Goals and strategies for physics lab classes

Ben Zwickl
Rochester Institute of Technology

Adapted from Natasha Holmes, Cornell

PhD in experimental physics

Taught intro, optics, electronics, advanced, and computational lab courses.

PER on labs for 12 yrs

Physics education research at RIT

Faculty

Ben Zwickl

Yasemin Kalender

Casey Miller

Scott Franklin

Grad/Postdoc

Dina Zohrabi Alaee (pd)

Mike Verostek (g)

Undergrads

Diana Ryder

Ridge Bennett

Rebecca Verchimak

Erik Pearson

Mark Flores

Keegan Tonry

Kayleigh Patterson

Mikayla McIntyre

Brandon Wright

Philip Reutter

REU program in STEM education research

RIT

Objective for this session

- Identify lab learning goals and which may be most suitable for your context
- Identify and describe pedagogical decisions that align with your goals
- Identify tensions and tradeoffs in lab education

Getting to know each other

What lab classes are you teaching or will teach?

- Algebra-based physics labs
- Calc-based physics labs (e.g., for engineers)
- Physics for life sciences
- Beyond first year labs (modern, optics, advanced, ...)
- Anything else?

What is the format of your lab courses?

- Standalone lab courses, not connected to a lecture
- Lab and lecture are separate, but synchronized
- Integrated lecture and lab (studio, workshop, ISLE, modeling instruction)

A scenario

Consider the following scenario

A penny pinching administrator doubts the value of lab courses.

- Labs suck up a lot of resources (instructors, equipment, space)
- Do they really help students learn better?
- Simulations are more “efficient” than real experiments
- The labs aren’t super popular with students anyway.

Mr. Krabs from Spongebob, Nickelodeon

Why not replace labs with online simulations?

Discuss with your neighbor for 3 minutes

How would you respond? Are any of the concerns legitimate?

Teaching labs in a theory-centric curriculum

Talk by Dr Eric Mazur: The Tyranny of the Lecture, June 7, 2013
https://youtu.be/TIz4sC_-5JY

Students' time is theory-centric

40 credits of lecture/theory	
University Physics I: Physics Majors	3
Special Relativity	3
University Physics I: Physics Majors	3
Sophomore seminar	1
Vibrations and Waves	3
Mathematical Methods in Physics	3
Classical Mechanics	3
Electricity and Magnetism	3
Modern Physics I	3
Modern Physics II	3
Quantum Mechanics	3
Thermal and Statistical Physics	3
Physics Electives	6

17 credits of lab	
Introductory Physics Lab	2
Electronic Measurements	3
Experiments in Modern Physics	3
Introduction to Computational Physics	3
Advanced Lab	3
Physics lab elective	3

You will probably feel that you have a lot to cram into a small number of lab courses

That feeling is normal.

Gatekeepers are theory-centric

Intro physics exams, not labs, cause students to fail.

Graduate School Admissions - GRE Physics Exam

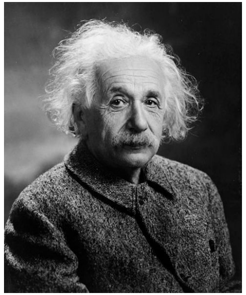
- only addresses short theoretical questions

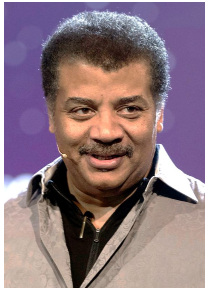
Progress in physics (undergrad and grad-level) heavily favors theory performance

Yet professional success involves computation, hands-on lab, open-ended designs, collaboration.

Is physics identity theory-centric?

Physics celebrities are generally theorists and astronomers

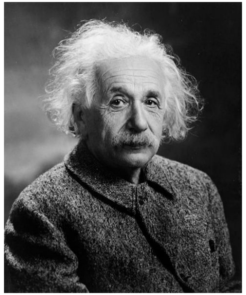




Labs offer a different way to be a "good" physicist.

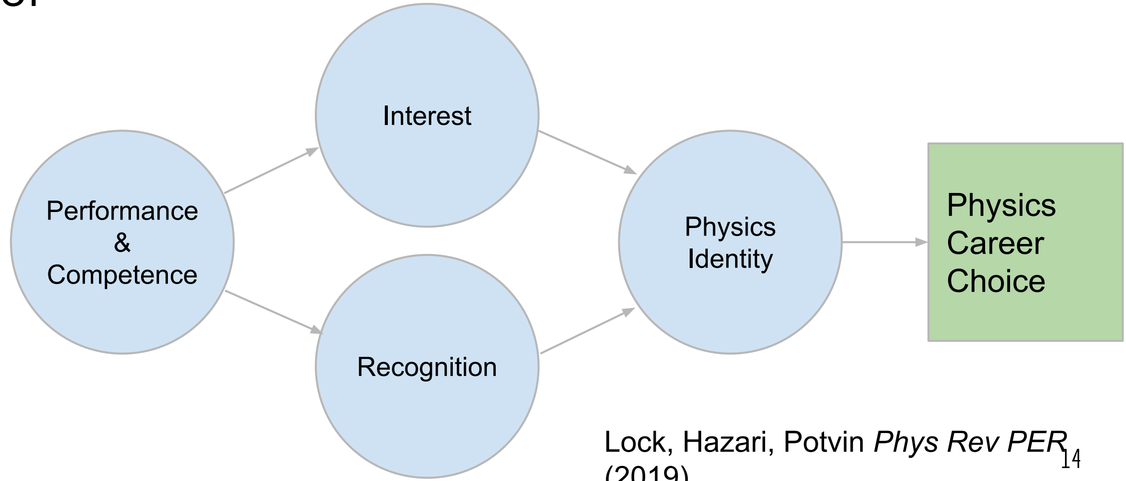
Is physics identity theory-centric?

- Physics celebrities are generally theorists and astronomers



- Most academic recognition is for theory, not lab, performance.

Labs offer a different way to be a "good" physicist.



Lock, Hazari, Potvin *Phys Rev PER* (2019)

Labs support career training

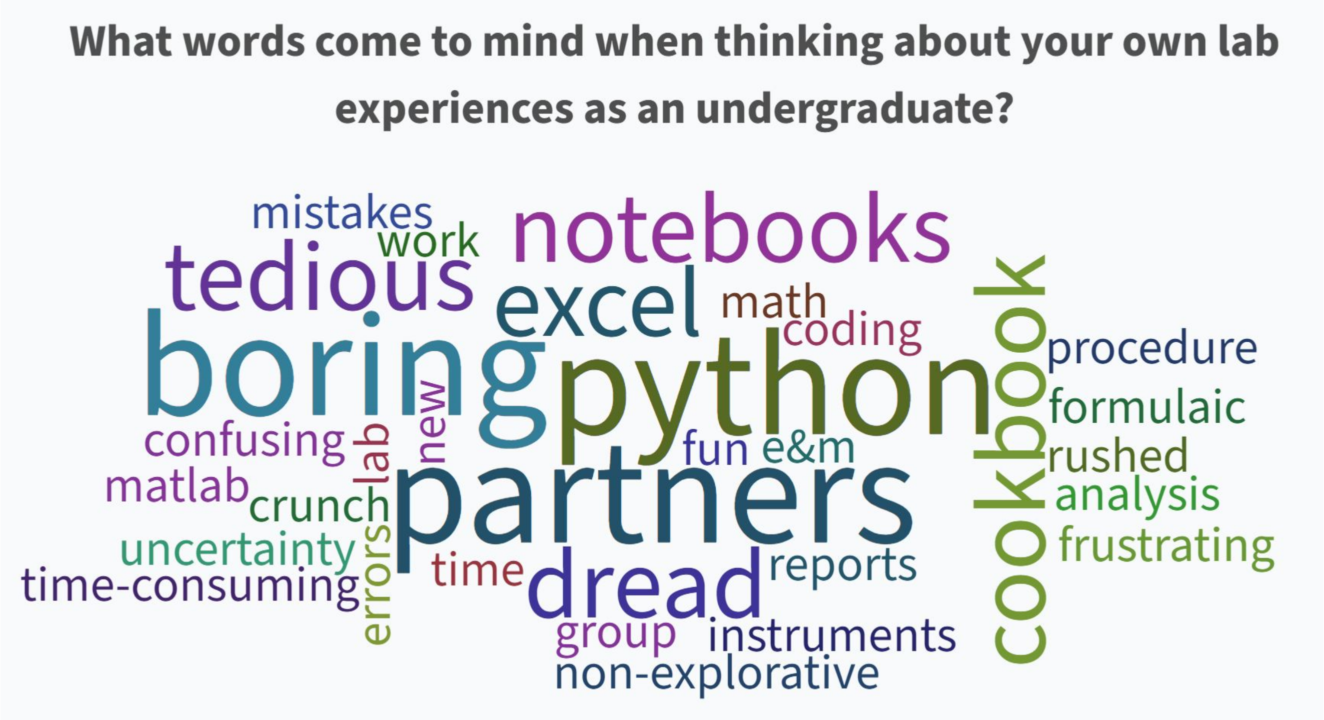
- Labs can provide relevant training for research and engineering
    - Technical skills
    - Computational modeling
    - Data analysis
    - Oral and written communication
    - Documentation

Think back to when you were a student...

Share with a neighbor (1 minute)

What words come to mind when thinking about your own lab experiences as an undergraduate?

Responses from 10 seniors and grad students



None of these students were doing experimental research

Purposes and goals of labs

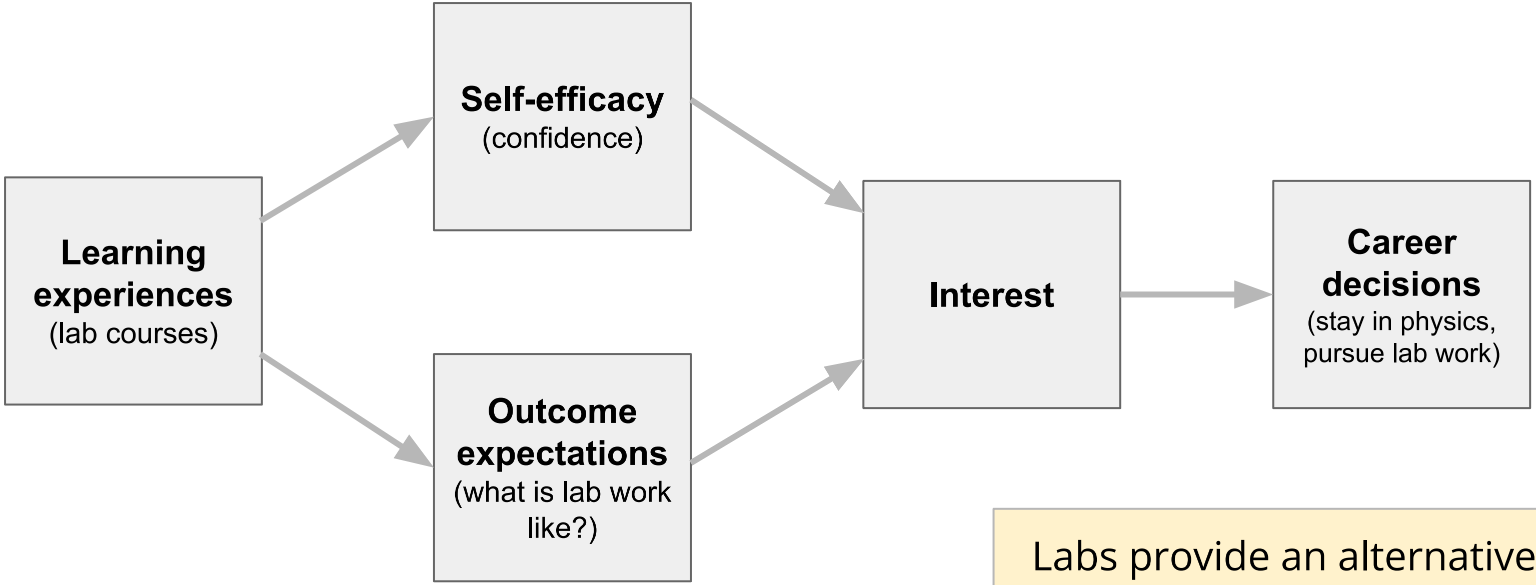
Broad categories of goals for labs

Skill and knowledge goals
- Reinforcing theoretical concepts
- Learning scientific practices
  - Data analysis, experimental design, presentation of results, etc.
- Developing scientific habits of mind
  - "nothing works the first time"

Psychosocial goals
- Positive affect and interest toward experimental work
- Self-confidence at lab work
- Sense of belonging in physics, identify as a "physics person"

Vermont Teddy Bear

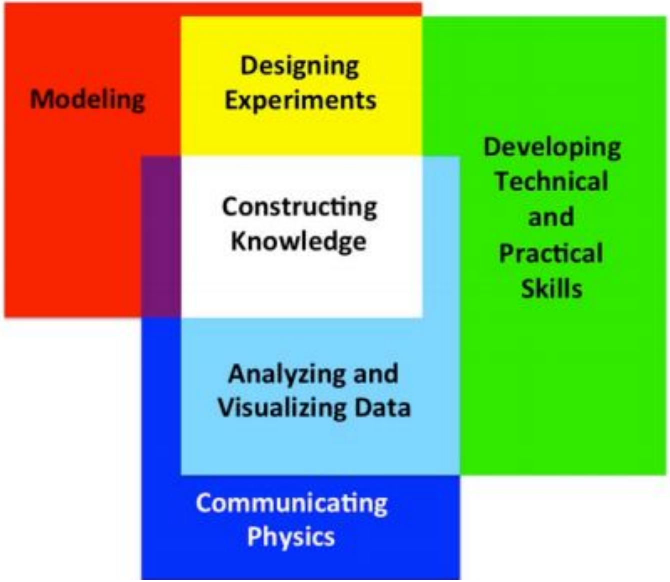
Why do the psycho-social factors matter?



Labs provide an alternative way to be **recognized** as successful and to **belong** to the physics community.

Harazi et al (2010) J. Res. Sci. Teac
Lent et al (1994) J. Vocational Behavior

AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum



AAPT Recommendations emphasize scientific practices and habits of mind

They move focus away from conceptual learning

https://www.aapt.org/resources/upload/labguidlinesdocument_ebendorsed_nov10.pdf

Discussion about Learning Goals

Organize into groups of 2-4

Introductory labs – general
Introductory labs – for life science majors
Labs beyond the introductory labs

Activity (5 minutes)

- What are dominant goals of the your current labs?
- Are there any goals you think should be added to the course?

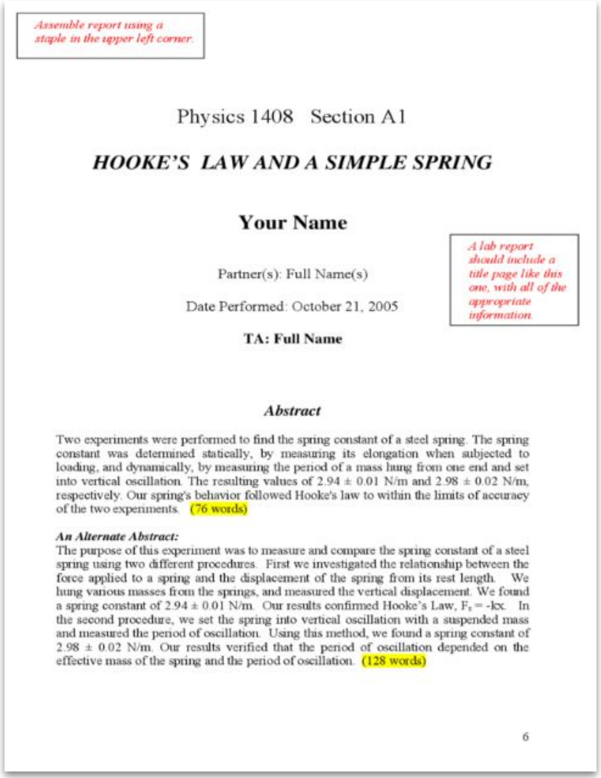
Aligning goals and assessments

Lab reports

Traditionally, lab reports have been a primary assessment in lab courses.

Discuss 1-2 minutes with your neighbor

- What goals are lab reports aligned with?
- What goals might be missed?



Assemble report using a staple in the upper left corner.

Physics 1408 Section A1

HOOKE'S LAW AND A SIMPLE SPRING

Your Name

A lab report should include a title page like this one, with all of the appropriate information.

Partner(s): Full Name(s)

Date Performed: October 21, 2005

TA: Full Name

Abstract

Two experiments were performed to find the spring constant of a steel spring. The spring constant was determined statically, by measuring its elongation when subjected to loading, and dynamically, by measuring the period of a mass hung from one end and set into vertical oscillation. The resulting values of 2.94 ± 0.01 N/m and 2.98 ± 0.02 N/m, respectively. Our spring's behavior followed Hooke's law to within the limits of accuracy of the two experiments. (76 words)

An Alternate Abstract:
The purpose of this experiment was to measure and compare the spring constant of a steel spring using two different procedures. First we investigated the relationship between the force applied to a spring and the displacement of the spring from its rest length. We hung various masses from the springs, and measured the vertical displacement. We found a spring constant of 2.94 ± 0.01 N/m. Our results confirmed Hooke's Law, $F_s = -kx$. In the second procedure, we set the spring into vertical oscillation with a suspended mass and measured the period of oscillation. Using this method, we found a spring constant of 2.98 ± 0.02 N/m. Our results verified that the period of oscillation depended on the effective mass of the spring and the period of oscillation. (128 words)

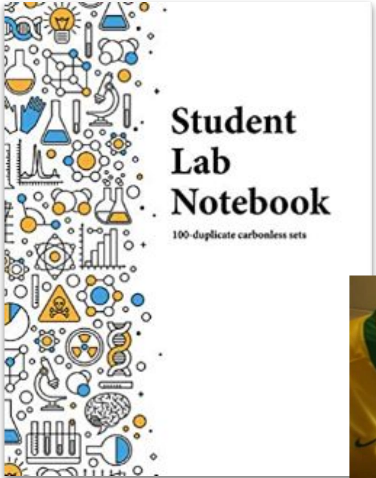
6

Unintended consequences of lab reports

1. Writing becomes strong(est) emphasis in lab
2. Grade largely depends on out-of-lab work
   a. Incentivizes getting out of lab quickly to have more time to write it up later.
3. Does not capture the “process” or “practice” learning goals
4. Generally, not a communicative. The “correct” results are already known by instructor.

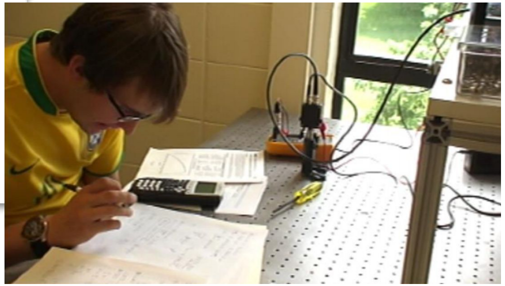
What other kinds of assessment formats are possible?

Lab skills ⟷ **Content knowledge**

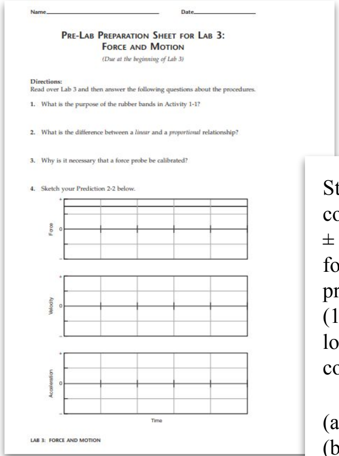


	Poor	Fair	Good	Excellent
Criterial 1				
Citerial 2				
Citieria 3				

Rubrics



Lab practical


Name____________ Date________

PRE-LAB PREPARATION SHEET FOR LAB 3:
FORCE AND MOTION
(Due at the beginning of Lab 3)

Directions:
Read over Lab 3 and then answer the following questions about the procedures.

1. What is the purpose of the rubber bands in Activity 1-1?
2. What is the difference between a *linear* and a *proportional* relationship?
3. Why is it necessary that a force probe be calibrated?
4. Sketch your Prediction 2-2 below.

LAB 3: FORCE AND MOTION

Worksheets

Student A measures the flow rate of water coming from a tap and reports it to be (90 ± 12) millilitres per second. Student B follows a different measurement procedure and reports the flow rate to be (110 ± 1) millilitres per second. How long would it take to fill a 1 litre container?

(a) 10.0 s
(b) 9.1 s
(c) 11.1 s
(d) 9.5 s
(e) 10.6 s

Concept test (CDPA)

Focus on alignment between goals and assessment

What other kinds of assessments are possible?

Beyond lab reports, what other assessment could be used in the lab?

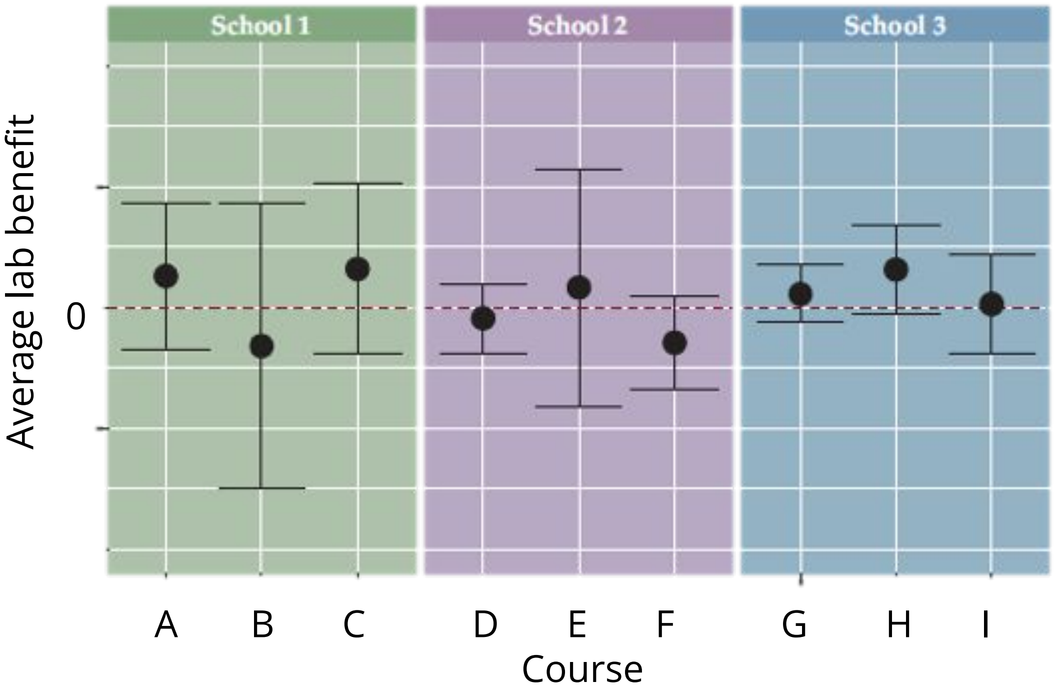
- What have you used?
- What creative ideas might you have?

What do labs actually teach?
(a little bit of PER)

What are the 2 most important outcomes for your labs?

- Students' identity as a physicist
- Conceptual learning
- Enjoyment of physics
- Problem-solving ability
- Beliefs about the nature of science
- Experimental skills and practices
- Confidence in doing experiments

Most labs don't improve conceptual learning



Labs that focus on conceptual understanding don't improve exam performance.

Holmes et al., (2017) *Phys. Rev. PER;* Holmes & Wieman (2017) *Physics Today*

Most labs don't improve conceptual learning

	Midterm 1	Midterm 2	Final
Design labs (strong focus on scientific practices)	96.0	104.7	174.9
Non-design labs (no focus on design)	97.8	98.4	170.8

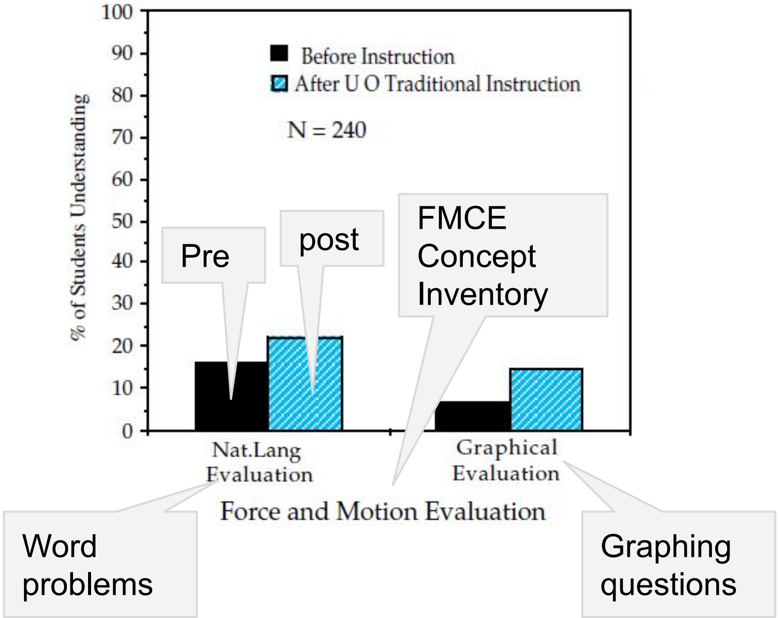
Labs that focus on scientific abilities (e.g., experimental design) don't negatively impact exam performance.

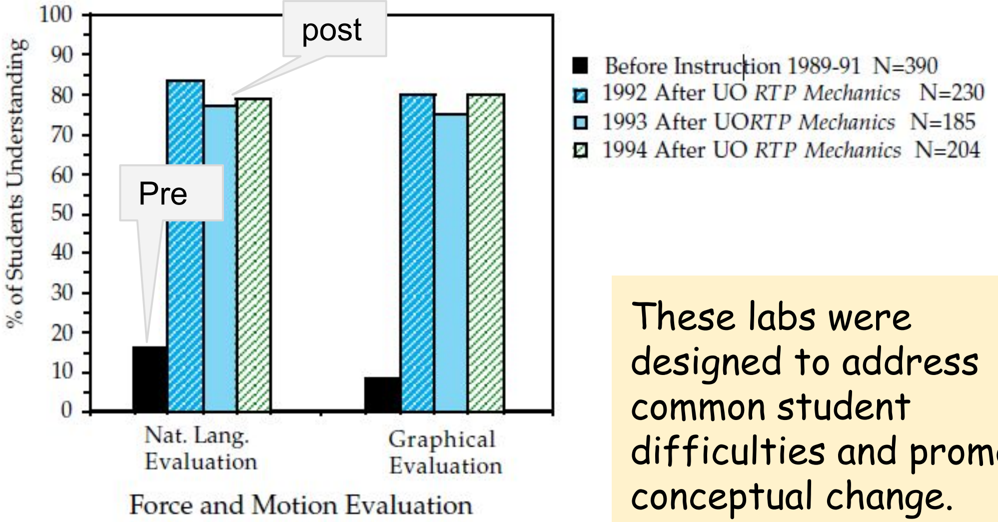
You can do something totally wacky in labs and not affect exam scores.

Etkina et al., (2010) *Journal of the Learning Sciences*

Some labs (especially in integrated lecture lab) can improve conceptual learning

Example of RealTime Physics curriculum

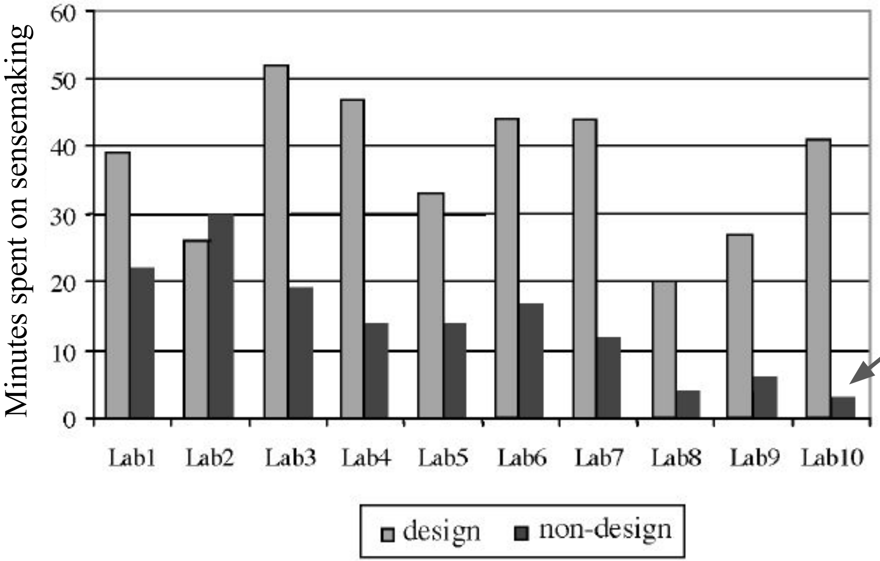




These labs were designed to address common student difficulties and promote conceptual change.

Labs can teach scientific abilities/practices

- More time sense-making in labs focused on scientific abilities
- Lab reports document higher levels of student reasoning

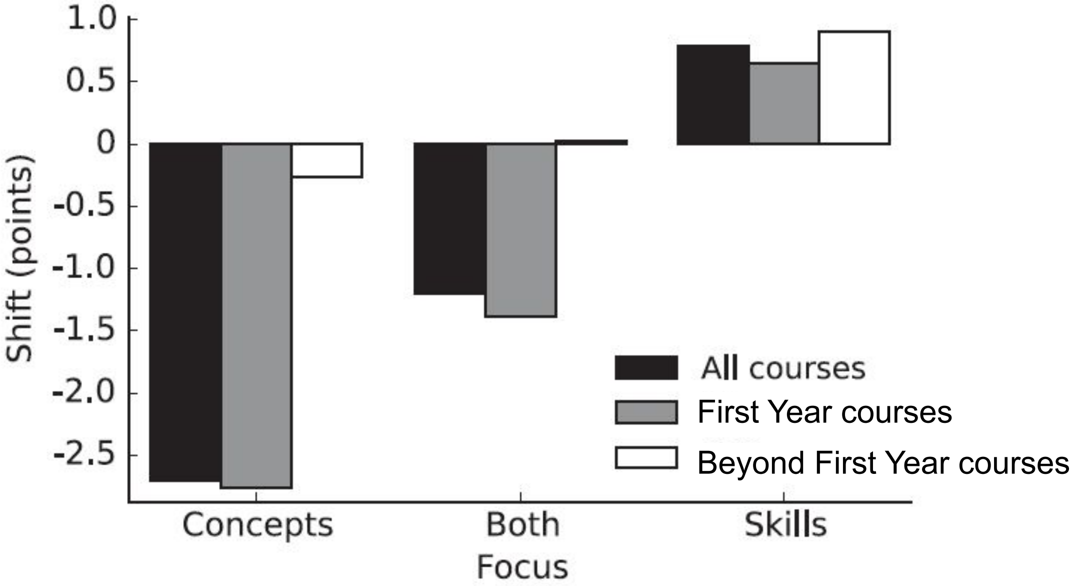


Yowzers!

Scary non-design labs had only 3 minutes of sensemaking!

Etkina et al., (2010) *Journal of the Learning Sciences*

Labs can shift learning attitudes



Data from the E-CLASS survey

Labs that focus on concepts may

- Verify a phenomenon

Labs that focus on skills may

- Provide more agency to make decisions

Wilcox et al., (2017) *Phys Rev PER*

Labs may send wrong message about experiments

Why are experiments a common part of physics classes?

	Intro Algebra N=75	Intro calculus N=28	Upper N=20	Ph.D. N=31
Supplemental learning				
Theory testing				
Foundation of physics				
Scientific abilities				
Science appreciation				
Career Preparation				

Hu, Dehui, and Benjamin M. Zwickl. “Examining Students’ Personal Epistemology: The Role of Physics Experiments and Relation with Theory,” 11–14, 2018. https://www.compadre.org/per/items/detail.cfm?ID=14680.

Labs may send wrong message about experiments

Why are experiments a common part of physics classes?

	Intro Algebra N=75	Intro calculus N=28	Upper N=20	Ph.D. N=31
Supplemental learning	0.91	1.00	0.70	0.55
Theory testing	0.15	0.21	0.55	0.42
Foundation of physics	0.04	0.07	0.20	0.74
Scientific abilities	0.01	0.11	0.30	0.35
Science appreciation	0.01	0.04	0.10	0.32
Career Preparation	0.00	0.04	0.20	0.26

"experiments help students visualize the theories that they are learning."

- Intro student

Hu et al, PERC Proceedings https://www.compadre.org/per/items/detail.cfm?ID=14680.

Labs may send wrong message about nature of scientific knowledge

How do you know if an experimental result is acceptable or trustworthy?

Criteria for validity		Codes	Intro algebra	Intro calculus	Upper	Ph.D.
Theory-based		Comparison with theory	0.39	0.68	0.35	0.50
Experiment-based	Results-based	Comparison with others	0.37	0.29	0.80	0.35
		Repeatability	0.15	0.39	0.25	0.71
	Process-based	Uncertainty evaluation	0.17	0.25	0.55	0.32
		Quality work	0.08	0.11	0.05	0.39
Authority-based		Authority figures	0.12	0.07	0.00	0.00

"If [the results] correspond to the theory answers. This is the best way to check if the results are acceptable."

- Intro physics student

Dehui & Zwickl.(2018) Phys Rev PER

Verification labs may teach students to fudge data

Most students expect lab is about verifying a model or equation…

…discrepant results appeared to lead to questionable research practices

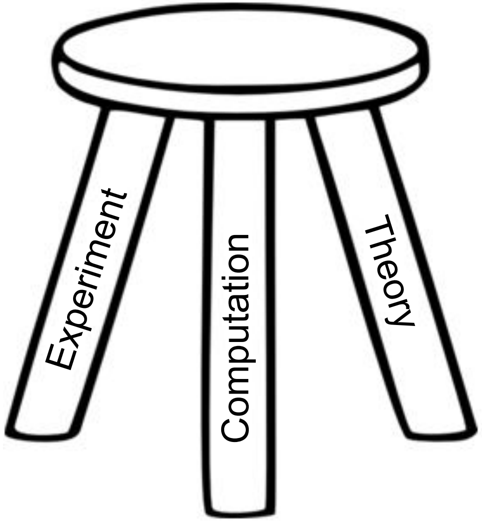
- Selectively analyzing data
- Ignoring contradictory results
- Assuming equipment was faulty

Smith et al (2020) Phys Rev PER

Labs can teach students they aren’t good at experiments

Interviewer: “Which [type of physics] would you say is your is your favorite to do work in?”

Student: “Anything except experimental...I know a lot of people enjoy, like, doing the physics with their hands. I'm definitely not that guy. I'd rather just see it through equations.”



Common elements of negative student experiences:

- Only exposure to experiment in lab courses (not research)
- No out-of-class practice
- No peer learning with experiments (outside of class)
- Lower self-confidence in experimental work

Cardona et al., (2021) *Proceedings of the Physics Education Research Conference*

Summary

The **goals** section was meant to get you excited.

The **evidence for learning** suggests labs often fall short.

Why do lab courses often fall short?

- **nebulous goals** (mostly concepts, but a hint of practices)
- **absent goals** (e.g., enjoyment, confidence, identity)
- **curricula not aligned** with relevant learning goals

Questions

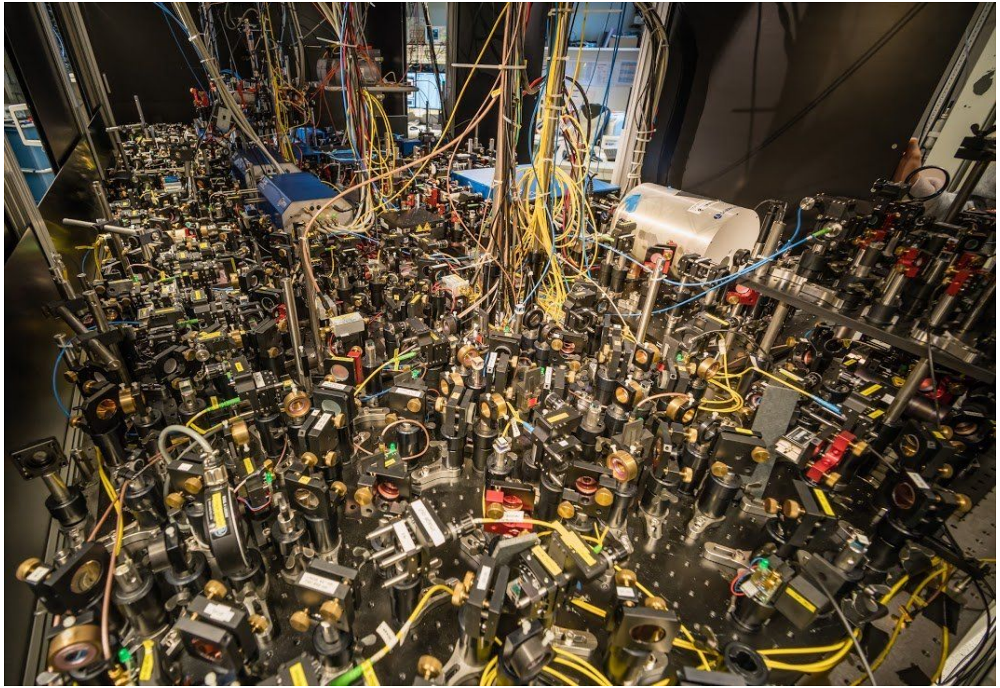
Questions about evidence for laboratory learning?

Confronting the complexity of labs

Acknowledging the complexity of labs

Complex research lab environment

- Natural phenomena
- Apparatus and measurement tools
- Scientific practices
- Multiple pathways to solutions (including failure and iteration)
- Integrate theory, experimentation, and computation together.
- Collaborate with other people
- Diverse goals



Ultracold Atom Lab, Immanuel Bloch

Acknowledging the complexity of labs

Complex research lab environment

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Examples of reductions of complexity

- Detailed procedures (cookbook)
- Idealized lab apparatus that matches simpler models
- Selecting lab equipment for students
- Simple data acquisition and plotting tools
- Frameworks for navigating decisions in the lab
- Focus on a small range of goals

Complexity: Why labs can be hard for students

- New physics ideas (e.g., force, acceleration)
  - What do these mean? How do they relate to the experiment?
- New problem-solving strategies (e.g., experimental design)
  - What makes an experimental design better or worse?
- New equipment
  - How does this work? What do the results mean? How do I use it?

Cognitive Load in Lab

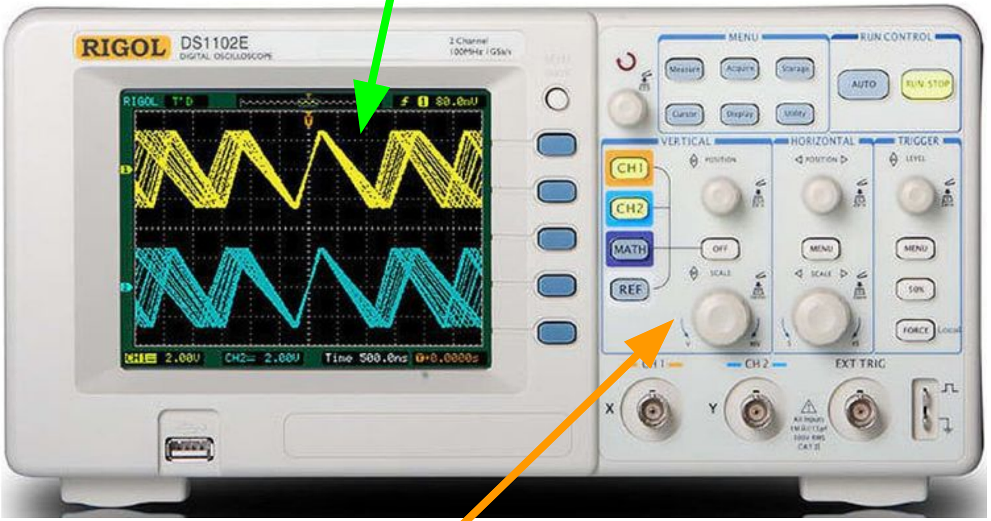
Working Memory - only about 4 pieces of information can be consciously worked on in the mind

Cognitive Load - How much of the working memory capacity is used up while learning

Intrinsic Cognitive Load - challenge essential to the task

Extraneous Cognitive Load - challenge irrelevant to the task

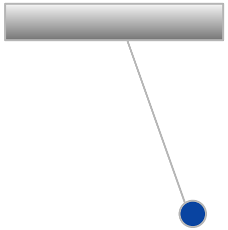
Intrinsic load: reading graphs, identifying frequency, amplitude, trigger condition



Extraneous load: where is the info displayed? Which button do I press? What does this knob do?

Cognitive Load Example: A “simple” data table

1. Make a pendulum.



2. Collect data showing how the period changes with length and with amplitude.

A bunch of decisions need to be made:

- What goes on rows vs columns?
- How many rows and columns?
- Does the order matter?
- Do I need multiple tables, or just one?
- Should I include calculations?
- Make it on paper, in Excel, Google Sheets?

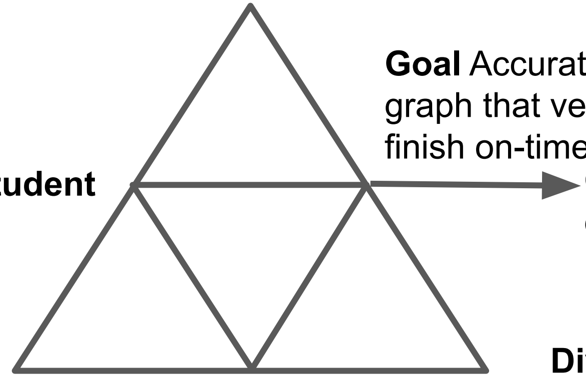
Reducing complexity and cognitive load with cookbooks

Cookbook lab

A recipe for efficient labs with accurate data

by

Lab Instructors Everywhere



Tools Detailed procedures, idealized lab equipment

Goal Accurate measurements, graph that verifies theory, finish on-time

Student

Outcome Lab report that describes process and data

Rules Follow instructions

Community Lab partner, instructor

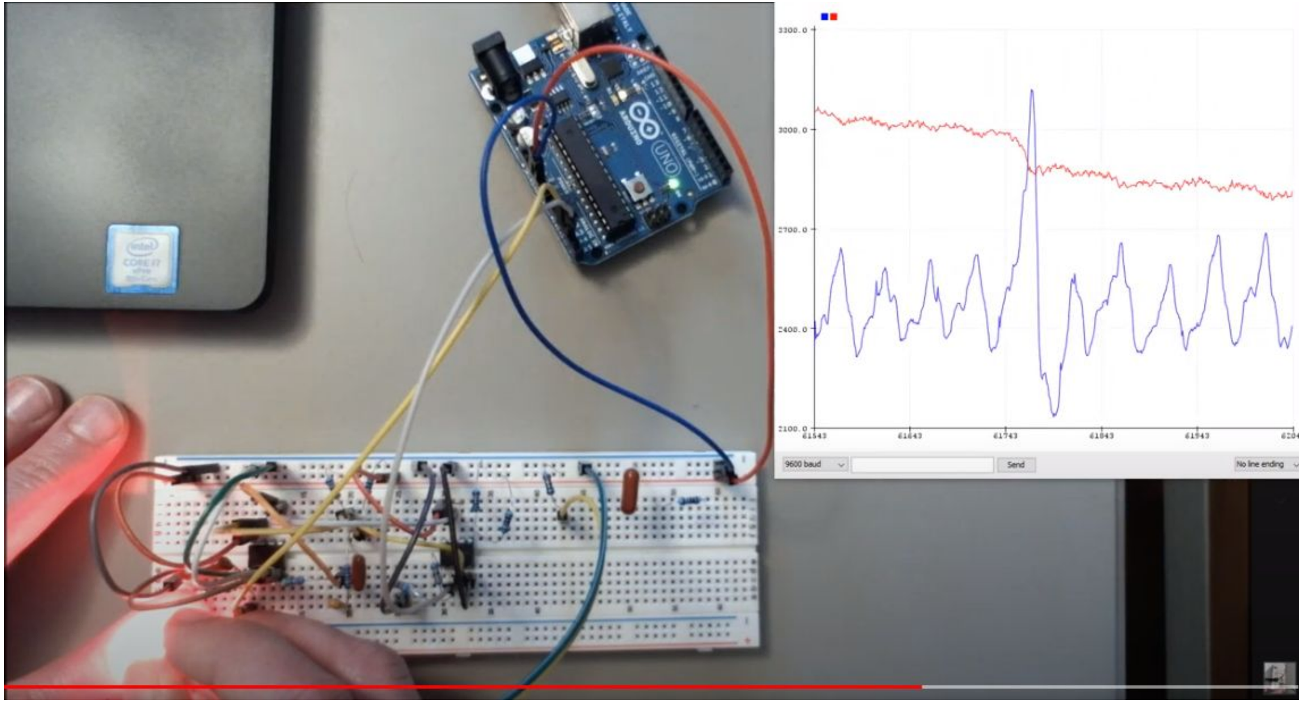
Division of Labor Instructor pre-selects equipment, students divide into “hands-on” and recorder roles

Other ways to reduce complexity and enhance learning

- Easier-to-use equipment
- Develop proficiency through repeated practice
- Provide scaffolding (increase complexity of lab throughout semester)
- Set fewer (but still meaningful) goals
- Simpler outcomes
- Don’t focus lab on teaching concepts, target different goals.

The challenge of low motivation

- Adding relevance



Optical pulse sensor from 2nd year electronics lab for physics majors

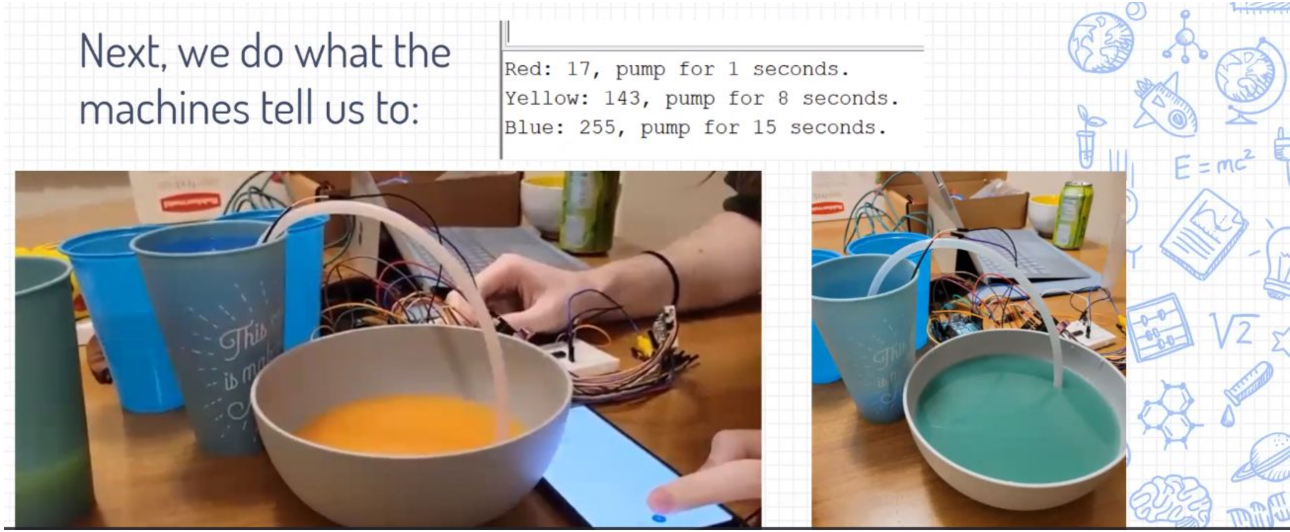
The challenge of low motivation

- Adding relevance
- Adding curiosity

The challenge of low motivation

- Adding relevance
- Adding curiosity
- Adding agency

Color Mix-a-tron 500



Pedagogical decisions for labs

Decision 1: When to introduce scientific practices

You overhear a colleague say...

“Labs focusing on scientific practices are great, but introductory students just aren’t ready to design their own experiments.”

Take 2 minutes to discuss with your neighbor

- Do you agree or disagree?
- Should practices like experimental design or modeling be reserved for more advanced students? Or only for physics majors?

Several intro-level curricula emphasize practices

I**ntegrated lecture-lab environments** with a big focus on multiple practices.

- Investigative Science Learning Environment (ISLE)
- Modeling Instruction (HS and Intro College)

Standalone labs that emphasize practices

- Cornell “Critical Thinking” Labs
- HS Labs aligned with Next Generation Science Standards

Several intro-level curricula emphasize practices

Integrated lecture-lab environments with a big focus on multiple practices.

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Standalone labs that emphasize practices

- Cornell "Critical Thinking" Labs
- HS Labs aligned with Next Generation Science Standards

Scientific Abilities

- represent information in multiple ways;
- use scientific equipment to conduct experimental investigations and to gather pertinent data to investigate phenomena, to test hypotheses, or to solve practical problems;
- collect and represent data in order to find patterns, and to ask questions;
- devise multiple explanations for the patterns and to modify them in light of new data;
- evaluate the design and the results of an experiment or a solution to a problem;
- communicate.

Comparing ISLE scientific abilities vs other lab goals

- represent information in multiple ways;
- use scientific equipment to conduct experimental investigations and to gather pertinent data to investigate phenomena, to test hypotheses, or to solve practical problems;
- collect and represent data in order to find patterns, and to ask questions;
- devise multiple explanations for the patterns and to modify them in light of new data;
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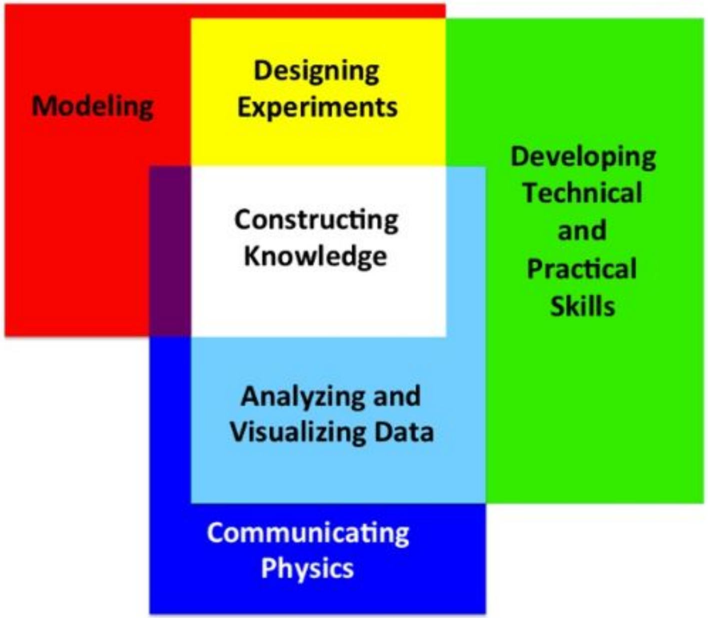
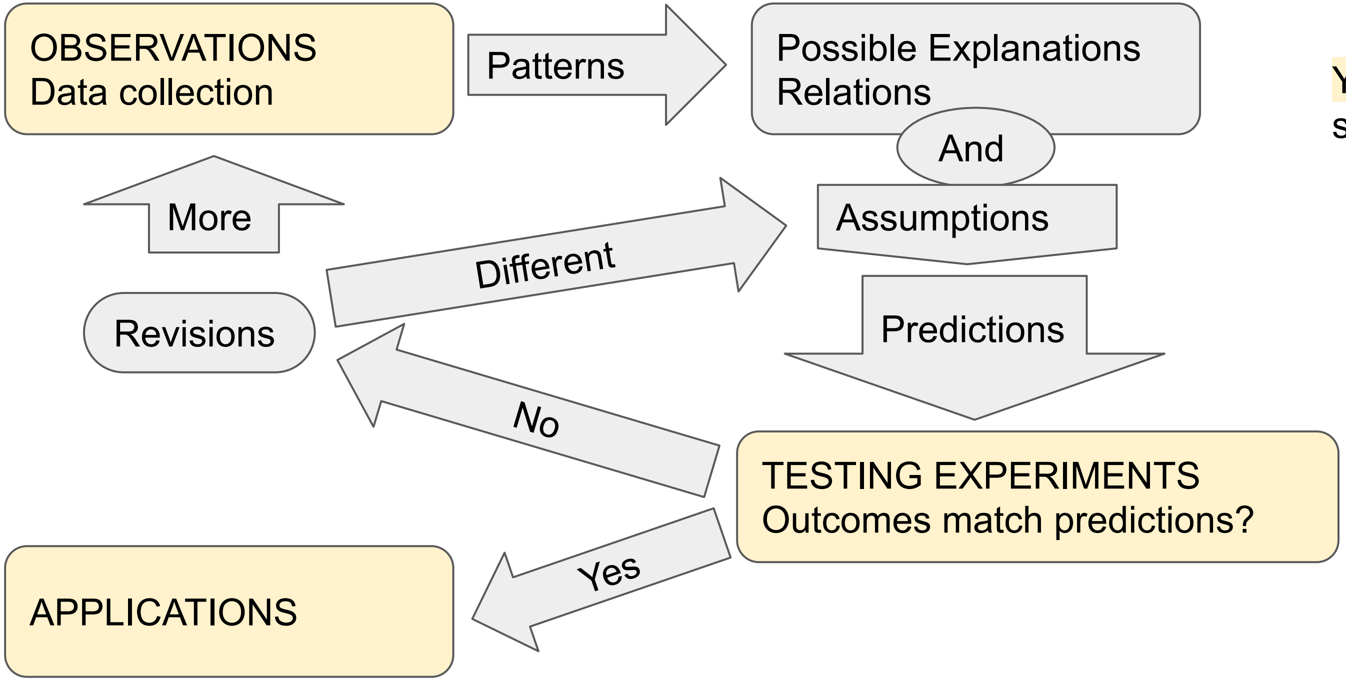


AAPT PHYSICS EDUCATION

AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum

https://www.aapt.org/resources/upload/labguidlinesdocument_ebendorsed_nov10.pdf

ISLE Learning cycle unfolds over several classes



Yellow boxes indicate specific lab activities

- Observations
- Testing
- Applications

ISLE Rubrics

Several sub-abilities under “design and conduct an observational experiment”

	RUBRIC B: Ability to design & conduct an observational experiment				
	Scientific Ability	Missing	Inadequate	Needs improvement	Adequate
B1	**Is able to identify the phenomenon to be investigated**	No phenomenon is mentioned.	The description of the phenomenon to be investigated is confusing, or it is not the phenomena of interest.	The description of the phenomenon is vague or incomplete.	The phenomenon to be investigated is clearly stated.
B2	**Is able to design a reliable experiment that investigates the phenomenon**	The experiment does not investigate the phenomenon.	The experiment may not yield any interesting patterns.	Some important aspects of the phenomenon will not be observable.	The experiment might yield interesting patterns relevant to the investigation of the phenomenon.
B3	**Is able to decide what physical quantities are to be measured and identify independent and dependent variables**	The physical quantities are irrelevant.	Only some of physical quantities are relevant.	The physical quantities are relevant. However, independent and dependent variables are not identified.	The physical quantities are relevant and independent and dependent variables are identified.
B4	**Is able to describe how to use available equipment to make measurements**	At least one of the chosen measurements cannot be made with the available equipment.	All chosen measurements can be made, but no details are given about how it is done.	All chosen measurements can be made, but the details of how it is done are vague or incomplete.	All chosen measurements can be made and all details of how it is done are clearly provided.
B5	**Is able to describe what is observed without trying to explain, both in words and by means of a picture of the experimental setup.**	No description is mentioned.	A description is incomplete. No labeled sketch is present. Or, observations are adjusted to fit expectations.	A description is complete, but mixed up with explanations or pattern. The sketch is present but is difficult to understand.	Clearly describes what happens in the experiments both verbally and with a sketch. Provides other representations when necessary (tables and graphs).
B6	**Is able to identify the shortcomings in an experimental and suggest improvements**	No attempt is made to identify any shortcomings of the experimental.	The shortcomings are described vaguely and no suggestions for improvements are made.	Not all aspects of the design are considered in terms of shortcomings or improvements.	All major shortcomings of the experiment are identified and reasonable suggestions for improvement are made.
B7	**Is able to identify a pattern in the data**	No attempt is made to search for a pattern	The pattern described is irrelevant or inconsistent with the data	The pattern has minor errors or omissions. Terms proportional are used without clarity- is the proportionality linear, quadratic, etc.	The patterns represents the relevant trend in the data. When possible, the trend is described in words.
B8	**Is able to represent a pattern mathematically (if applicable)**	No attempt is made to represent a pattern mathematically	The mathematical expression does not represent the trend.	No analysis of how well the expression agrees with the data is included, or some features of the pattern are missing.	The expression represents the trend completely and an analysis of how well it agrees with the data is included.
B9	**Is able to devise an explanation for an observed pattern**	No attempt is made to explain the observed pattern.	An explanation is vague, not testable, or contradicts the pattern.	An explanation contradicts previous knowledge or the reasoning is flawed.	A reasonable explanation is made. It is testable and it explains the observed pattern.

https://sites.google.com/site/scientificabilities/rubrics?authuser=0

ISLE Learning Cycle for Projectile Motion

Ball and Cart: Observational Experiment

Eugenia on Rollerblades: Observational Experiment

Galileo's Mast Experiment: Qualitative Testing Experiment

Projectile vs drop: Qualitative Testing Experiment

Projectile Motion: Quantitative Testing Experiment

Projectile problem: Application Experiment

Every cycle starts with observations before scientific terms are introduced

Preliminary models are articulated and tested against data, refined as necessary

Models are applied to a new situation

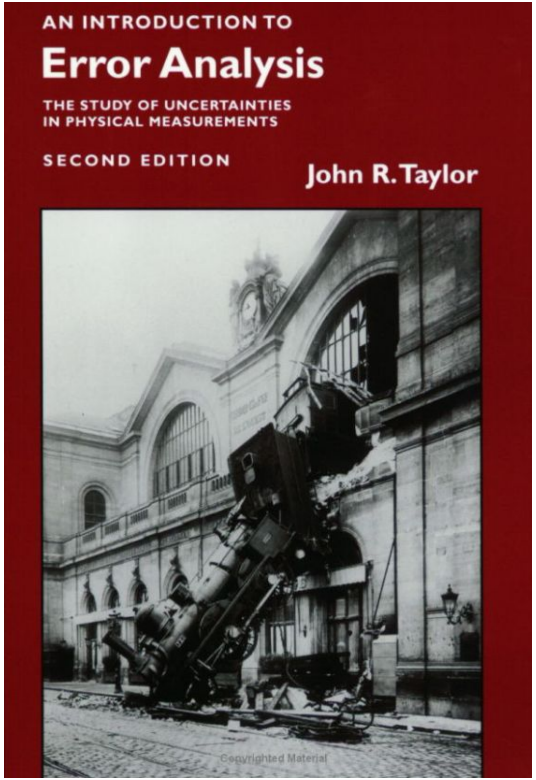
https://www.islephysics.net/pt3/index.php

Decision 2: What about uncertainty analysis?

Historically, a strong emphasis in lab courses

Procedural
Execute complex calculations
(error propagation with partial derivatives)

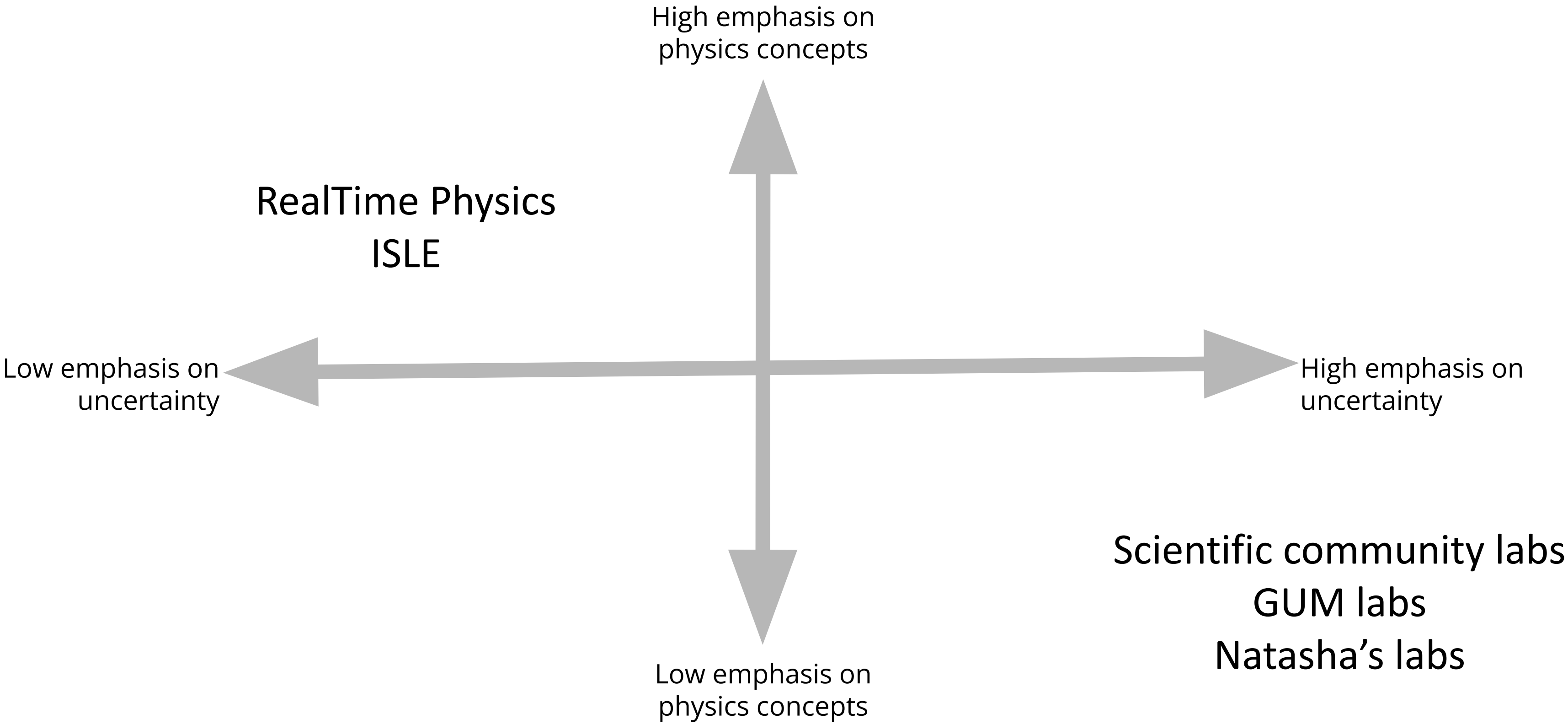
Conceptual
why is it important?
when to use it?
how to interpret it?



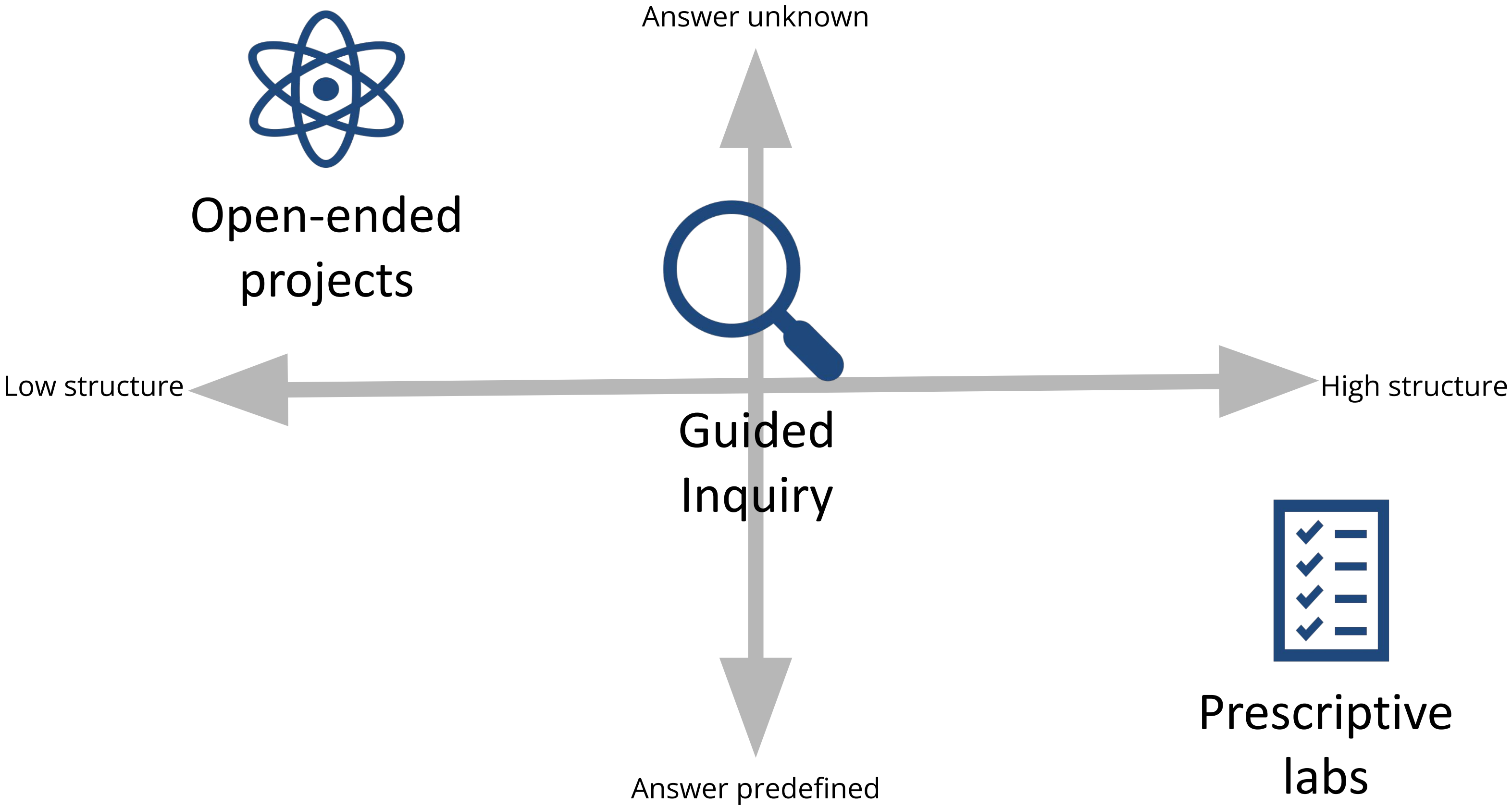
Curricula with a strong emphasis on uncertainty

Scientific Community Labs	Full semester learning progression on measurement and uncertainty as primary goal.
Guide to Uncertainty and Measurement (GUM) Labs	Full semester learning progression. Bayesian approach to uncertainty, emphasizes probability distributions
Cornell PHYS 1110 Labs	Uncertainty used to evaluate goodness of fit of models

Tension between uncertainty and conceptual goals



Decisions 3 and 4: Level of structure and discovery



Decisions 3 and 4: Level of structure and discovery

Structure

- Structure is not inherently bad.
- Structure is required for learning.
- Think more "scaffolding" students decisions than "telling students what to do".

Discovery

- Confirmation can lead to inauthentic experimentation behaviors and affect students' perceptions of experimental science.

Restructure: typical labs

- Provide some theoretical or procedural exposition.
- Let students make some decisions.
- Turns statements into cues, questions, or prompts.
- Have students reflect and iterate.
- Give students time (e.g., one lab over multiple weeks).

Take 10 trials.	• Decide how many trials to take. • Looking at your data, did you have enough trials? Too many? How do you know?
Plot your data with distance on the x-axis and counts on the y-axis.	• How should you plot your data to effectively present your results? • What is your independent variable? What is your dependent variable?
List any sources of error and describe what you could have done differently.	• How could you improve your measurements? • Implement those improvements and evaluate how the changes impact your results.

Holmes, Keep, & Wieman (2020) *Phys. Rev. PER*

Fading the scaffolding: Example from Cornell intro labs

1. **Does the period of a pendulum depend on the initial amplitude?**
   Question given. Lots of cues for decisions. Focus on quantifying uncertainty. Second week students explore explanations for discrepancies.*

2. **Do objects in flight follow a gravity-only or gravity+drag model?**
   Question given. Somewhat fewer cues for decisions. Choice of objects. Introduce fitting. Second week students explore explanations for discrepancies.

3. **How do stretchy objects behave?**
   Question loosely defined. Students choose their own object and what they want to test. Fewer cues (reminders, really).

4. **Project lab!**
   Students choose their own question. Very few cues.

*Etkina & Van Heuvelen (2007)

Restructure: Project labs

- Time and products for brainstorming ideas.
- Draft a proposal for their project that includes justifications for what they're going to do.
- Peer review proposals (and expert review).
- Team work contracts, mid-project feedback, and end-of-project evaluations.
- Weekly accountability assignments (e.g., lab notes).
- Deadlines for milestones.
- Presentations to others.

Burkholder, Hwang, Sattely, & Holmes (2021) *Chemical Engineering Education*

Questions about structure?

Discovery

Use labs with a surprising outcome

- Take advantage of model approximations and assumptions
- Pendulum, Ohm's law on light bulbs or LEDs

Discovery

Use labs with a surprising outcome

- Take advantage of model approximations and assumptions
- Pendulum, Ohm's law on light bulbs or LEDs

Use labs where the answer isn't googlable

- Study things from around the house, campus, or classroom.
- Hooke's law w/ stretchy things.

Discovery

Use labs with a surprising outcome

- Take advantage of model approximations and assumptions
- Pendulum, Ohm's law on light bulbs or LEDs

Use labs where the answer isn't googlable

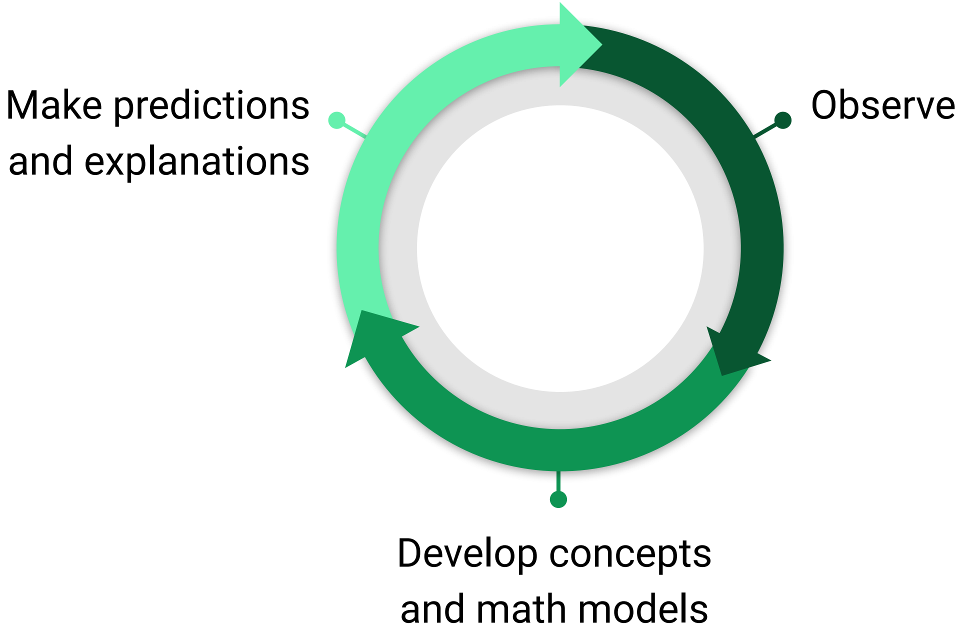
- Study things from around the house, campus, or classroom.
- Hooke's law w/ stretchy things.

Use labs where students ask the questions (and they ask different questions)

- Project lab!
    - Again, can be highly structured!

Questions about discovery?

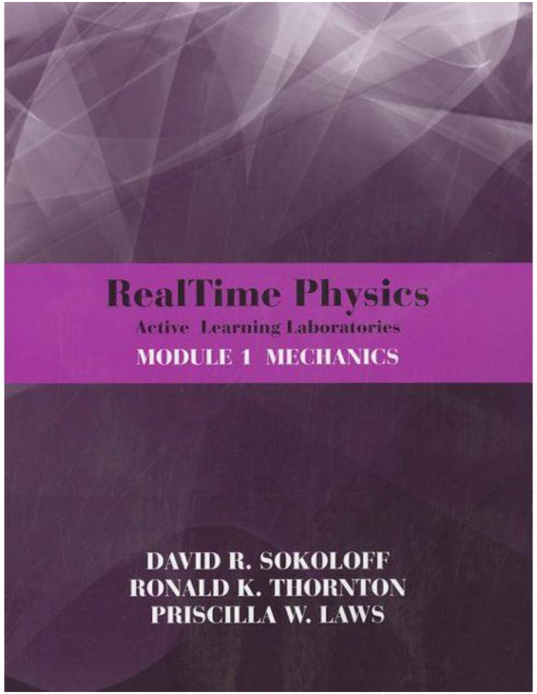
Decision 5: Is learning canonical content a key goal?



- Modeling Instruction
- Investigative Science Learning Environment
- RealTime Physics

RealTime Physics goals

1. Understand physics concepts
2. Direct experience with the physical world
3. Laboratory skills, especially collecting and interpreting data (graphs)
4. Reinforce topics covered in lecture



RealTime: Simplify data acquisition

- Easy, intuitive - minimal training
- Reliable - students
- Flexible - measure many things

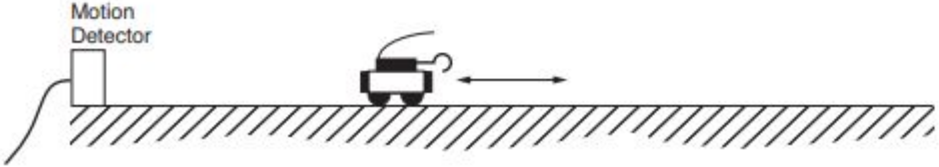
Microcomputer-Based Labs (1980’s lingo for sensors and data-acquisition)

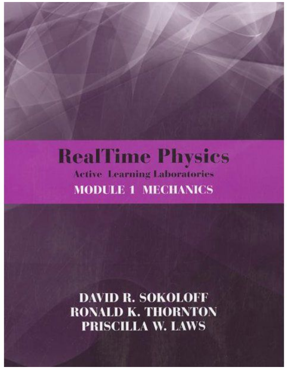
Guide students through predictions and tests

Activity 2-1: Pushing and Pulling a Cart

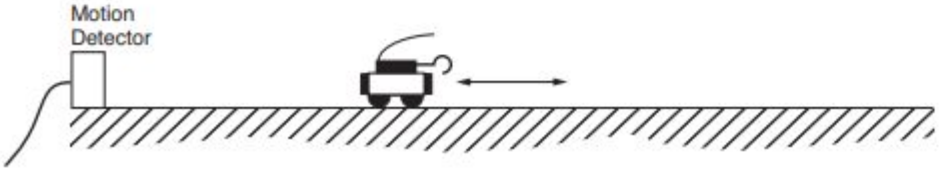
In this activity you will move a low friction cart by pushing and pulling it with your hand. You will measure the force, velocity, and acceleration. Then you will be able to look for mathematical relationships between the applied force and the velocity and acceleration, to see whether either is (are) related to the force.

1. Set up the cart, force probe, and motion detector on a smooth level surface as shown below. The cart should have a mass of about 1 kg with force probe included. Fasten additional mass to the top if necessary.

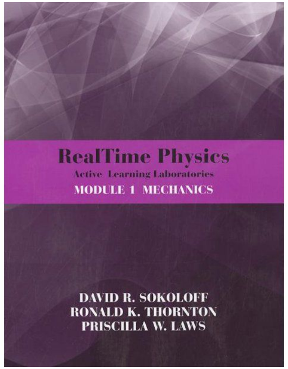




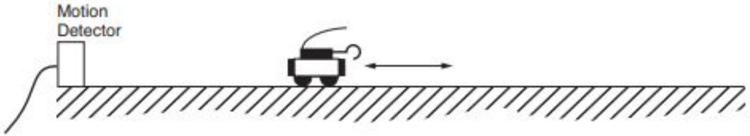
Guide students through predictions and tests

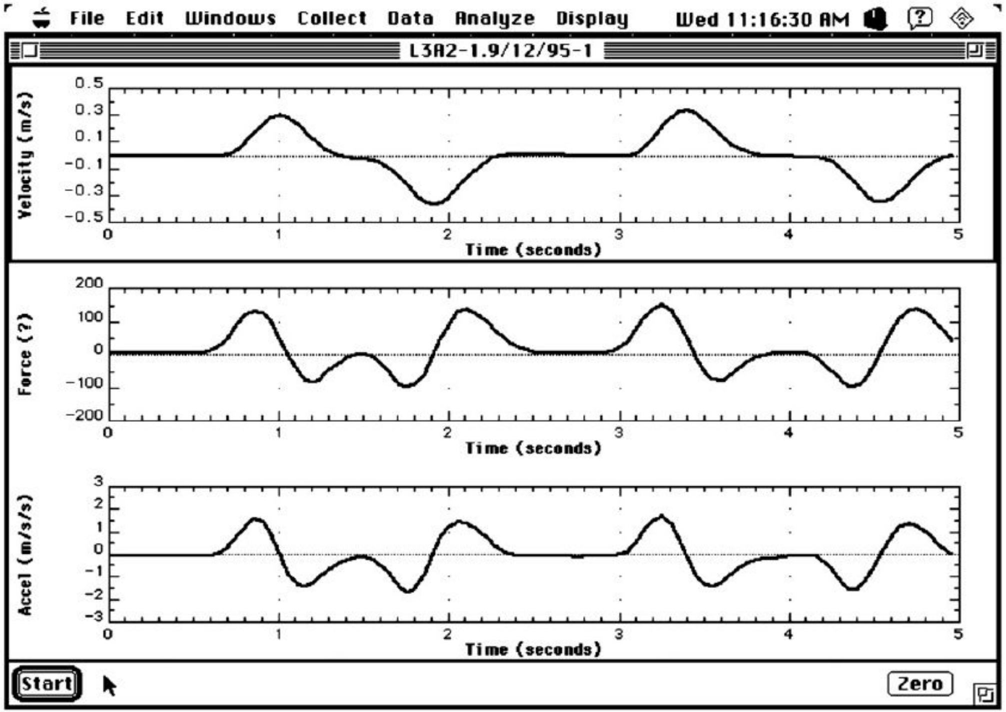


Prediction 2-1: Suppose you grasp the force probe hook and move the cart forward and backward in front of the motion detector. Do you think that either the velocity or the acceleration graph will look like the force graph? Is either of these motion quantities related to force? (That is to say, if you apply a changing force to the cart, will the velocity or acceleration change in the same way as the force?) Explain.



Collect data and reflect



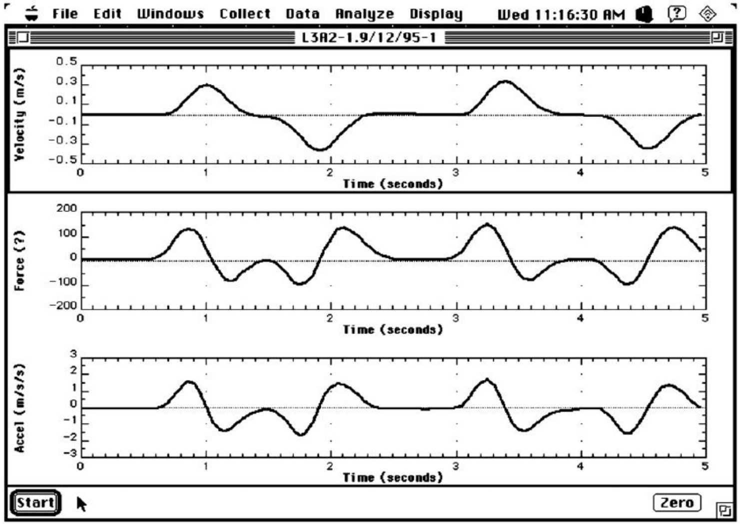


Question 2-1: Does either graph—velocity or acceleration—resemble the force graph? Which one? Explain how you reached this conclusion.

Question 2-2: Based on your observations, does it appear that there is a mathematical relationship between either applied force and velocity, applied force and acceleration, both, or neither? Explain.

Uncertainty analysis not emphasized in RealTime Physics

- Sensors are precise enough to visually ignore measurement uncertainty
- The quantity of data is large (100s or 1000s of points)
- Repeated measures are less common than plotting vs time or one sensor vs another sensor.



Conclusion

The good news

Generally more flexibility for labs than lecture courses - be creative!

Amazing breadth of meaningful goals

Nothing is more satisfying that seeing students grow as scientists

The hard news

Way more to do in labs than is possible.

Can be overwhelming - decision paralysis

You will make a lot of compromises

Resource intensive - think carefully about decisions

Faculty opinions can run high - build consensus

Find community!

1. AAPT Labs Community
2. Advanced Physics Lab Association (https://advlab.org/)
3. PhysPort

Warning: Thinking too hard about labs may induce decision paralysis

Thank you!

ben.zwickl@rit.edu