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USING PHYSICS LABS TO TEACH EXPERIMENTATION AND CRITICAL THINKING

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LEARNING GOALS

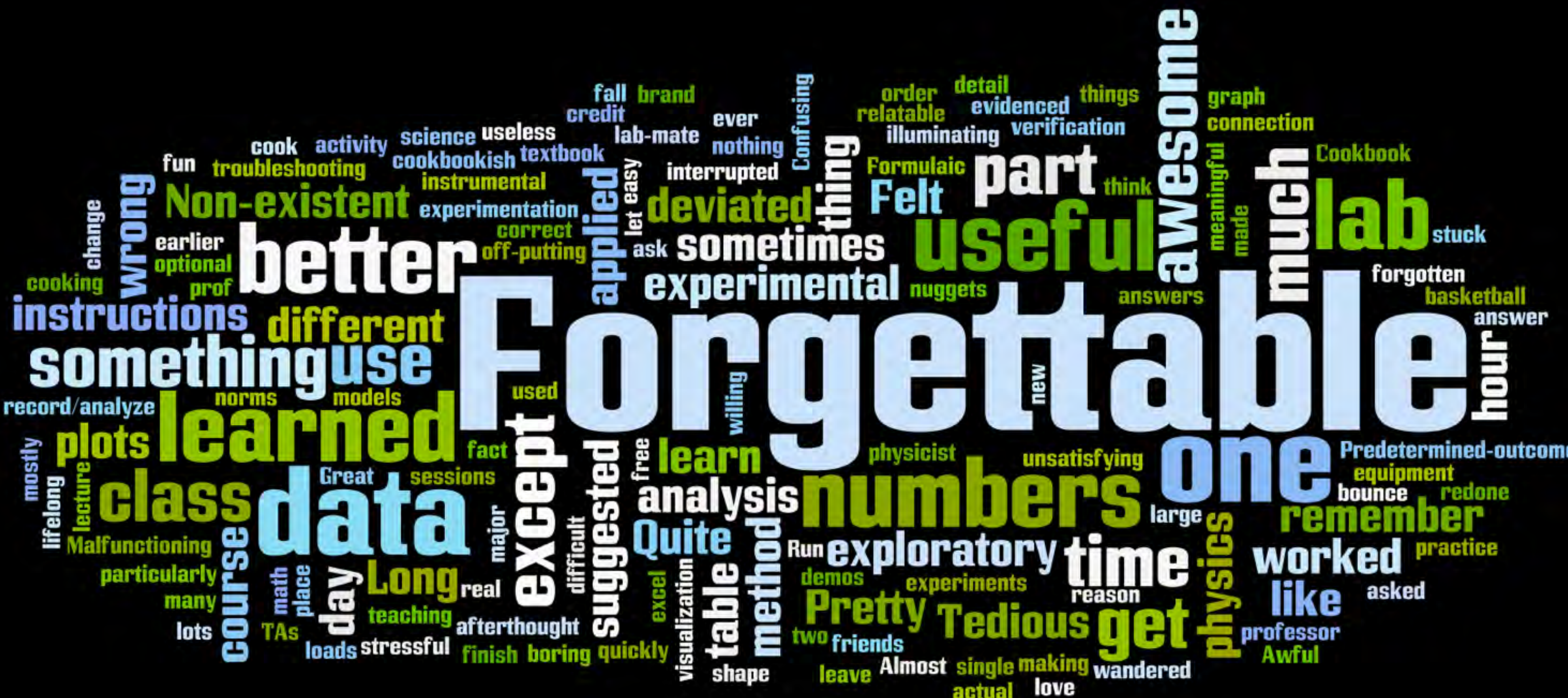
By the end of this session, you should be able to:

- List learning outcomes for lab instruction about experimentation,
- Describe fundamental principles for teaching experimentation skills, and
- Identify instructional decisions to implement those fundamental principles.

All our materials are on PhysPort.org/curricula/thinkingcritically

COMPLETE THIS SENTENCE:

MY INTRO PHYSICS LABS WERE…



Forgettable
fall
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credit
order
detail
things
graph
relatable
evidenced
connection
ever
Confusing
lab-mate
illuminating
verification
cook
activity
science
useless
nothing
Cookbook
fun
troubleshooting
cookbookish
textbook
interrupted
Formulaic
part
think
meaningful
change
wrong
instrumental
easy
thing
Felt
awesome
much
lab
Non-existent
experimentation
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better
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cooking
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Predetermined-outcome
mostly
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Awful
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PLAN

Big picture (What and why)

Sample activity (How)

Case study (How)

Big picture (How)

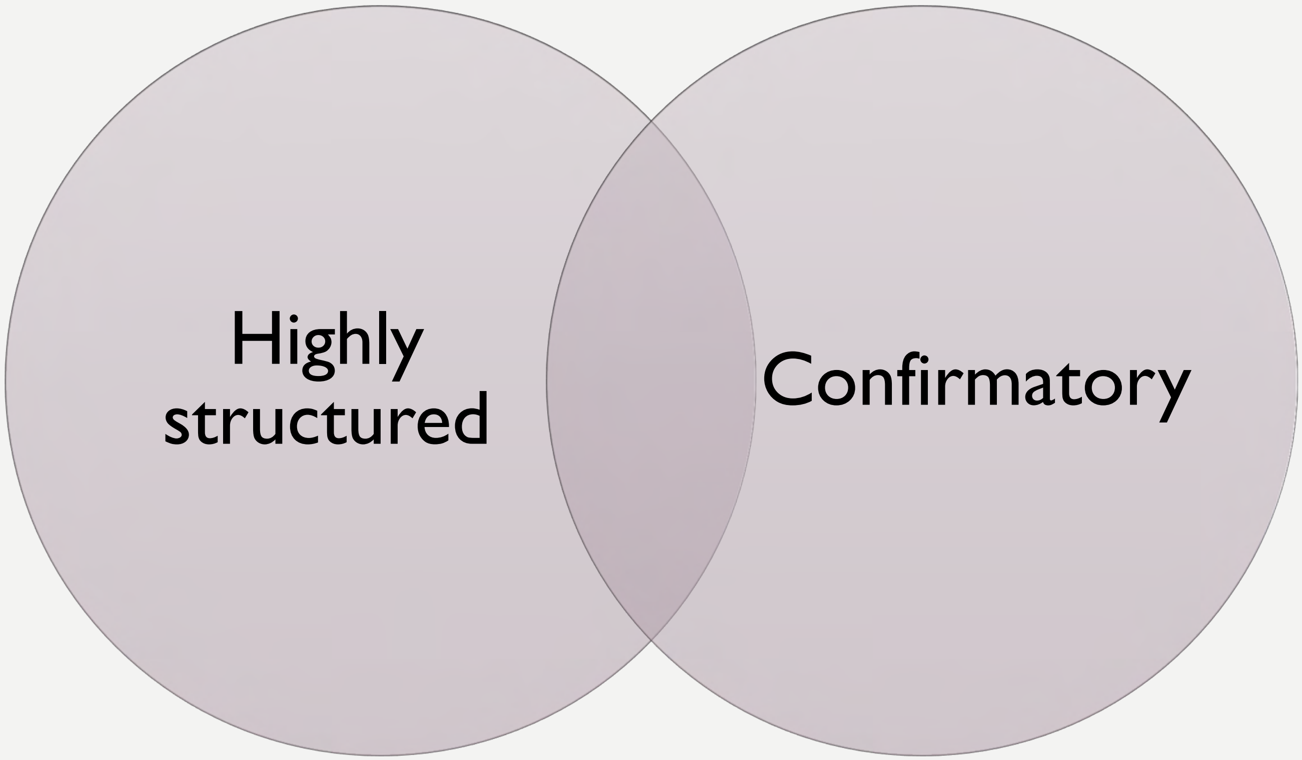
Choose your own adventure:

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

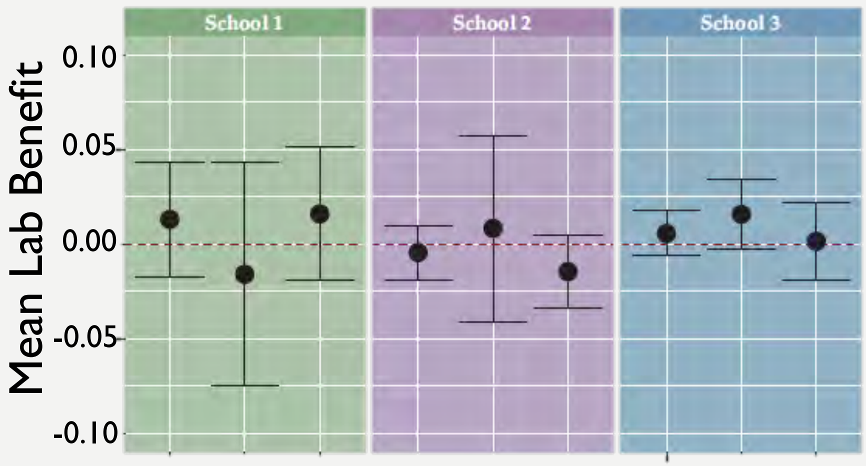
HOW DO WE DO EXPERIMENTS IN PHYSICS?

ANSWER THE QUESTION WITH YOUR NEIGHBOR

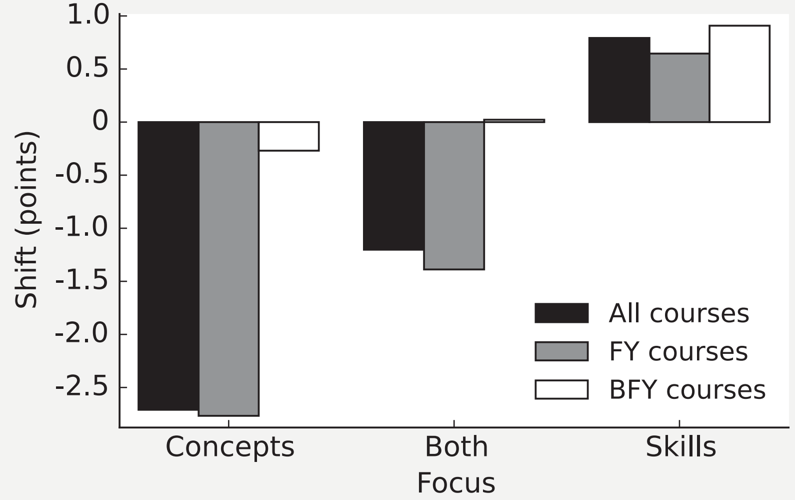
TRADITIONAL ‘VERIFICATION’ LABS



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)

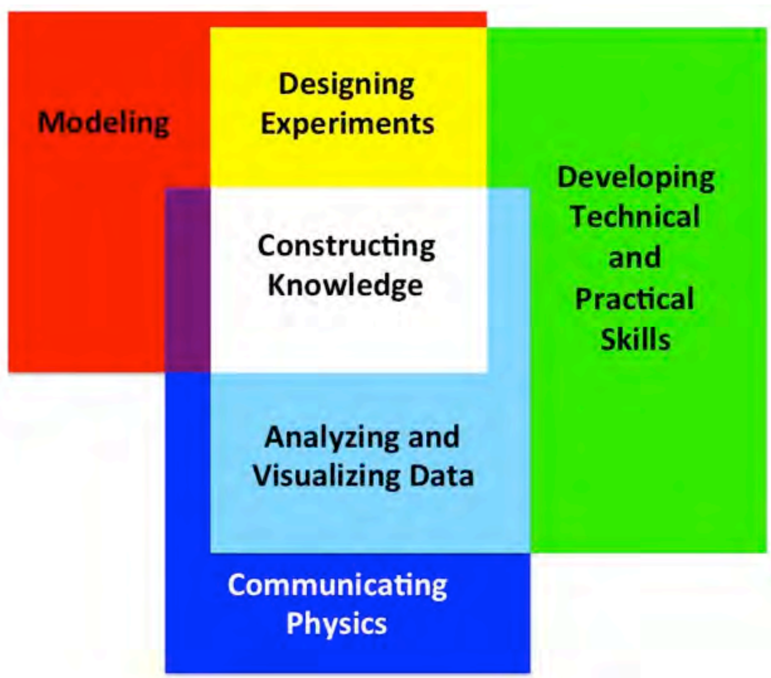
15. To better investigate the model, what should the Group 2 students do next?

16. Why should they do this?

I HATE labs. Theoretical only.

THE EXTREME CASE

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

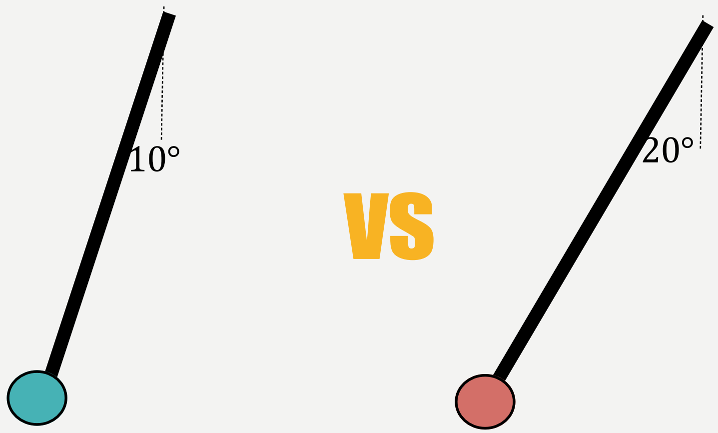
WHAT IS CRITICAL THINKING?

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

ACTIVITY: MODEL TESTING

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

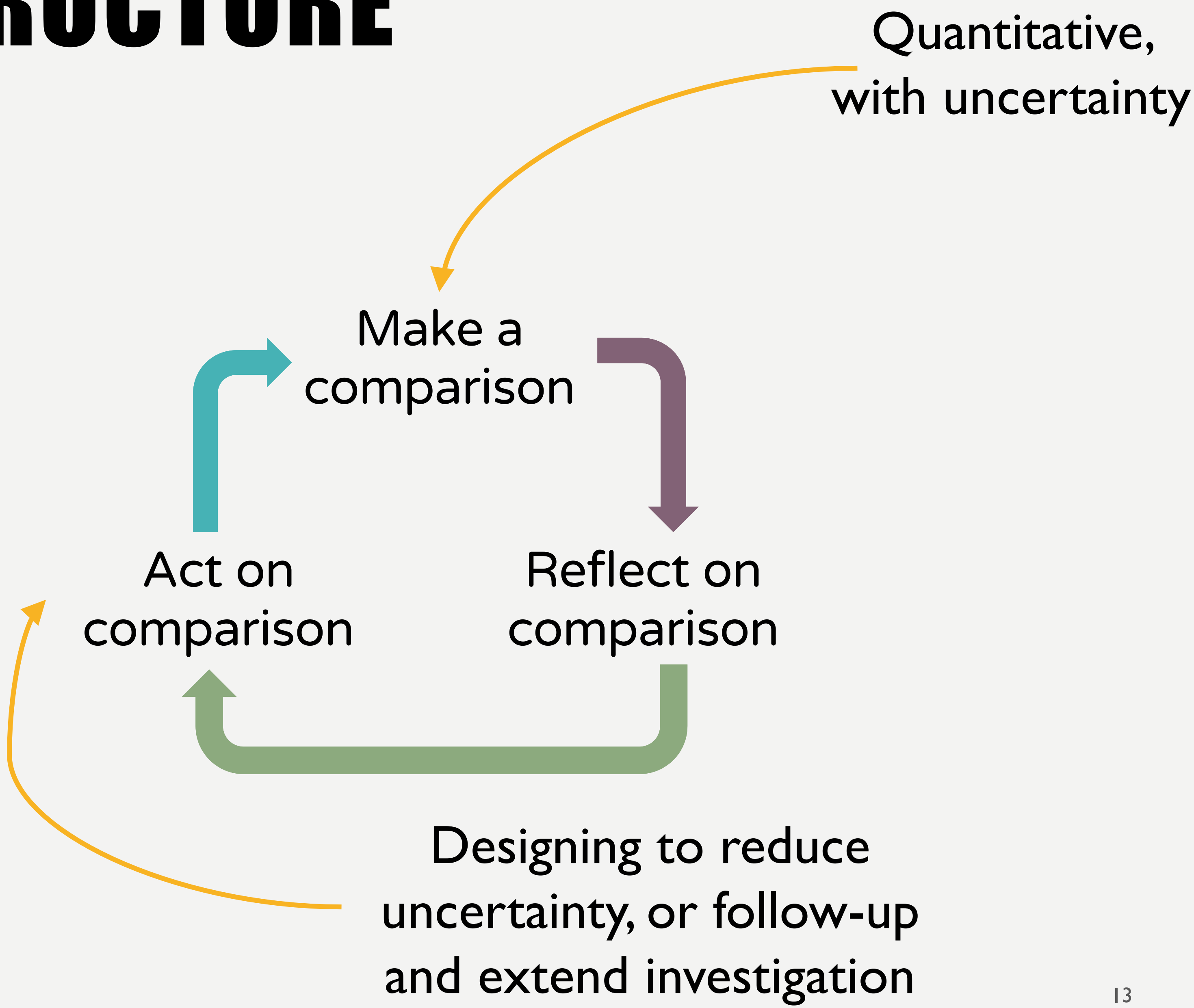
$$T = 2\pi\sqrt{\frac{L}{g}}$$



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.

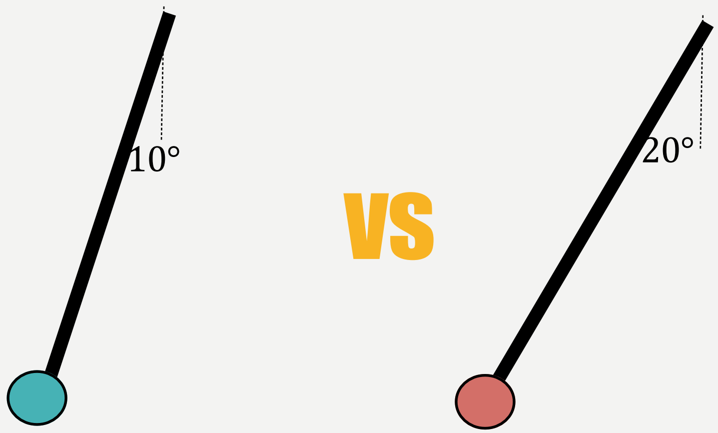
STRUCTURE



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

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

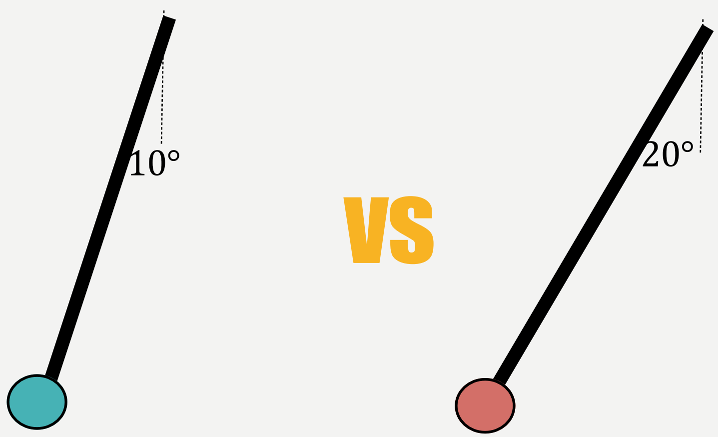
Holmes & Bonn (2015) The Physics Teacher

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 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:

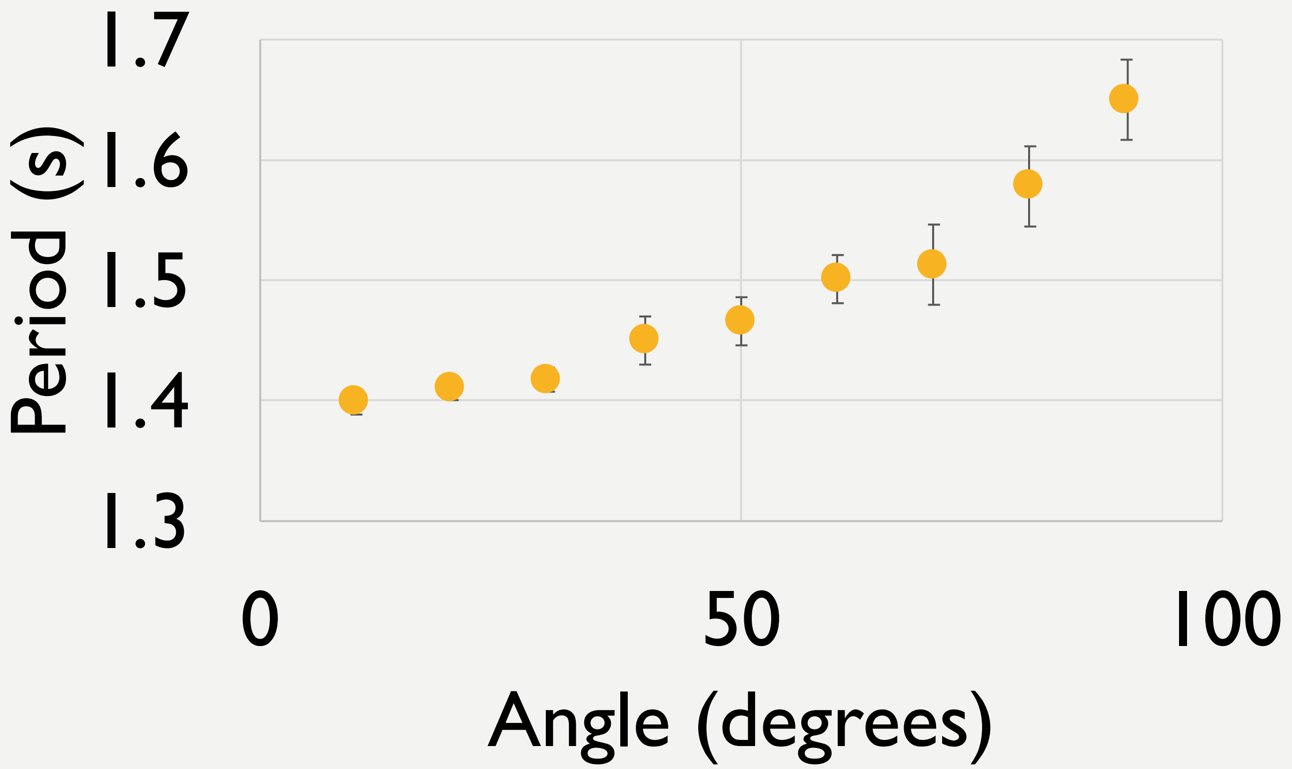
The period of a pendulum does depend on the angle with the vertical in the initial position.

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)

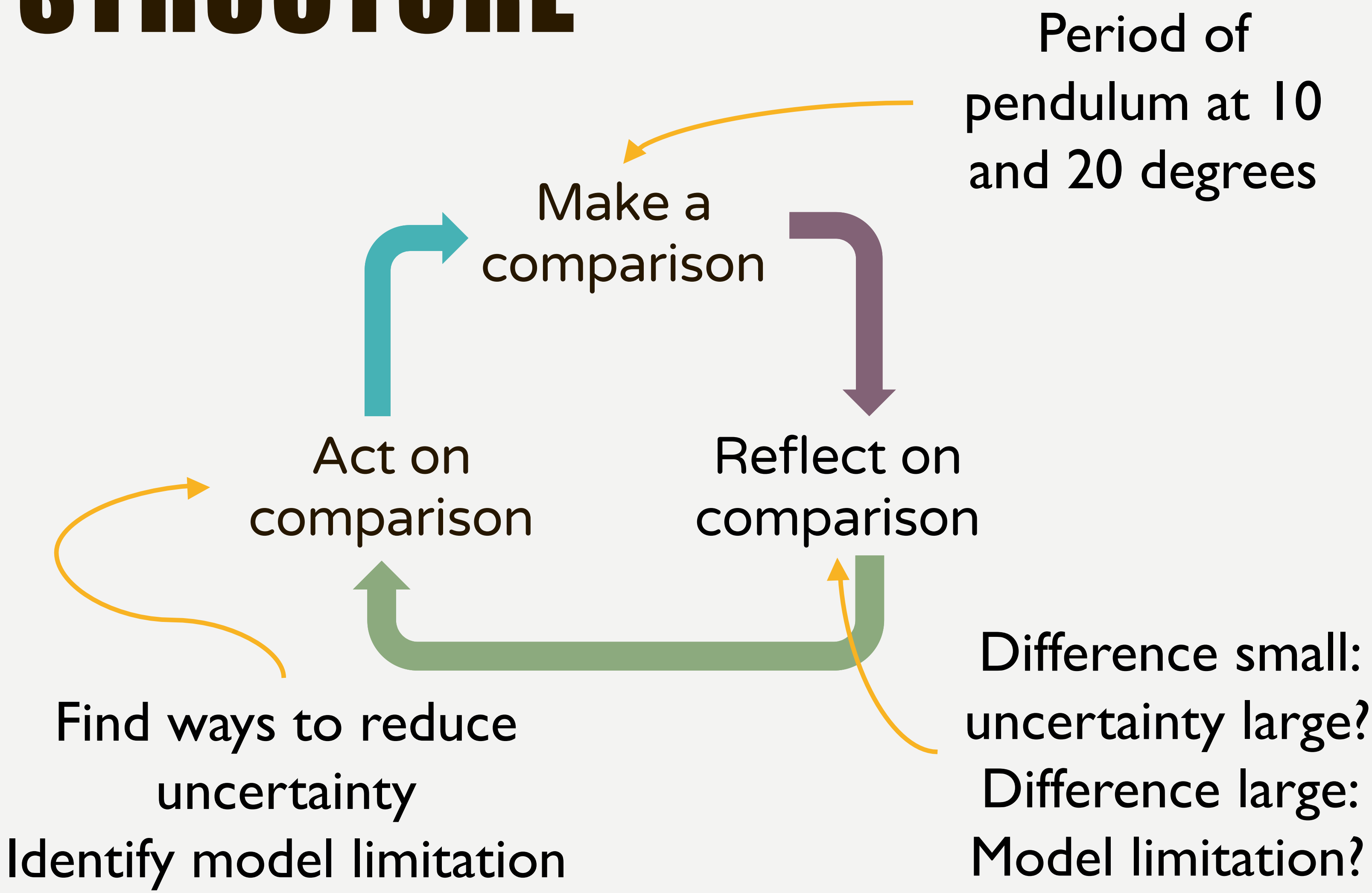
Case study (How)

Big picture (How)

Choose your own adventure:

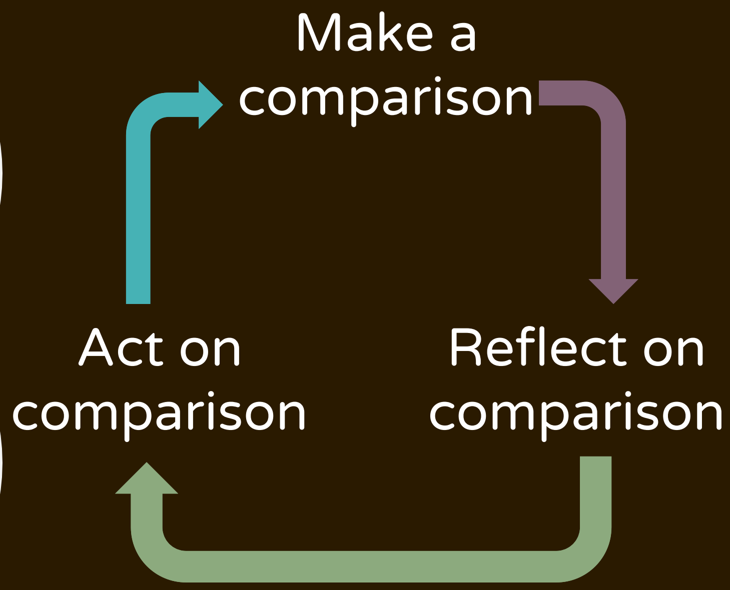
- What we do
- Design a lab
- TA training
- Grading…

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)
  - Students don't know the answer
  - Instructors don't know the answer



Gick & Holyoak (1980, 1983); Bransford et al. (1989); Ericsson et al. (1993); Bransford & Schwartz (1999); Kapur (2008)…

A NOTE ON STRUCTURE

Traditional

- Goal defined
- Specific equipment provided
- All experimental decisions made

Full open-ended

- No goal defined
- Room full of equipment provided
- 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

LAB ACTIVITIES

Mechanics:

1. Model Testing (Pendulum)
2. Model Testing & Ethics (Objects in flight)
3. Model Testing & Extending (Hooke's law)
4. Project Lab

E&M:

1. Model Building (Electrostatics)
2. Model Building & Testing (Circuits)
3. Model Building & Design (Faraday's Law)
4. Model Building & Predicting (Magnetic Fields)
5. What does this thing do (LEDs)

Waves & Optics:

1. What is this data? (analysis review)
2. Diffraction
3. Project Lab (5-6 weeks)

GRADING

Three components:

1. In-lab check-in (group)
2. Lab notes (group)
3. Post-lab exercise (individual)

Students also complete in-lab worksheets (individual, but ungraded). These are mostly to keep students on task.

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

TA TRAINING

- Use Socratic questioning – don't give students an "answer"
- Provide *some* feedback and guidance – offer multiple suggestions that students can choose from
- Formalize the "check-ins" – encourage students to ask each other for help with technical stuff
- Buy-in is hard – like all new forms of teaching, but this one shifts the goal as well as the method

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

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RESOURCES

Our webpage: cperl.lassp.cornell.edu

PhysPort: PhysPort.org/curricula/thinkingcritically

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

Holmes, N. G., Wieman, C. E., & Bonn, D. A. (2015). Teaching critical thinking. PNAS, 112(36), 11199–11204. https://doi.org/10.1073/pnas.1505329112

Thank you!!