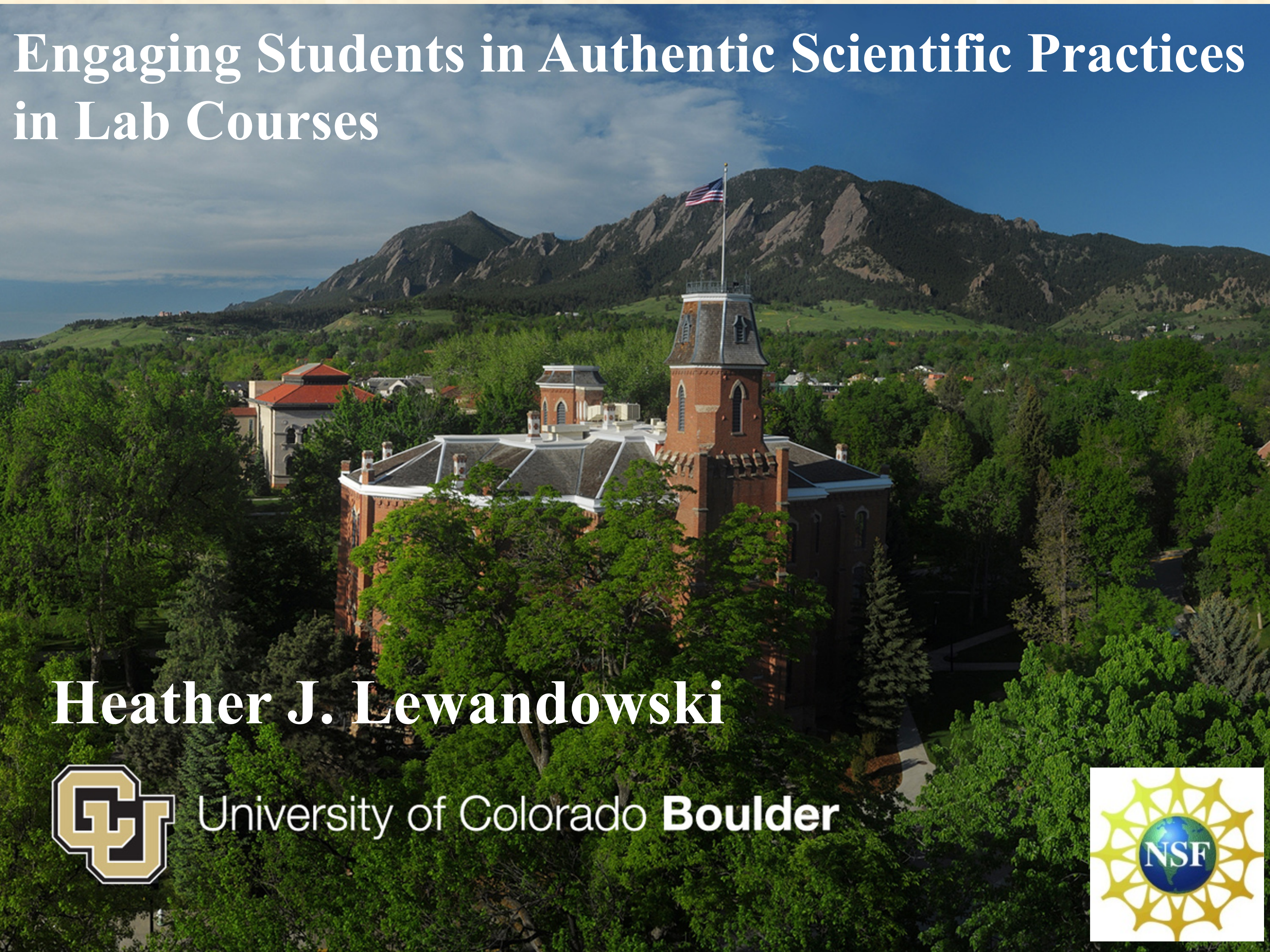
Engaging Students in Authentic Scientific Practices in Lab Courses

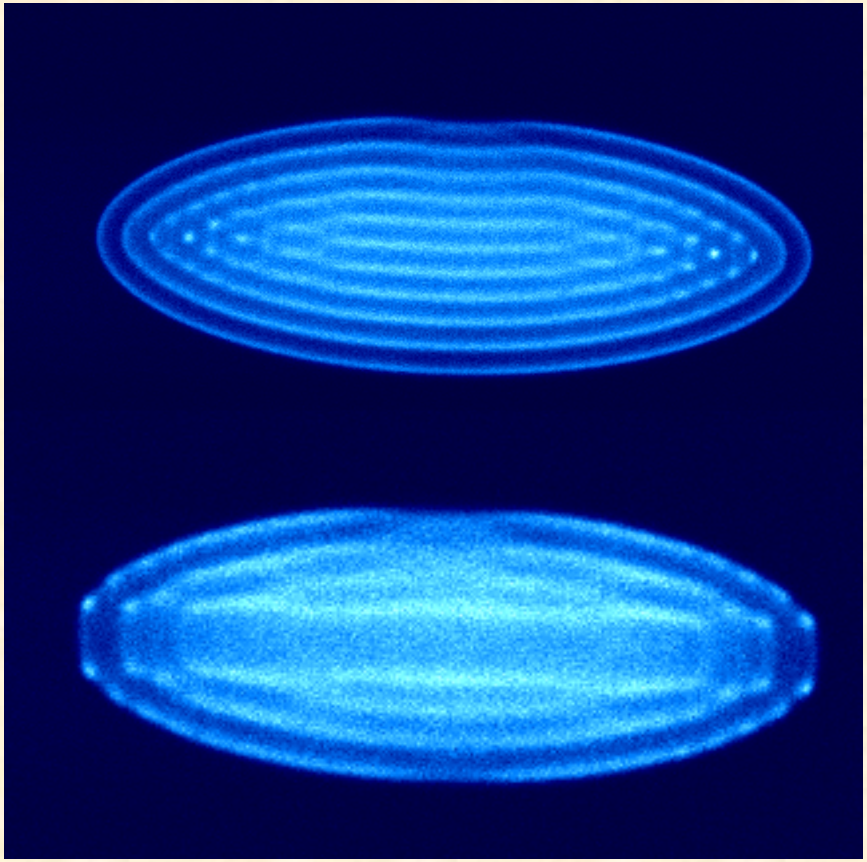


Heather J. Lewandowski

University of Colorado **Boulder**

Why am I doing this?

Atomic, Molecular, and Optical Experiment (Day Job)



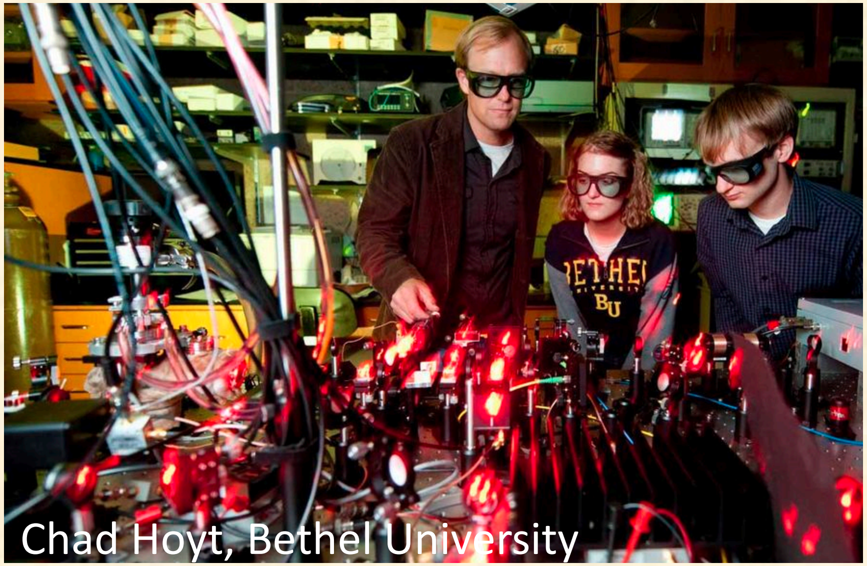
1) Hire undergraduates and beginning graduate students:

Most lack many transferable skills.

2) Taught Advanced Lab:

Best students were convinced they were not cut out for experimental physics.

Big Ideas



1) **We want to engage students in authentic experimental practice.**

Hopefully you can relate these ideas to your own research and teaching.

2) **Physics Education Research (PER) needs to happen at the upper-division level and in the laboratory.**

Our labs are not achieving our learning goals for our students.

3) **PER is possible in this complex laboratory space.**

Our group has started to make an impact in this area.

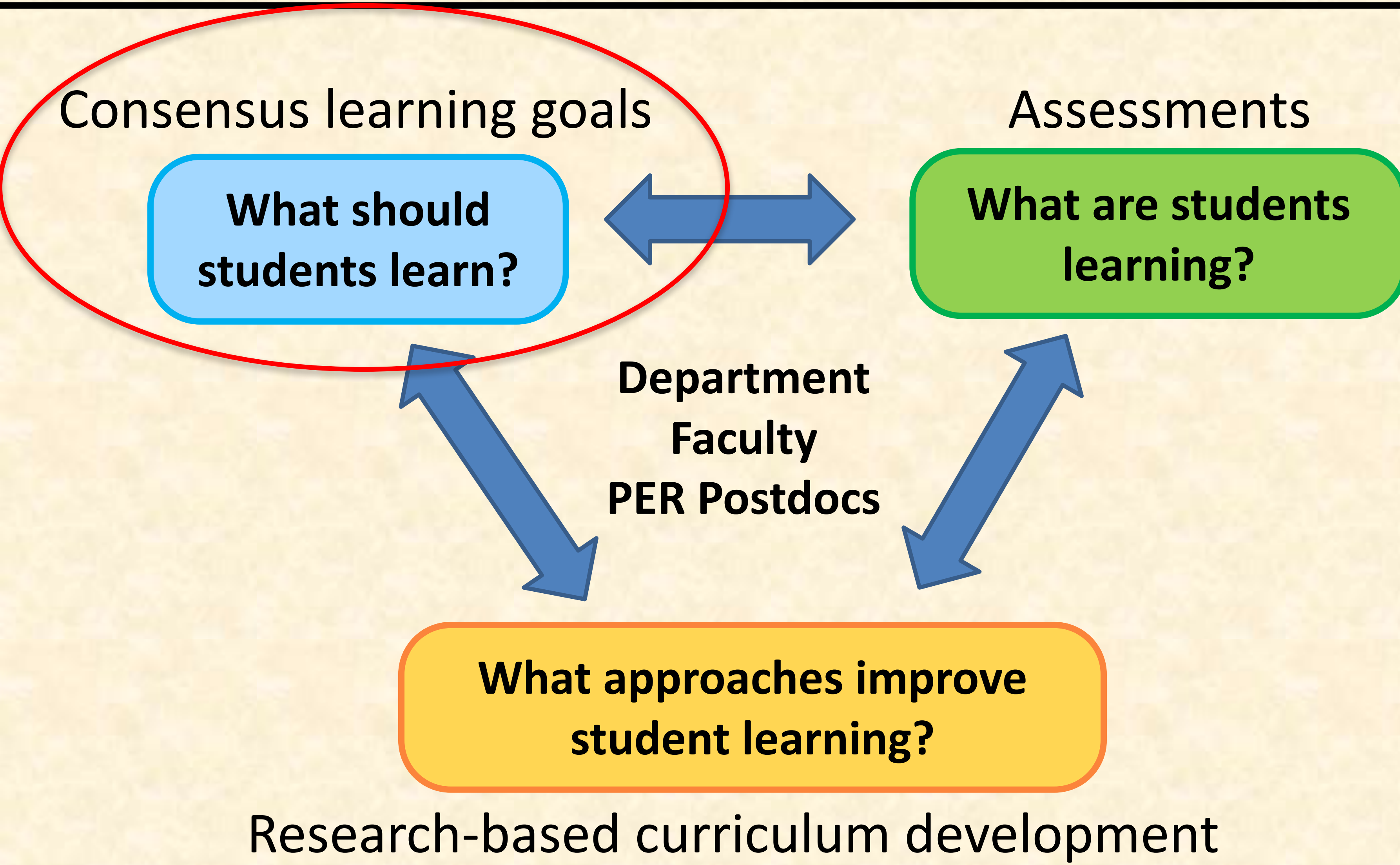
Colorado Upper-Division Labs

Third-year Electronics course – required
(~100 students/year)

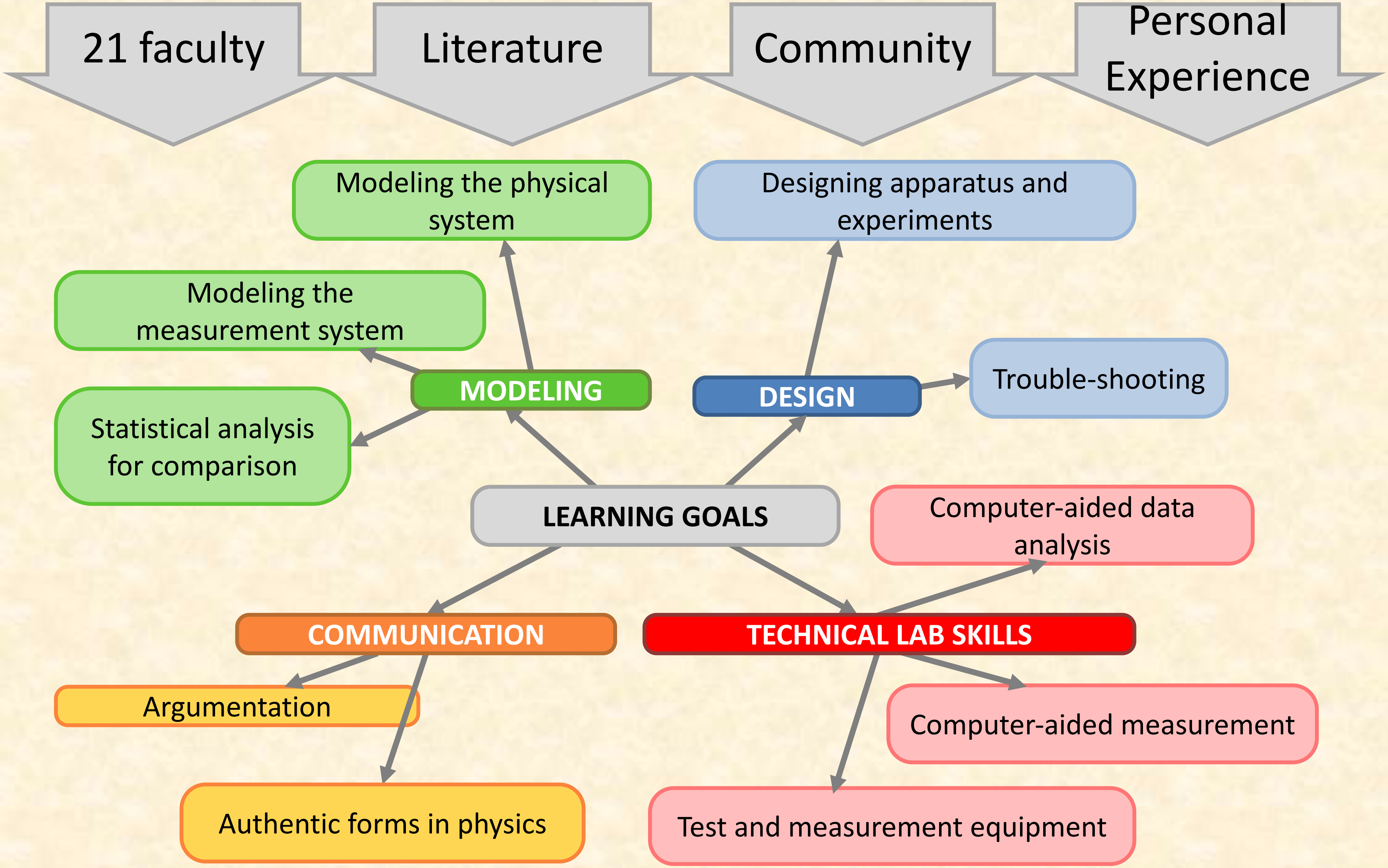
Fourth-year Advanced Lab – one of many options
(~30 students / year)

(10 Weeks guided labs + 5 Weeks student designed projects)

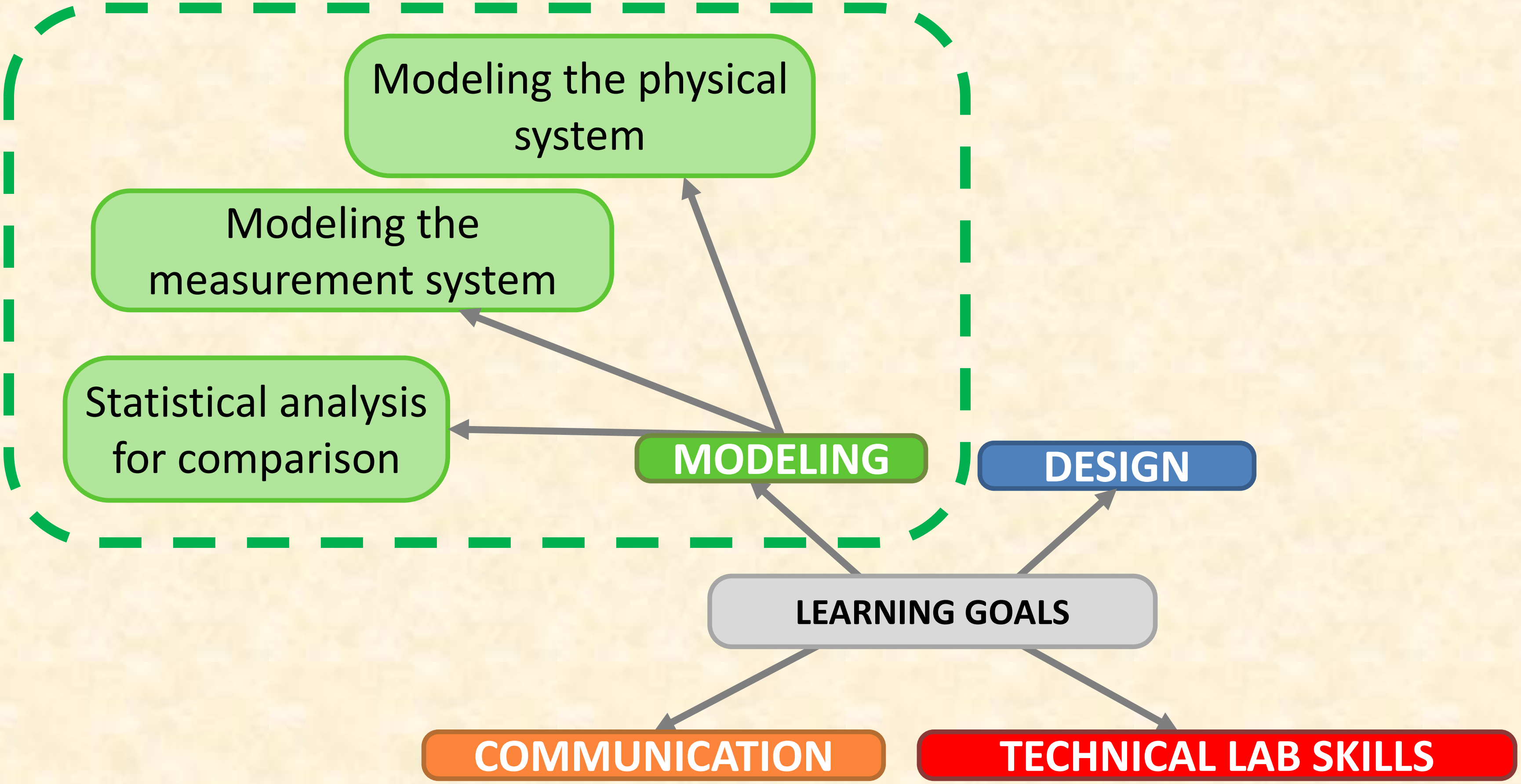
Transformation Model



Development of Overall Learning Goals

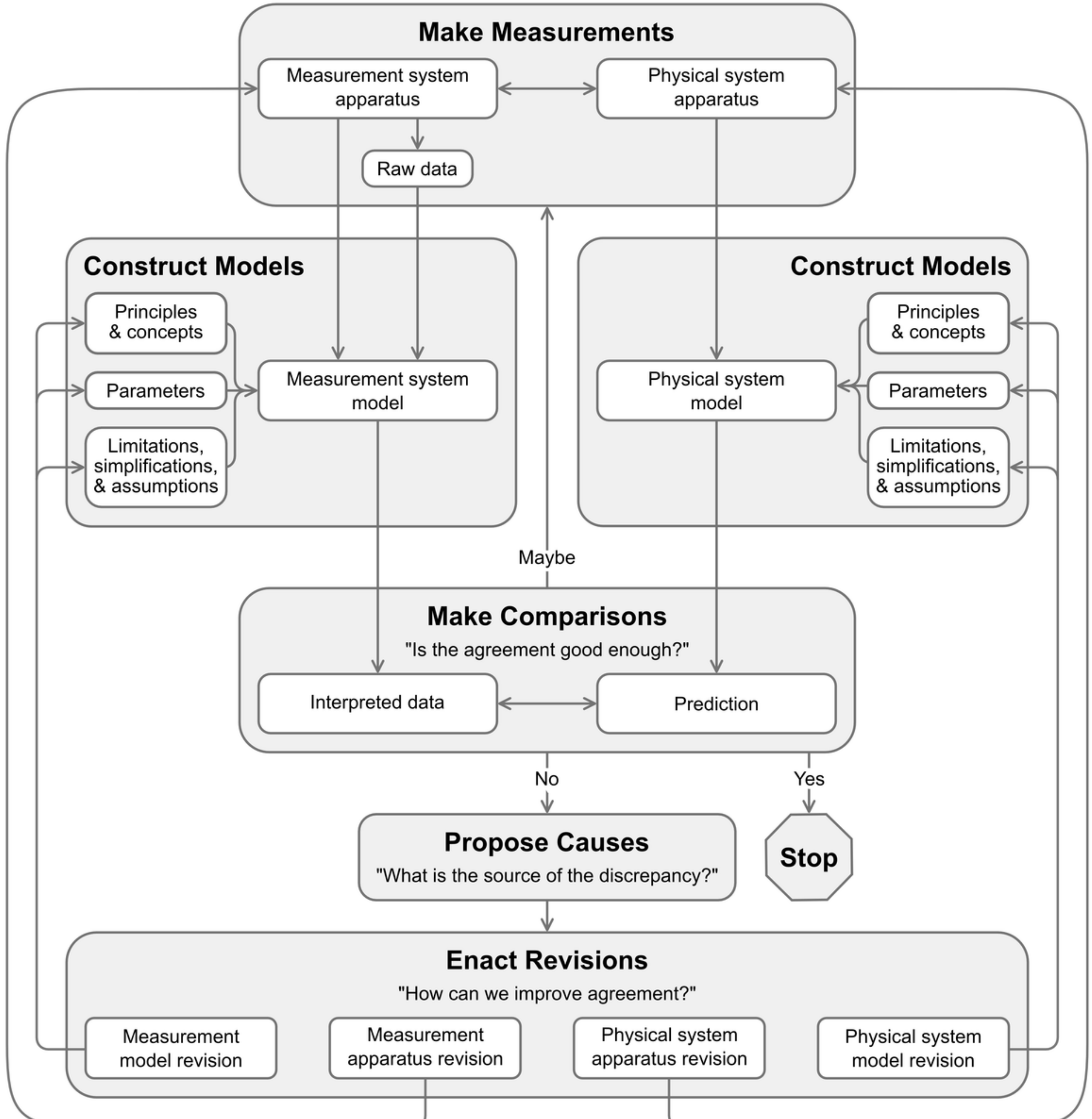


Implementing Modeling Learning Goals

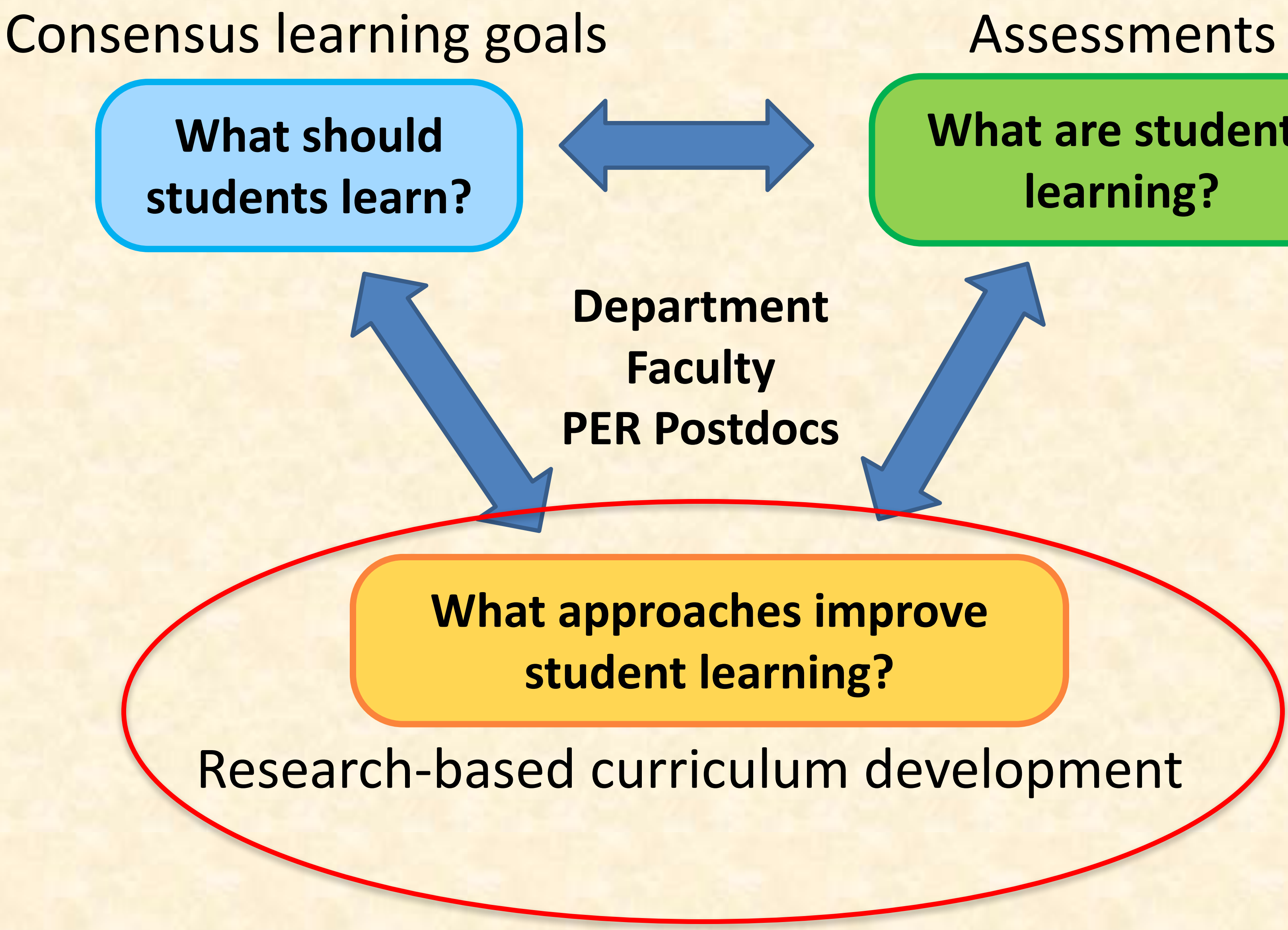


Model: An abstract representation of a real physical system that **(1) simplified, (2) predictive, (3) has specified limits to its applicability.**

Modeling: The process of constructing, testing, and refining models.


Make Measurements
Measurement system apparatus
Physical system apparatus
Raw data
Construct Models
Principles & concepts
Parameters
Limitations, simplifications, & assumptions
Measurement system model
Construct Models
Physical system model
Principles & concepts
Parameters
Limitations, simplifications, & assumptions
Maybe
Make Comparisons
"Is the agreement good enough?"
Interpreted data
Prediction
No
Yes
Propose Causes
"What is the source of the discrepancy?"
Stop
Enact Revisions
"How can we improve agreement?"
Measurement model revision
Measurement apparatus revision
Physical system apparatus revision
Physical system model revision

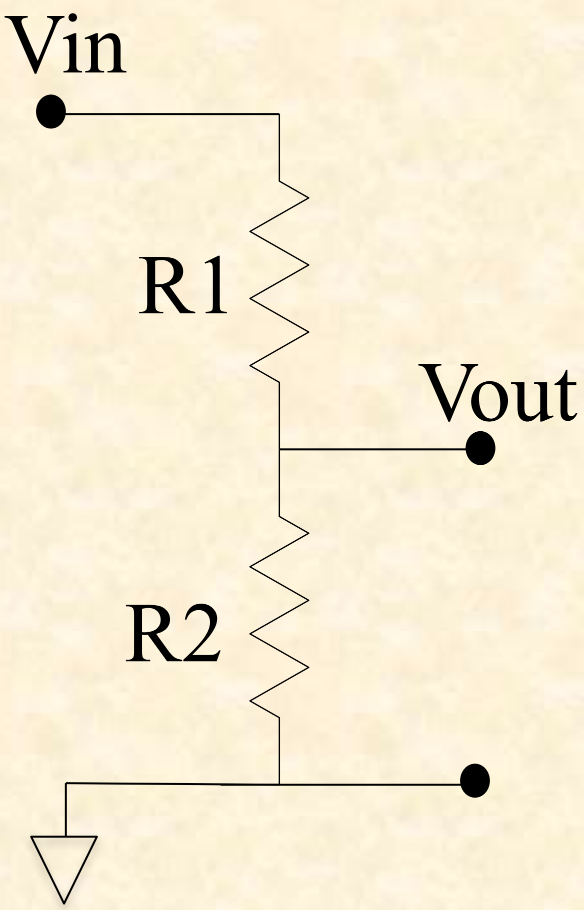
Transformation Model



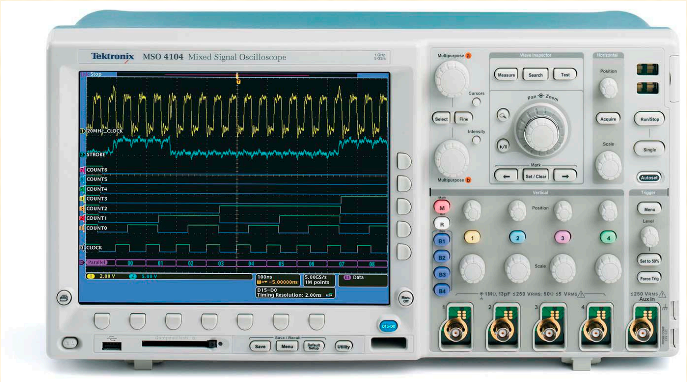
Lab Skill Activities (Tutorials)
New Lab Guides
New Course Structure
Abandoned Lab Reports!

Focused activities on Modeling

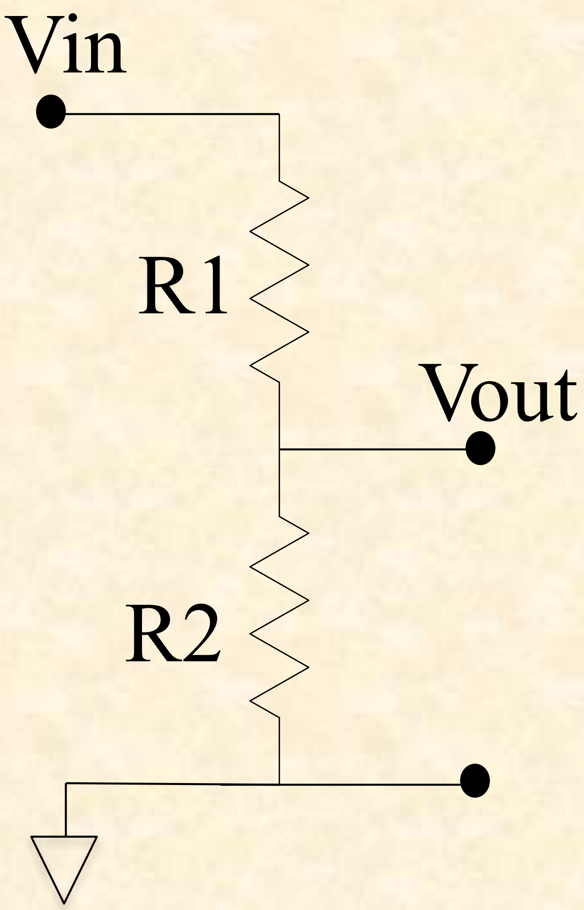
Voltage Divider



1) Build three different voltage dividers with R's of 1kΩ, 1 MΩ, and 10 MΩ.
2) Measure the output voltage using both a DMM a oscilloscope.



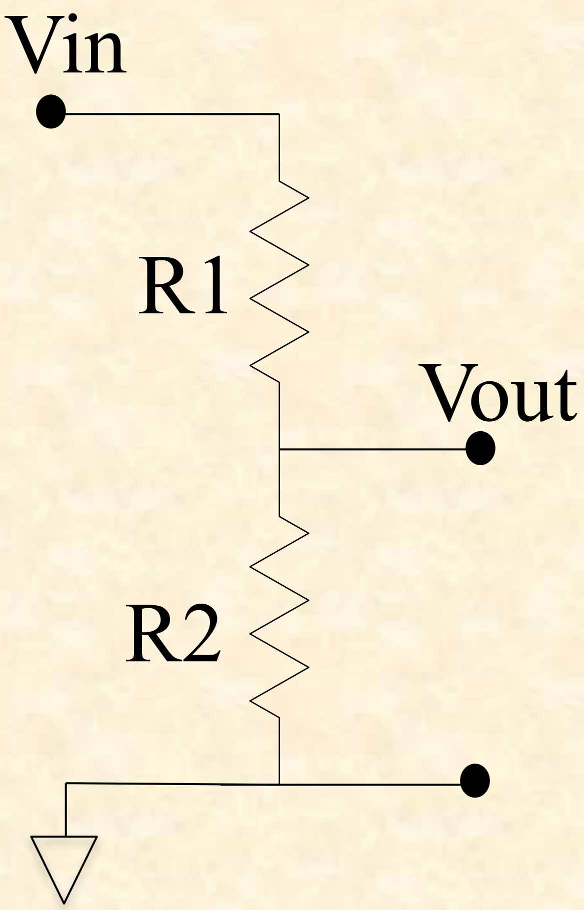
Voltage Divider (traditional)



"Compare the voltages you expected to the voltages you measured. What does this tell you about the input impedance of your instruments?"

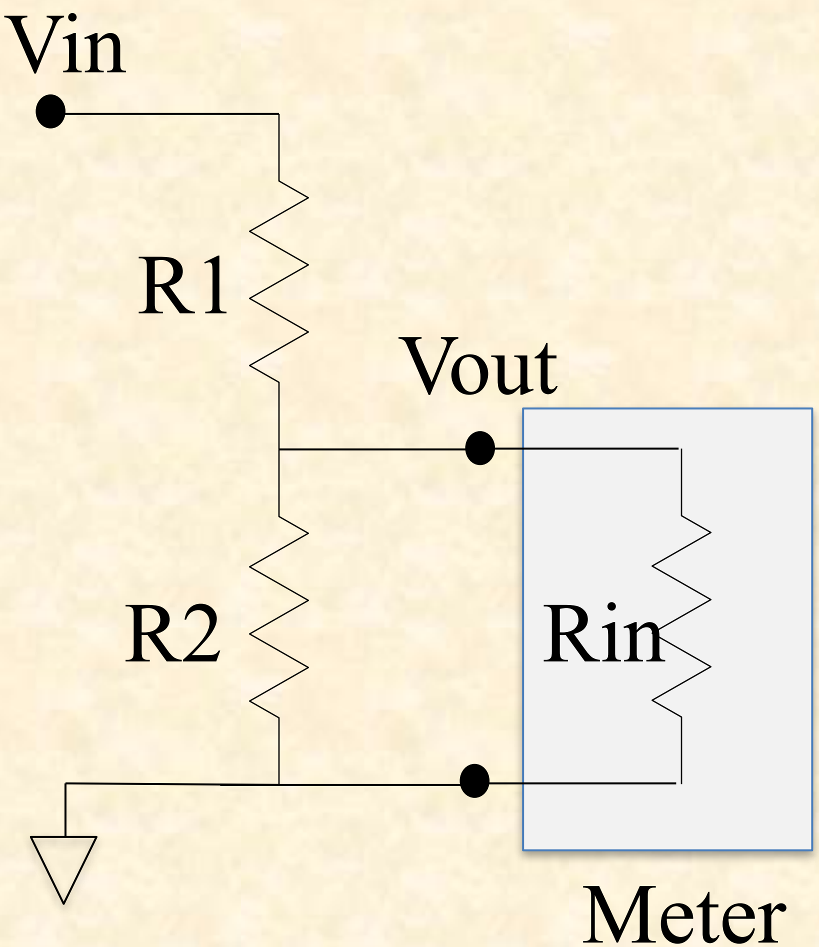
$$Vout = Vin \frac{R_2}{R_1 + R_2}$$

Voltage Divider (transformed)



"If your model and measurements did not agree, you will have to either refine your model or your experiment. Let's start by refining your model. Consider the input resistance of your measurement device. Draw a circuit diagram that includes that resistance. Use this new model to determine the input resistance of measurement device."

Refined Model



$$Vout = Vin \frac{R_3}{R_1 + R_3}$$

$$\frac{1}{R_3} = \frac{1}{R_2} + \frac{1}{R_{IN}}$$

Before Transformation

"Our measured voltage became far less accurate when we increased the resistance of R1 and R2."

"Scope has a smaller input impedance than the DMM."

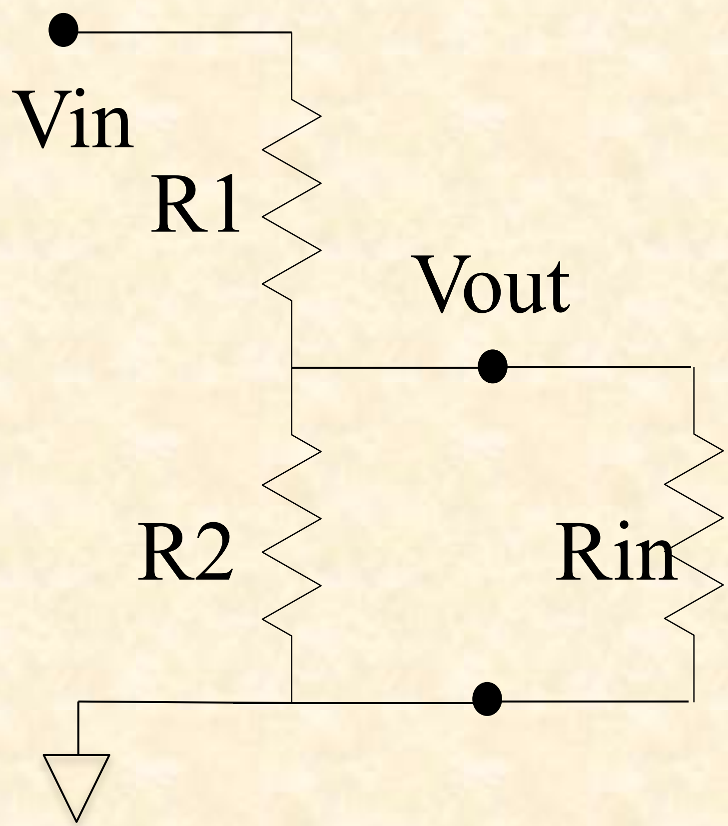
"Discrepancies in the measured values and the expected values may be attributed to improper wiring (due to the difference in the expected value)."

After Transformation

"The model is starting to break down."

"Neither the DMM or Osc agree very well, so must revise model."

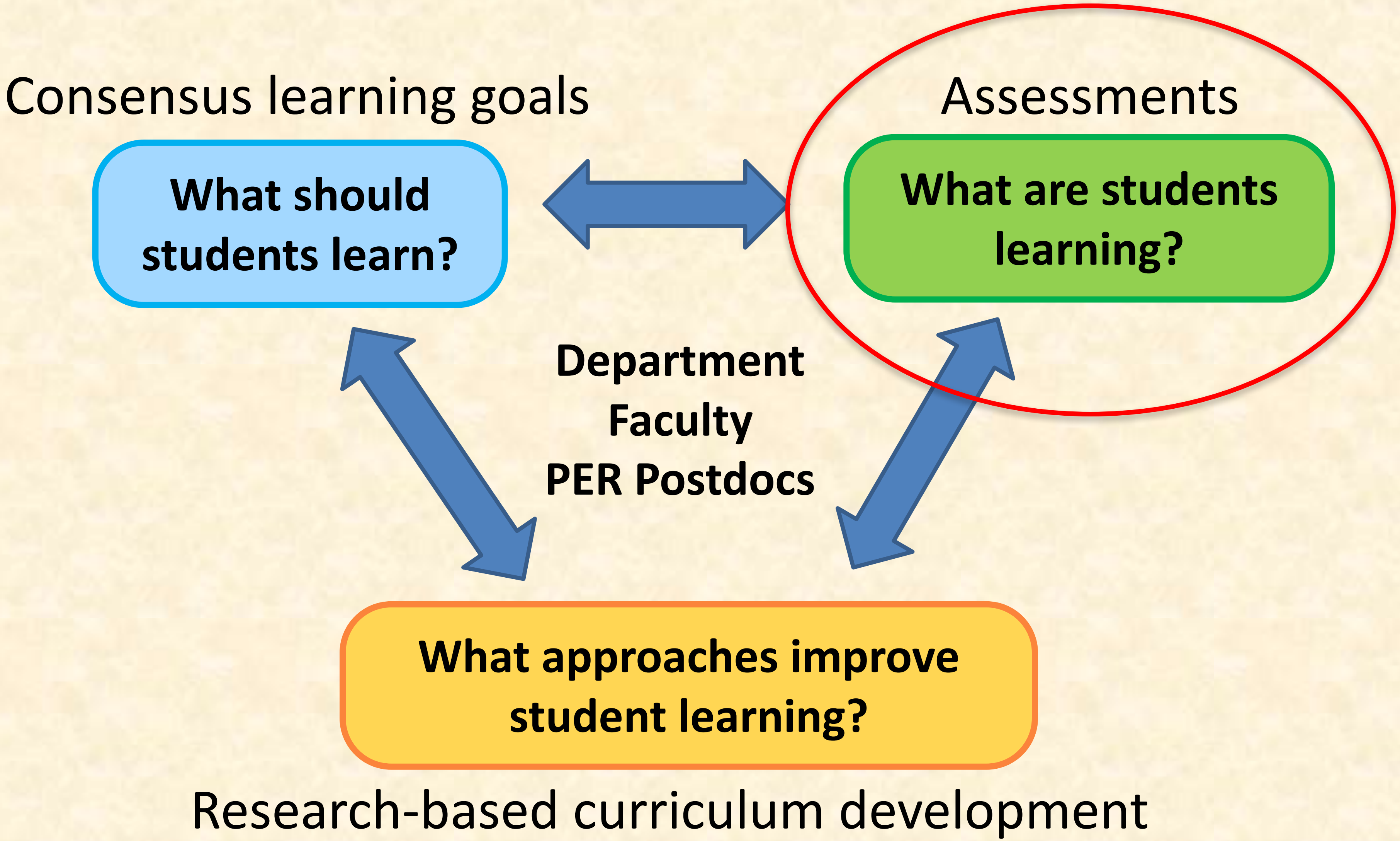
"Neither measurement was close to the prediction, so something must be wrong with the model."



No longer allowed to blame the equipment.

Systematic effects are just an incomplete model!

Transformation Model



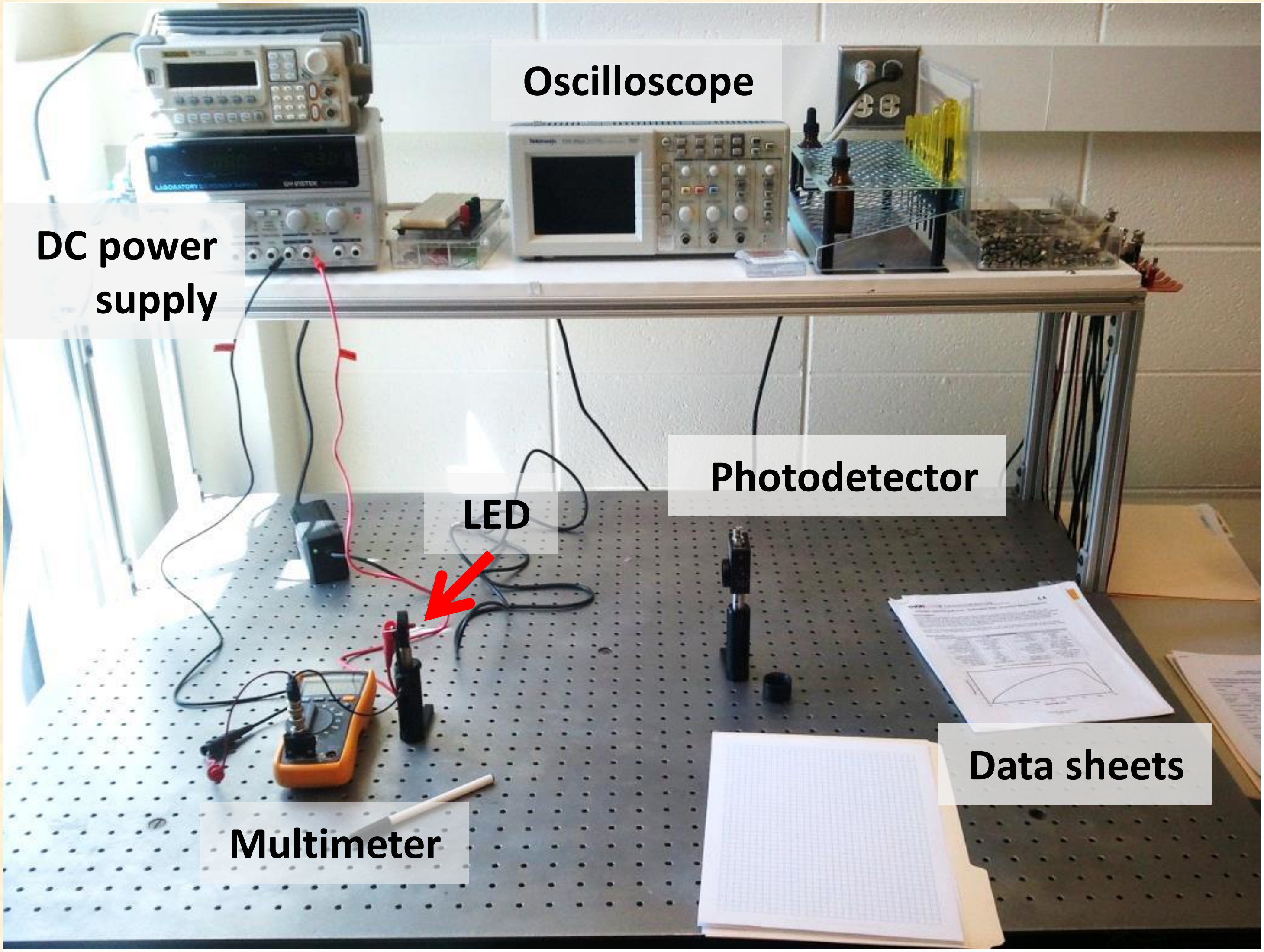
Research and Assessment

1) **Measure students' engagement with modeling**

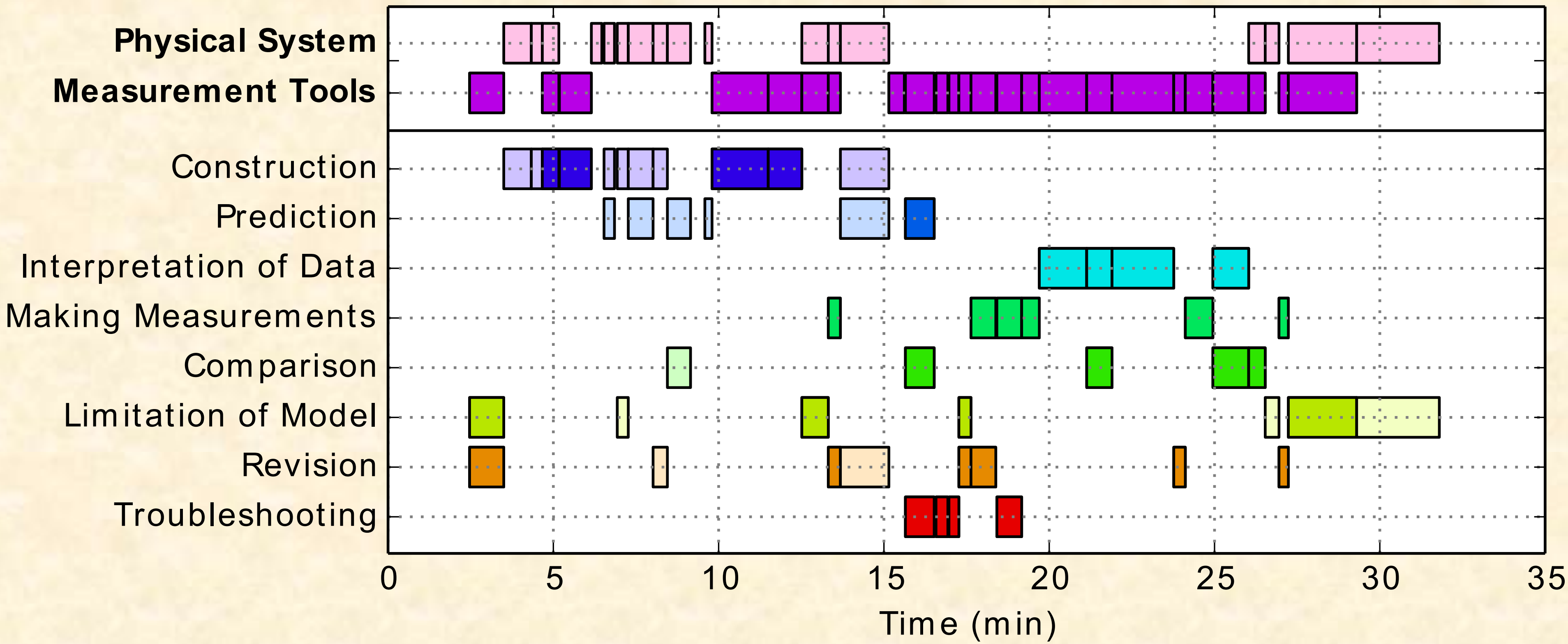
2) **Assess students' views about experimental physics**

Think-aloud Activity

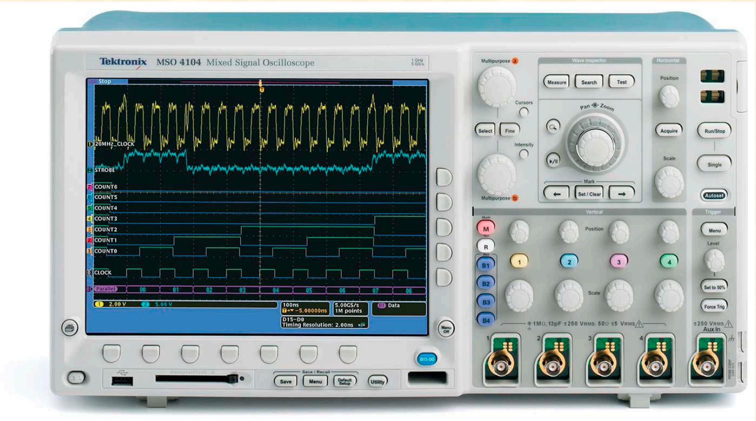
Framing: Test a new high-efficiency LED.

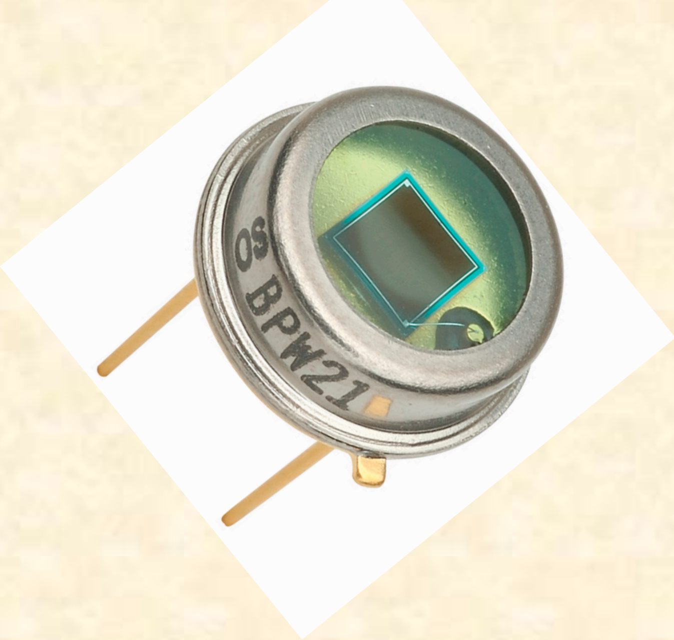


Think-aloud Activity Coding

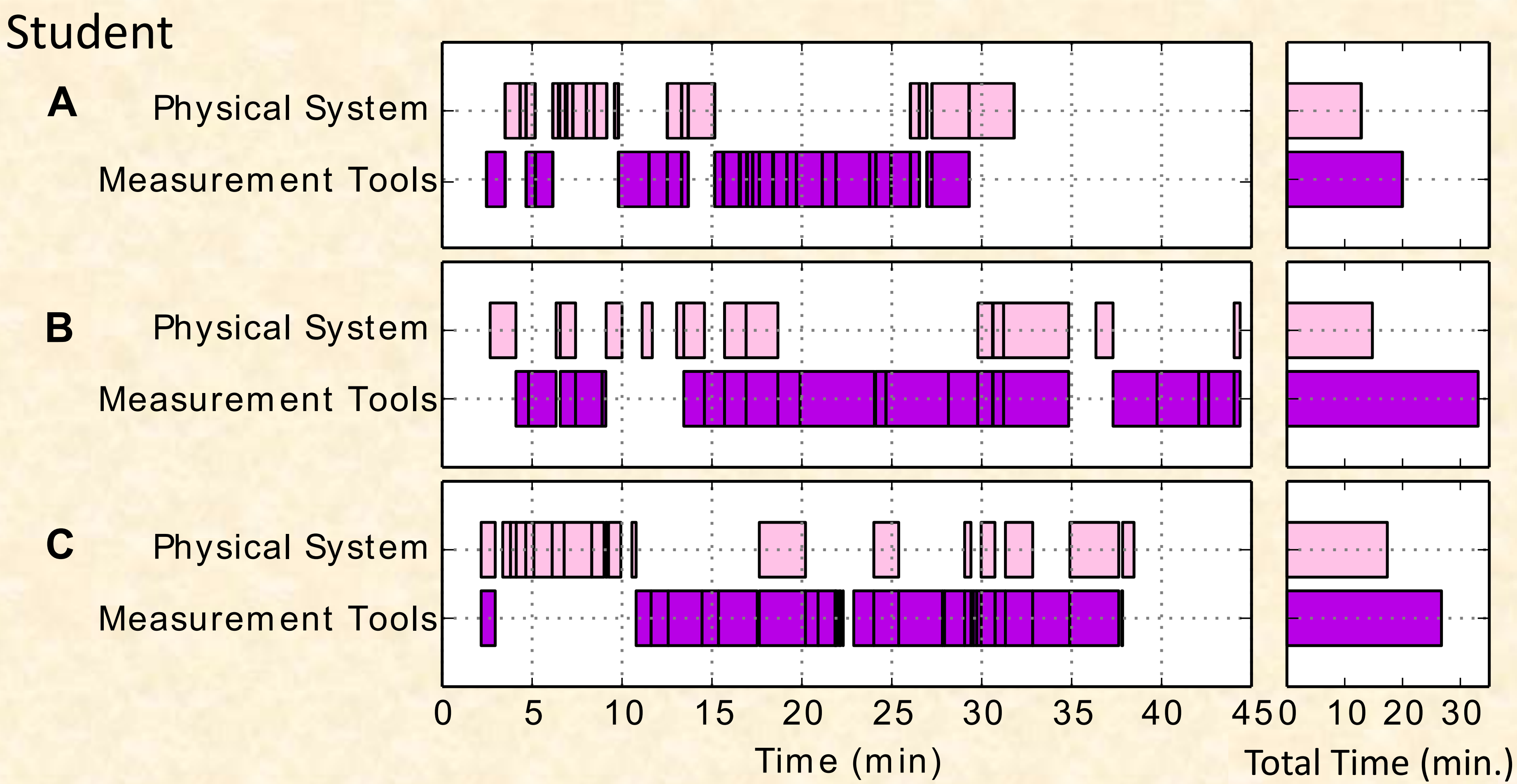


1) Modeling measurement tools is an important activity .



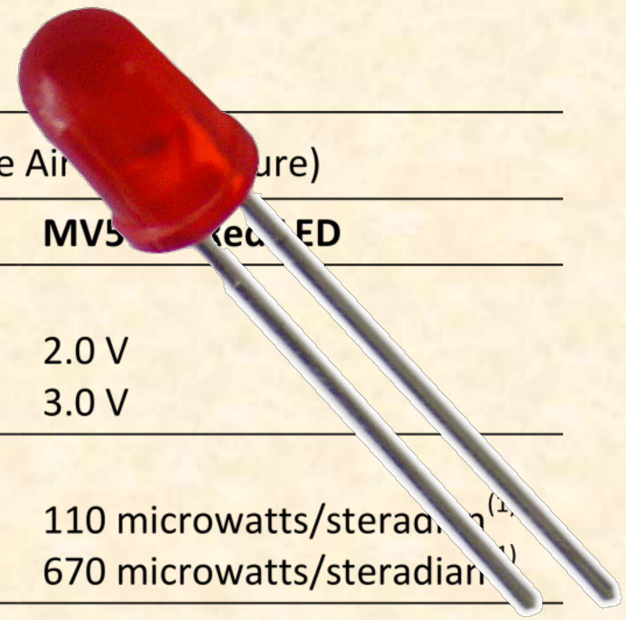


Time on task with Measurement Tools



Model Construction: Identifying Limitations

*"I think I'm just gonna put the photodiode directly in front of the LED and **hope that it's in between the 23 degrees of the viewing angle** so I get approximately 100 percent of the relative intensity...I just put the photodiode close so, that makes sure that I get as much of the intensity as I can."*

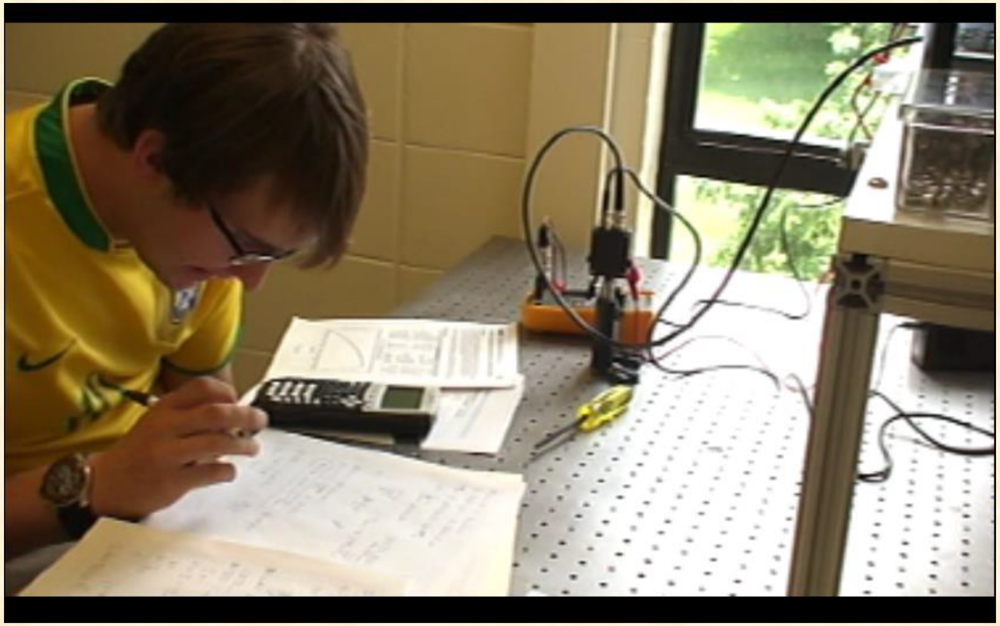


ELECTRO-OPTICAL CHARACTERISTCS (25°C Free Air [illegible]ure)

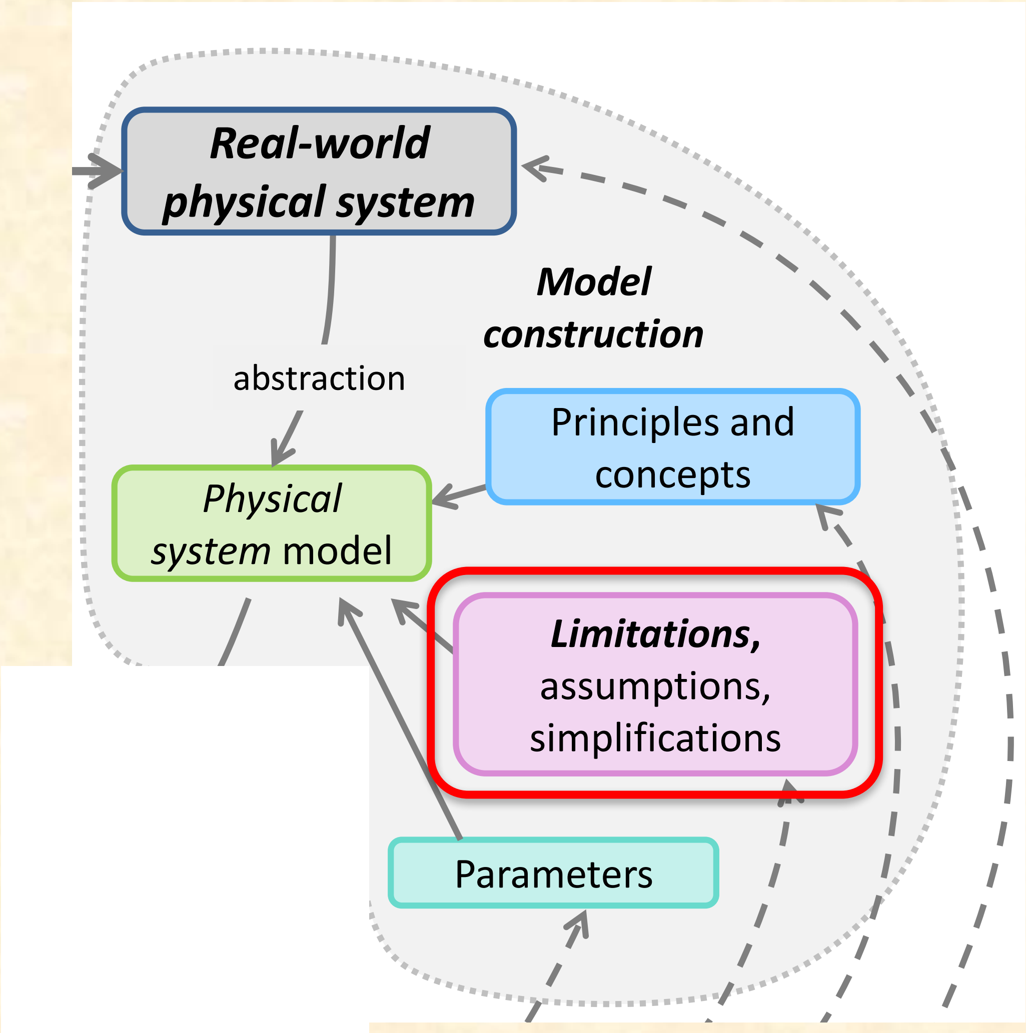
	TEST CONDITIONS	MV5[illegible] Red LED
Forward voltage (V_F)		
Typical	I_F = 20 mA	2.0 V
Max	I_F = 20 mA	3.0 V
Angular intensity		
Min	I_F = 20 mA	110 microwatts/sterad[illegible]n[1]
Typical	I_F = 20 mA	670 microwatts/steradian[1]
Peak wavelength	I_F = 20 mA	635 nm
Spectral line width (full width half max)	I_F = 20 mA	45 nm
Viewing angle (total)	(See Fig. 3)	28 degrees

Refinement: Apparatus and Model

“ Okay the photo diode is detecting a lot of sunlight. It's detecting the diode but the sunlight is definitely affecting the reading I'm just trying to think of the best way to get it. I think I'm just ***gonna put the diode right up against this thing to minimize all the stray light.*** *It looks like* ***with the LED off there's an offset voltage of just under 20 mV****. ...With the LED on, the voltage goes up to 39.2 mV....The difference is 23.2 mV from the diode being on to off.*



2) Not articulating assumptions can hinder the modeling process.



Unidentified assumptions are not going to be justified and unlikely to inspire any iterative refinements to the experiment.

Articulating Assumptions is Challenging

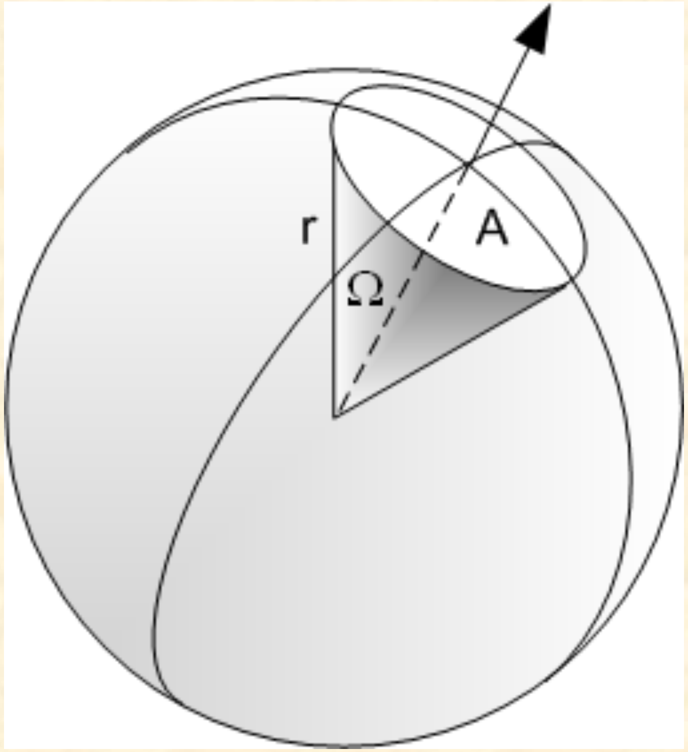
“I need to predict that total power of the LED. And so the power is the current times the voltage. And the forward voltage drop is like 2 volts . . .well, I'll try and put 20 milliamps in it because that's what it told me to do... which means my power should ***be 2 volts times 0.02 is 0.04 watts.*** *So predicted power is 0.04 Watts, so good stuff."*

This assumes:

Power dissipated = Optical Power

< 100% efficient

3) Incomplete prior knowledge can hinder the sophistication of the model.



$$\Omega = A / r^2$$

Incomplete Physics Knowledge is Limiting

"I am calculating the power IV for the diode according to the data sheet. I'm not sure what to do with the angular intensity. I don't know the units of microwatts per steradian."

ELECTRO-OPTICAL CHARACTERISTCS (25°C Free Air Temperature)		
	TEST CONDITIONS	**MV5752 Red LED**
Forward voltage (V_F)		
Typical	I_F = 20 mA	2.0 V
Max	I_F = 20 mA	3.0 V
Angular intensity		
Min	I_F = 20 mA	110 microwatts/steradian[1]
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Peak wavelength	I_F = 20 mA	635 nm
Spectral line width (full width half max)	I_F = 20 mA	45 nm
Viewing angle (total)	(See Fig. 3)	28 degrees

Labs don’t support Theory

Theory supports Lab!

Introductory Lab	Electronics Lab
Modern Physics Lab	Advanced Lab

Intro Mechanics	Particle and Nuclear	Solid State
Thermo & Stat Mech	Intro Mechanics	Optics
Modern Physics	Intro Mechanics	Quantum II
Classical Mechanics I	Classical Mechanics II	Quantum I
E&M I	E&M II	Intro E&M

Assessing Beliefs about Experimental Physics

E-CLASS

Colorado Learning about Science Survey for Experimental Physics

1) A new epistemology and expectations survey focused on experimental physics.

2) Validated for all levels of university students.

3) A common formative assessment tool than can be applied to a variety of lab experiences across the world.

Dimensions Probed

Affect
Scientific argumentation
Confidence
Experimental design
Math-Physics-Data connection
Modeling the measurement system
Physics community
Purpose of labs
Statistical uncertainty
Systematic error
Troubleshooting

E-CLASS Design

Paired Questions

Pre and Post

1. Students' personal attitudes and beliefs

2. Students' view of experts

Core Statement: (*e.g.,* Whenever I use a new measurement tool, I try to understand its performance limitations.)

Post only

3. Does this practice help to earn a good grade?

Actionable Evidence for Instructor

Example Results

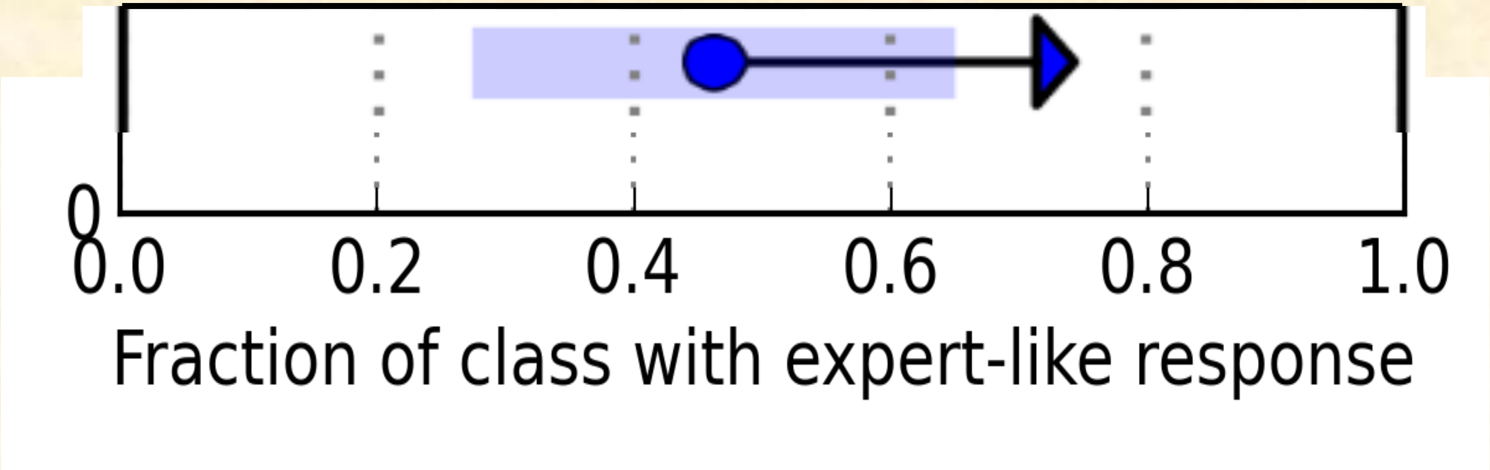
Advanced Lab Course (physics majors)

Elite Research Institution (not CU)

N = 49 (nearly 100% response)

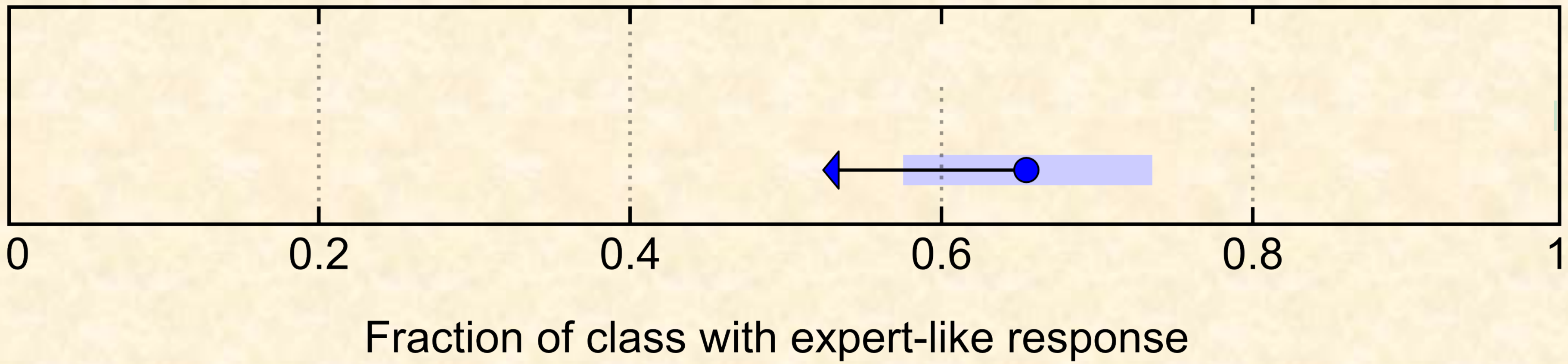
Pre-Post Shift Visualization

Bar: 95% confidence interval



Pre-post shifts : Positive

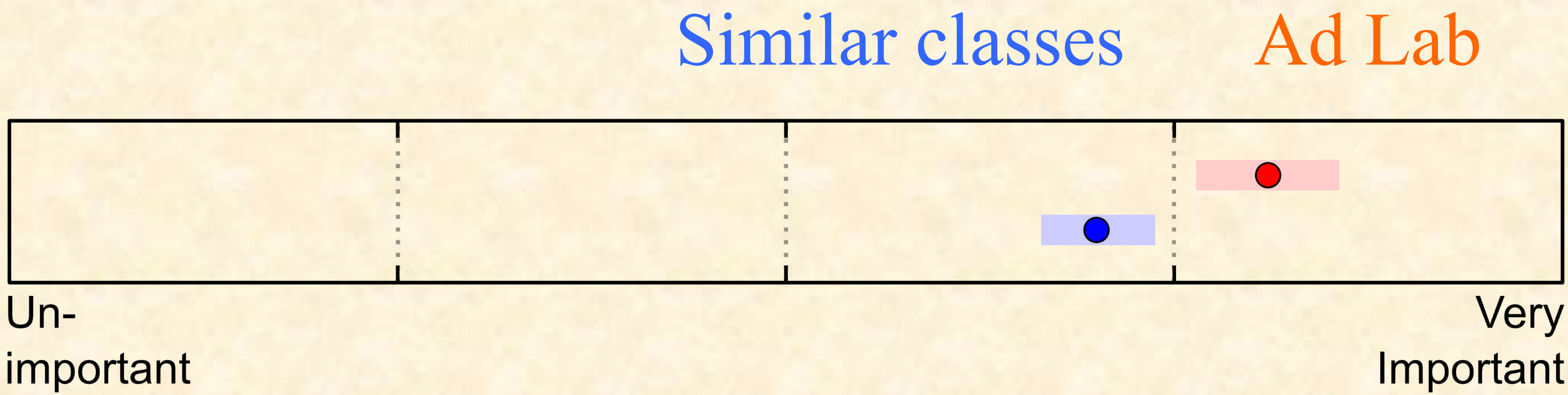
When doing an experiment, I just follow the instructions without thinking about their purpose.



- What do you think? (Ad Lab)
- What would expert say?
- What do you think? (similar classes)

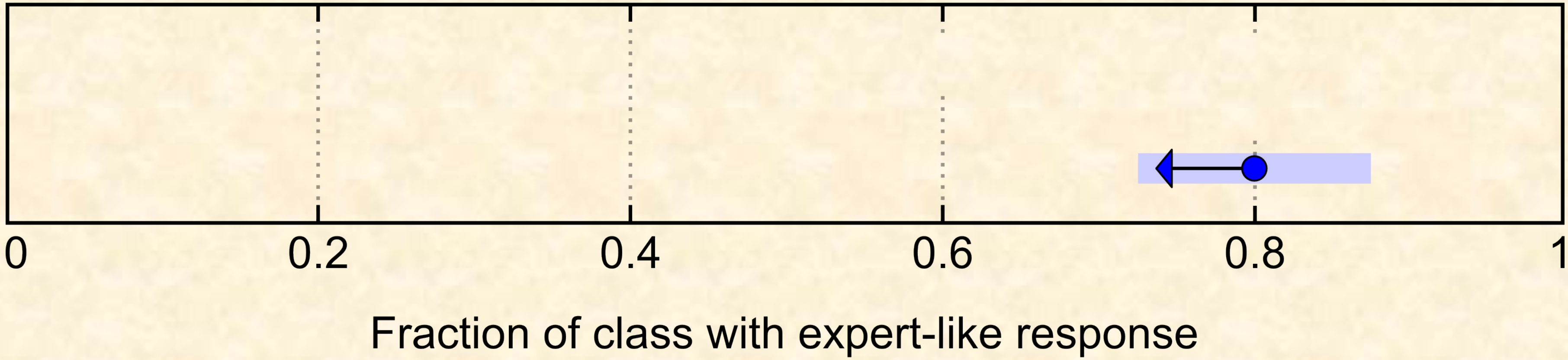
Course Expectations

How important for earning a good grade in this class was **thinking about the purpose of the instructions in the lab guide?**



Pre-post Shift: Negative

Designing and building things is an important part of doing physics experiments.



- What do you think? (Ad Lab)
- What would expert say?
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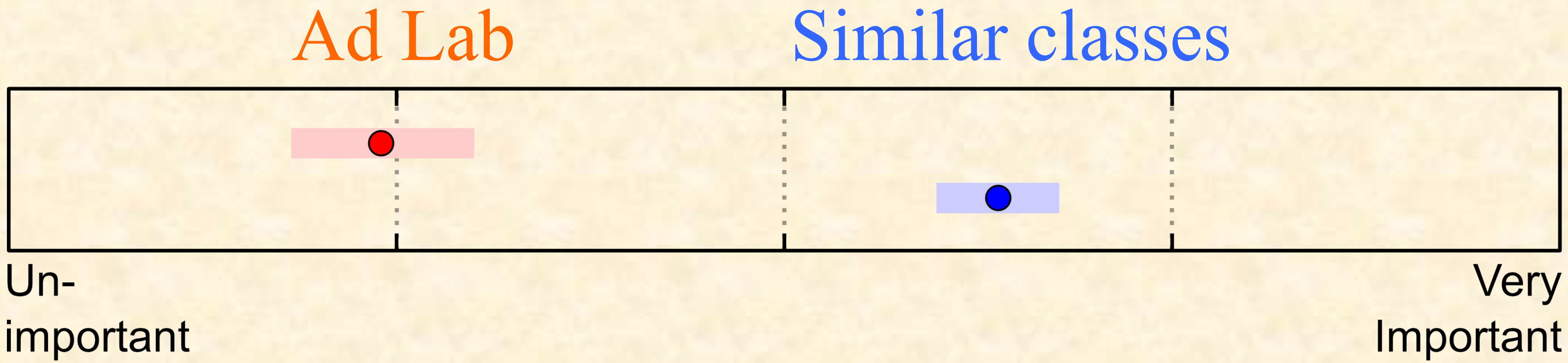
Course Expectations

How important for earning a good grade in this class was **designing and building things?**



Ad Lab Instructor Reported Goals

	Not at all important				Very important
When doing an experiment, I just follow the instructions without thinking about their purpose.	○	○	○	○	●
Designing and building things is an important part of doing physics experiments.	○	○	●	○	○

Wide Participation (8 semesters)

Countries	6
Institutions	80
Distinct Courses	>130
Total students	>10,000

All levels of university education

Broad Results from E-CLASS

1. "Named" intro labs (ISLE, Studio, Scale-up) do better than traditional labs

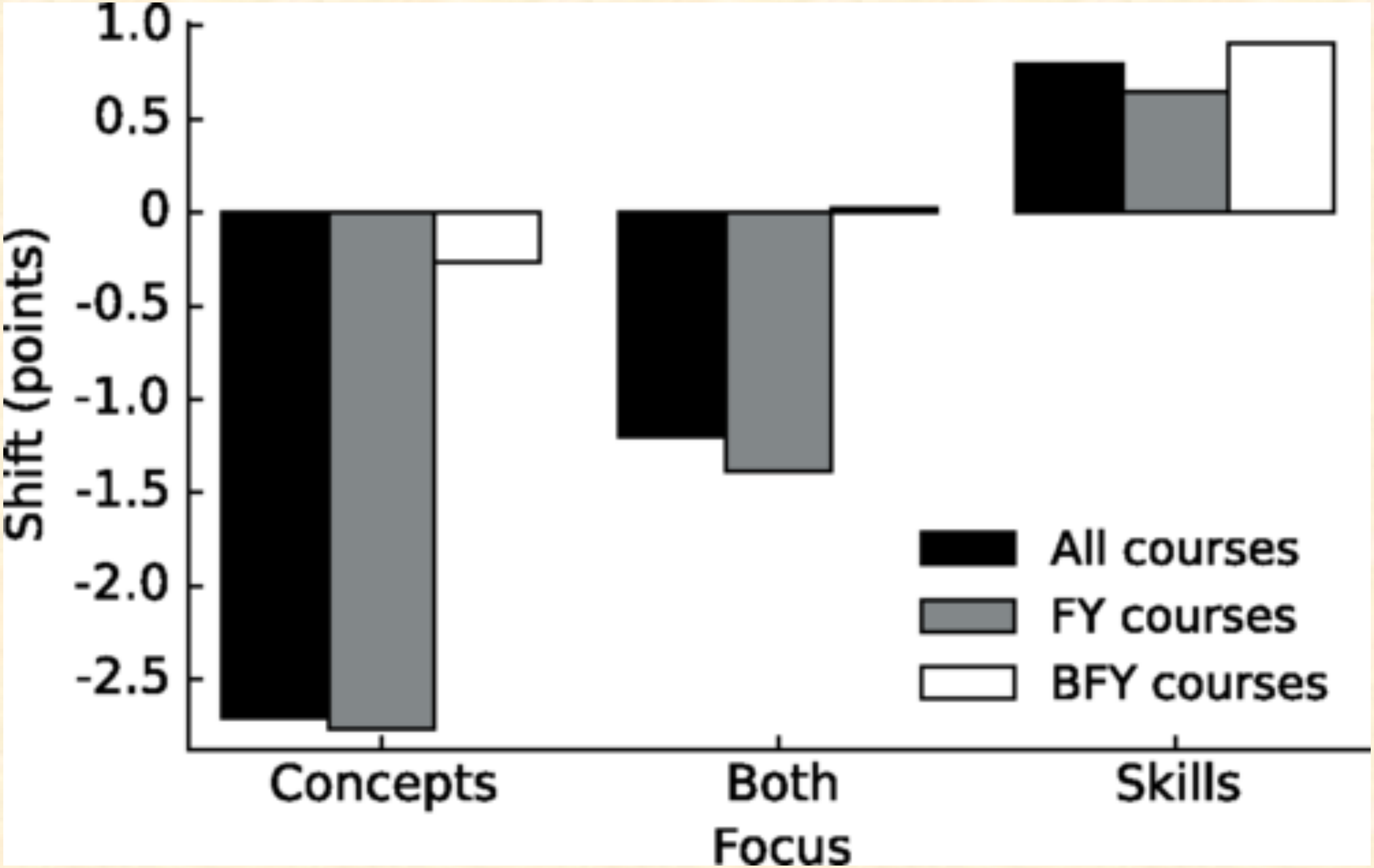
2. Partially open-ended labs score higher than 100% guided lab courses.

3. "Skills-based" courses score higher than courses that reinforce concepts. (Can eliminate or reverse gender gap)

4. Even when students have novice personal ideas, they know what experts think.

5. Perception of grading scheme can affect E-CLASS performance.

Skills vs Concepts Focused Courses



Other PER Projects in My Group

Lab Assessments :

E-CLASS (all levels of university physics)

- Measures students ideas about nature of experimental physics
- Use it easily in your own classes (tinyurl.com/ECLASS-physics)

Experimental Physics Modeling Assessment (3rd- 4th year classes)

- Measures students proficiency with modeling experiments
- Analog Electronics and Optics versions (in development)

Measurement and Uncertainty (1st-2nd year classes)

- Measures students ideas about experimental measurements
- Frequentist vs. Bayesian (set vs. point)
- In development

Still more PER Projects

1. **Troubleshooting in the lab (especially in electronics)**
2. **Lab notebook documentation as authentic scientific practice**
3. **Students' ownership of lab projects**
4. **Supporting project-based lab courses**
5. **Measurement and uncertainty in intro lab courses**
6. **Access to undergraduate research experiences**
7. **Graduate bridging program in Cape Town, South Africa**

The Team

Dimitri Dounas-Frazer (Postdoc CU)
Laura Rios (Postdoc CU)
Ben Pollard (Postdoc CU)

Ben Zwickl (now faculty at Rochester Institute of Technology)
Bethany Wilcox (now faculty at Colorado School of Mines)
Jacob Stanley (now lecturer at CU)
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PER
@ CU-Boulder

Publications and Resources

http://jila.colorado.edu/lewandowski/research/physics-education-research