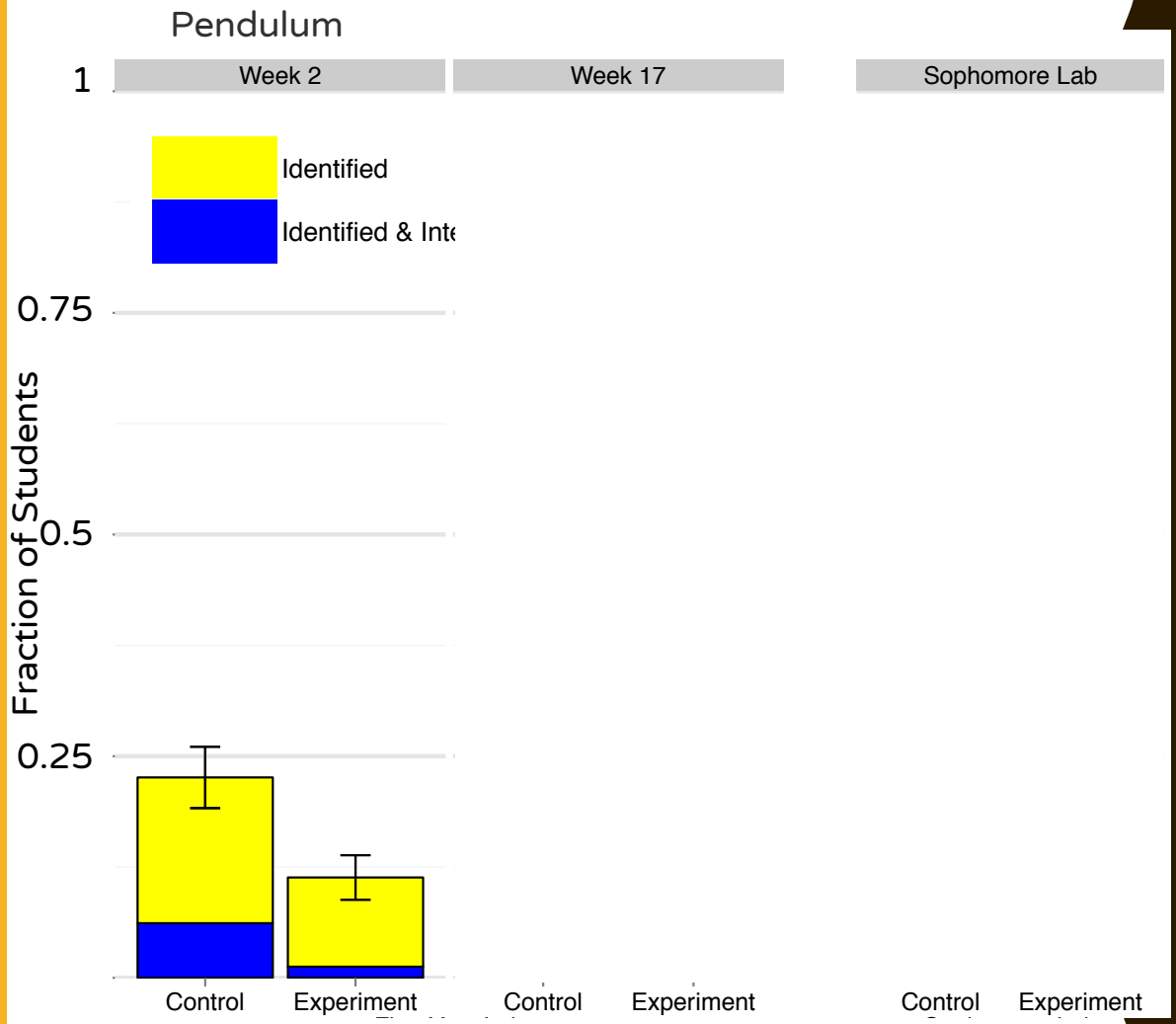

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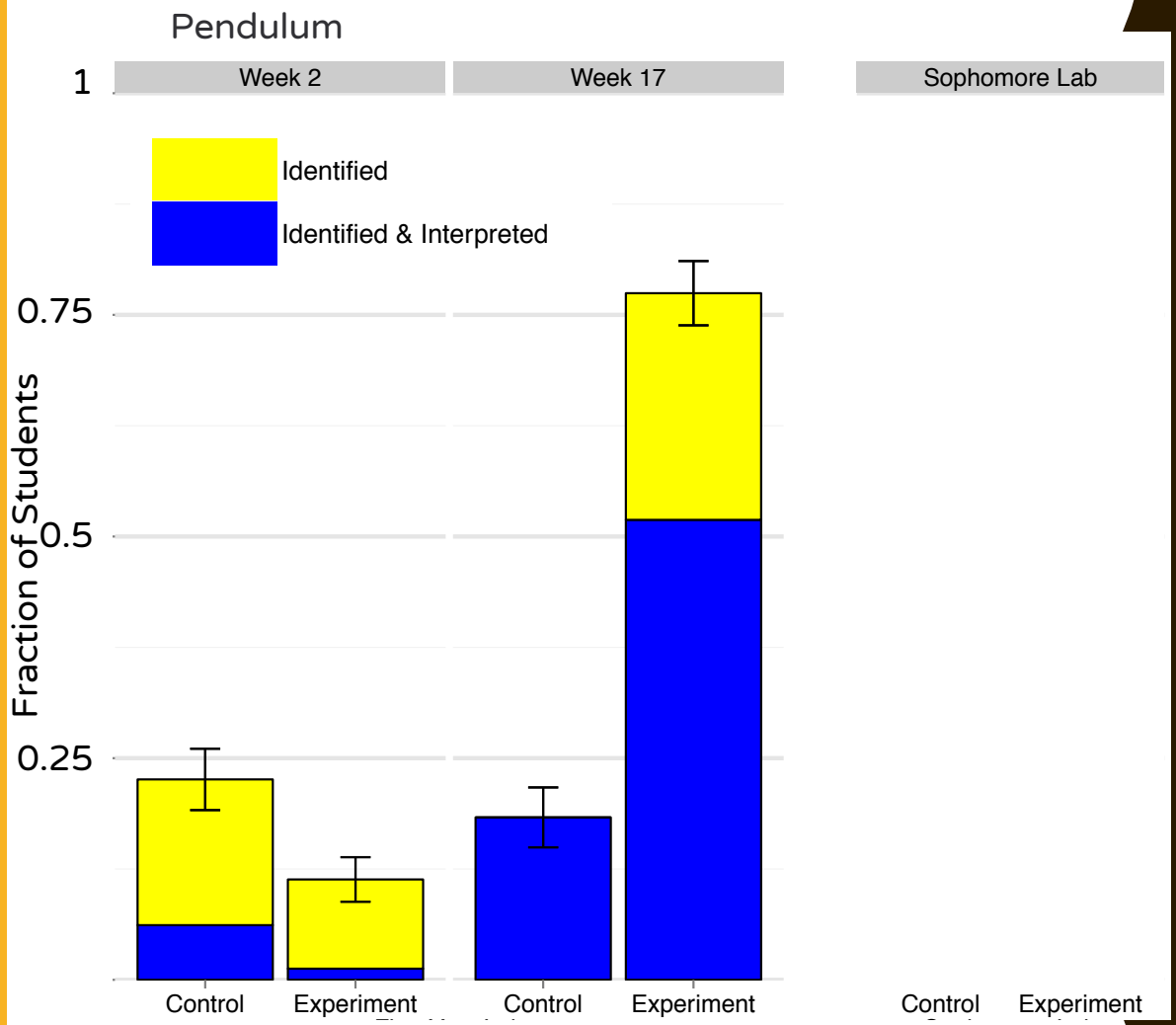

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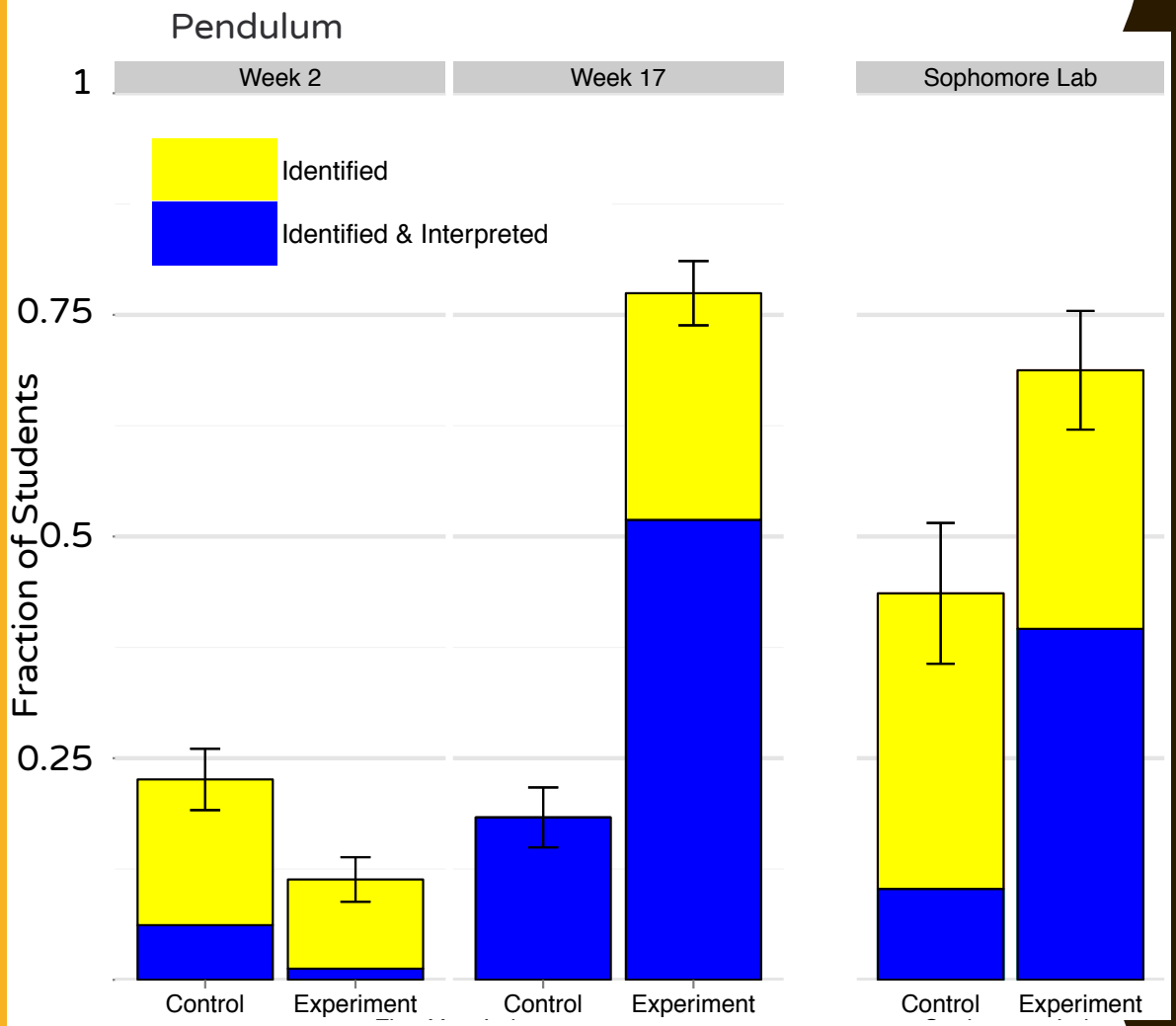

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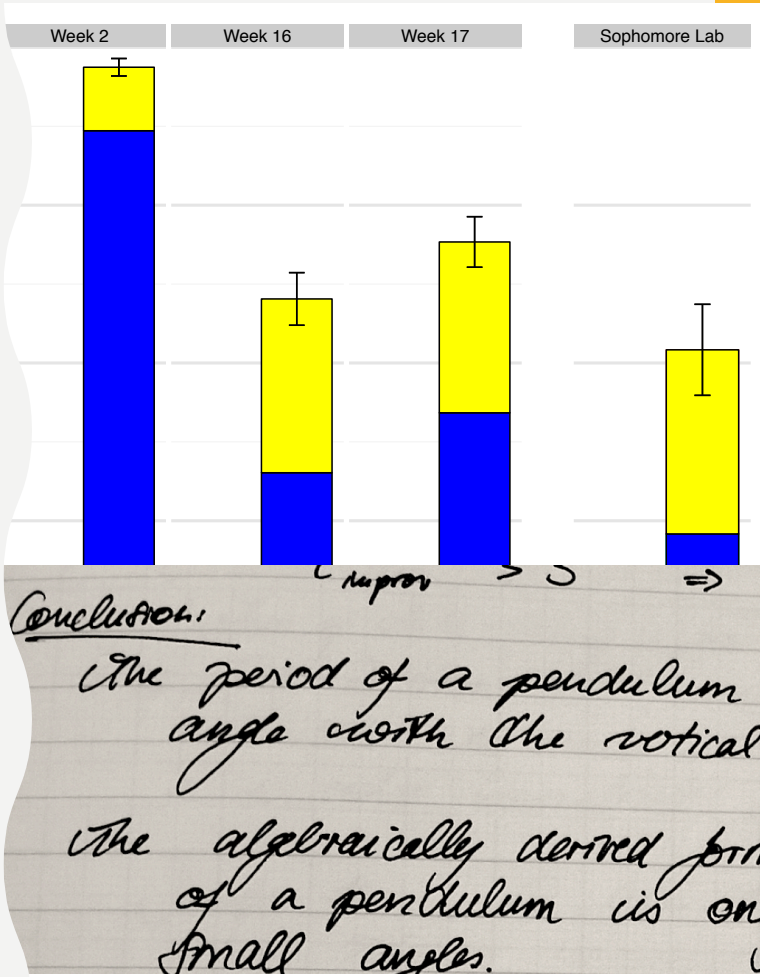
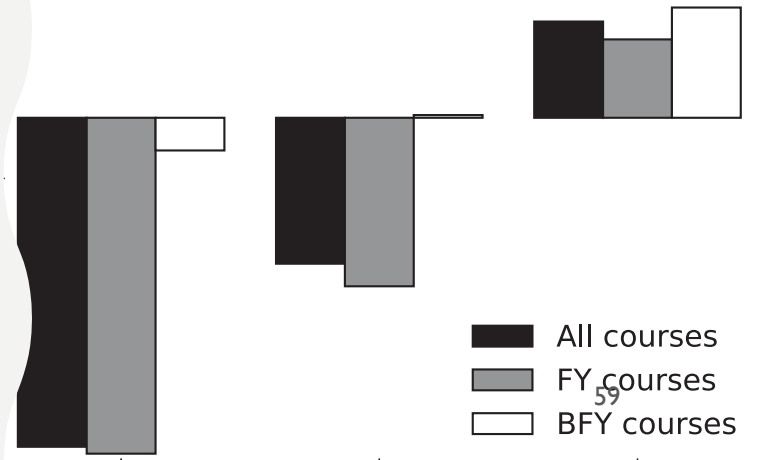
IMPLEMENTING AT YOUR INSTITUTION: FIRST STEPS

- Change the goals to focus on process rather than product
- Spread labs over multiple sessions
- Give students agency:
  - Remove some of the structure and let students play in a constrained space
  - Use experiments where students don't know the answer
- If concerned about time, safety, etc.:
  - Week 1: Use structured lab
  - Week 2: Students design and carry out their own extension: new variables, improvements to design, extend range…

WHAT ABOUT MEASURING LEARNING?

- Look at what students do in lab via lab books
- E-CLASS
- …?





PHYSICS LAB INVENTORY OF CRITICAL THINKING

PLIC

Assess critical thinking in an efficient, standardized way

Useable by instructors in different courses at any institution

Katherine Quinn (grad student)

Cole Walsh (grad student)

Carl Wieman

DUE-1611482- 01

THE PHYSICS LAB INVENTORY OF CRITICAL THINKING

Questions:

- Evaluate experimental methods and data of two groups doing mass on a spring experiment
- Decide what the groups should do next

Format

- ~30 minutes
- Closed-response assessment
- Web-based
- Automatically generated reports that compare your class to those of other classes

TWO FICTIONAL GROUPS

Group 1

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- Use 2 masses
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Trend motivates need for intercept

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- Use 10 different masses
- Linearized plot, residuals, find k

Trend motivates need for intercept

Questions:

- Do k-values agree?/ Do data fit the line?
- How good are the methods?
- What should they do next?
- Which group is better?

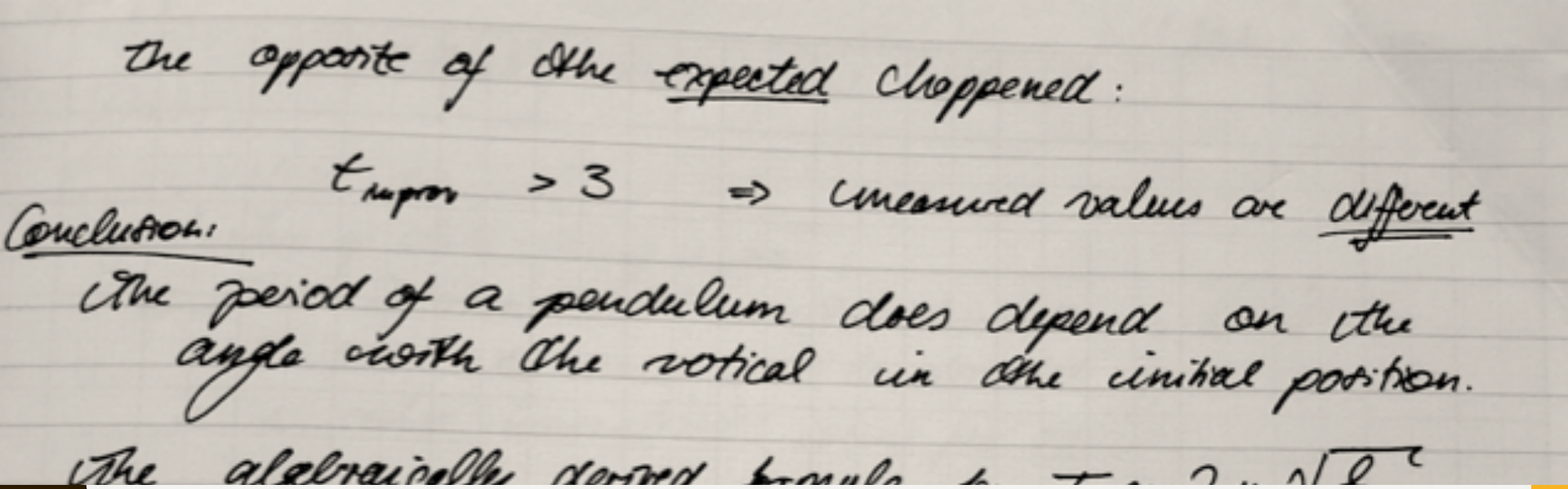
PLIC: CURRENT STATUS

Katherine Quinn (grad student) | Cole Walsh (grad student) | Carl Wieman

- Collected over 1000 unique student responses last semester
- Using those data to refine and conduct validity/reliability tests

Interested in using the PLIC?
Visit cperl.lassp.cornell.edu/PLIC or
contact me ngholmes@cornell.edu

We're also looking for more expert responses!



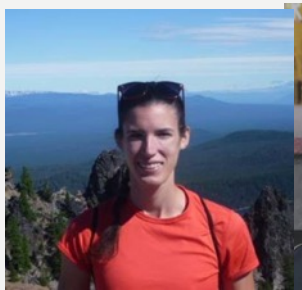
HOW DOES HAVING AN EXPECTATION ABOUT A RESULT INFLUENCE BEHAVIORS IN A LAB?

"The pendulum experiment we did at the beginning of the year, I think that really made a mark on me. Because I went in there expecting it [the period at 10 and 20 degrees] to be the same, because that's what I was taught. And then, when you finally figure out that, 'oh, it's supposed to be different,' and then I was like, 'Oh! I probably shouldn't be doing experiments with bias going in.'"

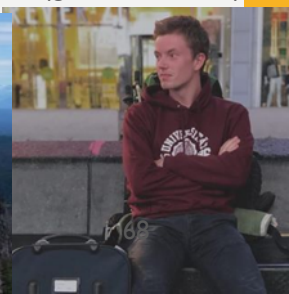
CONFIRMATION BIAS IN THE PENDULUM EXPERIMENT

- "We did not take out the outlier trial because it **did not match the average values we wanted to get**; we decided to redo the outlier trial because there was a procedural error in the trial"
- "t' = 1.7047 … We will **attempt to reduce this number** through additional measurements"
- "We chose to go back to individual oscillations because **we liked the low t' values** of method 1 and we wanted to see if we could recreate that."

Emily Smith (postdoc)



Martin Stein (grad student)



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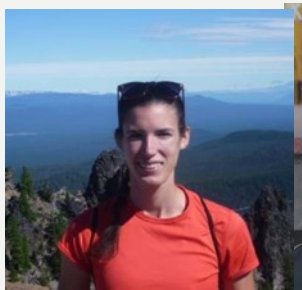
Qs:

- *How prevalent are these behaviors over time?*
- *How does what they write compare with what they do? (video vs notes)*

Emily Smith (postdoc)



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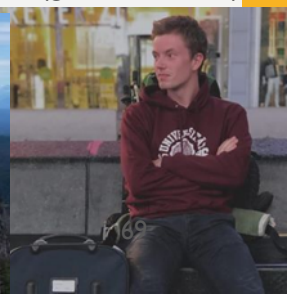
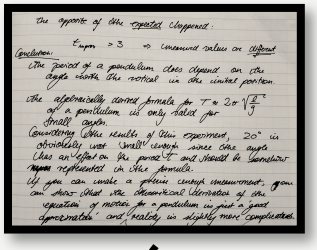
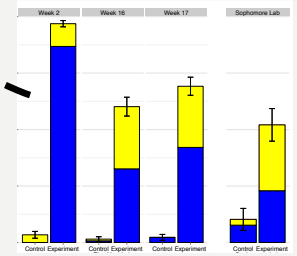


SUMMARY

Score on lab-related questions

Score on non-lab-related questions





What should students be learning?

What instructional approaches improve student learning?

What are students learning?

PLIC

Make a comparison

Reflect on comparison

Act on comparison

CORNELL PHYSICS EDUCATION RESEARCH LAB

PI: Natasha G. Holmes

Visiting faculty: Michelle Smith

Postdoc: Emily Smith

Collaborator: Carl Wieman

Grad students:

Michelle Kelley

Jack Madden

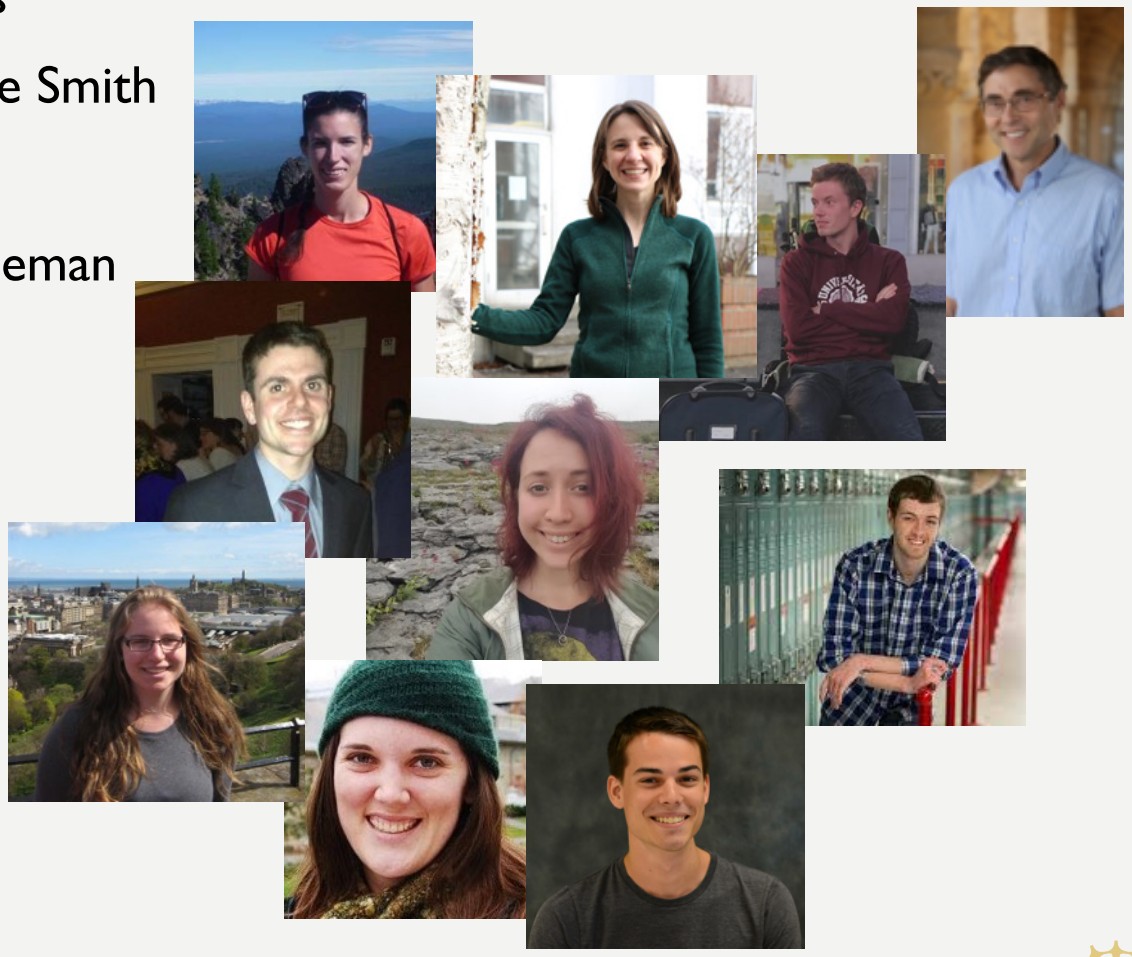
Kathryn McGill

Katherine Quinn

Martin Stein

Ryan Tapping

Cole Walsh



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