Natasha G. Holmes
LASSP, Cornell University

From Cookbook to Authentic Research:

Rethinking introductory physics lab courses

@ng_Holmes
ngholmes@cornell.edu

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Cornell Physics Education Research Lab

Natasha Holmes

Katherine Quinn

Your photo here?

We're recruiting postdocs, grad students, and undergrad students! Contact me!

DUE-1611482- 01

Collaborators

Stanford University

Carl Wieman
Isabella Rios
Adam Stanford-Moore
Ruqayya Toorawa

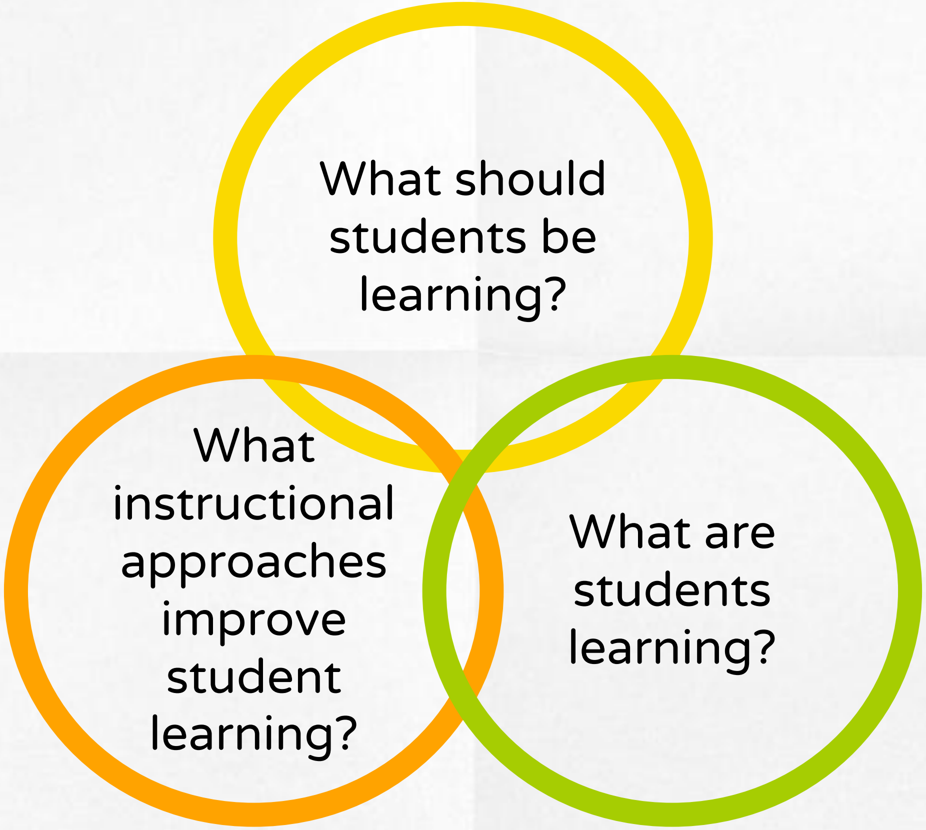
University of British Columbia

Doug Bonn
James Day
Sarah Gilbert
Joss Ives
Dhaneesh Khumar
Ido Roll

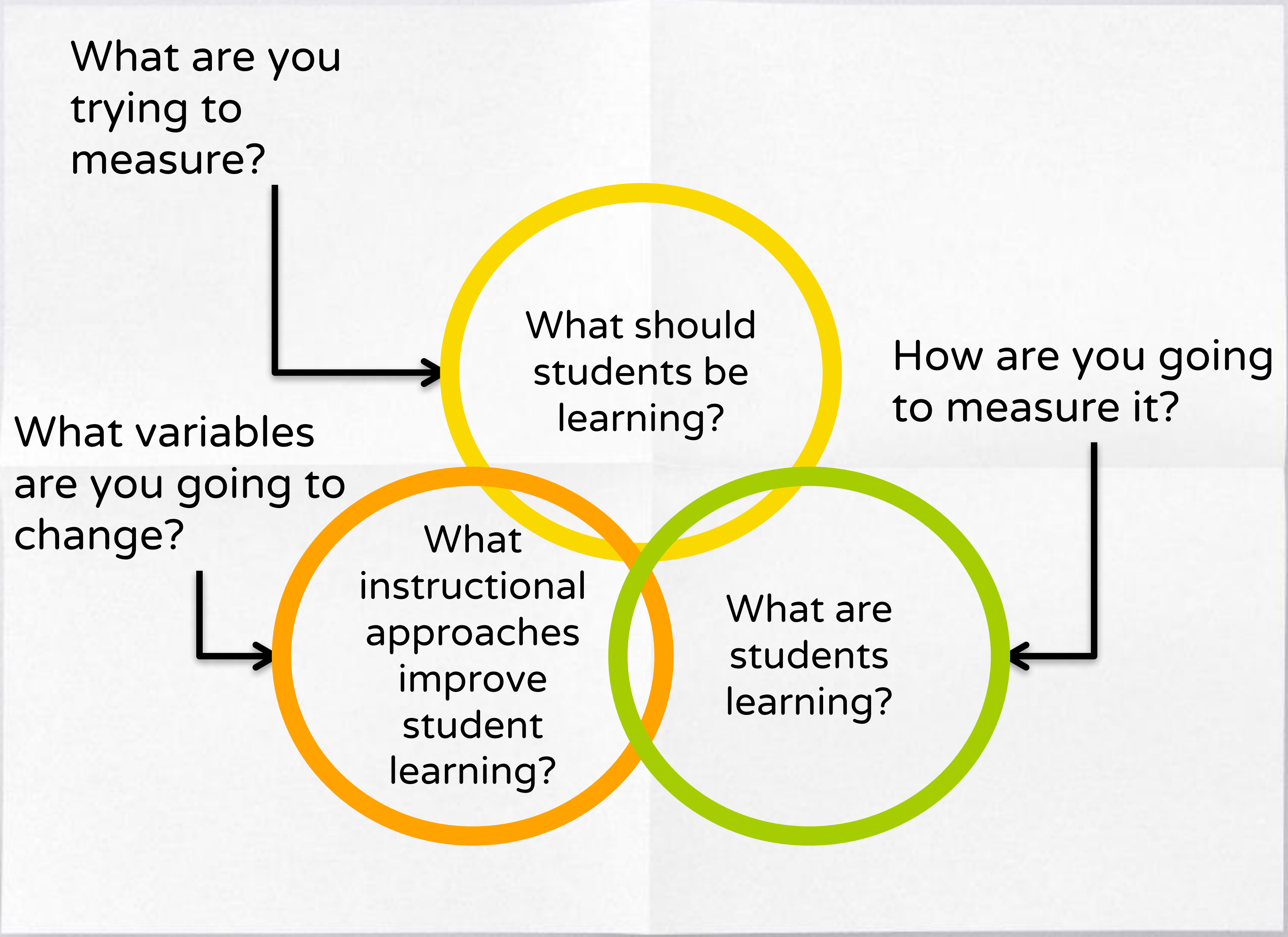
Other

Jack Olsen (University of Washington)
James Thomas (University of New Mexico)

Guiding questions



Modified from CWSEI “three-pronged approach”


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?

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)

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

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)

Hofstein & Lunetta (1982; 2004)

Many Lab courses target…

Understanding scientific concepts

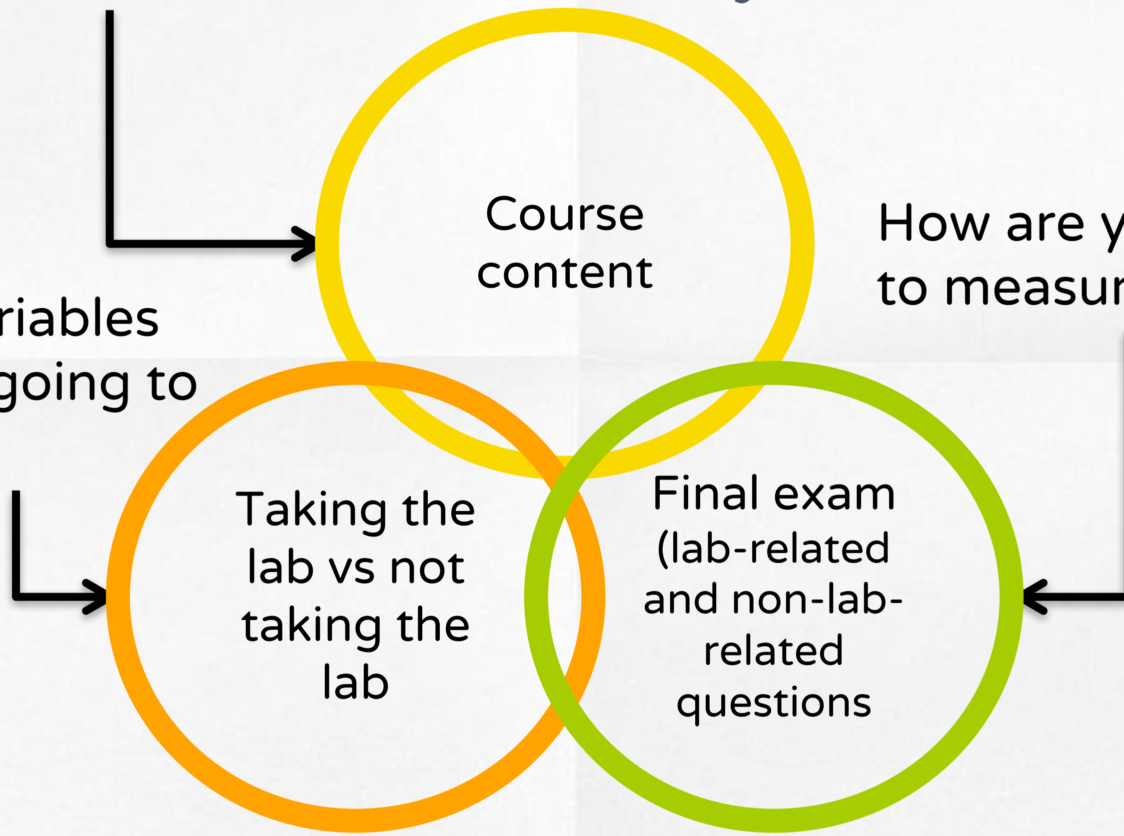
Interest and motivation

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



Holmes & Wieman (2016) *Am. J. Phys.*
Holmes et al. (submitted)

Must account for selection effects

Students who take the lab

≠

Students who do not take the lab

Holmes & Wieman (2016) *Am. J. Phys.*
Holmes et al. (in prep)

Score on lab-reinforced questions

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

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

Multi-institution study

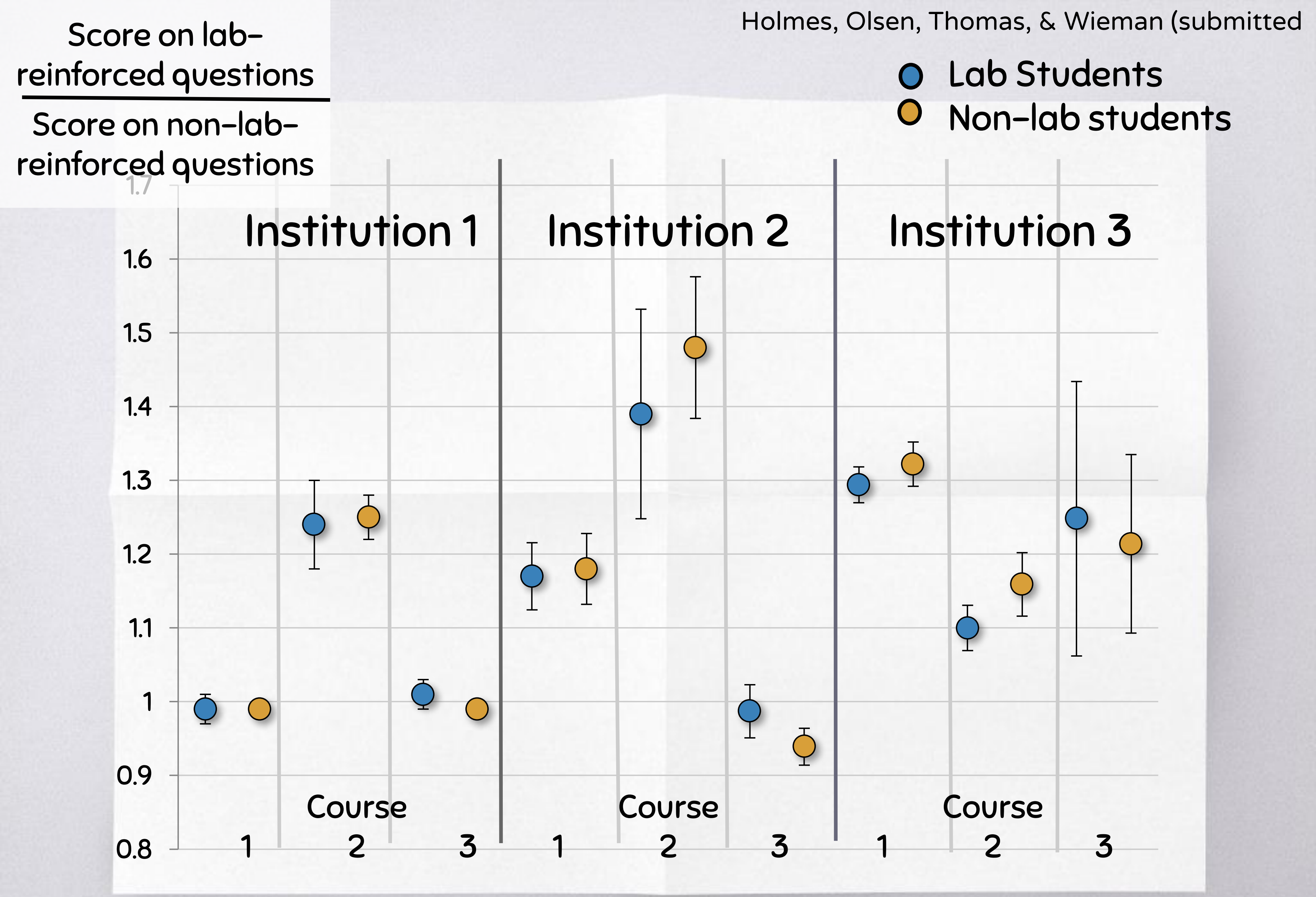
Features:

- 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


Holmes, Olsen, Thomas, & Wieman (submitted
Score on lab-reinforced questions
Score on non-lab-reinforced questions
Lab Students
Non-lab students
Institution 1
Institution 2
Institution 3
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
Course
1
2
3

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.

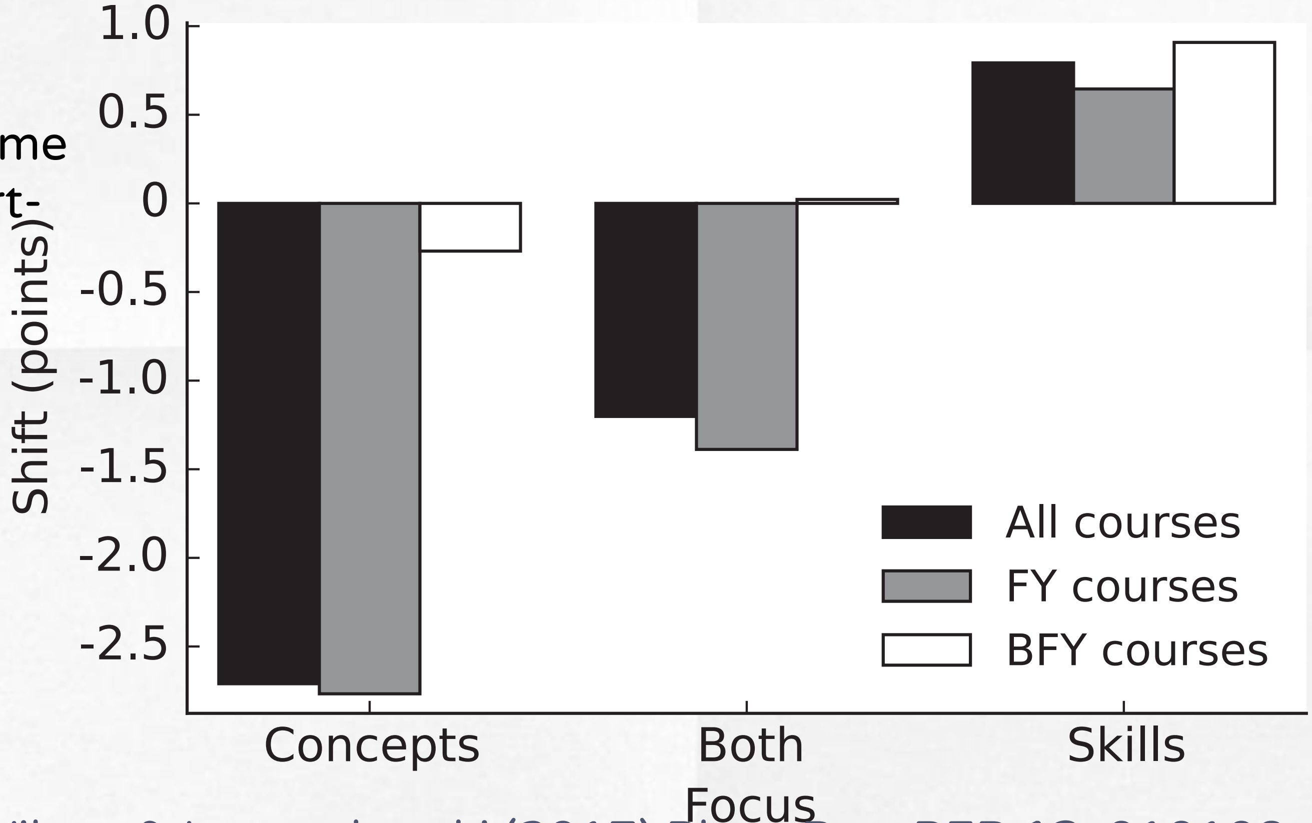
- When doing an experiment, I try to understand how the experimental set up works.
- When doing a physics experiment, I don't think much about sources of systematic error.

Scores aligned with expert responses

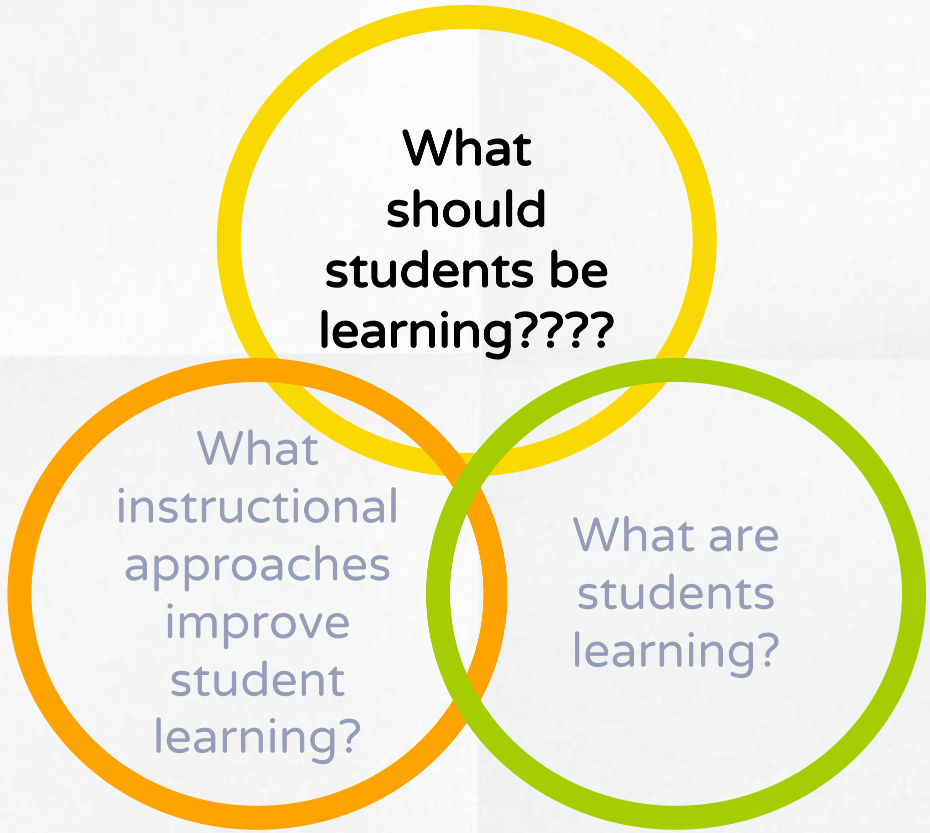
Zwickl BM, Hirokawa T, Finkelstein N, Lewandowski HJ (2014) *Phys Rev Spec Top - Phys Educ Res* 10(1):10120.

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


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

Cognitive tasks in experimental physics research

(Wieman, *Phys. Teach.* 2015)

1. Establish research goals
2. Define criteria for suitable evidence
3. Determine feasibility of experiment
4. Experimental design
5. Construction & testing of apparatus
6. Analyzing data
7. Evaluating results & analyzing implications
8. Presenting the work

Do students experience these tasks?

Numbers:
- 8 focus-group interviews
- 2-8 URE students per interview

Semi-structured
- questions about URE with comparisons to coursework

Analysis
- Look for instances where students talk about one of the cognitive tasks

Holmes & Wieman (2016) *Phys. Rev. PER*

Do students experience these tasks?

Holmes & Wieman (2016) *Phys. Rev. PER*

Structured Labs vs Design Labs vs UREs

- Goals and protocol laid out
- Students follow steps to obtain result predicted by theory
- New experiment every week

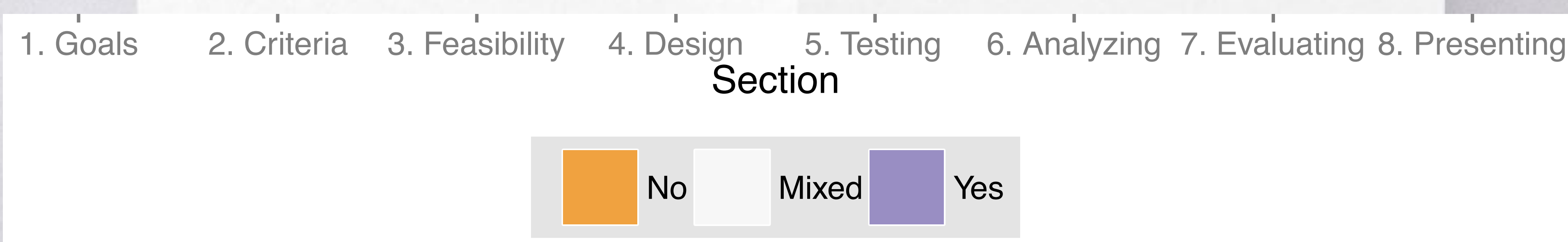
- Students choose research question and design experiment
- 1-2 experiments over 10 weeks

Holmes & Wieman (2016) *Phys. Rev. PER*

What cognitive tasks do they do where?

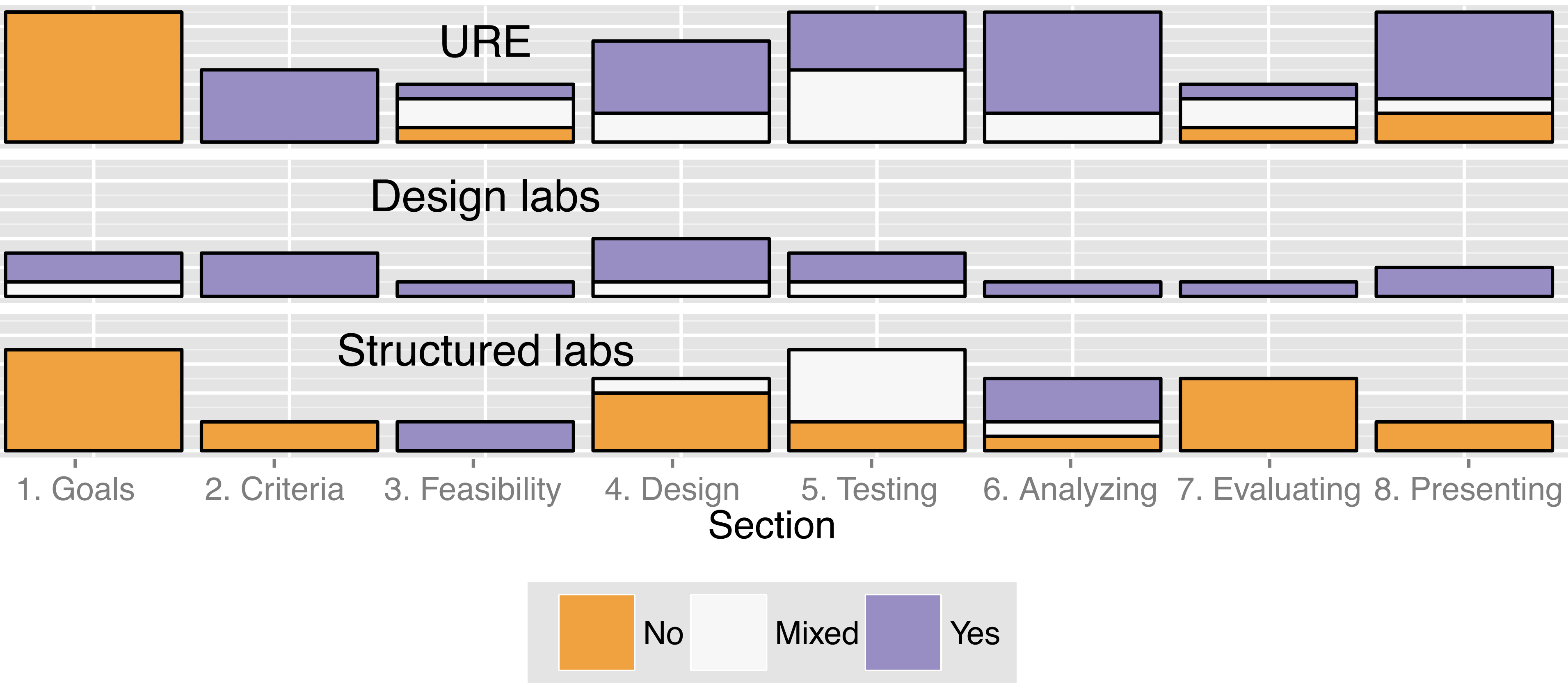
Looking at # interviews where it comes up

- If something does not come up, we cannot claim it does not happen
- If students explicitly say they do not do it, we can claim it does not happen
- Mentions in repeated interviews provide strength to claim



Holmes & Wieman (2016) *Phys. Rev. PER*

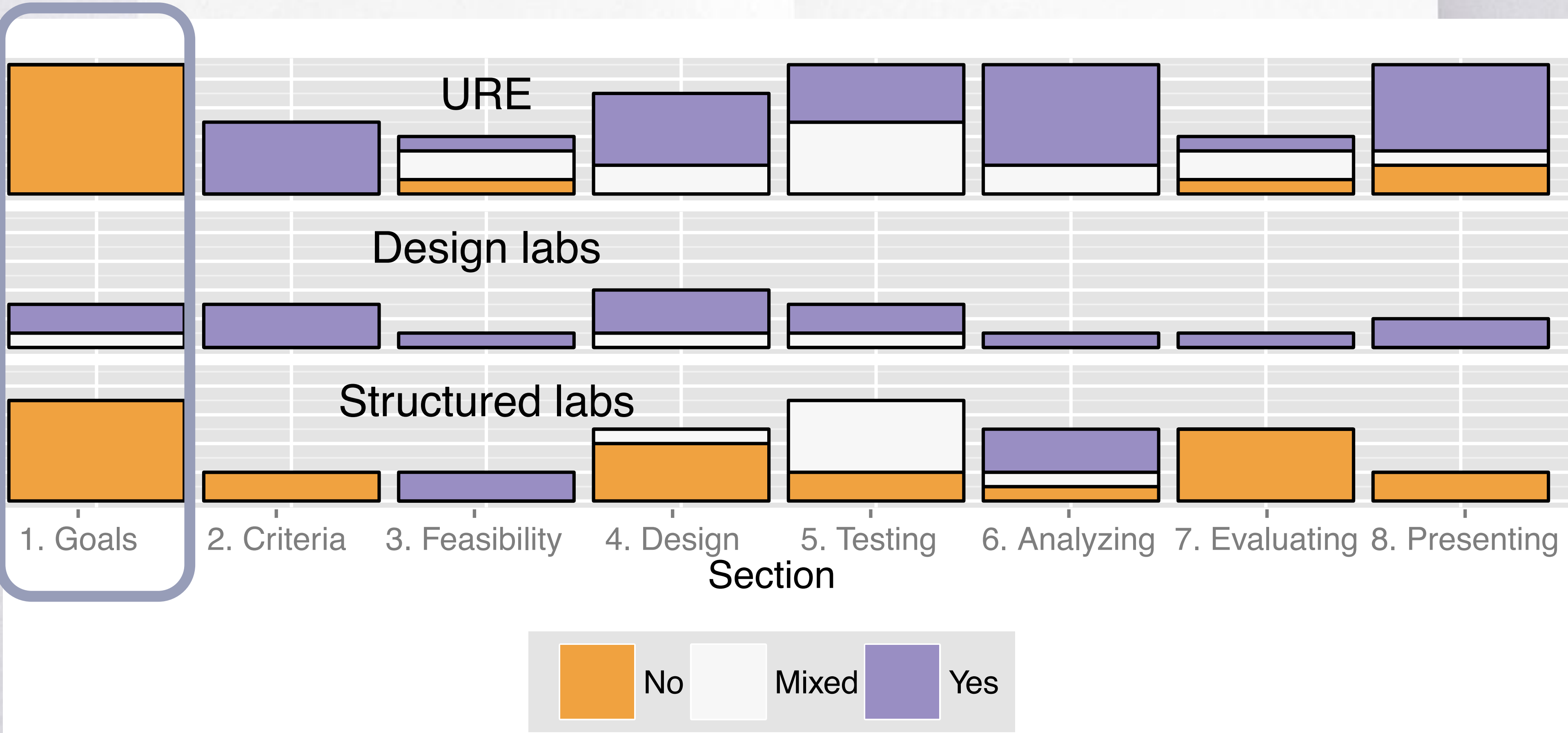
- URE doing most of the things
- Structured labs explicitly not doing the things
- Design labs, unclear – consistent “yes” but rarely discussed



Holmes & Wieman (2016) *Phys. Rev. PER*

Goal Setting:

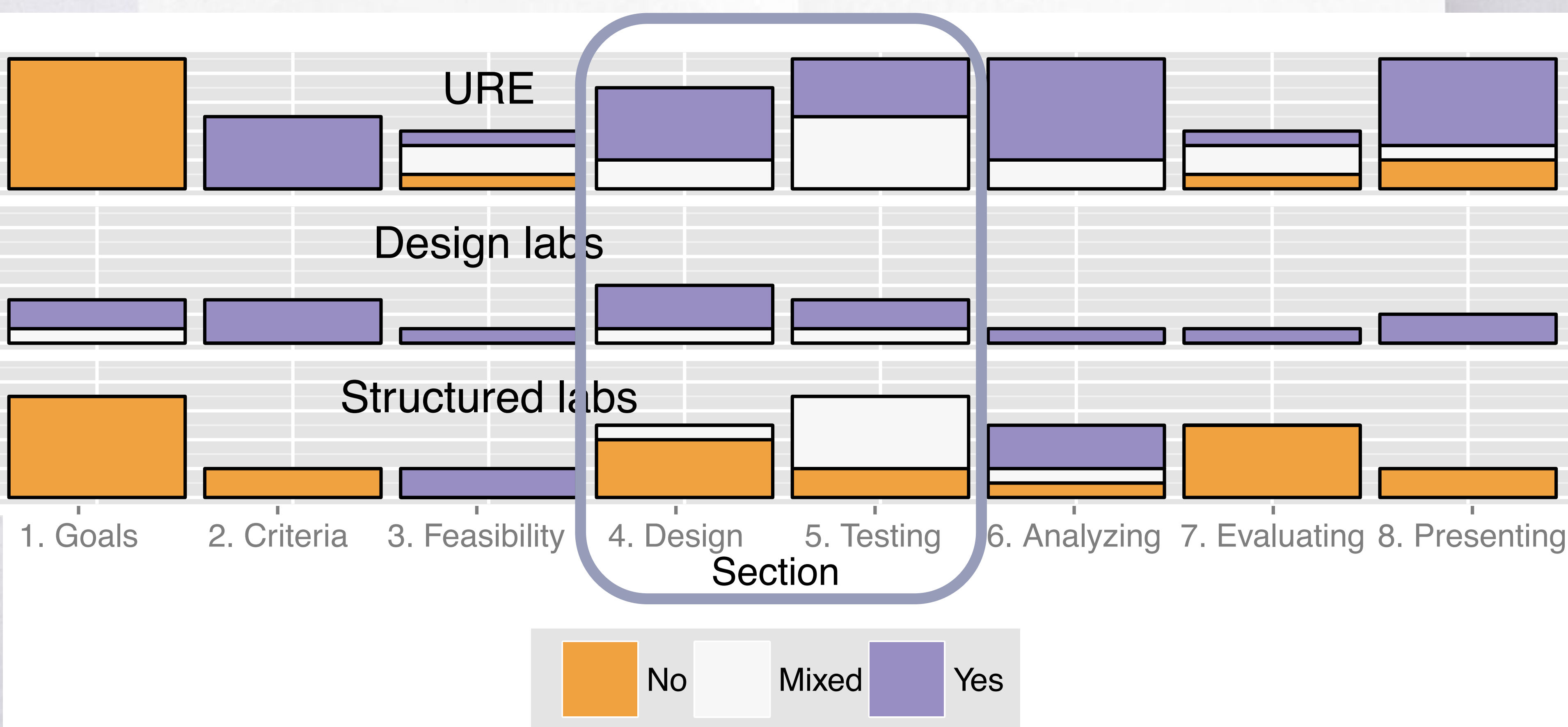
- Goals given in URE & structured labs
- Students choose research question in design-labs



Holmes & Wieman (2016) *Phys. Rev. PER*

Design & Testing (passionate responses):

- In URE and design labs: students had ownership, autonomy, and time to figure things out
- Lack of this in structured labs was frustrating



Holmes & Wieman (2016) *Phys. Rev. PER*

“

S1:

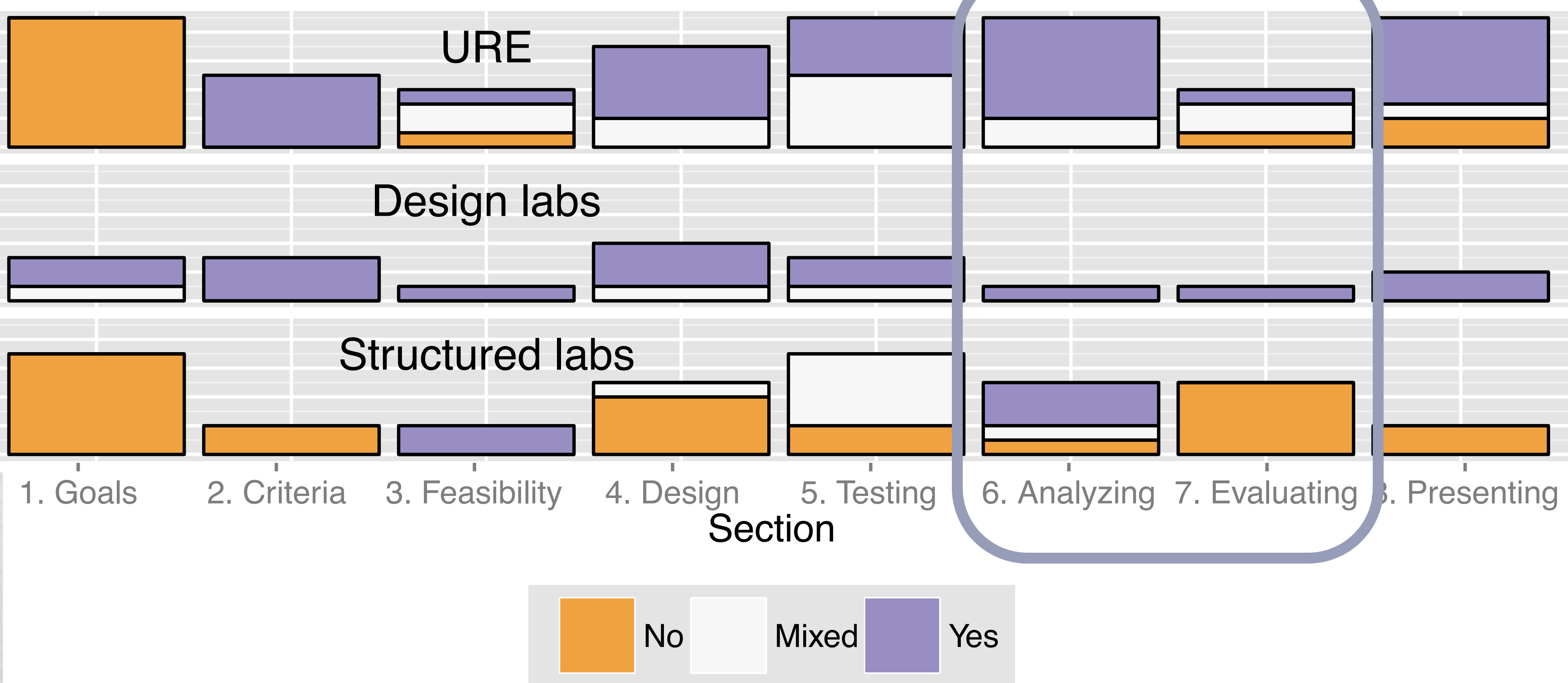
When you break a machine in the one way that the professor said, ‘Do not break the machine because they don’t make spare parts for this thing anymore.’ But then you manage to fix it anyways and then the thing starts working again, that’s good… Overcoming obstacles.

S2:

I completely agree with that. Yesterday I was struggling all day long with how to fit this one graph a certain way and I was so upset and this morning I came in early and then it magically worked and I got it to work and I was so happy and it’s carried me through the whole day.

Analyzing data, evaluating results

- Despite lots of data analysis, less evaluating – not there in the UREs
- Structured labs….



Holmes & Wieman (2016) *Phys. Rev. PER*

“

…having the sort of, basically the amount of freedom that research does give you, having the time and the space to step back a bit and say, ‘What can we actually learn from this?’ instead of just trying to blindly get a result.

“

…And then sometimes when those labs, when you don’t get the results you want, you’re tempted – because you know exactly what result you want - so it’s tempting to just massage what you’ve gotten until it looks like something like a distant relative of what you want.”

UREs offer a lot that labs can't

e.g.

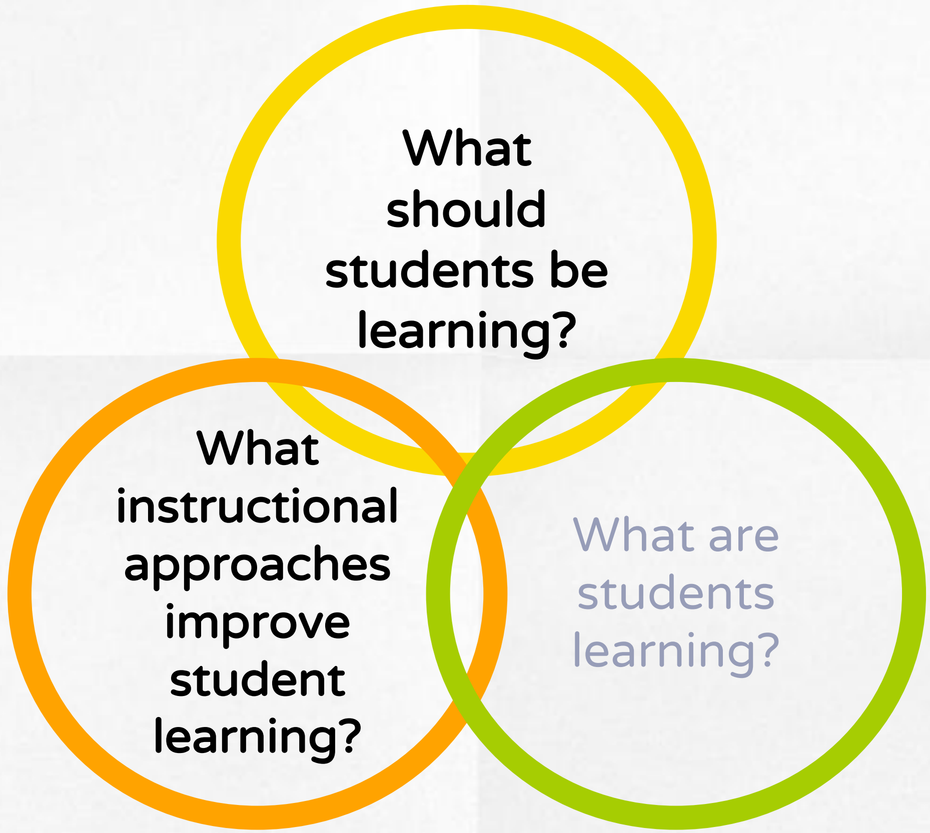
Clarifying career aspirations

What a professor does

What grad student life is like

Cutting edge research experiences

But labs can offer a lot more than they do now


What should students be learning?
What instructional approaches improve student learning?
What are students learning?

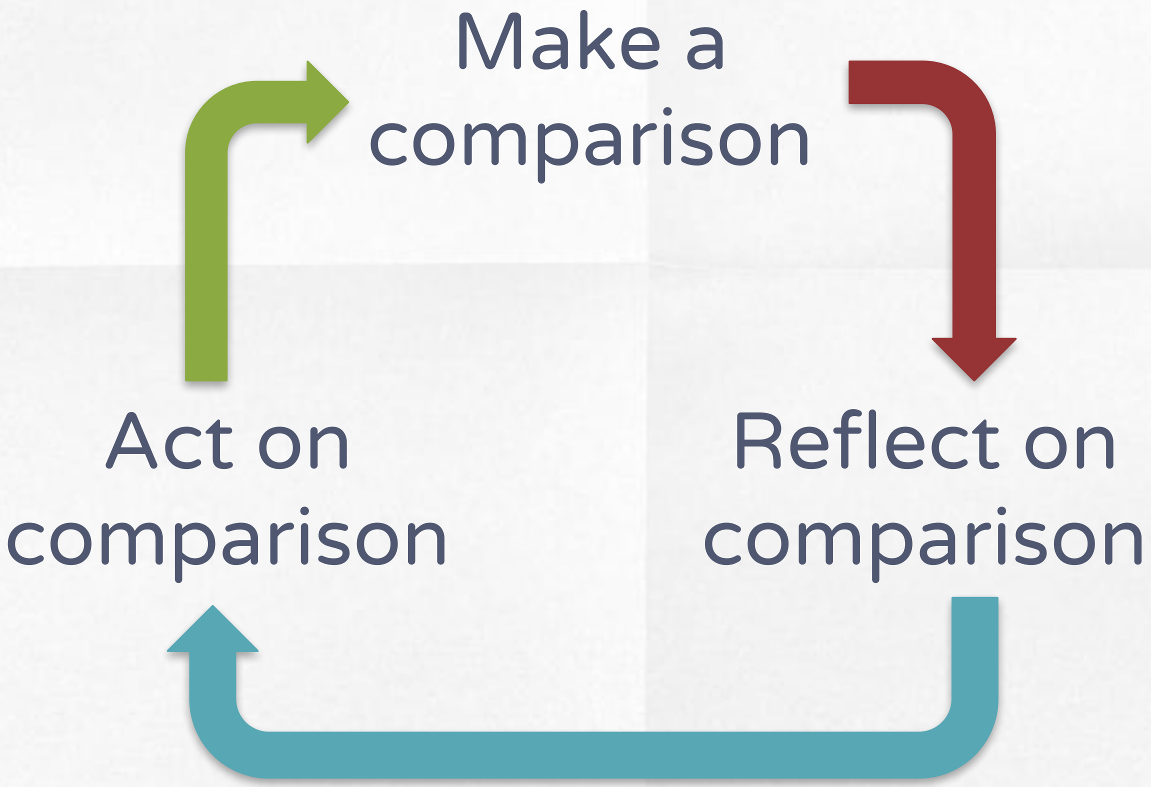
Quantitative critical thinking

Quantitative critical thinking

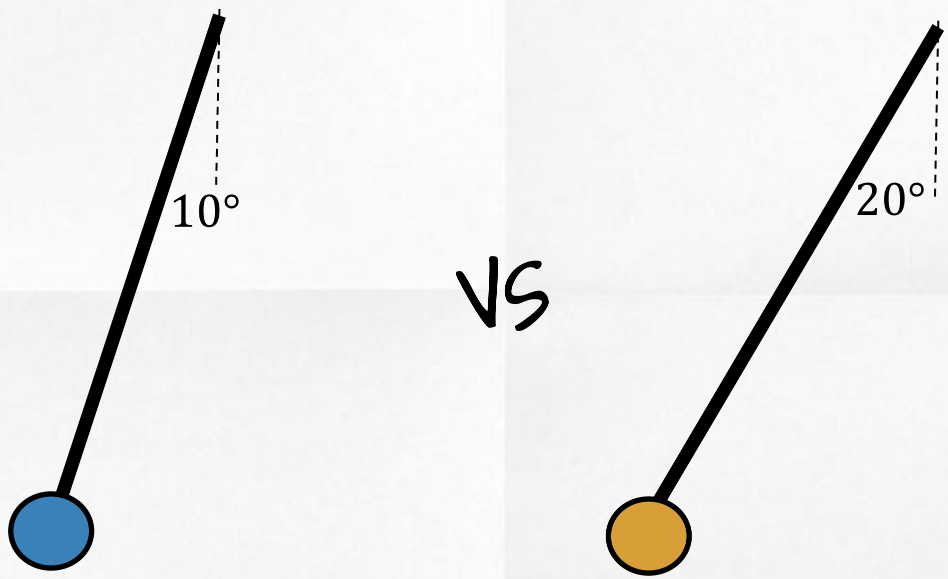
The process through which you decide what to believe

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

Quantitative critical thinking

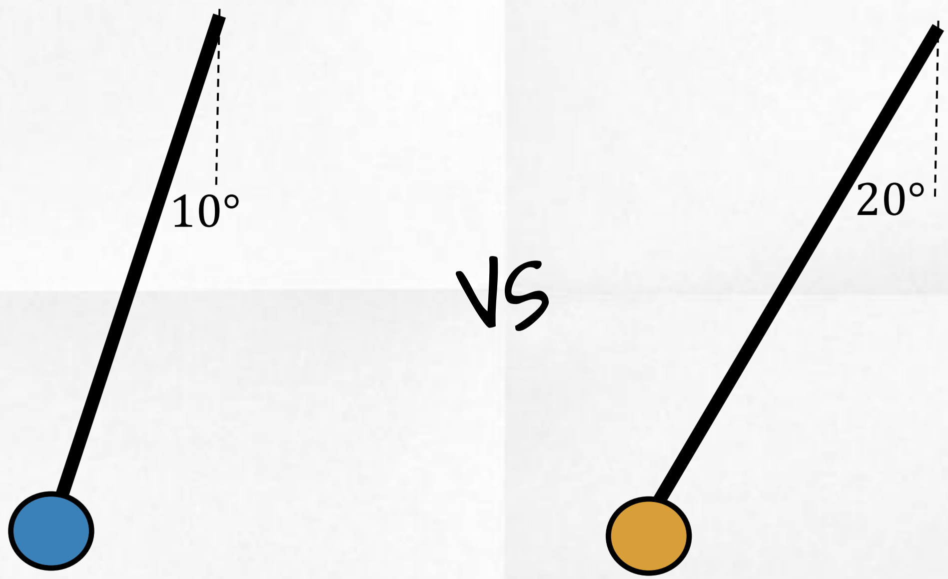


Compare period of pendulum at different amplitudes



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

Compare period of pendulum at different amplitudes

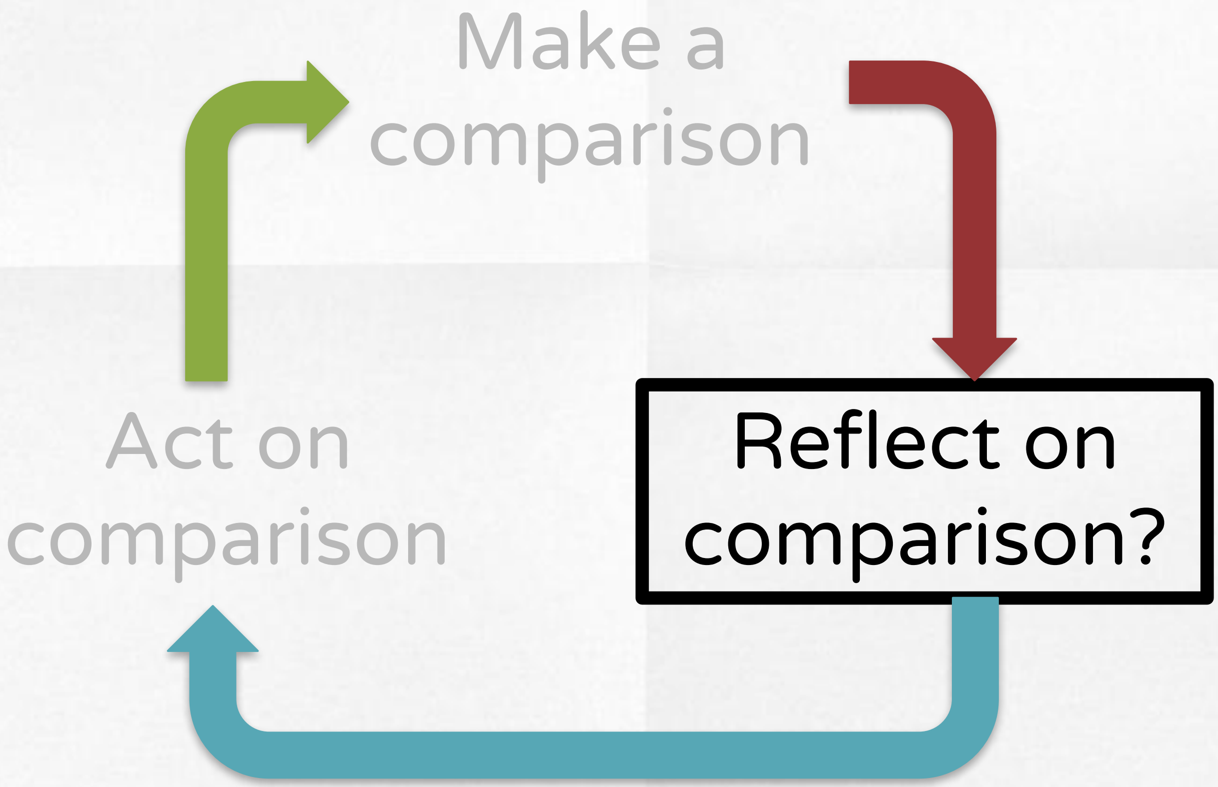


Diff
$\sim 0.2\sigma$

T= 1.84 ± 0.08 s

T= 1.81 ± 0.08 s

Quantitative critical thinking



What might a difference of $\sim 0.2\sigma$ mean?

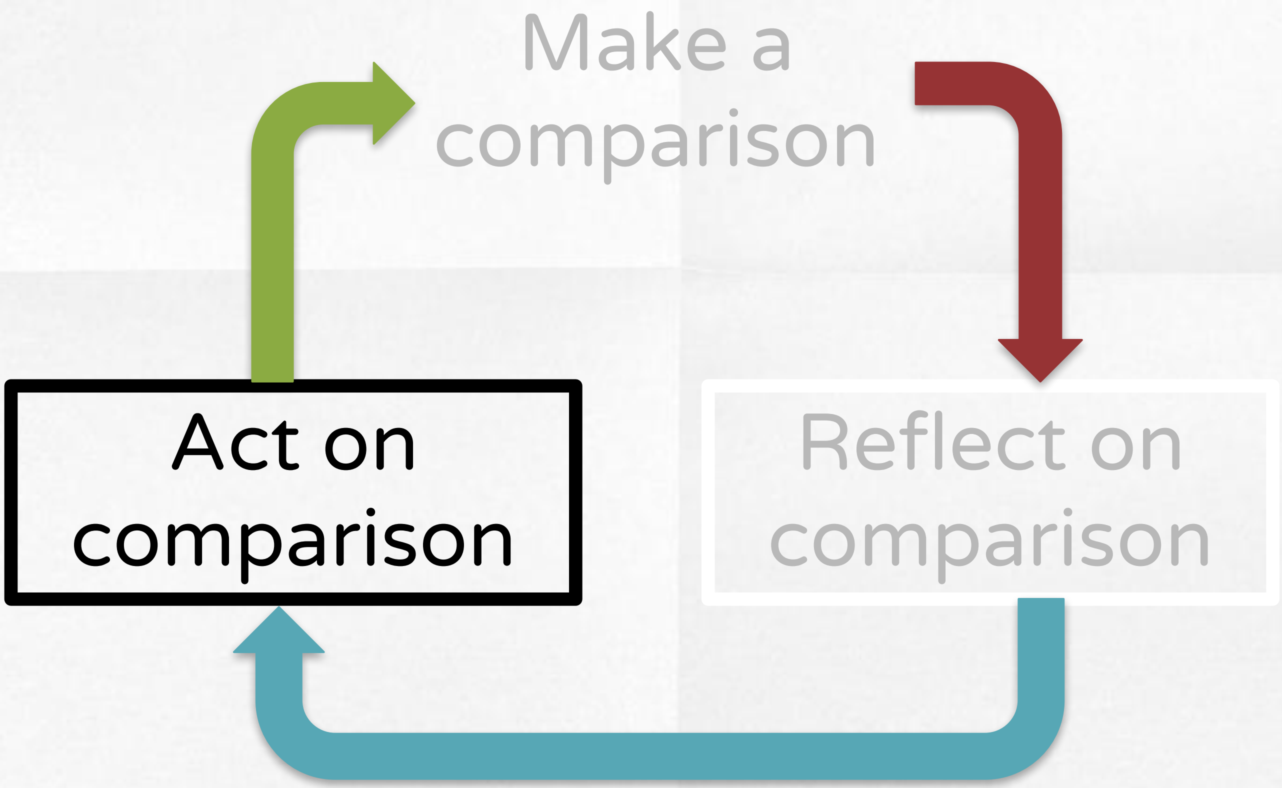
What might a difference of $\sim 0.2\sigma$ mean?

1. The periods agree
2. The periods don't agree
3. The uncertainty is too large
4. The uncertainty is too small

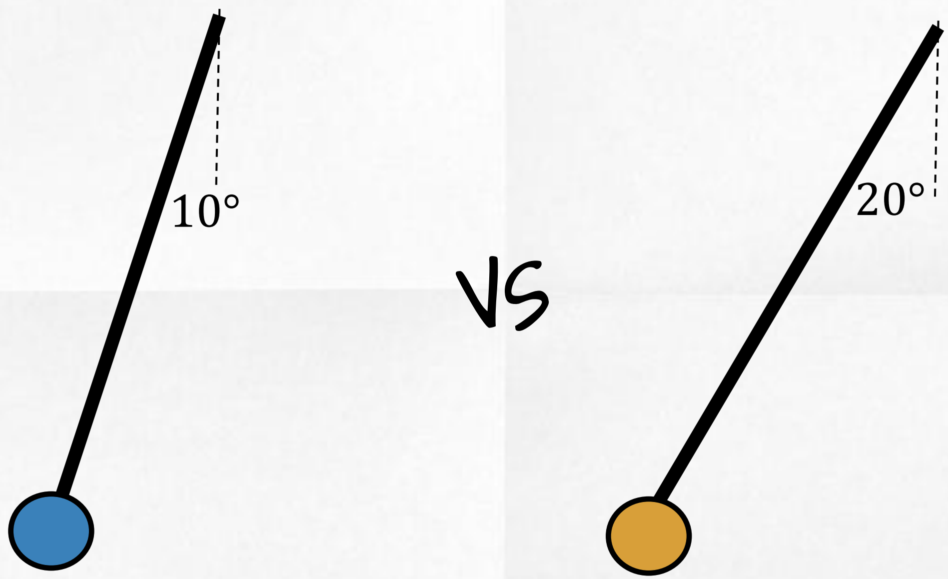
$$Diff = \frac{T_{10°} - T_{20°}}{Uncertainty}$$

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

Quantitative critical thinking



What should they do next?



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

What should 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

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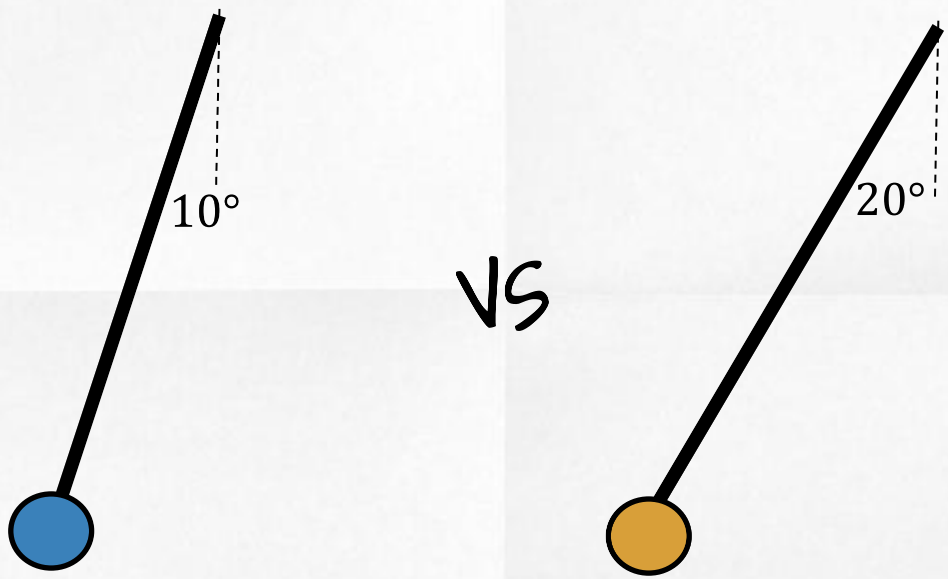


Diff
$\sim 3.7\sigma$

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, etc.

The opposite of the expected happened:

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

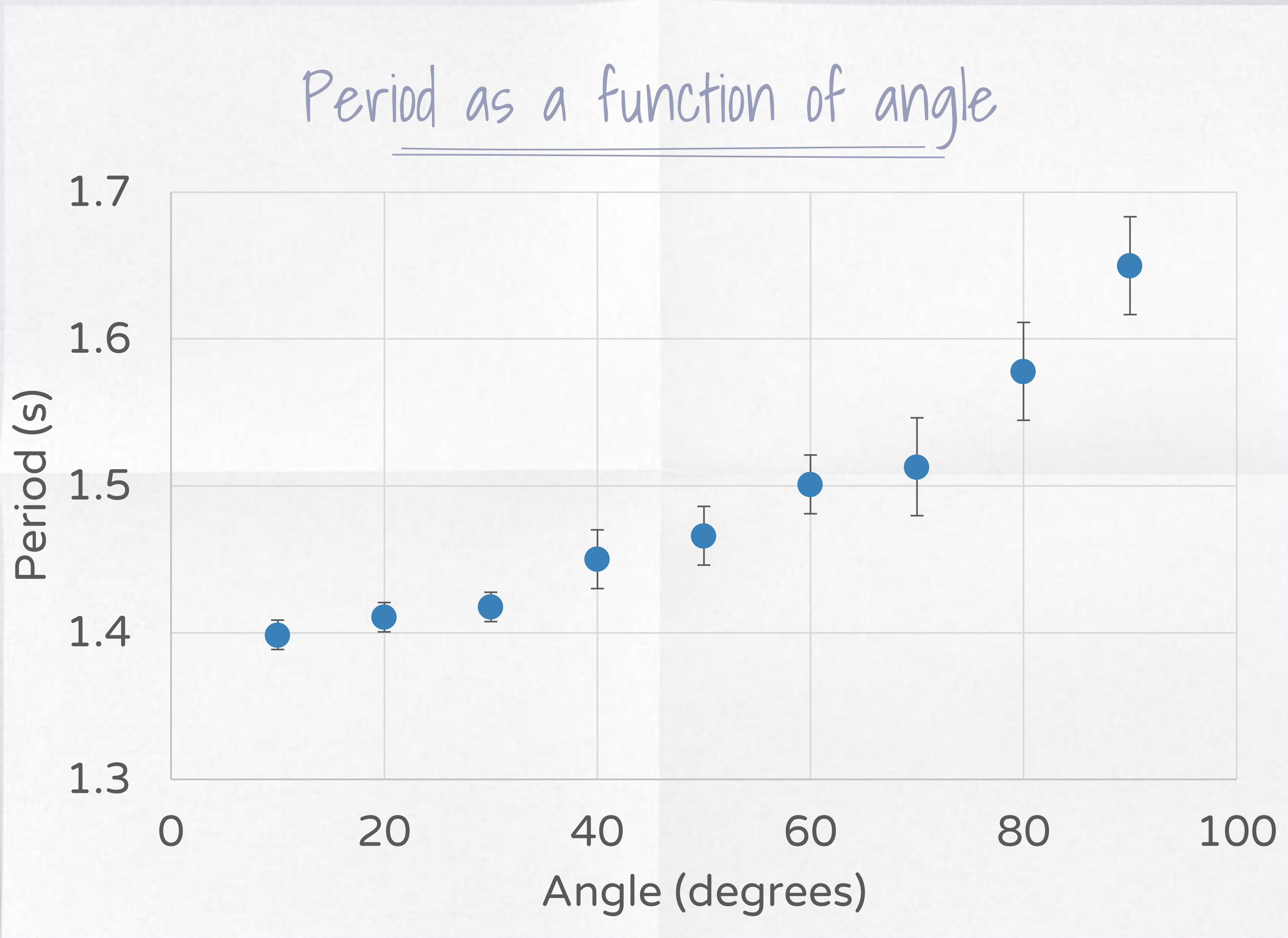
Conclusion:

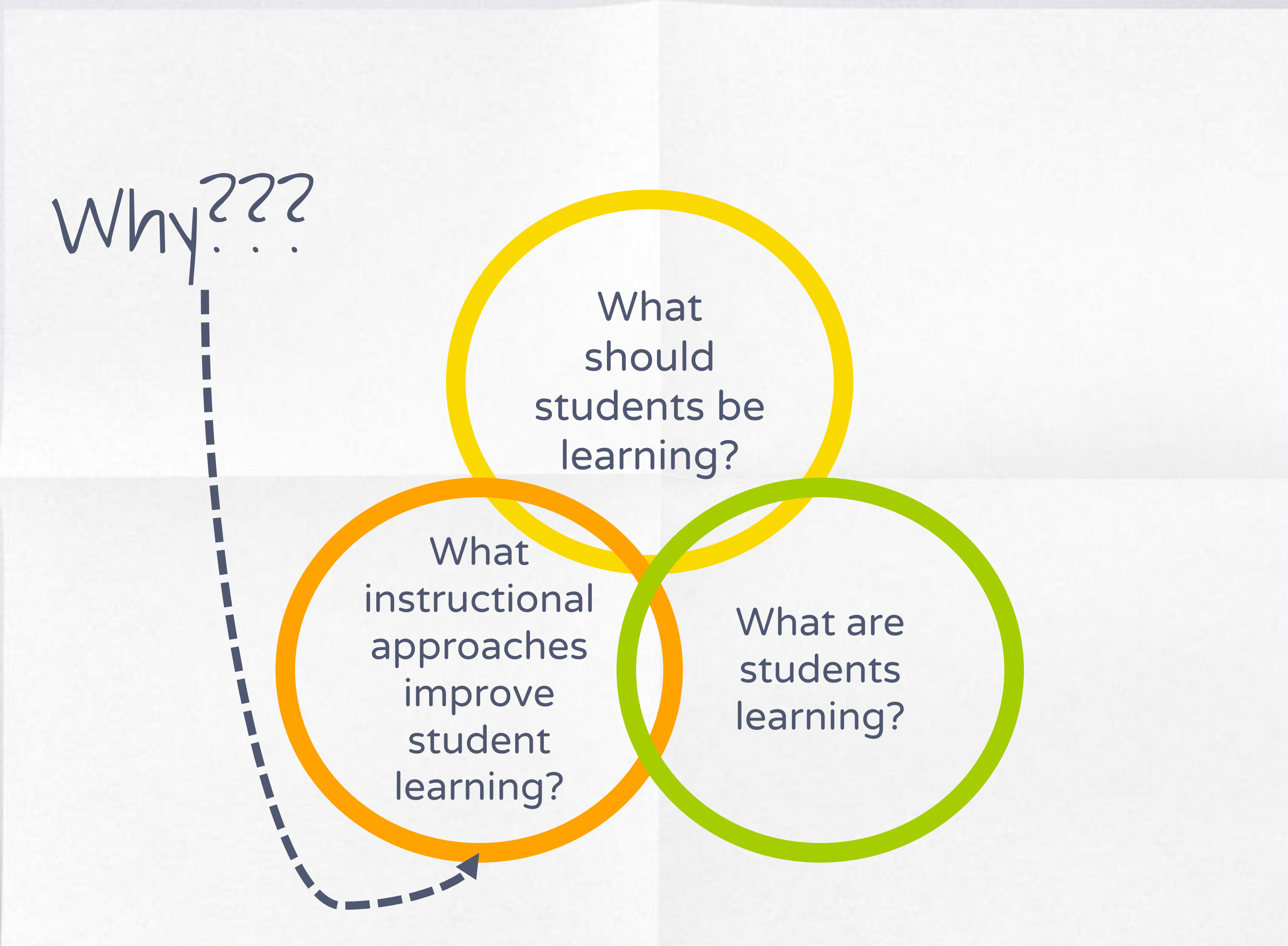
The period of a pendulum does depend on the angle with the vertical in the initial position.

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

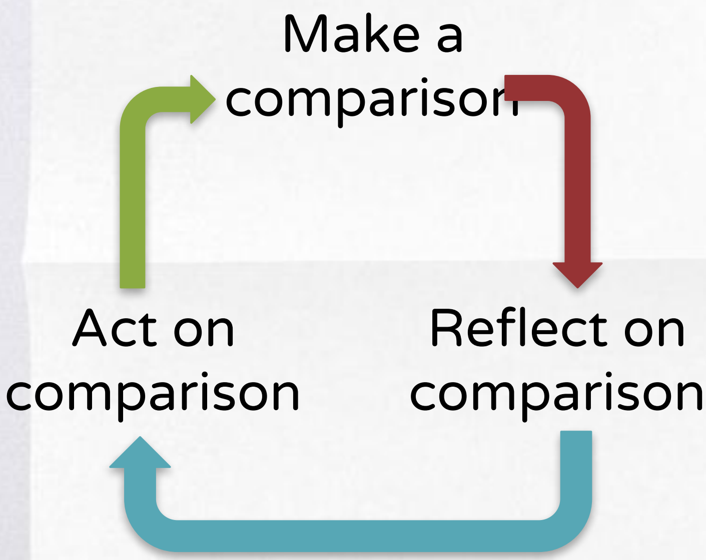
Considering the results of this experiment, 20° is obviously not 'small' enough since the angle has an effect on the period T and should be somehow represented in the formula.

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
1.7
1.6
1.5
1.4
1.3
Period (s)
0
20
40
60
80
100
Angle (degrees)


Why???
What should students be learning?
What instructional approaches improve student learning?
What are students learning?

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)...

Can we get *all* students doing this?

Assessing comparison cycles instruction

	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 NG, Wieman CE, Bonn DA (2015) *PNAS*

Pendulum

Week 2	Week 16	Week 17	Sophomore Lab

1

0.75

0.5

0.25

Fraction of Students

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%

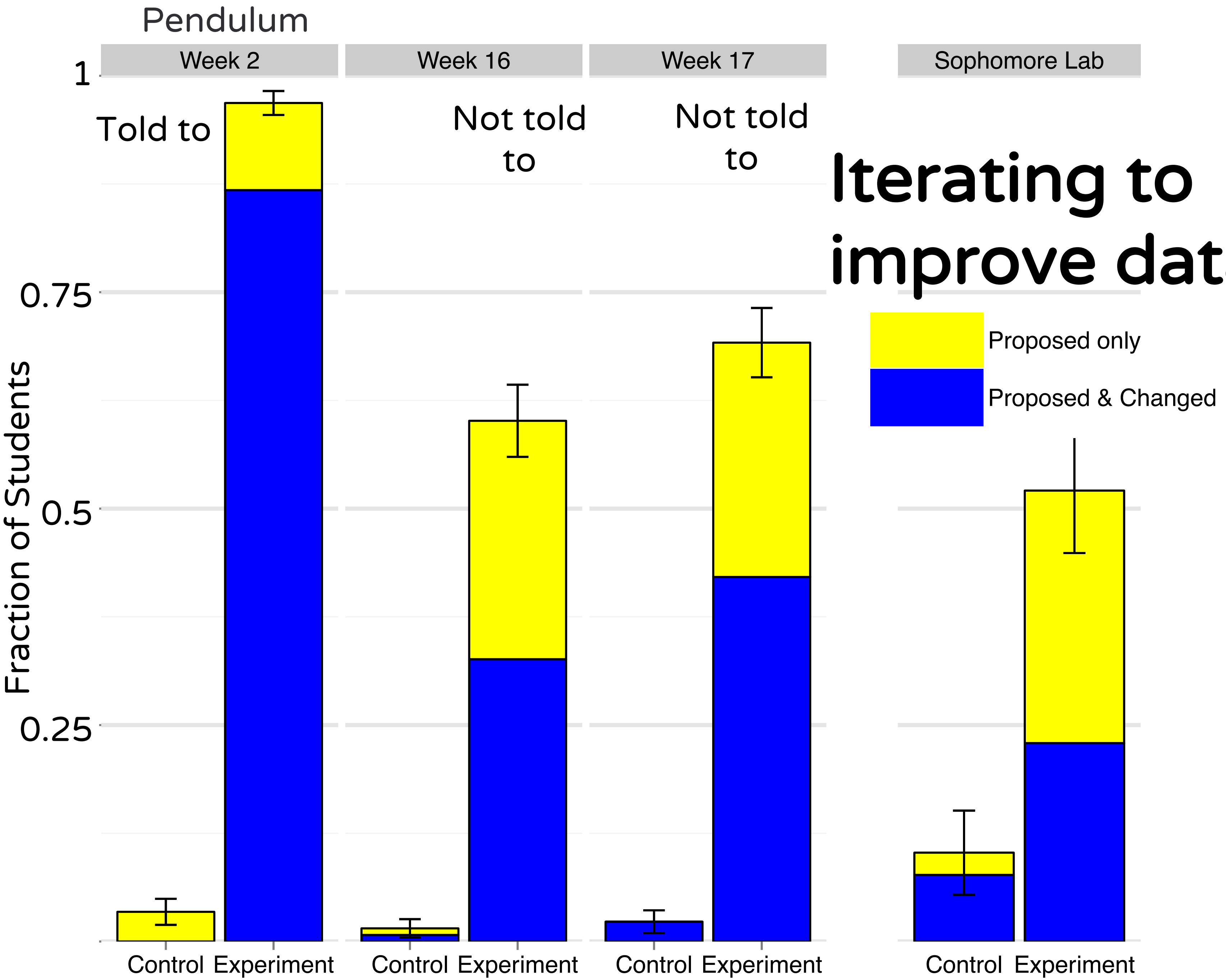
Iterating to improve data

Proposed only

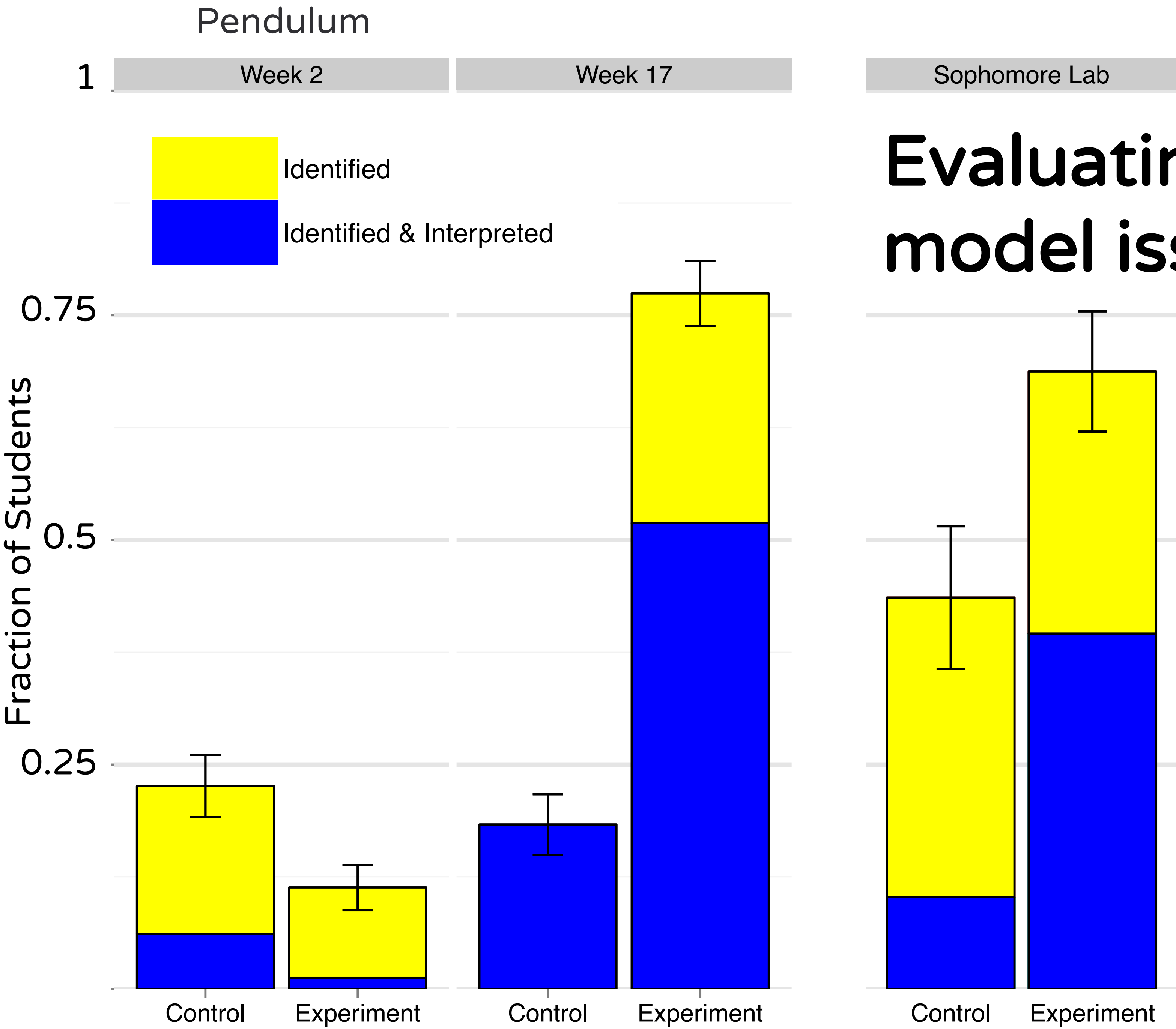
Proposed & Changed

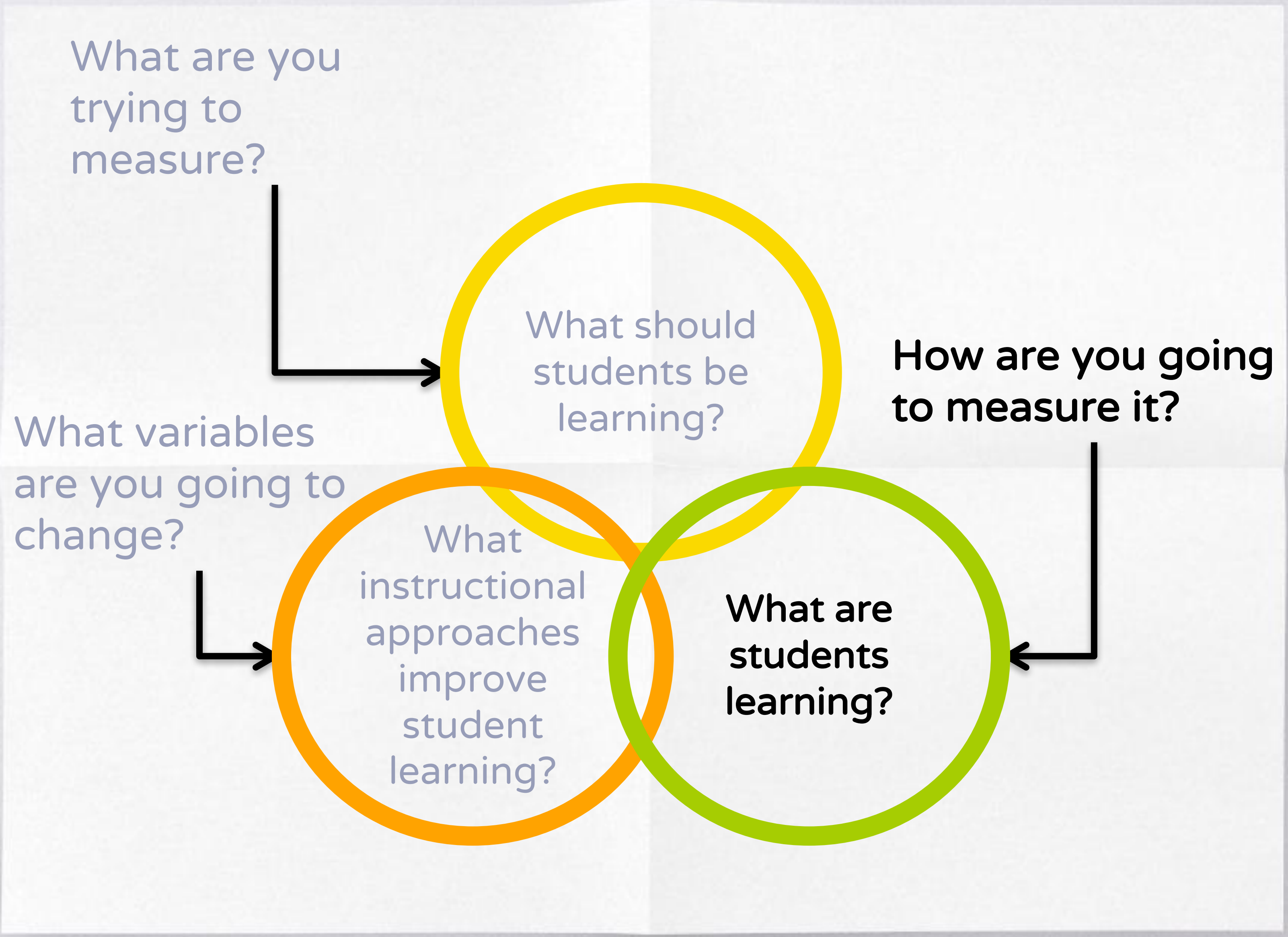
Control Experiment Control Experiment Control Experiment Control Experiment

Iterating to improve data



Evaluating model issues




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?

1. Read through their lab notes

the opposite of the expected happened:

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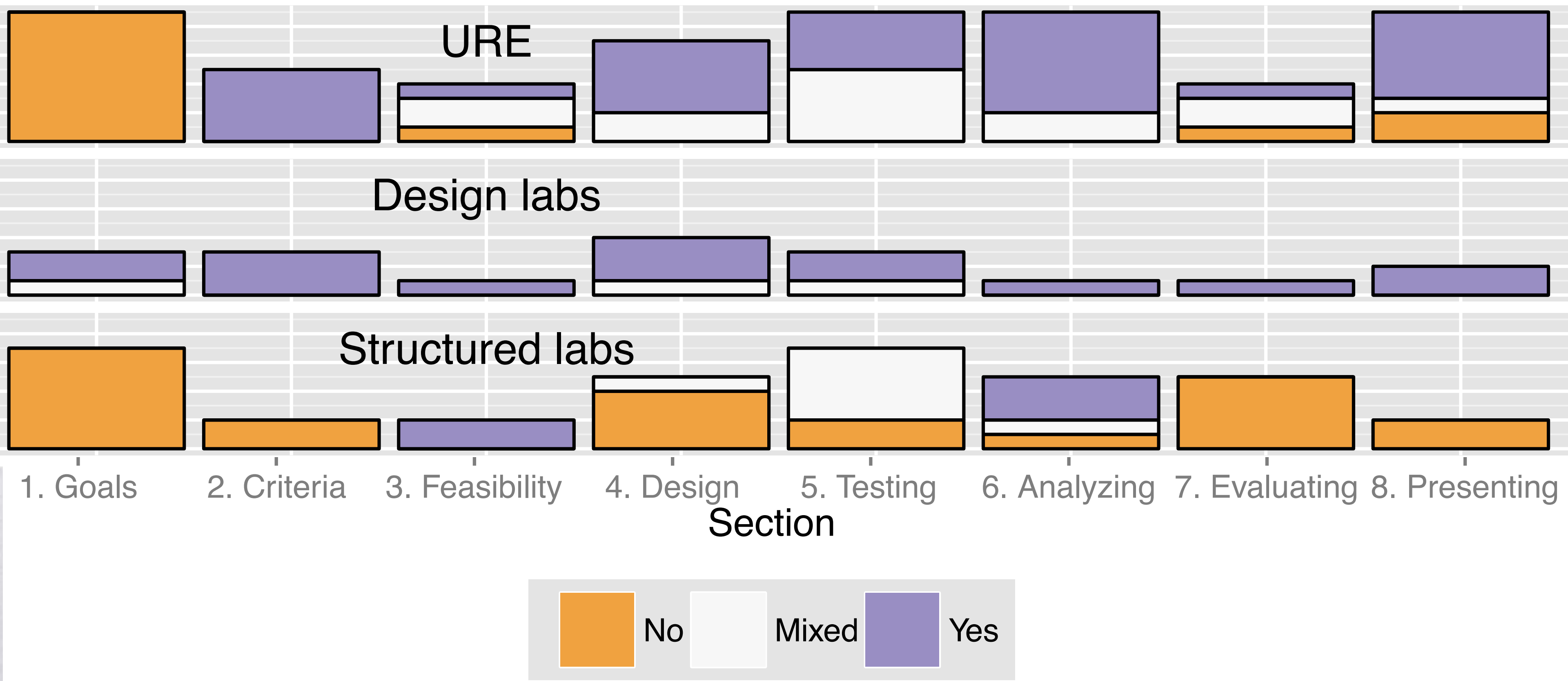
If you can make a precise enough measurement, you can show that the theoretical derivation of the equation of motion for a pendulum is just a 'good approximation' and reality is slightly more complicated.

2. Interview them



3. Design something more efficient

- Assess critical thinking in an efficient, standardized way
- Useable by instructors in different courses at any institution

Physics Lab Inventory of Critical thinking

PLIC

PLIC context

- Case studies of two student groups completing a mass on a spring experiment

Structure

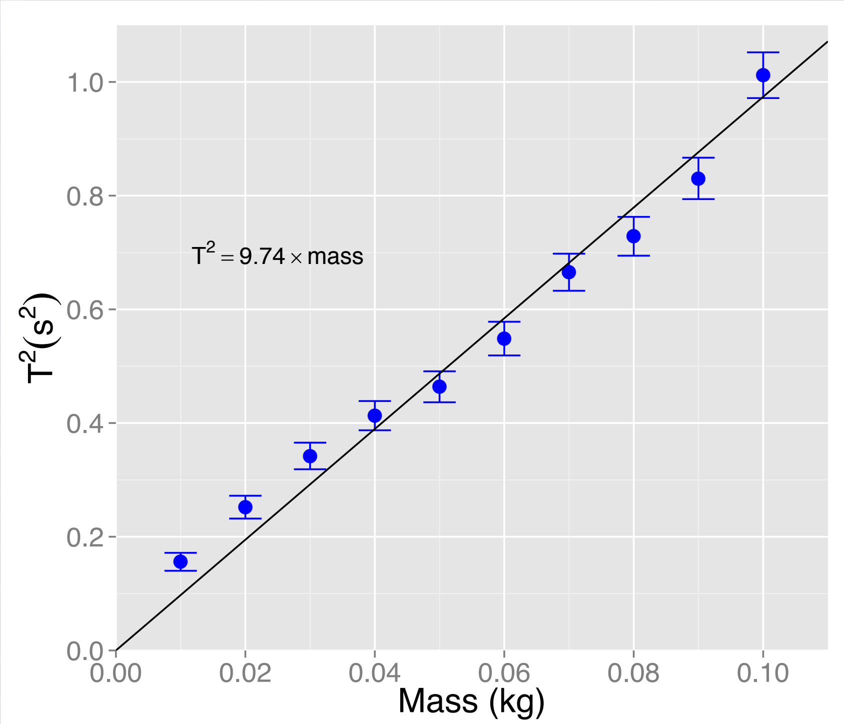
- Online (Qualtrics)
- 4 sections, 2-4 questions per section
- Scoring based on alignment to experts (like C-LASS, E-CLASS)
- Paired questions (similar to Coupled Multiple Response)
  - Wilcox BR, Pollock SJ (2014) *Phys Rev ST- PER*

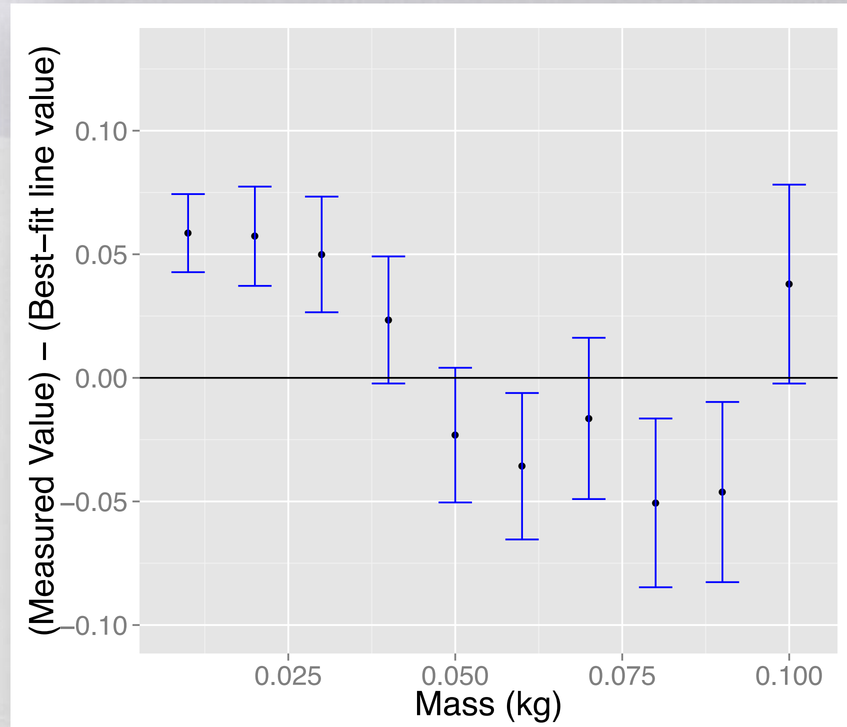
For example

Students record the time for 5 bounces of a spring with 10 different masses hanging.

↓

They plot the period (squared) as a function of mass and get:

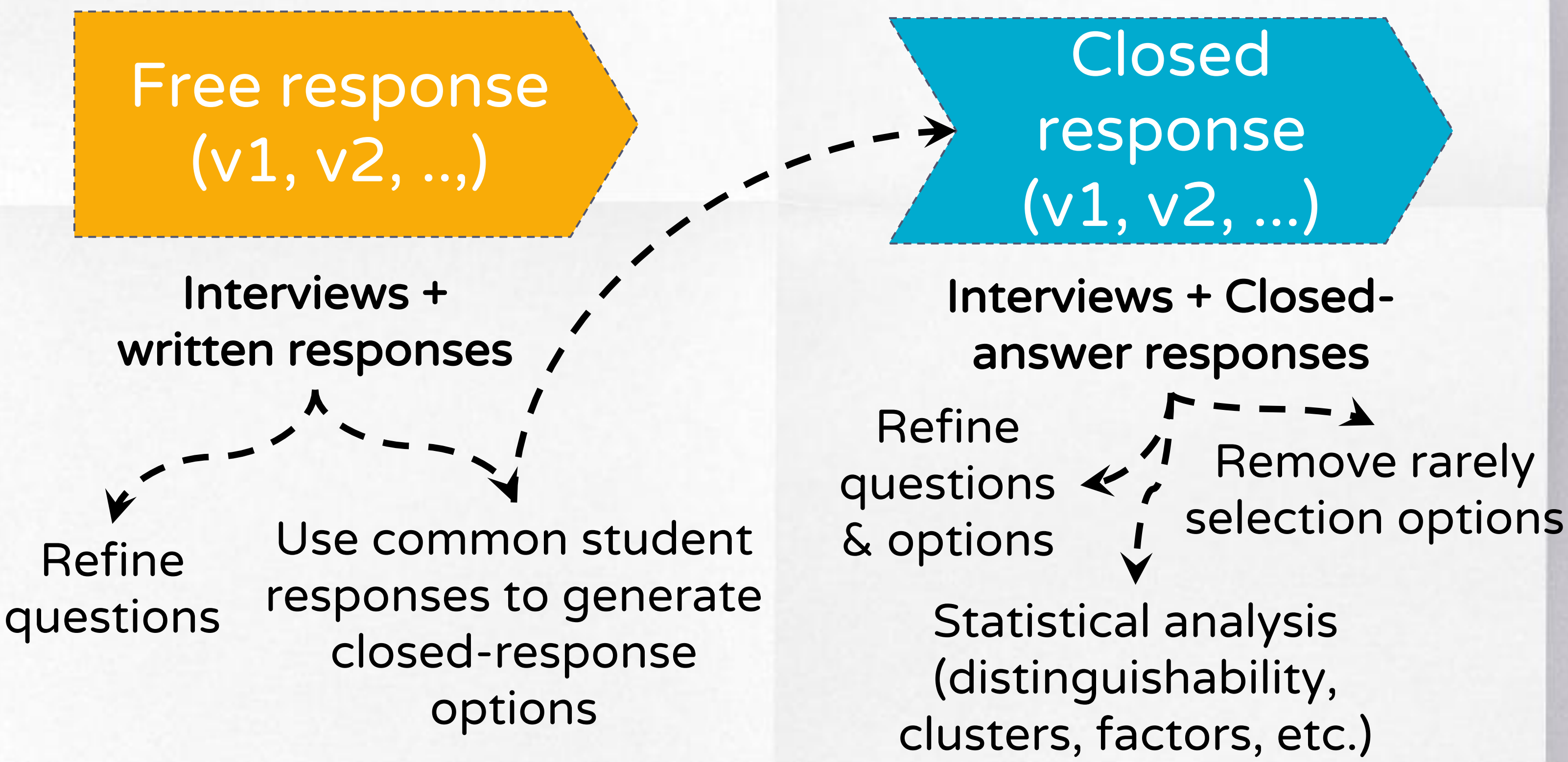




a) How well do you think the data fit the line?
(Scale 1 [very bad fit] to 5 [very good fit])

b) Which items below best support your reasoning?
- The data are in a straight line
- There are the same number of points above and below the line
- The points are randomly distributed above and below the line
- The points are close to the line
- There are too few points with error bars crossing the line…

Generating a closed-response survey



Want to use the PLIC?

Contact me (ngholmes@cornell.edu)

Also looking for responses from experts!

Next up...

But how?

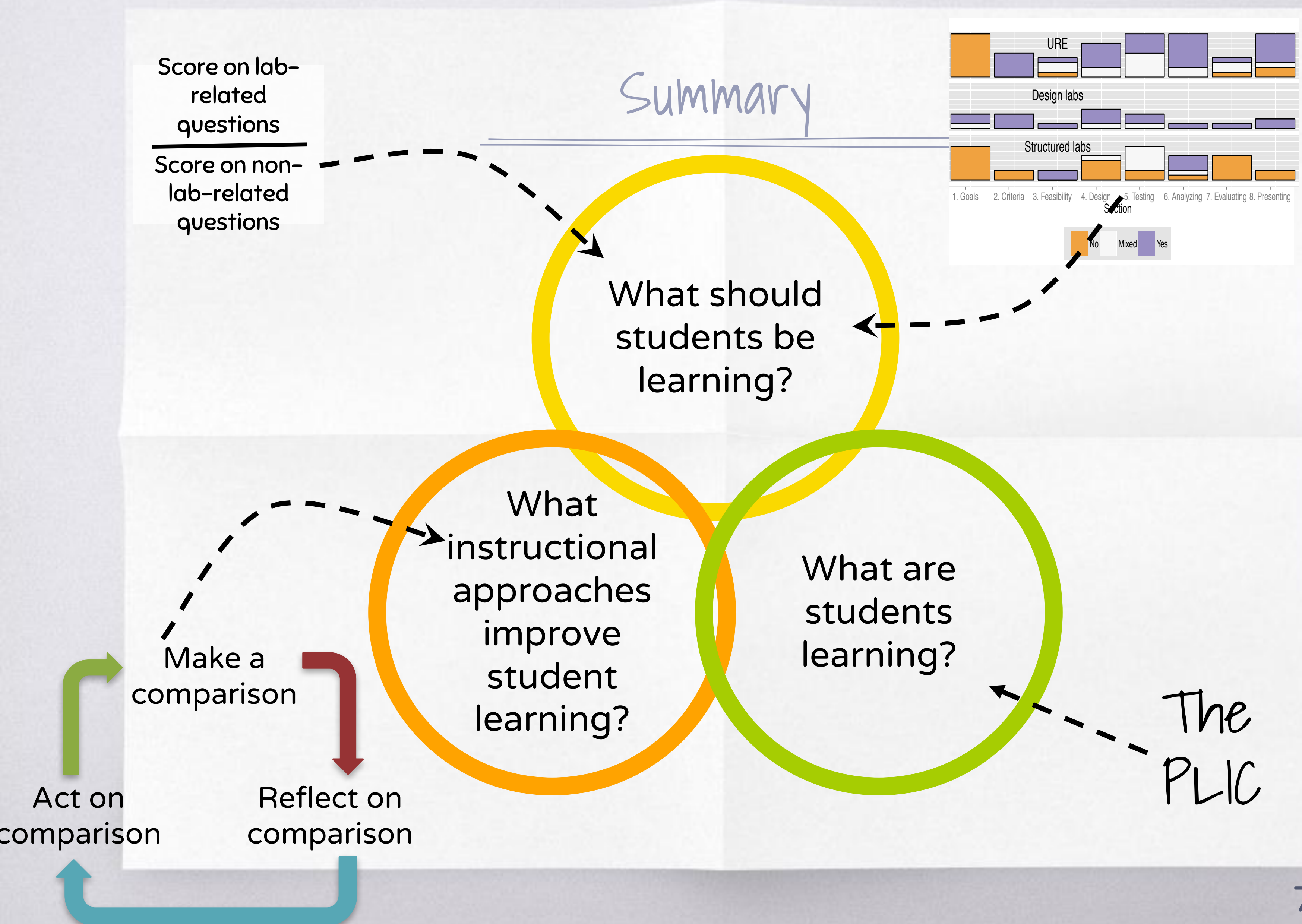
- Digging into the mechanism of developing critical thinking

So what?

- Does critical thinking in intro physics transfer?

For who?

- Does critical thinking instruction differentially impact different students?


Score on lab-related questions
Score on non-lab-related questions
Summary
URE
Design labs
Structured labs
1. Goals
2. Criteria
3. Feasibility
4. Design
5. Testing
6. Analyzing
7. Evaluating
8. Presenting
Section
No
Mixed
Yes
What should students be learning?
What instructional approaches improve student learning?
What are students learning?
The PLIC
Make a comparison
Reflect on comparison
Act on comparison

Cornell Physics Education Research Lab

Natasha Holmes

Katherine Quinn

Your photo here?

We're hiring postdocs and recruiting students! Contact me!

Collaborators

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

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

Other
Jack Olsen (University of Washington)
James Thomas (University of New Mexico)

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