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USING PHYSICS LABS TO TEACH EXPERIMENTATION AND CRITICAL THINKING

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LEARNING GOALS

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

- List learning outcomes for lab instruction about experimentation,
- Describe the *iterative cycles* framework and explain how it teaches critical thinking, and
- Identify instructional decisions that facilitate the iterative cycles.

I will share all our materials with you after the workshop!

PLAN

Big picture (What and why)

Hands-on example (How)

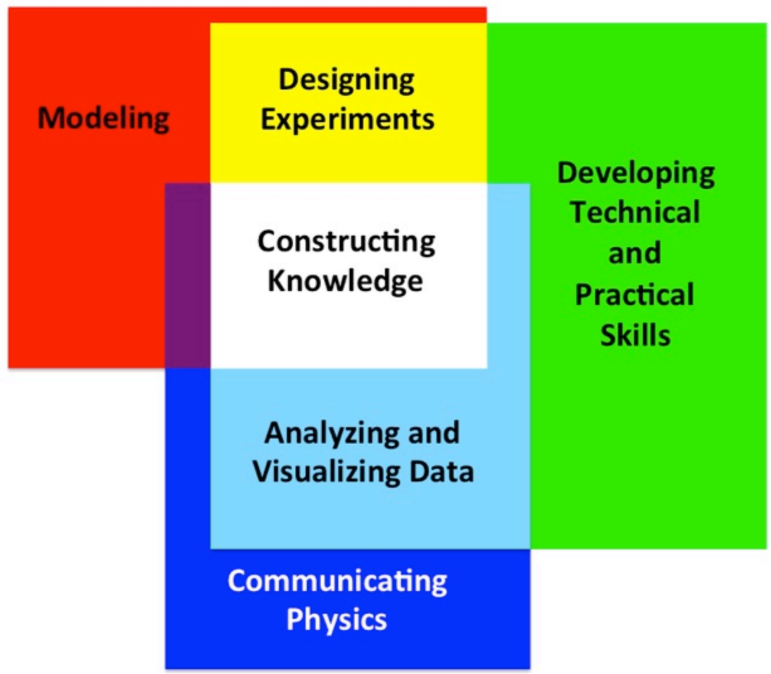
Case study (How)

Big picture (How)

Choose your own adventure:

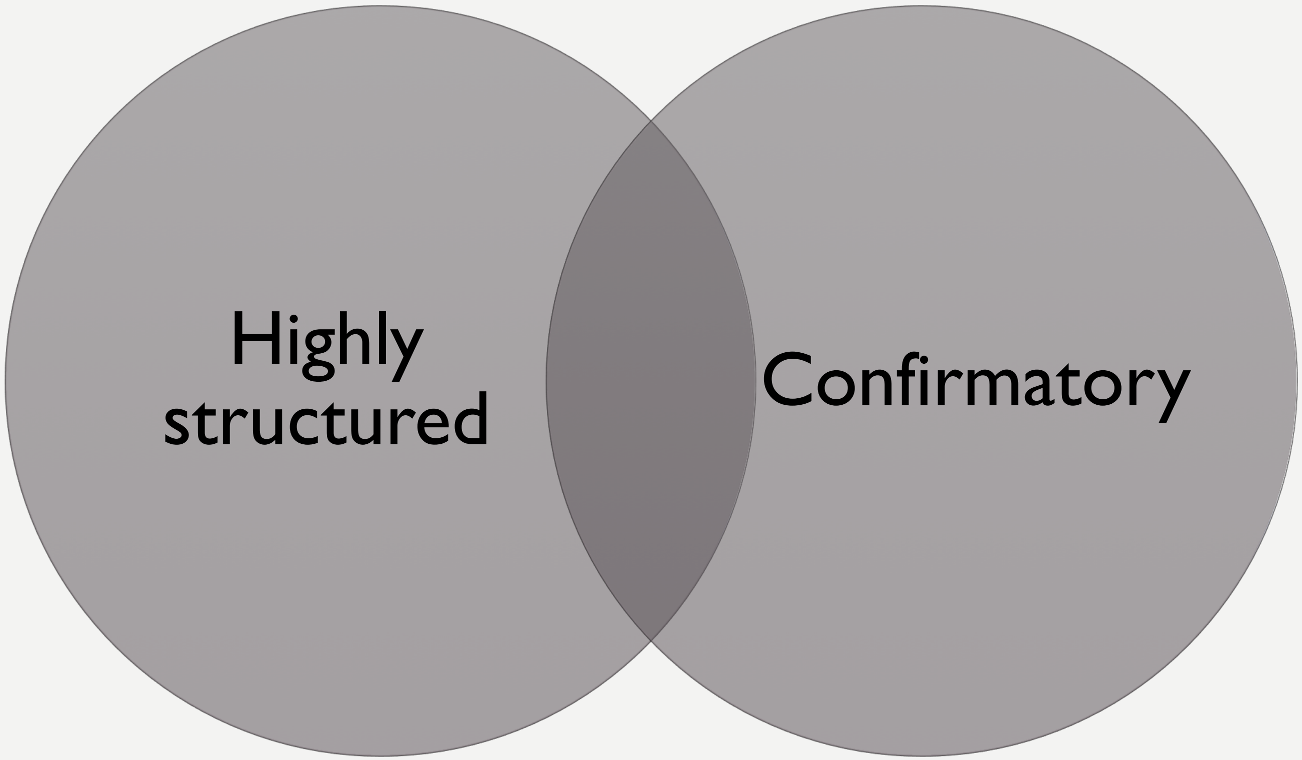
- What we do
- Design a lab
- TA training
- Grading…

AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum

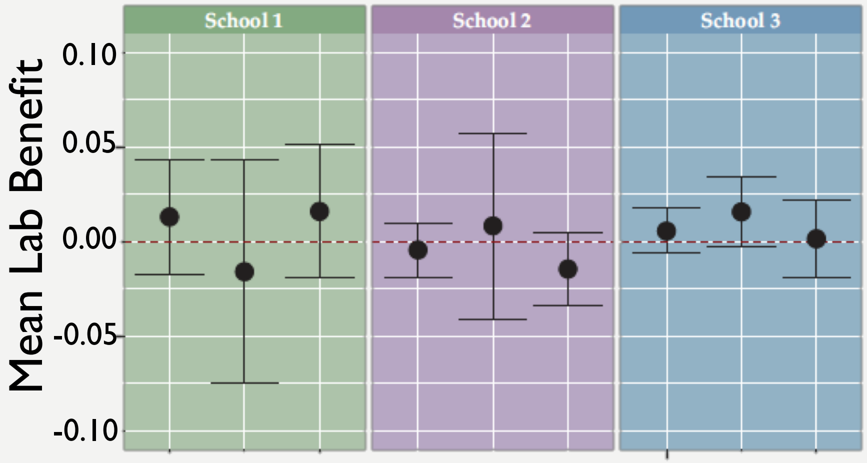


Report prepared by a Subcommittee of the AAPT Committee on Laboratories
Endorsed by the AAPT Executive Board
November 10, 2014

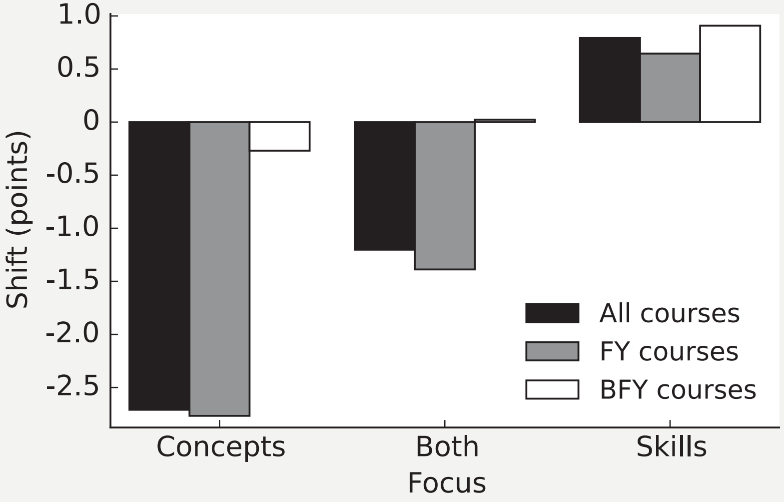
TRADITIONAL ‘VERIFICATION’ LABS



No measurable added value to learning content

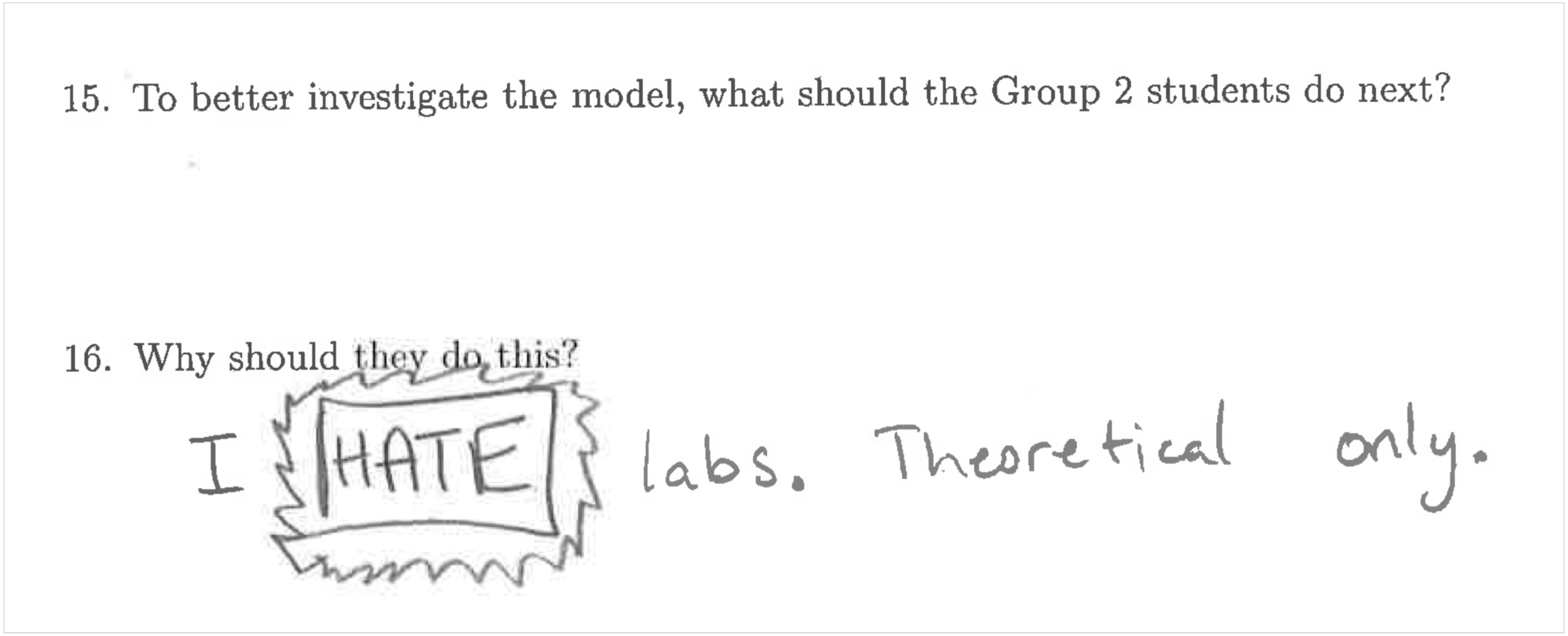


Deteriorate student attitudes towards experimental physics



THE THING ABOUT VERIFICATION LABS

Holmes & Wieman (2018); Holmes, Olsen, Thomas & Wieman (2017)
Wilcox & Lewandowski (2016, 2017)



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.

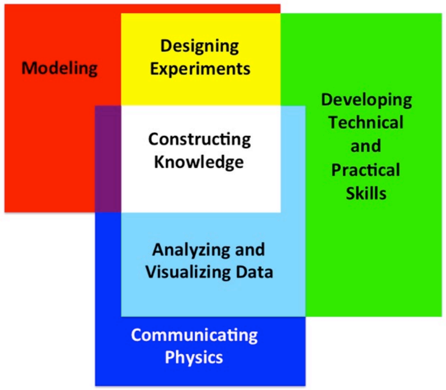
THE EXTREME CASE

WHAT IS CRITICAL THINKING?

The ways in which you make decisions about what to trust and what to do.

WHY CRITICAL THINKING?

AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum



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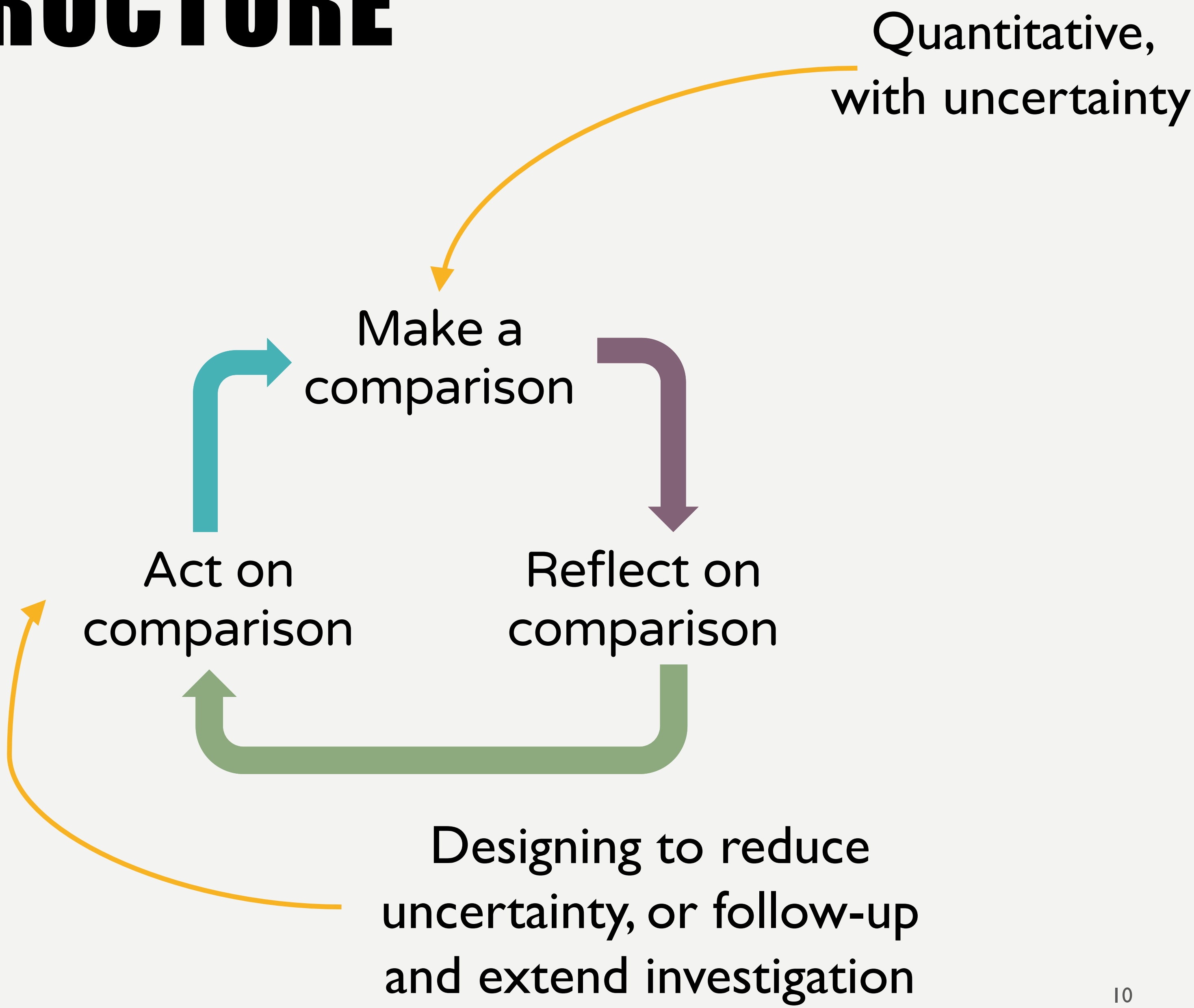
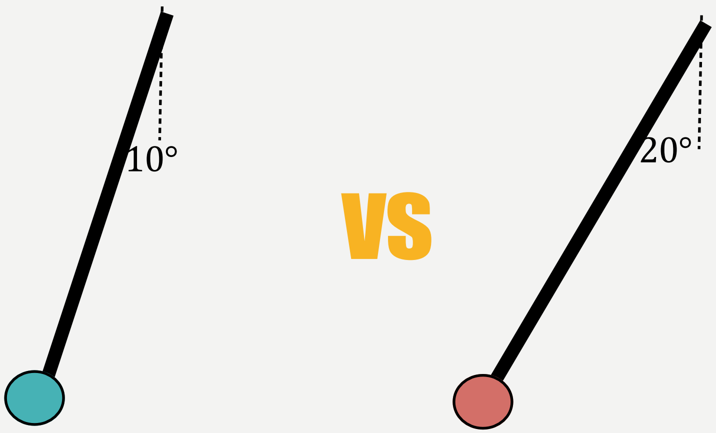
STRUCTURE


Quantitative, with uncertainty
Make a comparison
Reflect on comparison
Act on comparison
Designing to reduce uncertainty, or follow-up and extend investigation

ACTIVITY: PENDULUM FOR PROS

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

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

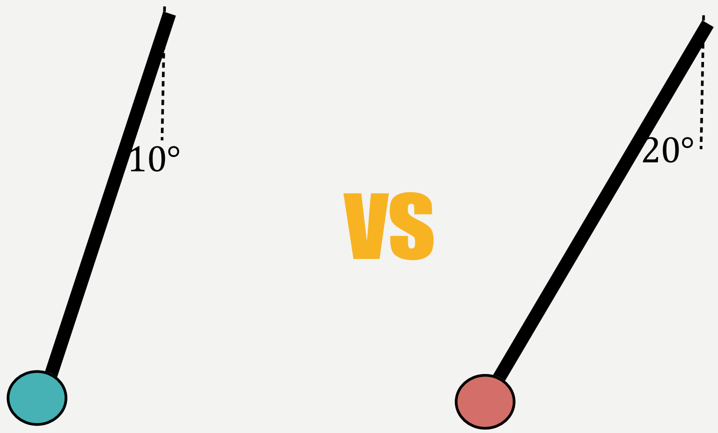


Handout:

- Make a plan, discuss plan with another group, carry out plan.
- Find ways to improve plan, discuss improvements with another group, carry improved plan out.

LAB QUESTION:

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



Diff ~0.2σ

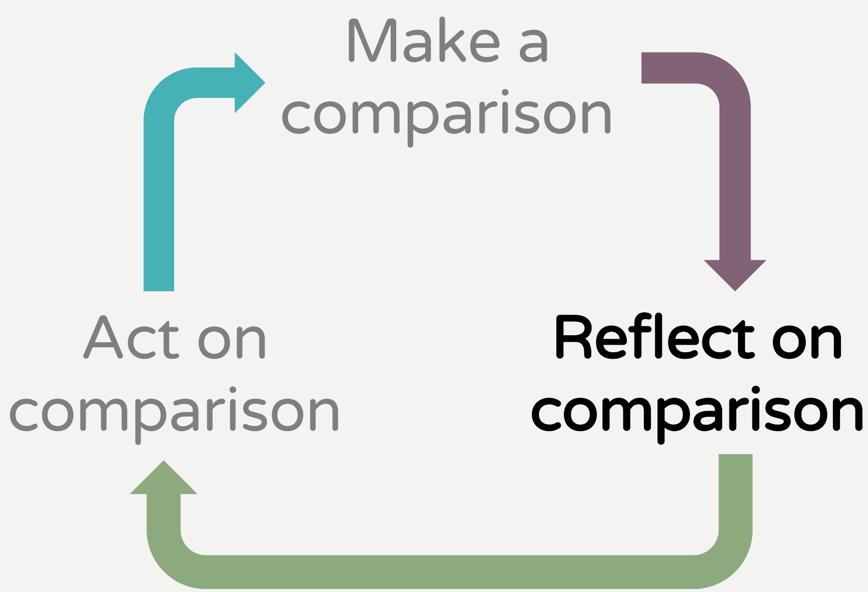
Case study:

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

STRUCTURE

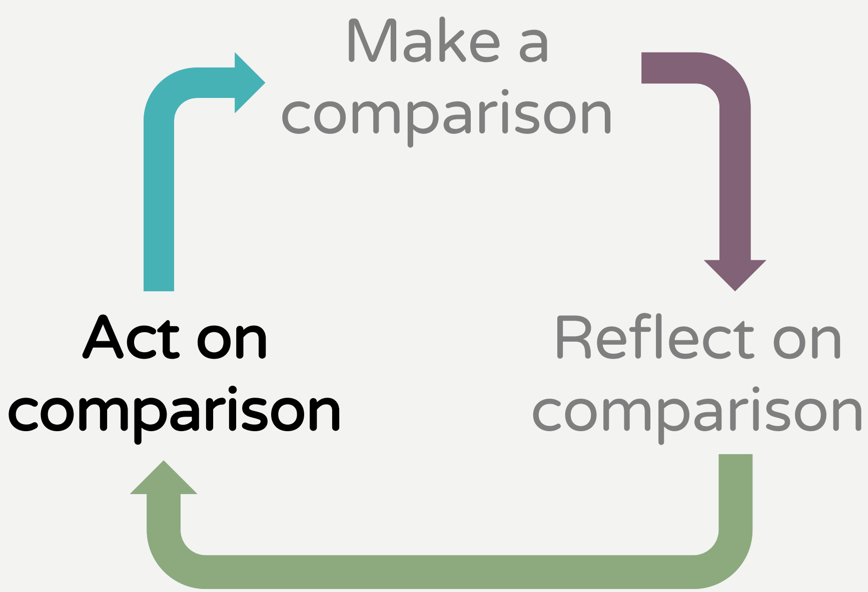


What might a difference of 0.2σ mean?

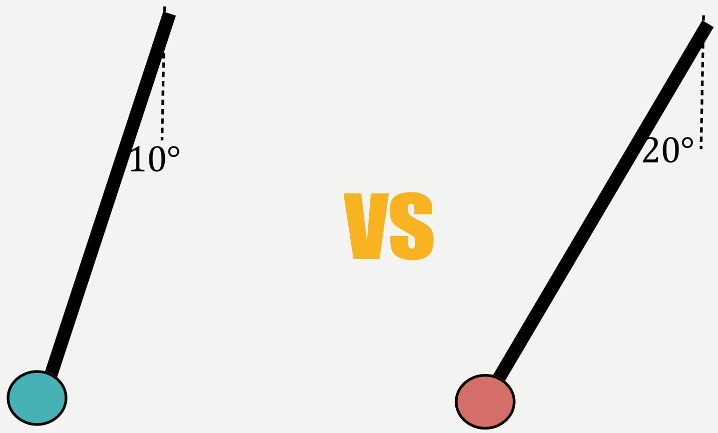
$$t' = \frac{T_{10°} - T_{20°}}{Uncertainty}$$

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

STRUCTURE



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:

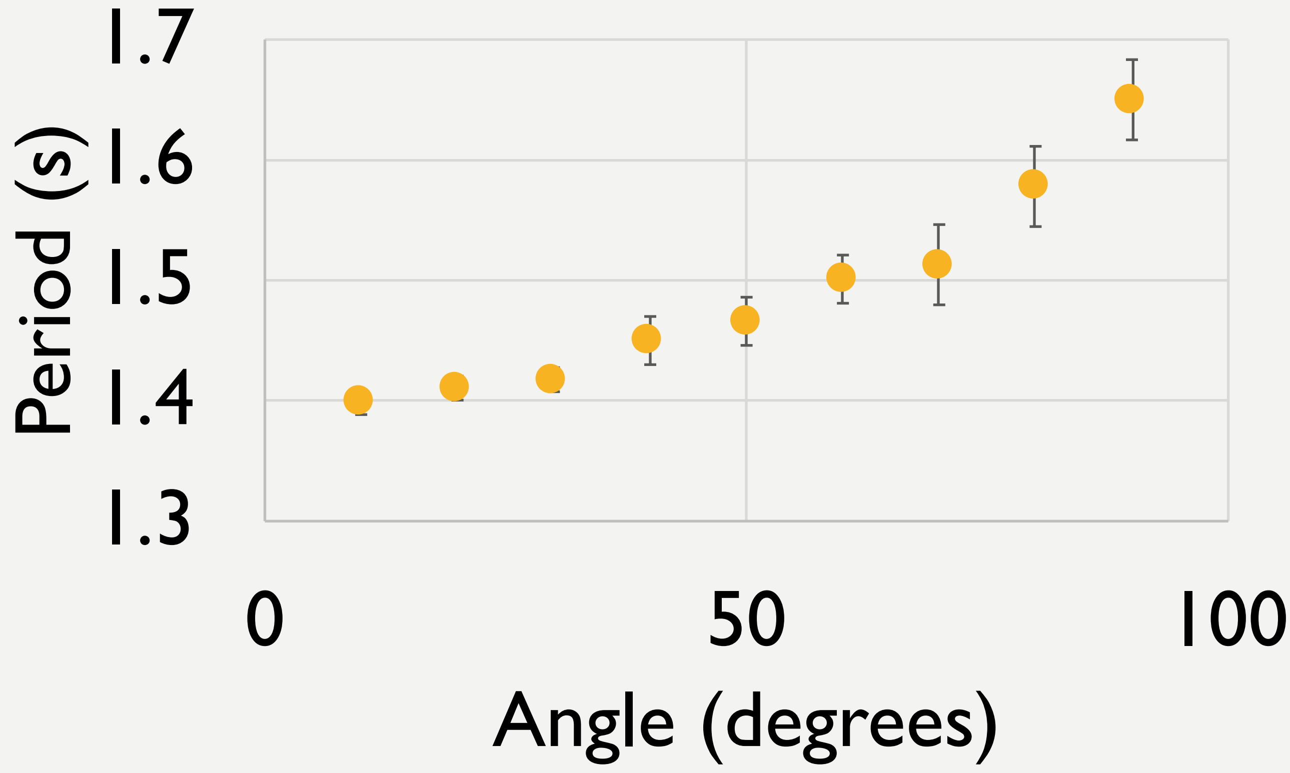
The period of a pendulum does depend on the angle with the vertical in the initial position.

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 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



"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.'"

PLAN

Big picture (What and why)

Hands-on example (How)

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Big picture (How)

Choose your own adventure:

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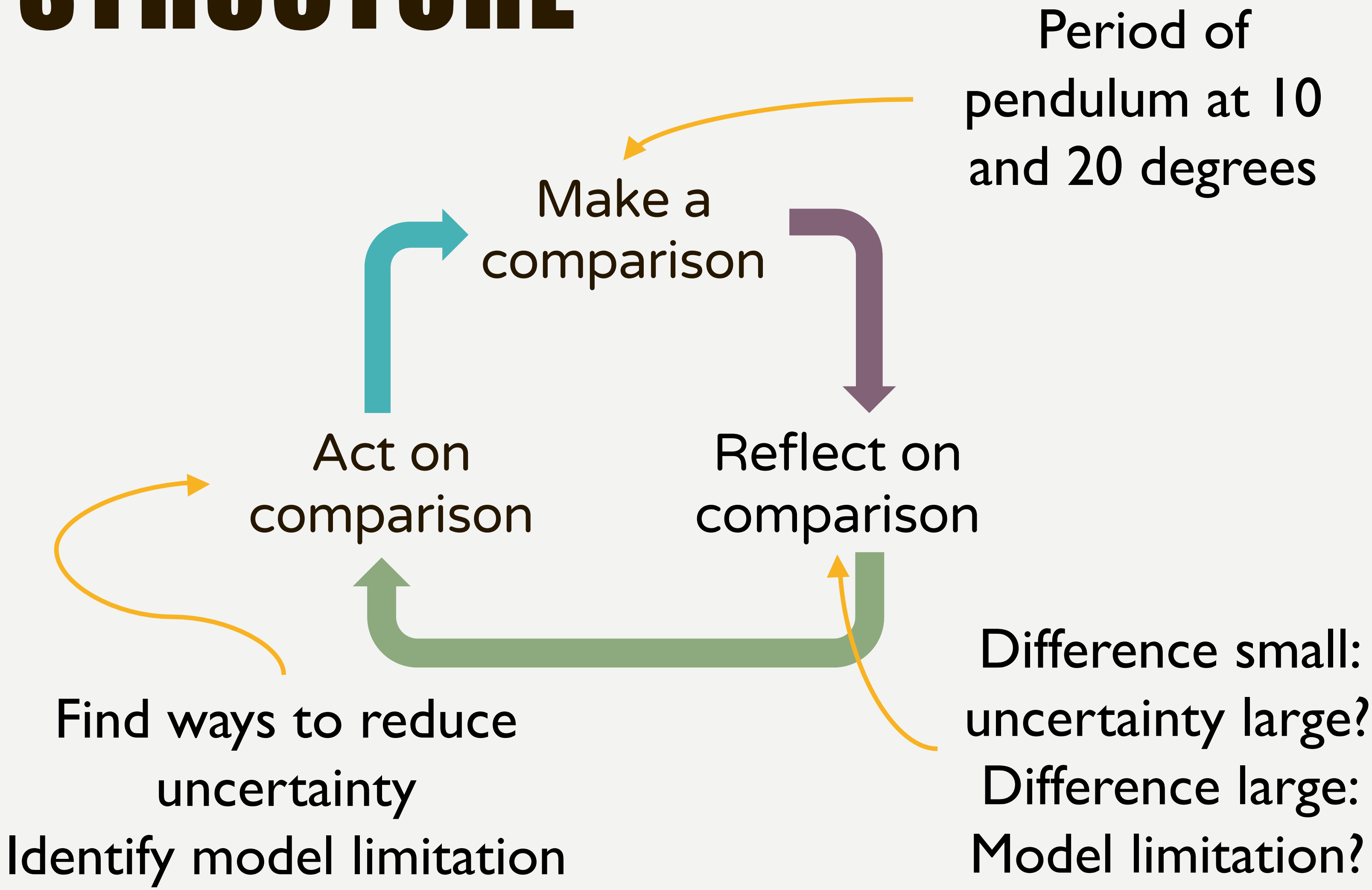
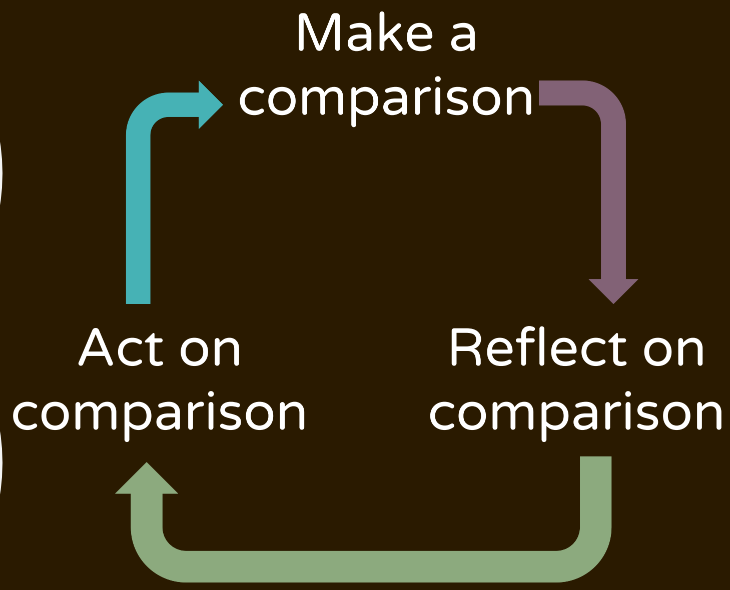
CRITICAL THINKING STRUCTURE



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)...

A NOTE ON STRUCTURE

Traditional	Full open-ended
Goal defined	No goal defined
Specific equipment provided	Room full of equipment provided
All experimental decisions made	No experimental decisions made

↔ ?

CORNELL INTRO LAB LEARNING GOALS:

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.

Visit cperl.lassp.cornell.edu for the full list

CORNELL LAB ACTIVITIES

Lab	Mechanics	E & M	Waves & Optics
1	Pendulum for Pros	Circuits	Polarization
2			Diffraction
3	Bouncing Ball	Faraday’s Law	Standing Waves
4	Terminal Velocity		
5		Magnetic field from a coil	Project Lab
6	Hooke’s Law		
7		LEDs project lab	
8	Project Lab		
9			

Note: Each course has 15 weeks of instruction, but 9 weeks of lab sessions.

GRADING

Rubrics score student lab notes on five elements:

Three that repeat each week:

- What are you doing?
- Why are you doing it?
- What will you do next?

And two that are week-specific.

REPEATED RUBRIC ELEMENTS:

General		Proficient (1)	Beginning (0.5)	Missing (0)
Experimental Process	What are you doing?	Detailed descriptions of experimental procedures, data analysis, and decisions are provided throughout the investigation.	There are some descriptions of what was done, but some detail is missing.	No description of the experimental process in the lab notes.
	Why are you doing it?	Justification for all decisions is provided including for choices in experimental procedure, data collection, and data analysis. Most justifications come from evidence such as data.	Justifications for decisions are rarely provided or justifications rarely come from evidence.	No decisions or methods are justified.
	What will you do next?	Follow-up actions are suggested based on experimental results and at least one follow-up is pursued, especially to improve methods or models.	Follow-up actions are suggested but not pursued.	No follow-up is proposed.

PENDULUM RUBRIC

Pendulum for Pros		Proficient (1)	Beginning (0.5)	Missing (0)
Points of Emphasis	Experimental uncertainty	Major physical sources of uncertainty are identified and experimental methods include plans to quantify and minimize their impact. The size of uncertainty is reflected on throughout, especially after attempts to minimize them.	Major physical sources of uncertainty are identified but missing plans to quantify, plans to minimize, or reflections.	There is no discussion of physical sources of uncertainty.
	Comparing measurements	Measurements (values and uncertainties) are compared and appropriately interpreted. A decision about what to do with the information is clearly communicated and follows logically from the comparison.	Measurements (values and uncertainties) are compared. The interpretation or follow-up are inappropriate or missing.	Measurements (values and uncertainties) are not compared.

HOW TO ASSES THE LABS (NOT THE STUDENTS)

- 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

THE BIG THINGS:

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

THE BIG THINGS:

- Change the goals to focus on process rather than product
  - Narrow and focus goals per lab
  - Grade for their decision-making, not their result
- Spread labs over multiple sessions
  - Give them time to go deep in a few experiments
- Give students some agency
  - Remove some of the structure and let students make decisions in a constrained space
  - Use experiments where students don't know the "answer" so they use experiment for discovery, not confirmation
  - Use experiments where the result is surprising

LEARNING GOALS:

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- Identify instructional decisions that facilitate the iterative cycles.

RESOURCES

Our webpage: cperl.lassp.cornell.edu (more to appear on PhysPort.org soon)

Contact me: ngholmes@cornell.edu

Other materials also at: sqilabs.phas.ubc.ca

Citations:

Holmes, N. G., & Wieman, C. E. (2018). Introductory physics labs: We can do better. Physics Today, 71(1), 38–45. https://doi.org/10.1063/PT.3.3816

Holmes, N. G., & Smith, E. M. (2018). Operationalizing the AAPT Learning Goals for the Lab (accepted to The Physics Teacher)

Holmes, N. G., Olsen, J., Thomas, J. L., & Wieman, C. E. (2017). Value added or misattributed? A multi-institution study on the educational benefit of labs for reinforcing physics content. Physical Review Physics Education Research, 13(1), 010129. https://doi.org/10.1103/PhysRevPhysEducRes.13.010129

Holmes, N. G., & Bonn, D. A. (2015). Quantitative Comparisons to Promote Inquiry in the Introductory Physics Lab. The Physics Teacher, 53(6), 352–355. https://doi.org/10.1119/1.4928350

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Thank you!!