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Rethinking introductory physics lab courses

AAPT New Faculty Workshop, June 13th 2017

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a place of mind

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...

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.

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

Awful

Outdated!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.

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.

formulaic.

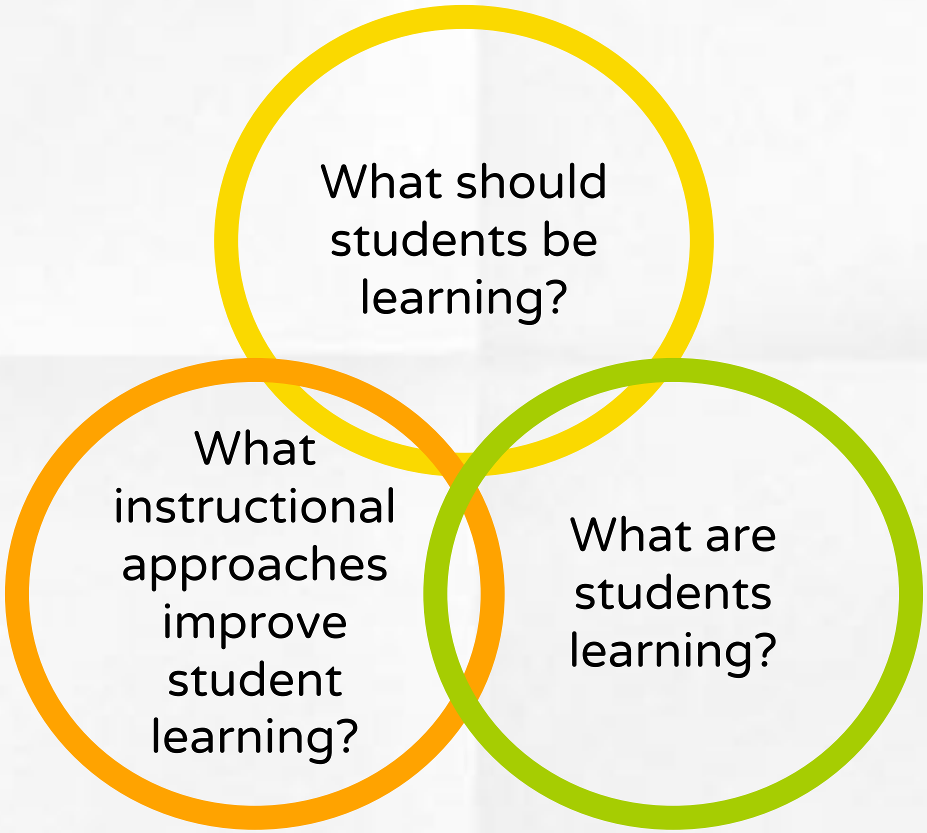
cookbook.

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

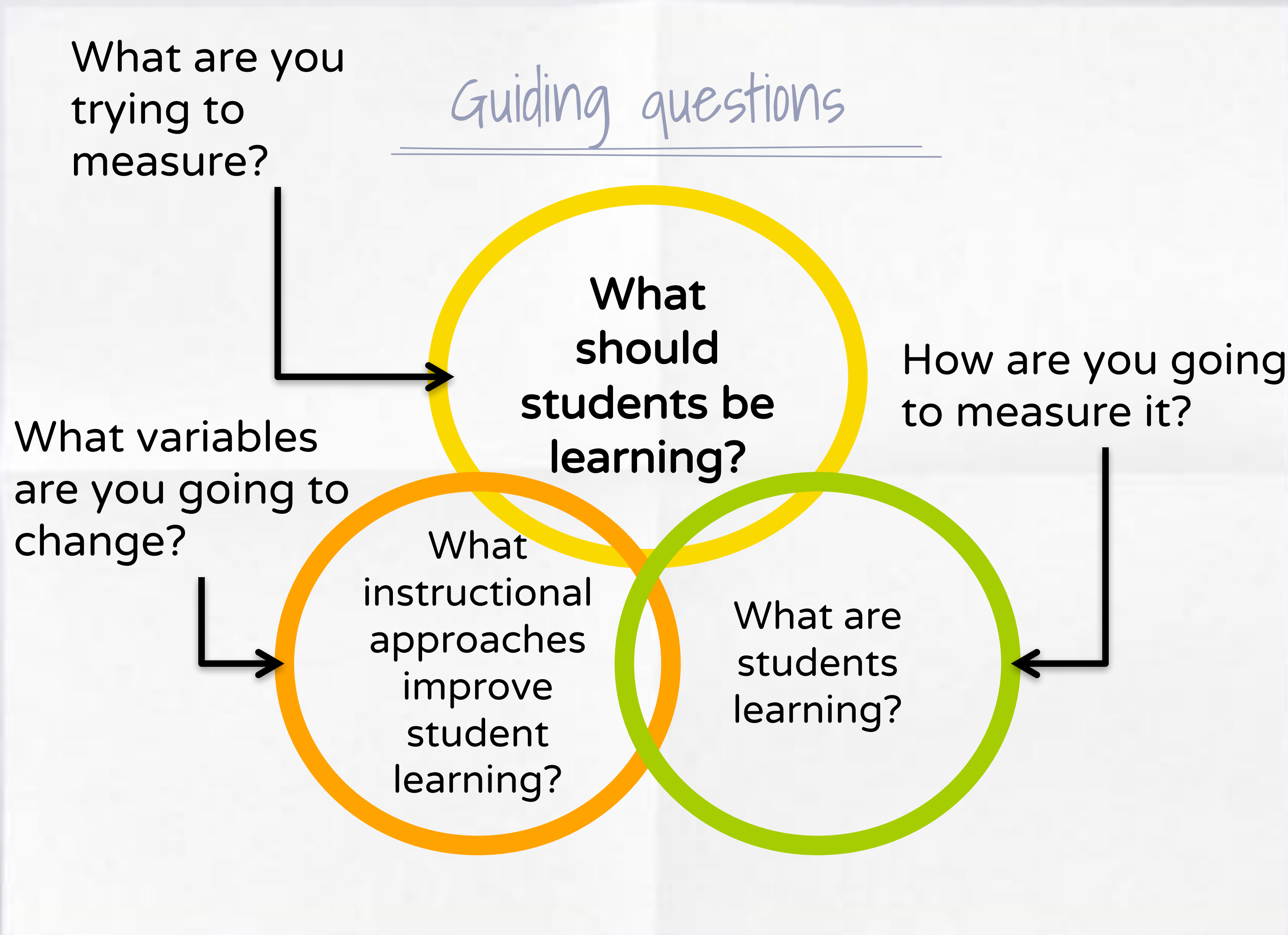
pretty cookbookish, felt very disconnected from the physics we were learning in the courses.

..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

Guiding questions



Modified from Science Education Initiative “three-pronged approach” for course transformation



Modified from Science Education Initiative "three-pronged approach" for course transformation

What are the goals of physics lab courses?

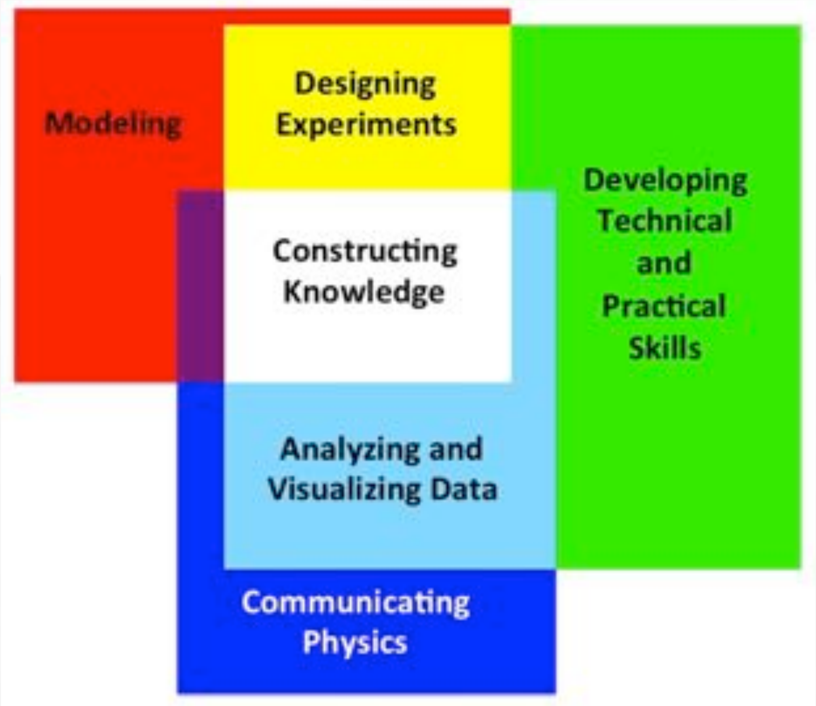
- ***Think*** :
  List some goals of intro physics labs
- ***Pair*** :
  Discuss them with your neighbor
- ***Share***:
  Discuss with the group

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...

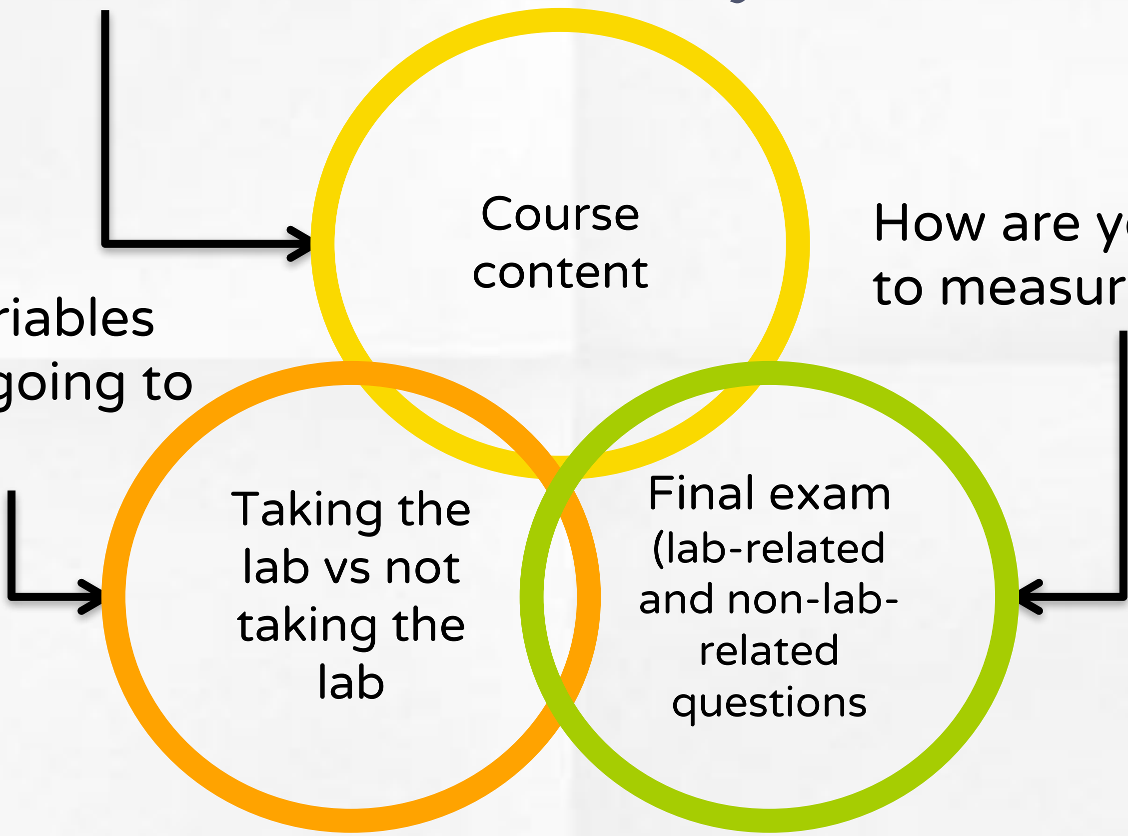
- Understanding scientific concepts
- Interest and motivation
- Practical skills and problem solving abilities
- Scientific habits of mind
- Understanding the nature of science and measurement

Studying the impact of labs on reinforcing course content

What are you trying to measure?

What variables are you going to change?

How are you going to measure it?



Holmes, Olsen, Thomas, & Wieman (2017) *Phys. Rev. PER*
Holmes & Wieman (2016) *Am. J. Phys.*

Must account for selection effects

Students who take the lab

≠

Students who do not take the lab

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

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

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

Features:

- 3 very different populations of students

- Varied instructional approaches

- All three shared the goal to reinforce material in the rest of the course

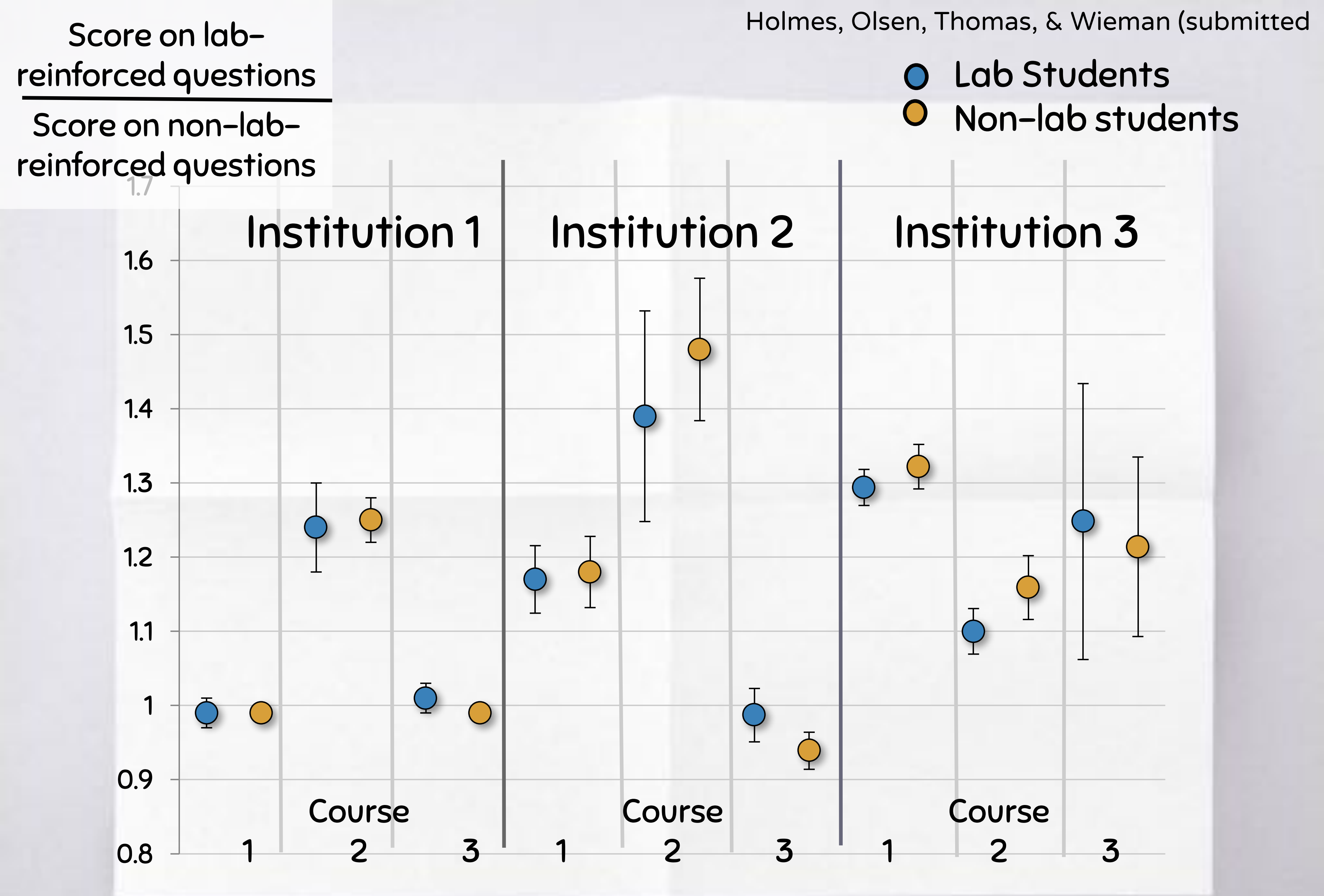
Labs were designed to achieve that aim (e.g. making predictions, comparing results to predictions, etc.), generally quite prescribed

Prediction

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

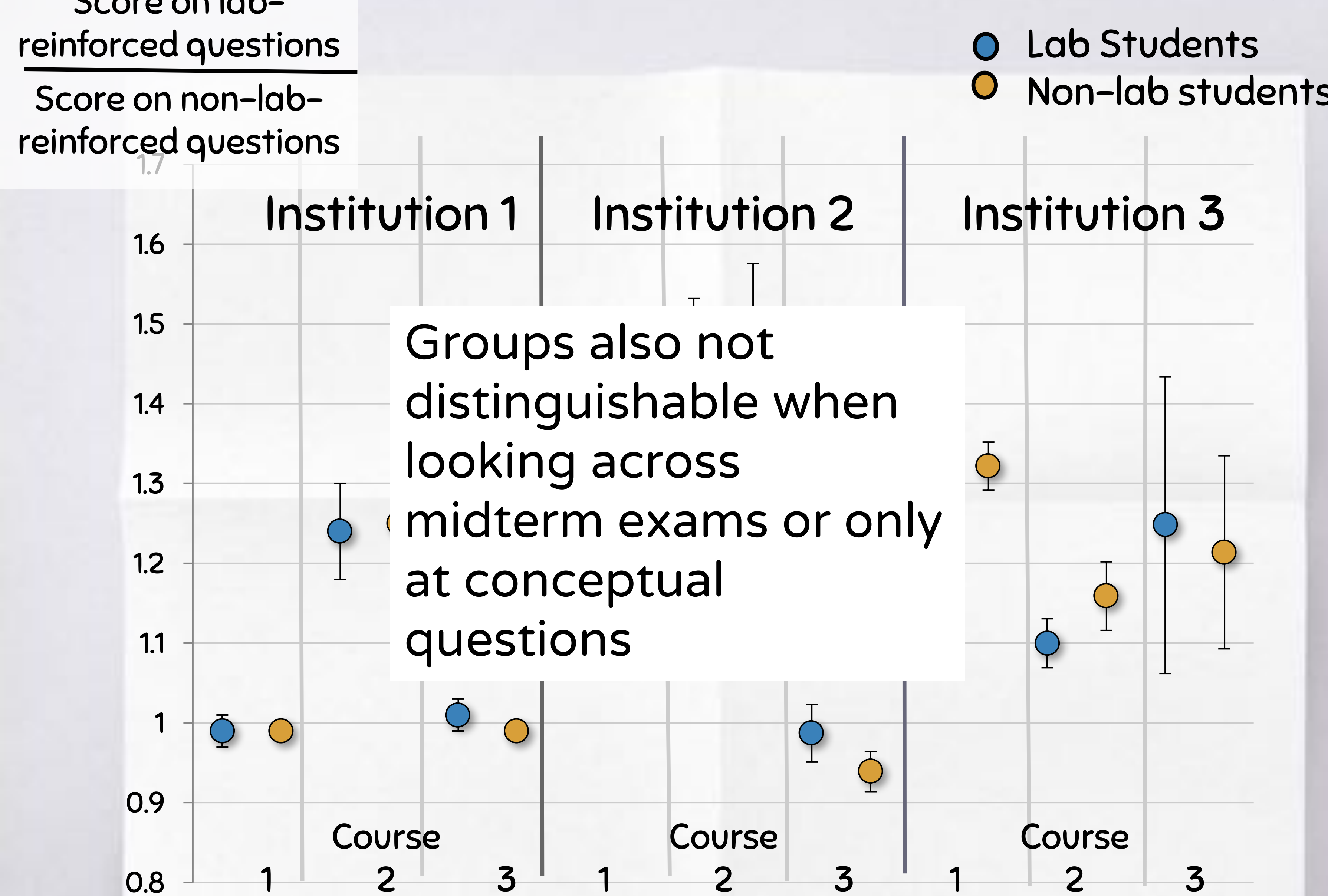
A. Ratio will be greater for lab students
B. Ratio will be greater for no-lab students
C. Ratio will be the same for both groups

Holmes, Olsen, Thomas, & Wieman (submitted



Final exams

Holmes, Olsen, Thomas, & Wieman (submitted



Groups also not distinguishable when looking across midterm exams or only at conceptual questions

Final exams

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.

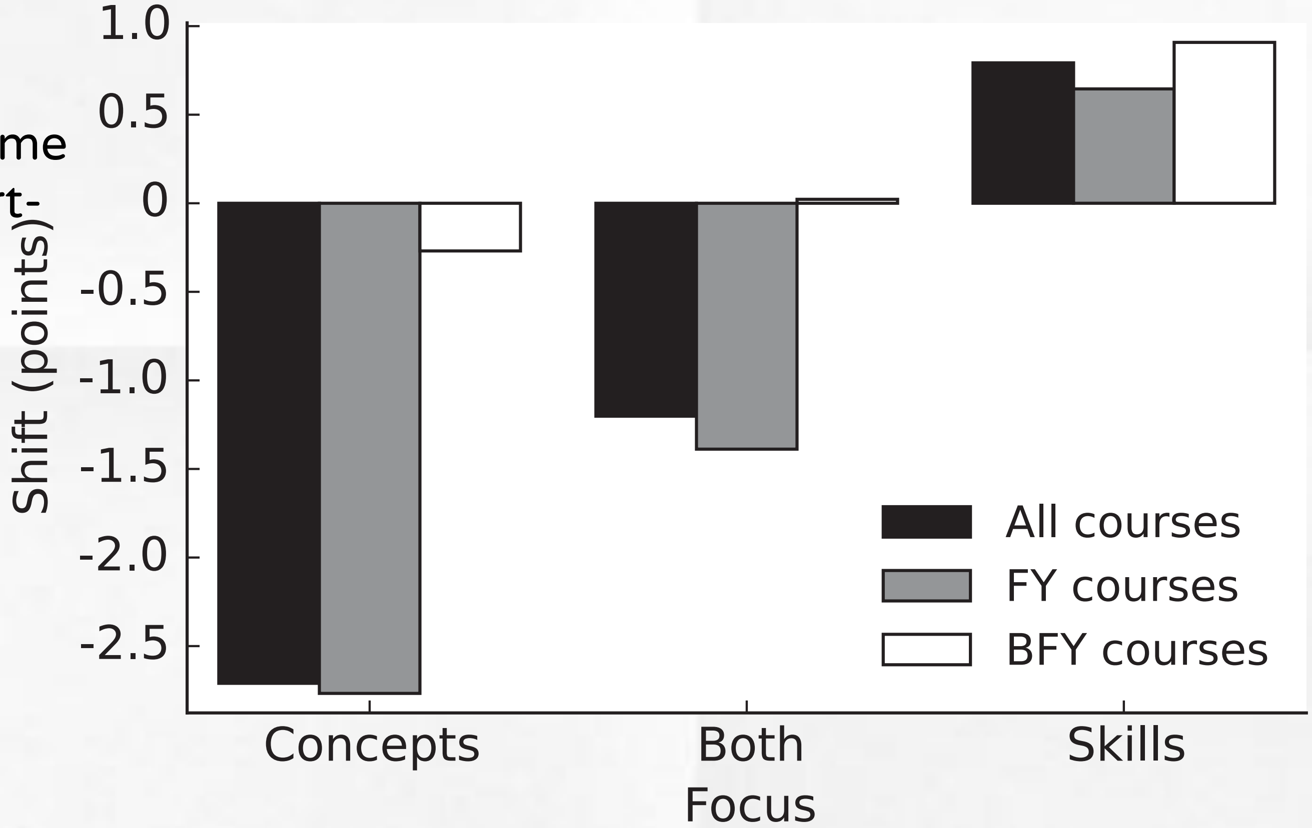
- When doing an experiment, I try to understand how the experimental set up works.
- When doing a physics experiment, I don't think much about sources of systematic error.

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

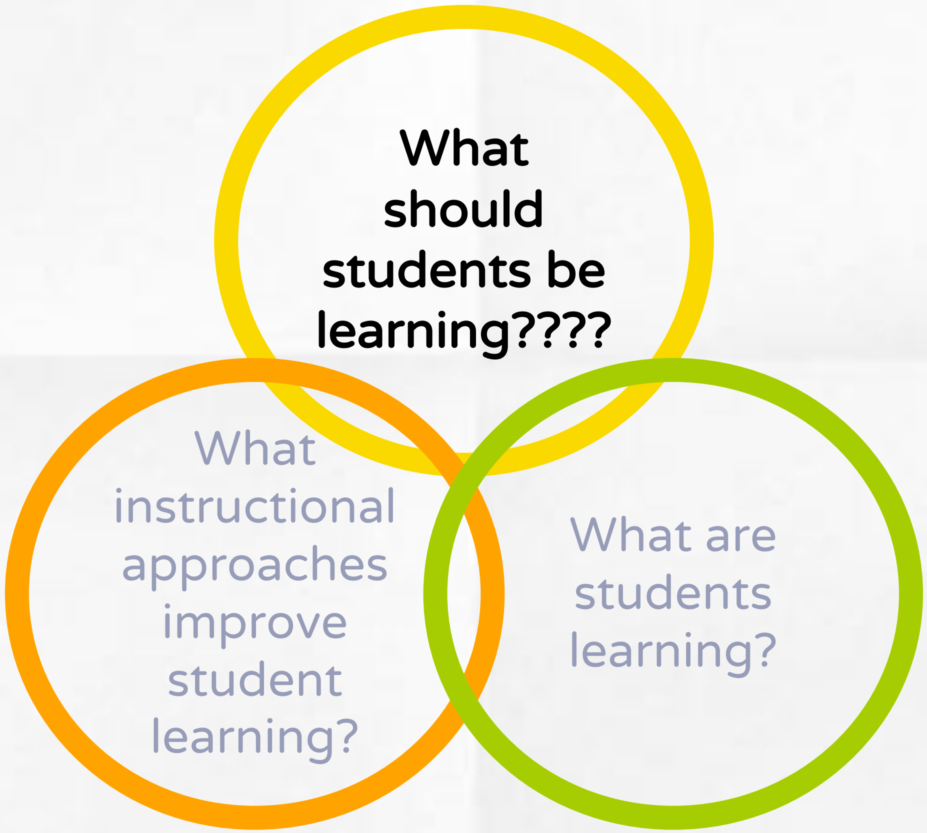


Wilcox & Lewandowski (2017) Phys. Rev. PER **13**, 010108

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

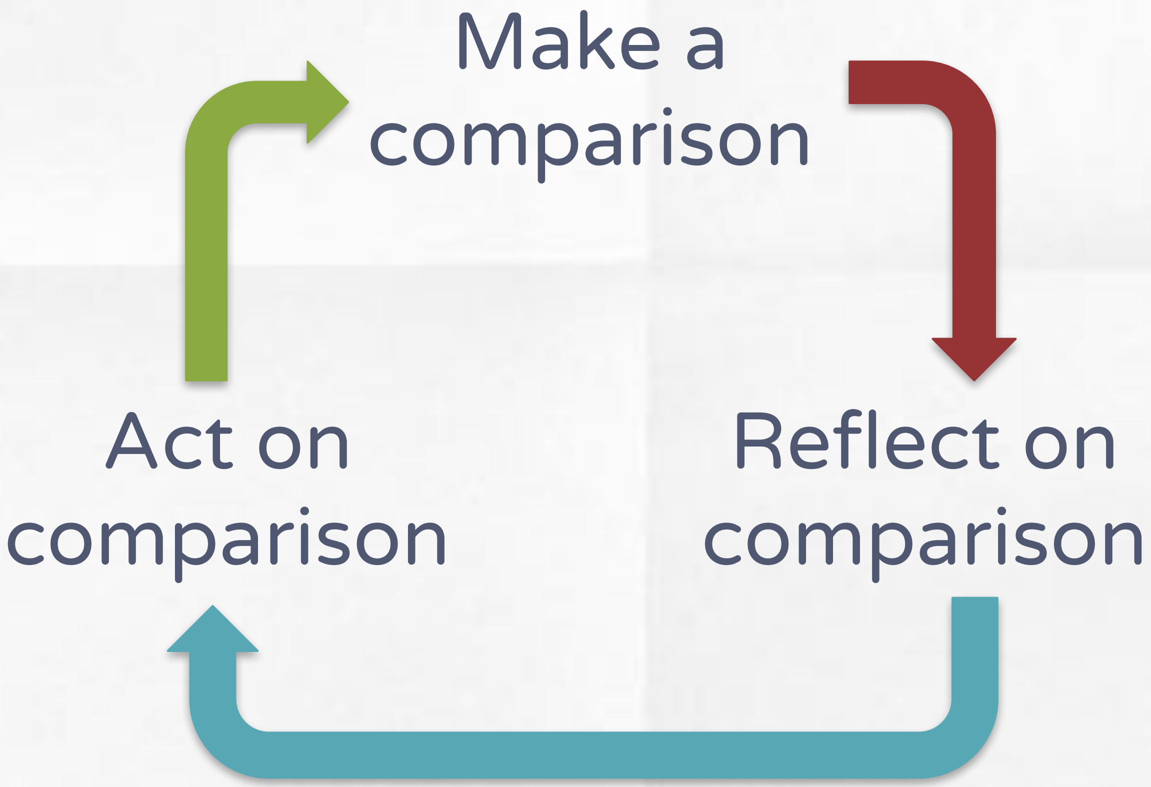
Understanding the nature of science and measurement

Quantitative **critical** thinking

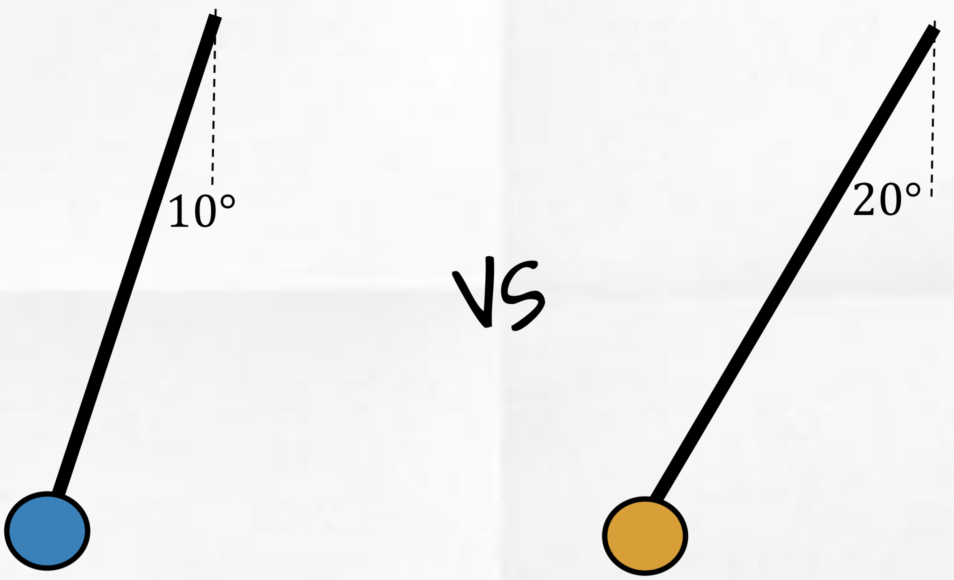
The process through which you make **decisions** and decide what to believe

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

Quantitative critical thinking

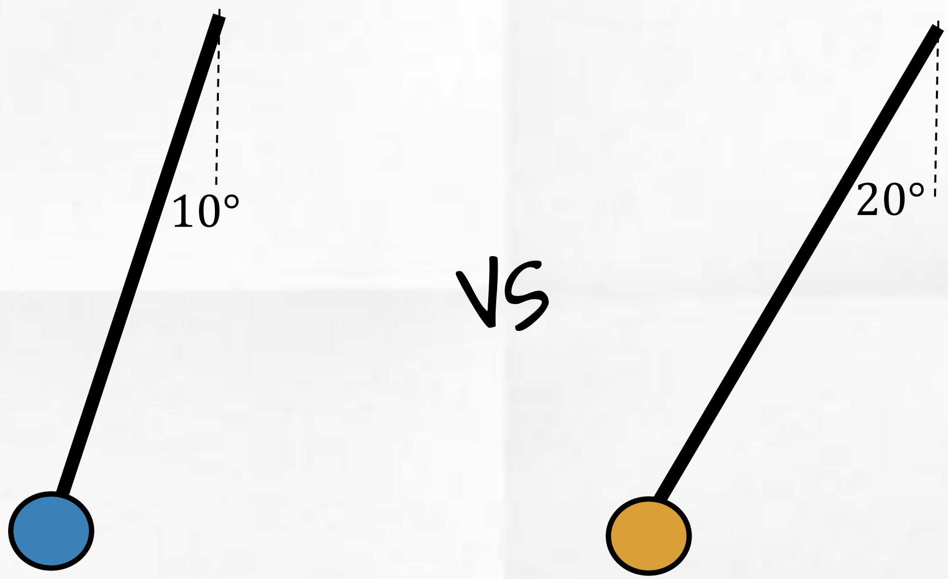


Compare period of pendulum at different amplitudes



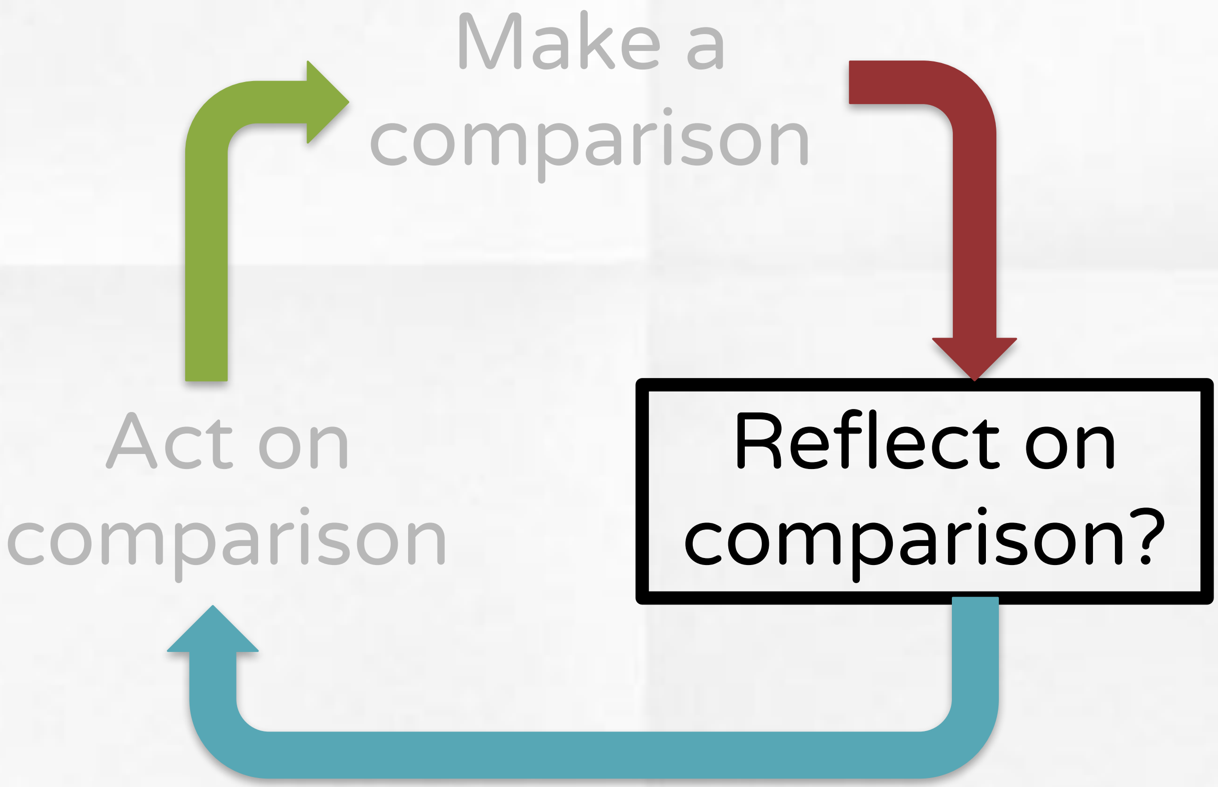
- Measure time for single period, T
- Repeat 10 times, find average, standard error

Compare period of pendulum at different amplitudes



T= 1.84 ± 0.08 s   T= 1.81 ± 0.08 s

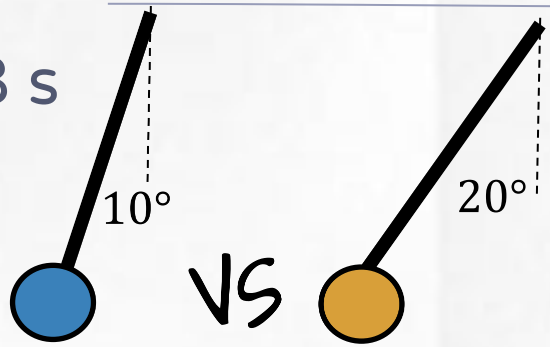
Quantitative critical thinking



Compare period of pendulum at different amplitudes

T= 1.84 ± 0.08 s

T= 1.81 ± 0.08 s



$$T_{10} - T_{20} \approx 0.2\sigma$$

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

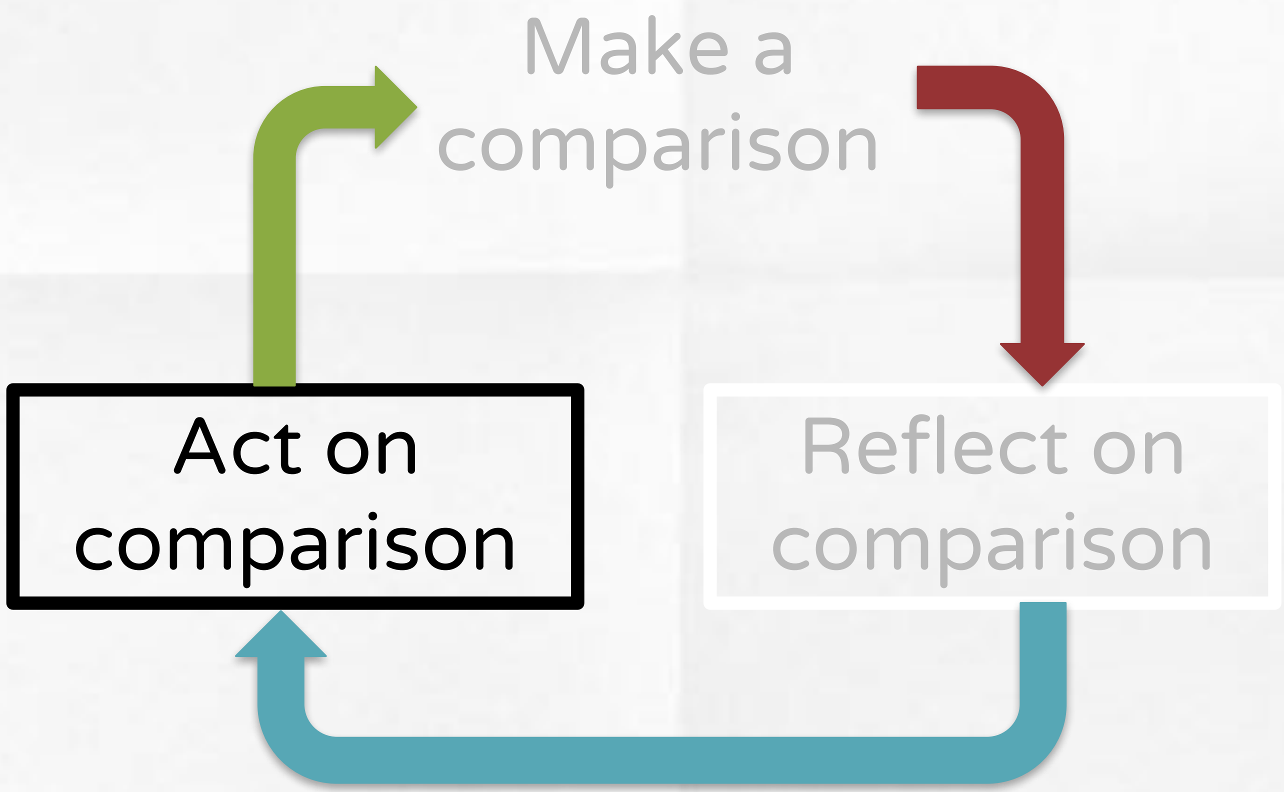
What might a difference of $\sim 0.2\sigma$ mean?

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

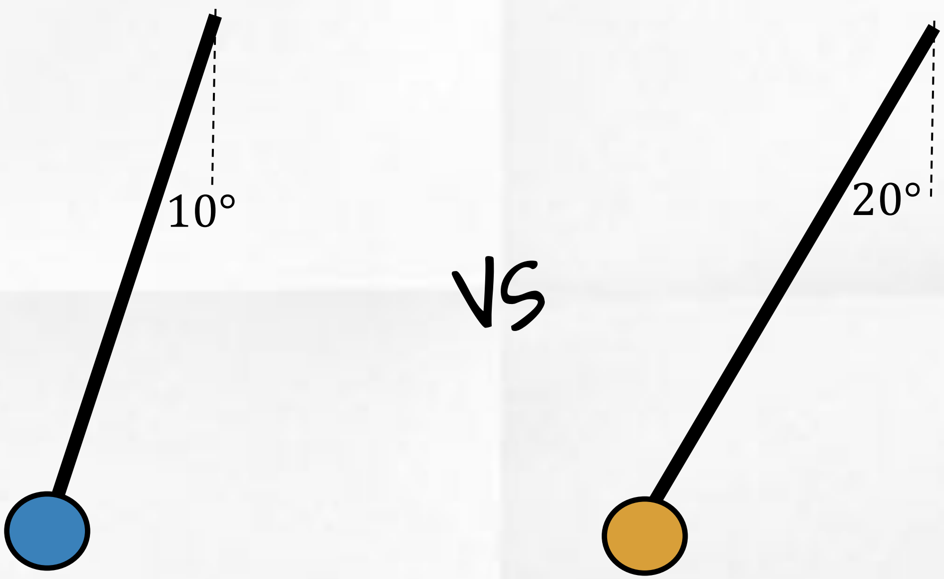
$$Diff = t' = \frac{T_{10°} - T_{20°}}{Uncertainty}$$

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 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?

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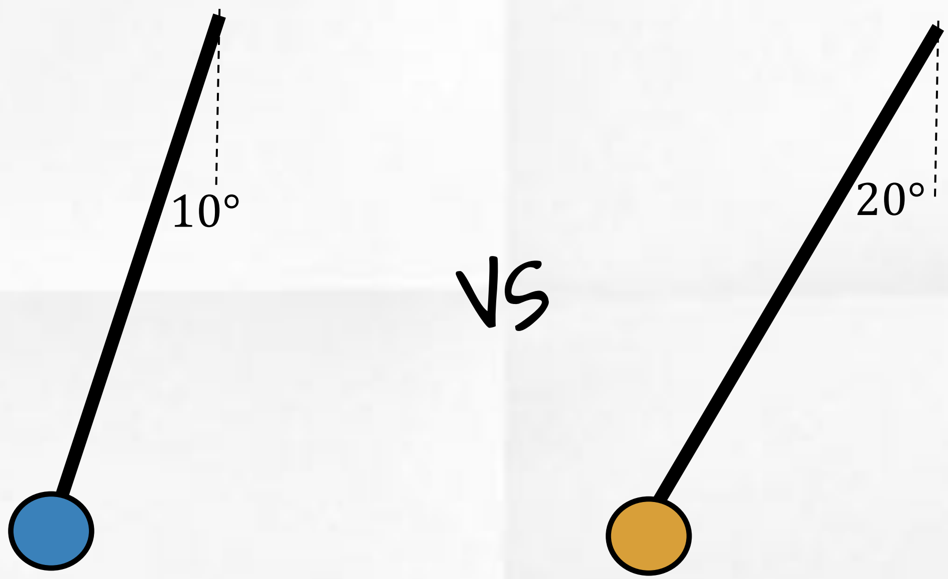
What should they do next?



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:

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

Conclusion:

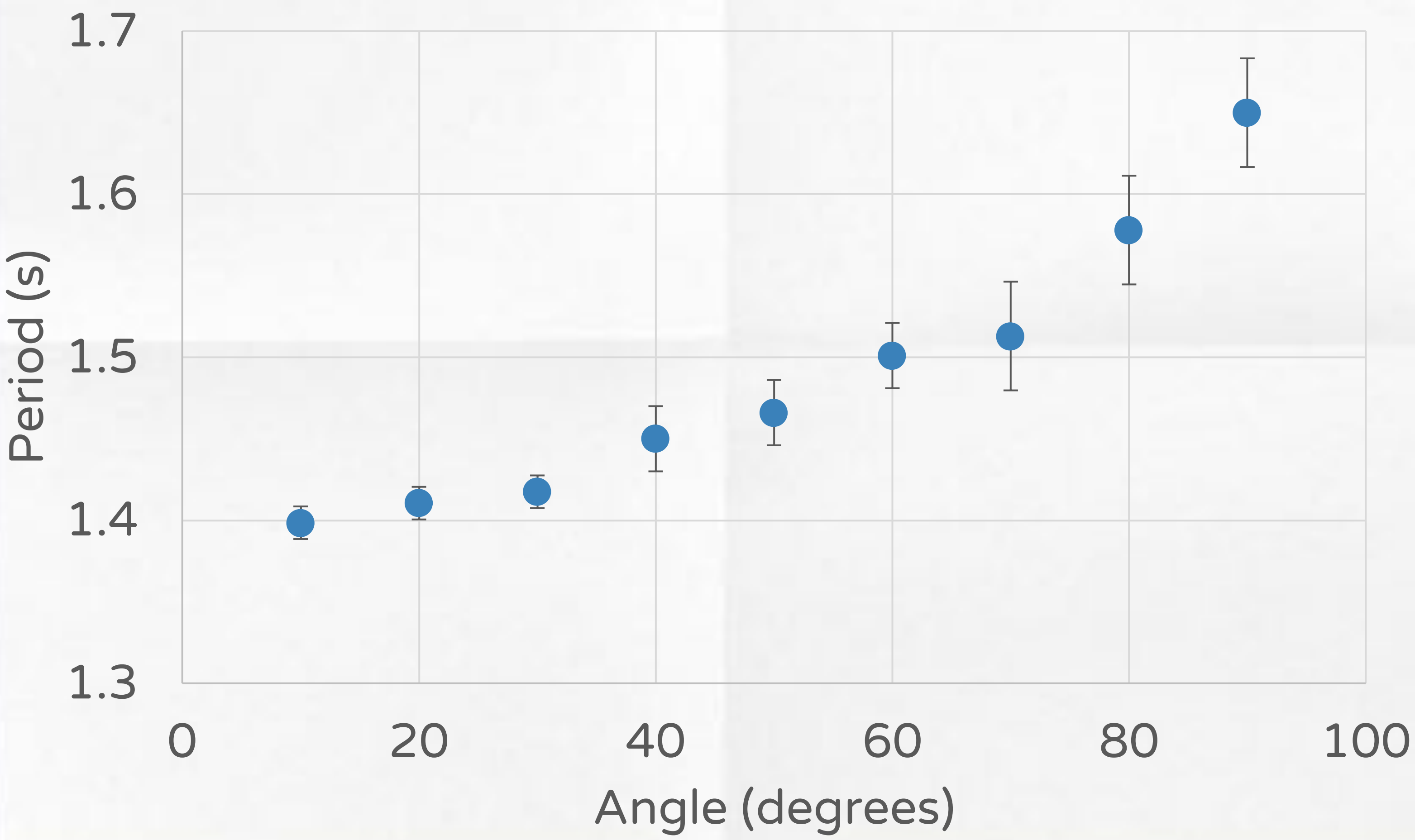
The period of a pendulum does depend on the angle with the vertical in the initial position.

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

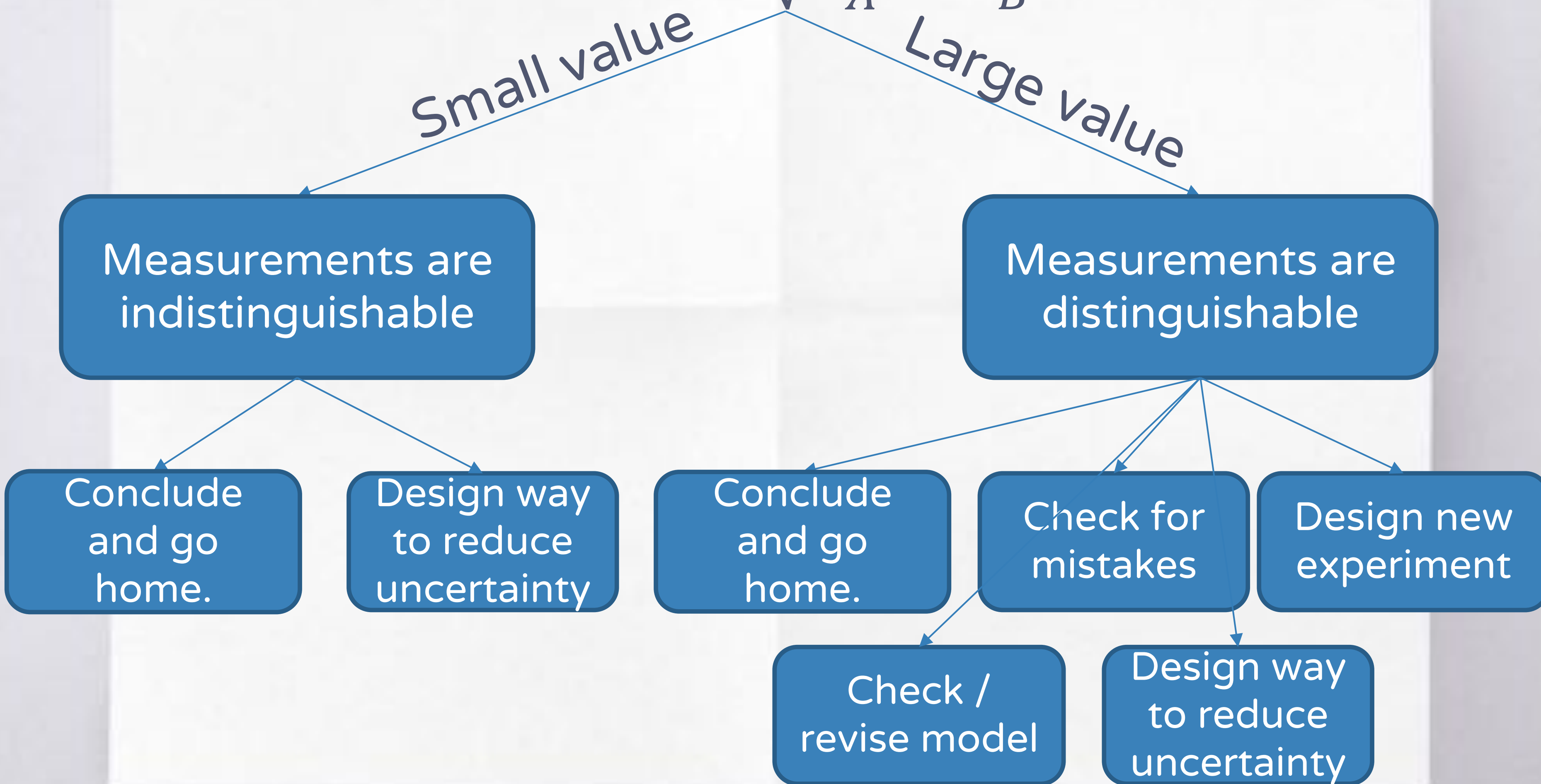
Considering the results of this experiment, 20° is obviously not 'small' enough since the angle has an effect on the period T and should be somehow represented in the formula.

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

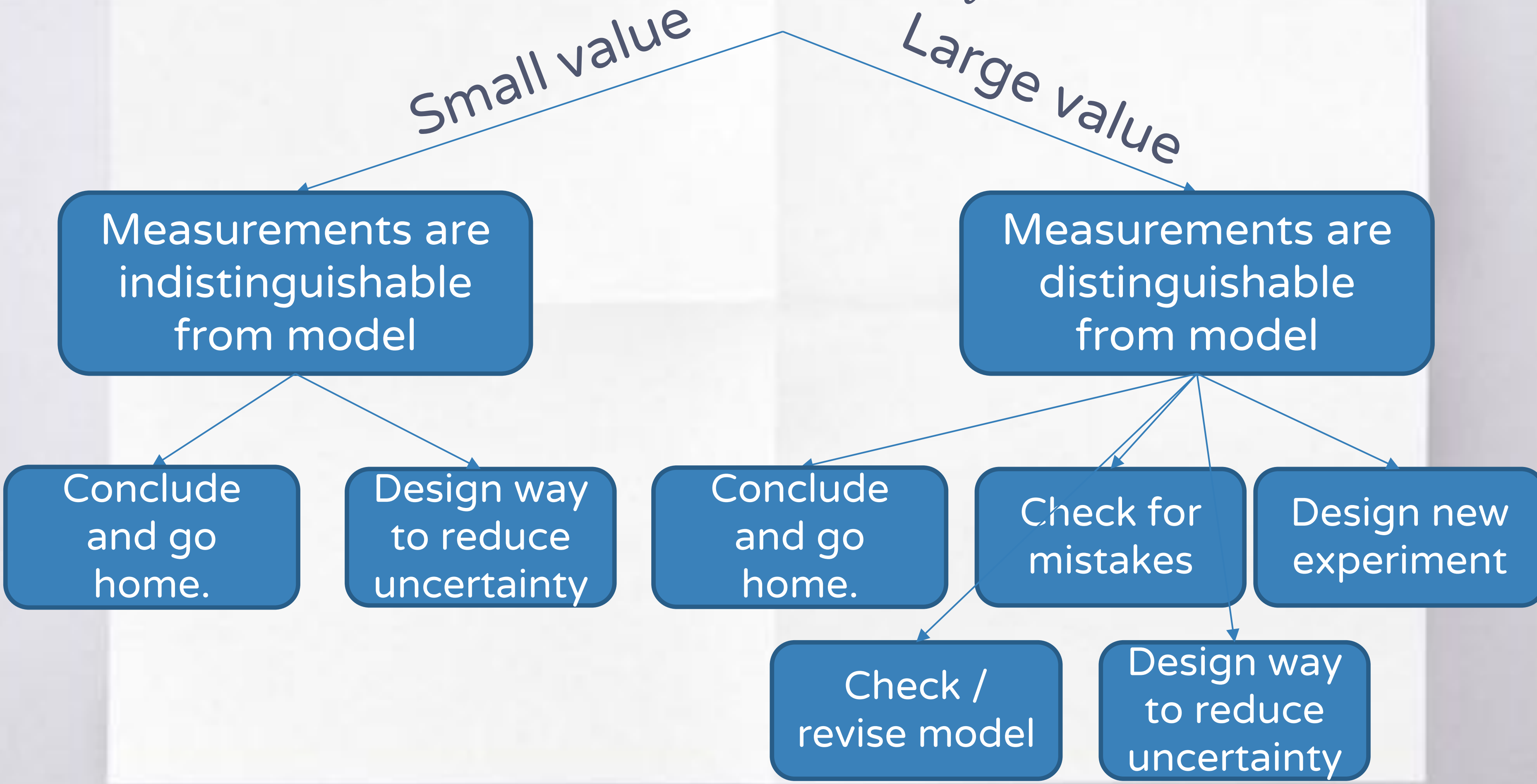
Period as a function of angle



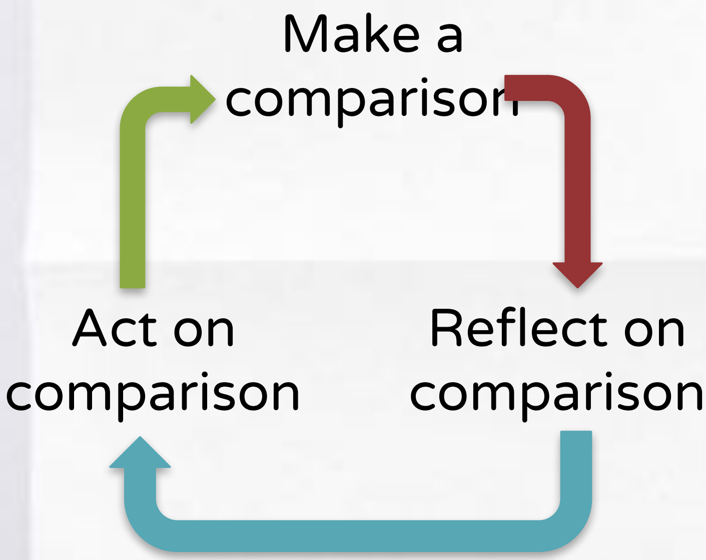
$$Diff = \frac{A - B}{\sqrt{\delta_A^2 + \delta_B^2}}$$



$$\chi^2 = \frac{1}{N}\sum \frac{(f(x_i) - y_i)^2}{\delta y_i^2}$$



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?
- …

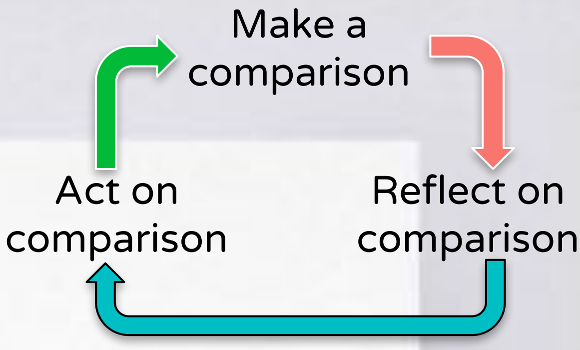
Ways to assess

- 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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