Teaching Students to be Scientists in a First Year Physics Lab

Presented by:

Matthew Robbins
Assistant Professor, Teaching Stream

June 22, 2026

UNIVERSITY OF TORONTO

Canadian Association of Physicists

DEFY GRAVITY

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Reframing Introductory Physics Labs to Build Scientific Thinking

Work in Progress

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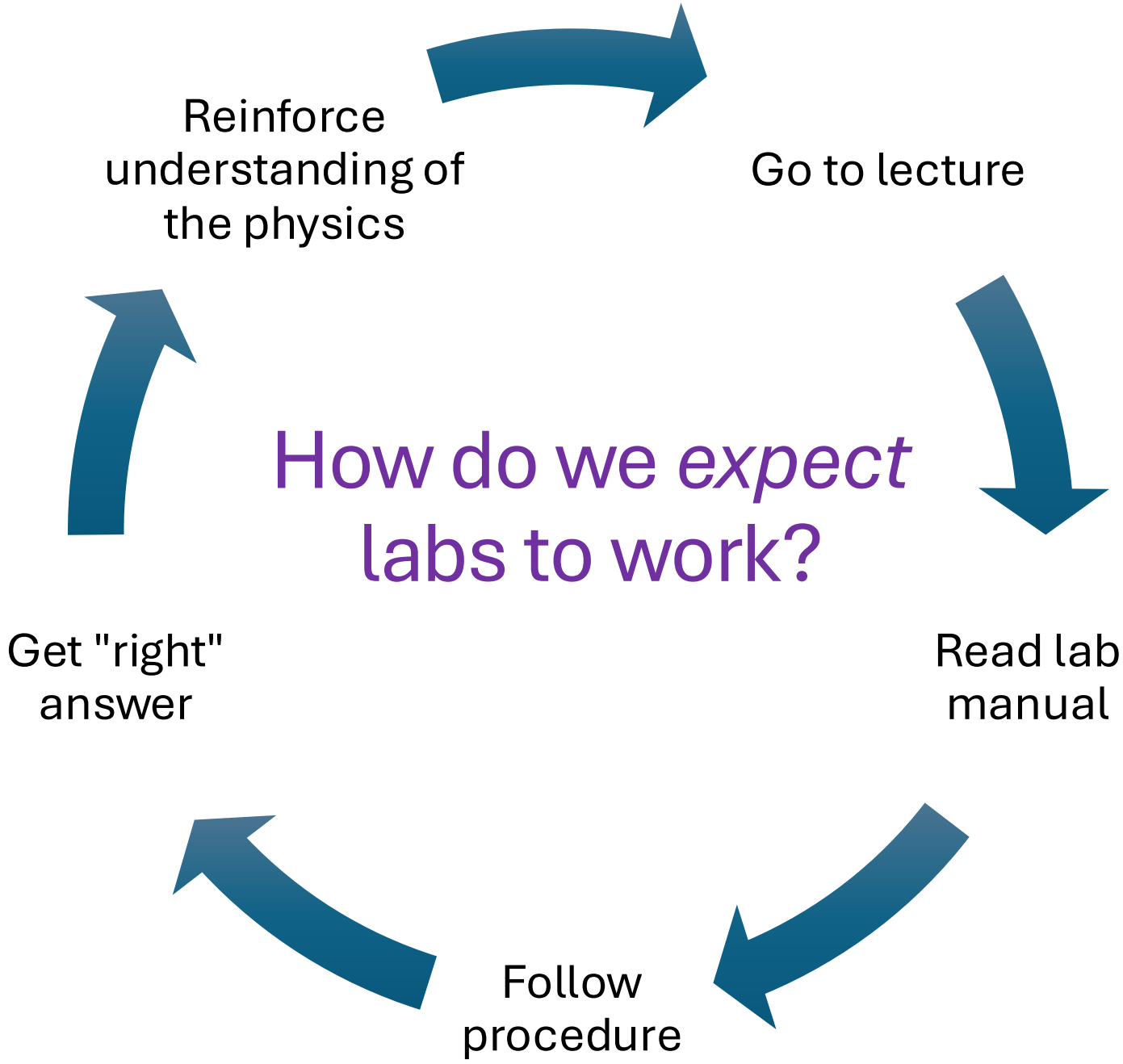

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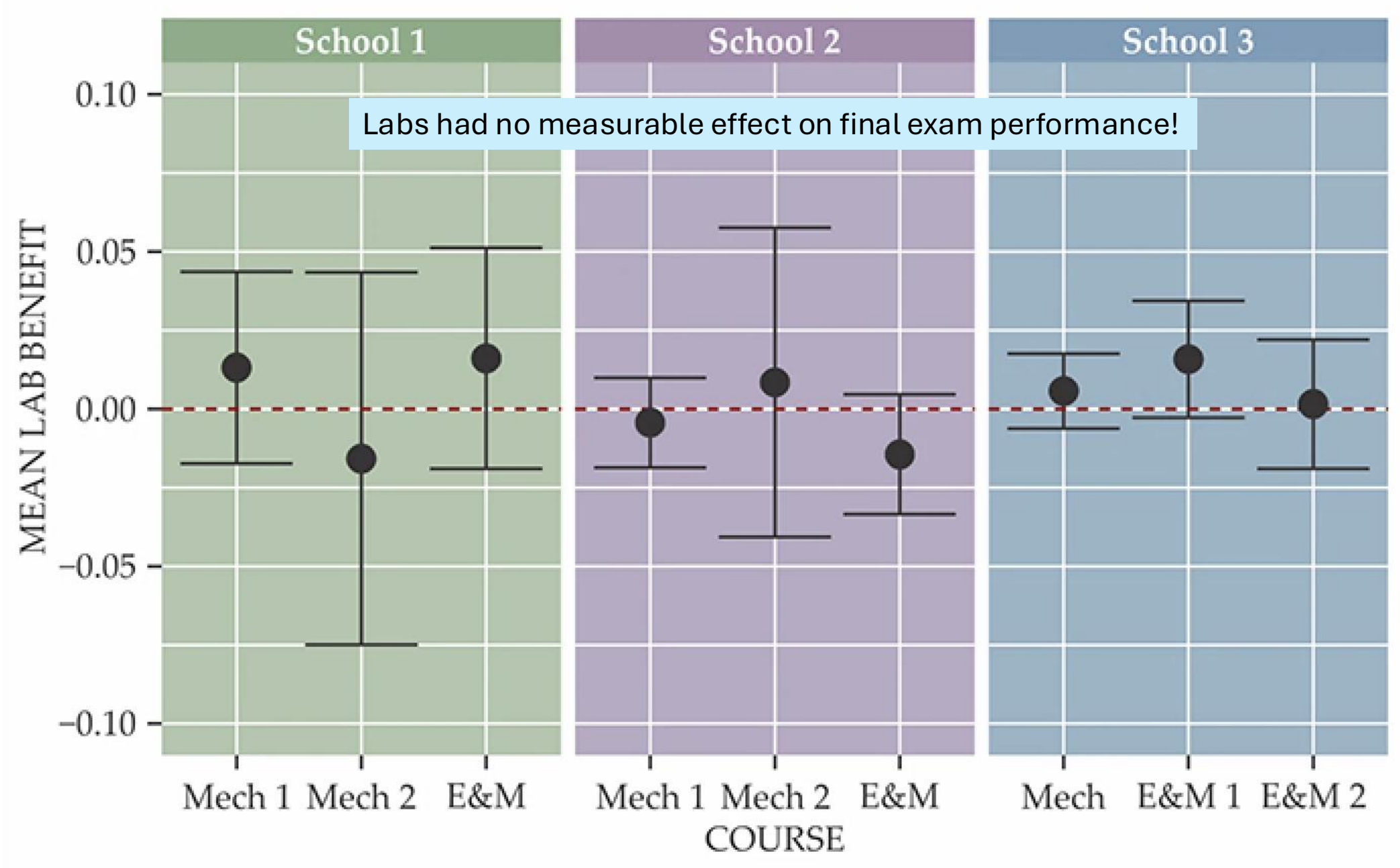

Each lab was designed to reinforce the instructional material

In each course, the labs were optional

Image source: https://physicstoday.aip.org/features/introductory-physics-labs-we-can-do-better
Adapted from: N. G. Holmes, et al. Phys. Rev. Phys. Educ. Res. **13**, 010129

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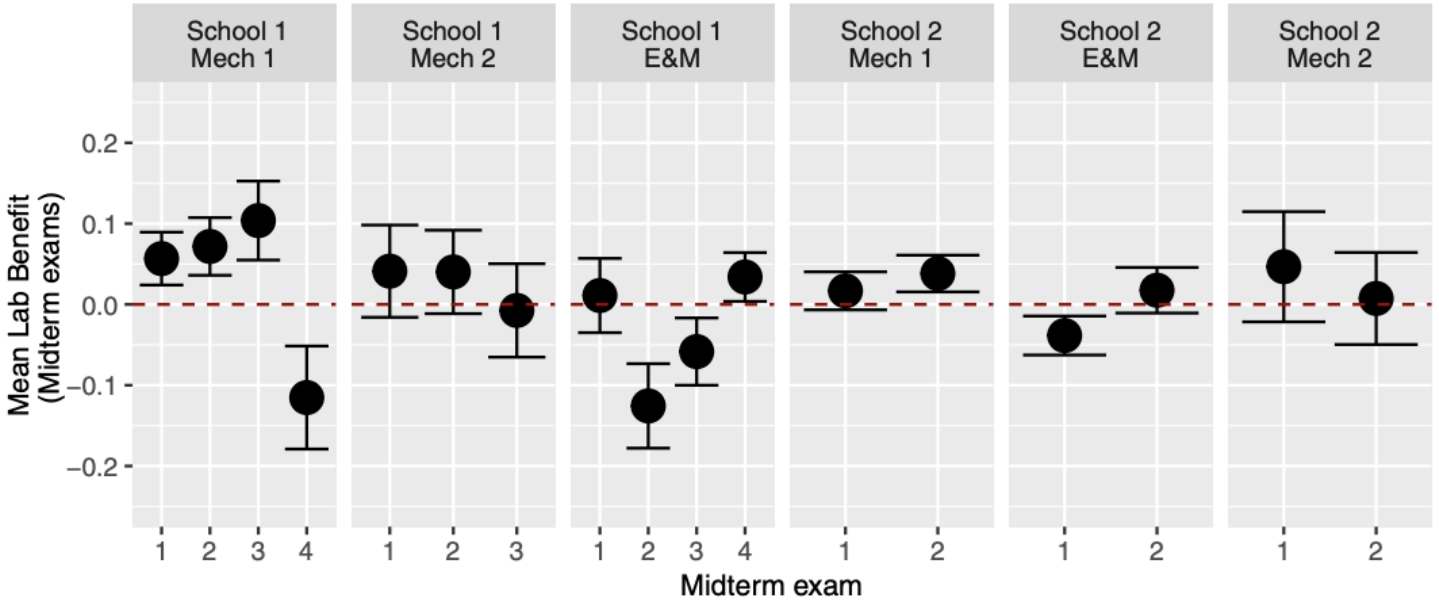
Even the midterms show no clear improvement!



(a) Difference scores on the full test across midterm exams.

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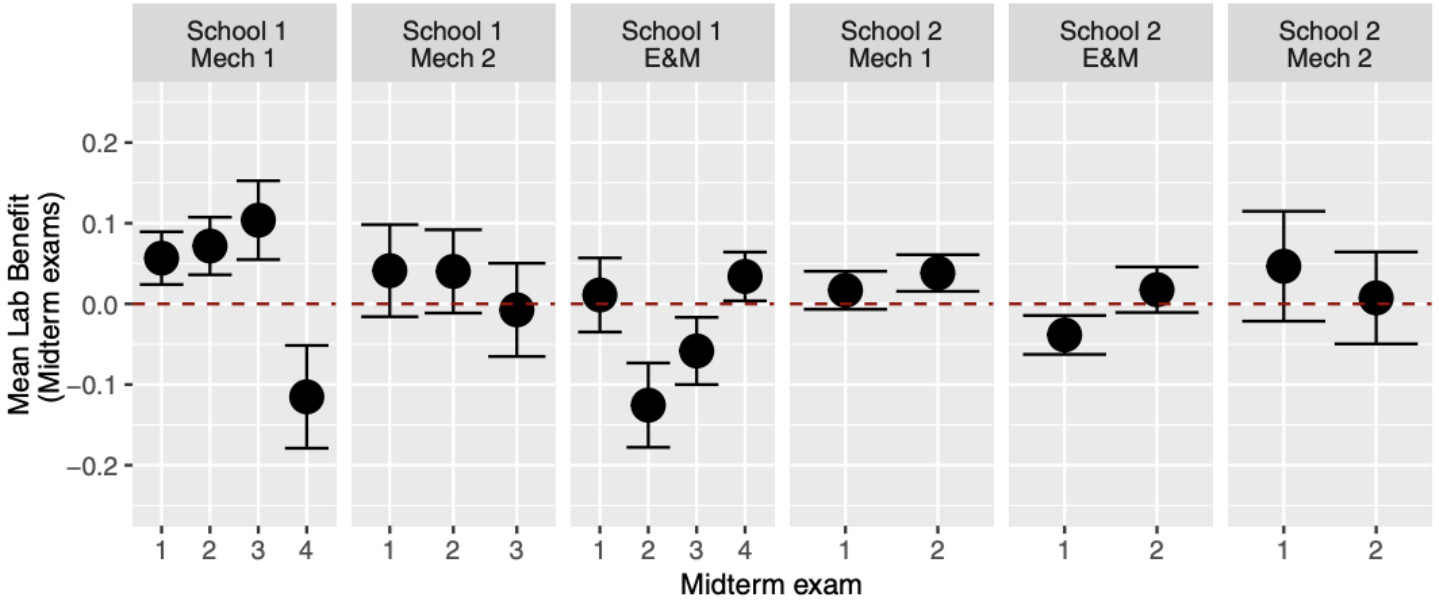
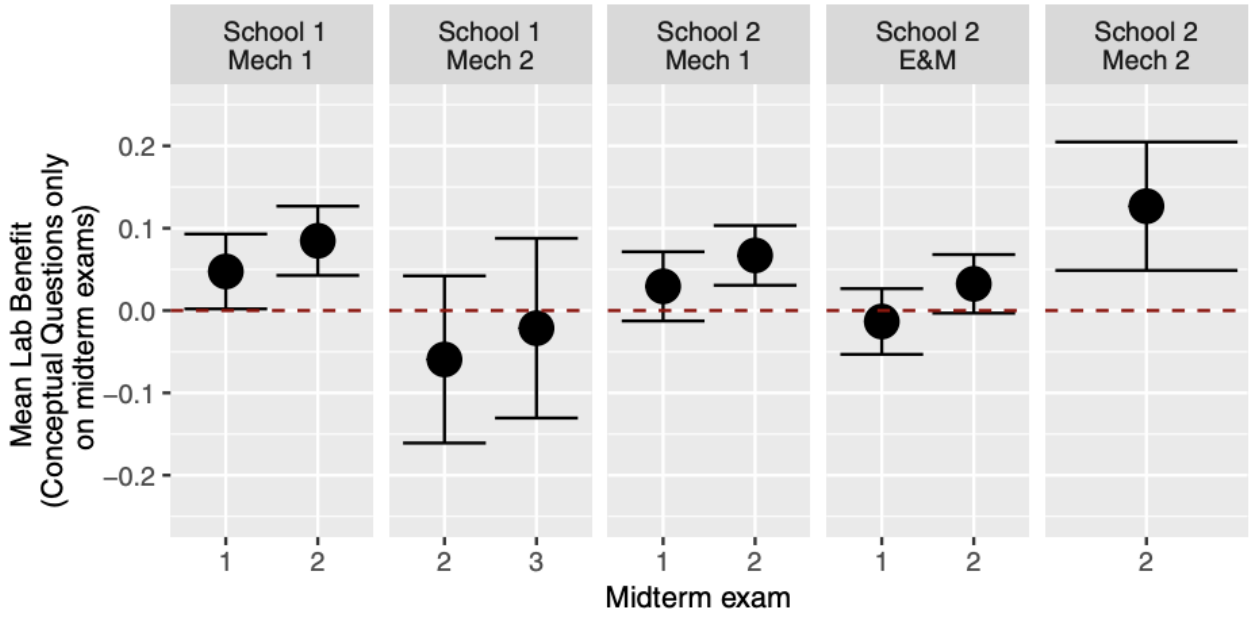


(a) Difference scores on the full test across midterm exams.



(b) Difference scores on the conceptual-items only across midterm exams.

N. G. Holmes, et al. Phys. Rev. Phys. Educ. Res. **13**, 010129

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So… traditional labs seem not to work as we expect.

Let’s take a step back and ask what it means to be a scientist

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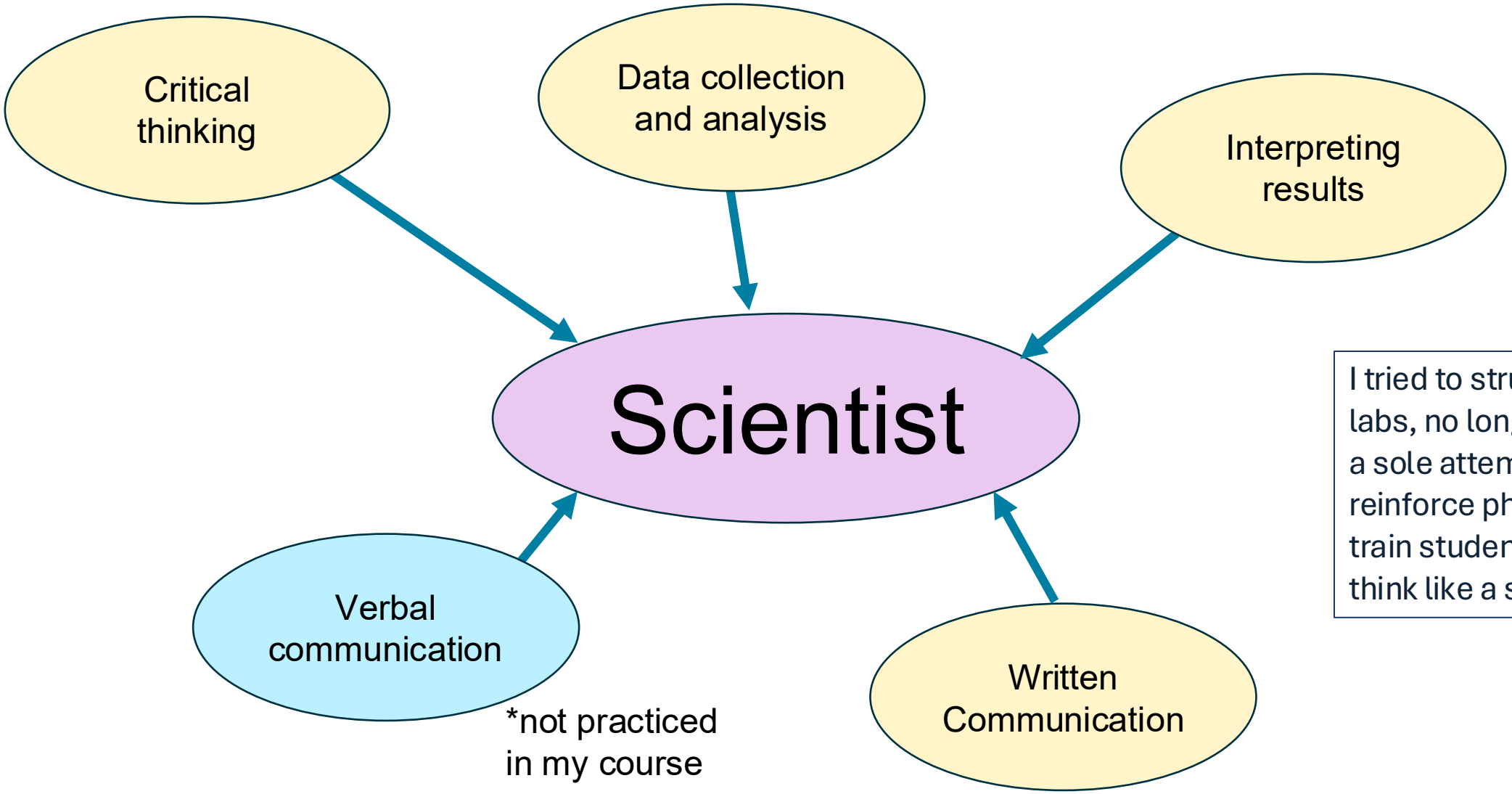
What sort of skills should scientists develop?



I tried to structure the labs, no longer as as a sole attempt to reinforce physics, but to train students how to think like a scientist

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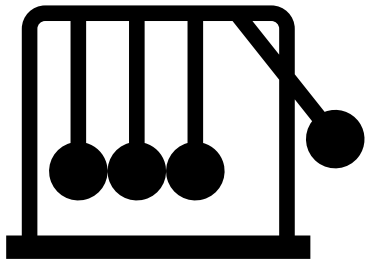
Week 1: Experiment (2 hours)



Design experiment

- Practice scientific notebook keeping

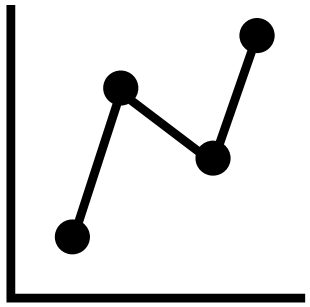
Data collection

- How should data be collected?
- How can uncertainties be minimized?

Preliminary analysis

- Plot data
- Identify key trends in the data

Week 2: Data analysis (2 hours)



Introduction to data analysis

- Develop data presentation skills (e.g. plotting, captions)

Data analysis

- Apply linear regression techniques to estimate slope, intercept, and their uncertainties

Interpret results

- What does the answer mean?
- What defines a “correct” answer?

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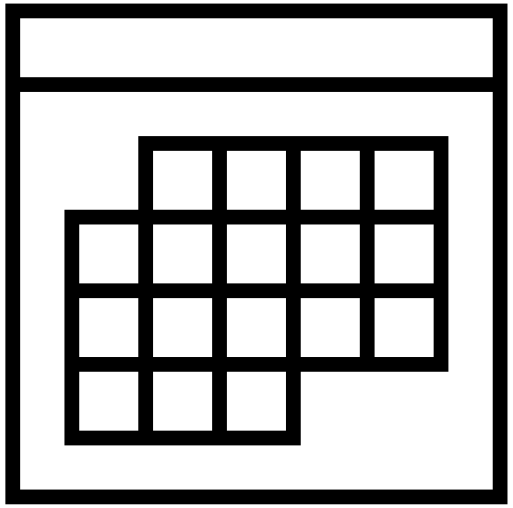
What was the schedule during the semester?



Week 1: Introduction to uncertainty

- Learn how to do calculations with uncertainties and significant figures

Weeks 2-3: Evaluating scientific models

- Experiment: Dropping a ball vs a paper plate
- Learn how to plot and linear regression (slope)
- Learn how to compare different models, only from the data

Weeks 4-5: Designing Experiments

- Experiment: Measure the coefficient of kinetic friction of a block
- Learn how to design an experiment
- Practice uncertainty calculations of more complicated expressions
- Make a caption for a plot

Weeks 6-7: Understanding collisions

- Experiment: Elastic collision of a cart with a stationary object
- Measure the transfer of momentum using different methods (and compare with uncertainty)
- Learn linear regression (intercept)

Weeks 8-10: Project

- Experiment: Rolling *with* slipping
- Practice experimental and data analysis skills developed throughout the semester

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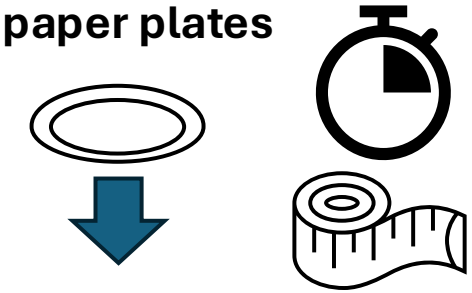
Week 2: Evaluating scientific models

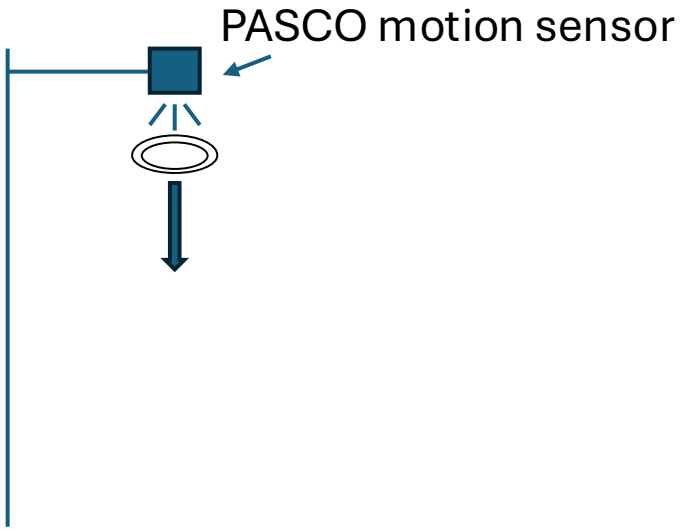
- For which objects does the free fall model work best? When do the models break down?

PART 1: Determine average acceleration of falling paper plates



Design	Calculation	Interpretation
• What data is collected? • How is a lab notebook used?	• What is the average acceleration and its uncertainty?	• Is free fall an appropriate model?

PART 2: Compare a falling ball to a falling plate



Design/Data Collection	Sketching	Interpretation
• (Mostly) outlined to students (to learn how to use motion sensor)	• What is the shape of each position vs time graph?	• Is free fall an appropriate model?

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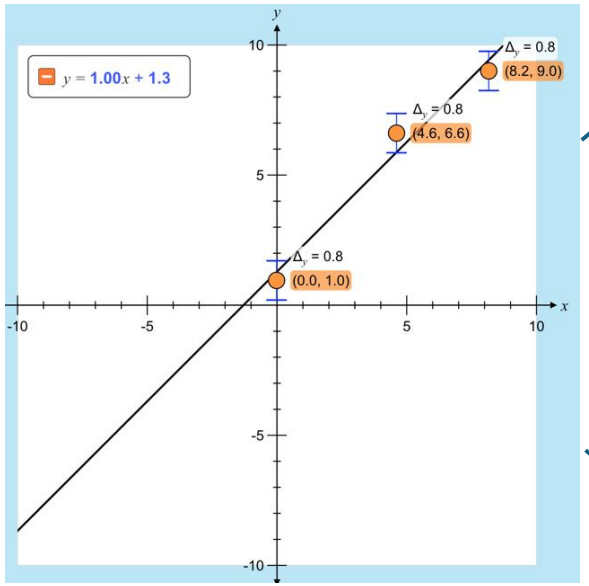
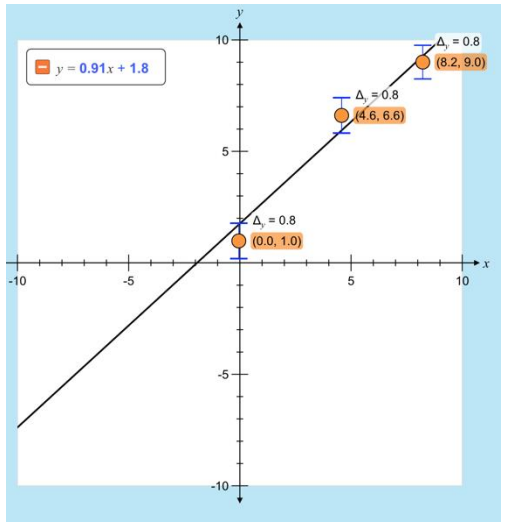
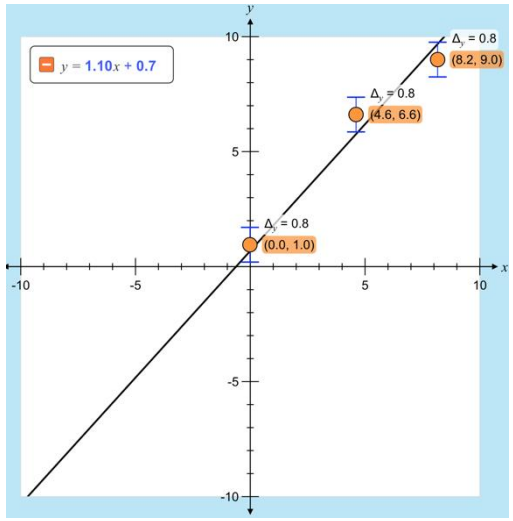
Week 3: Evaluating scientific models

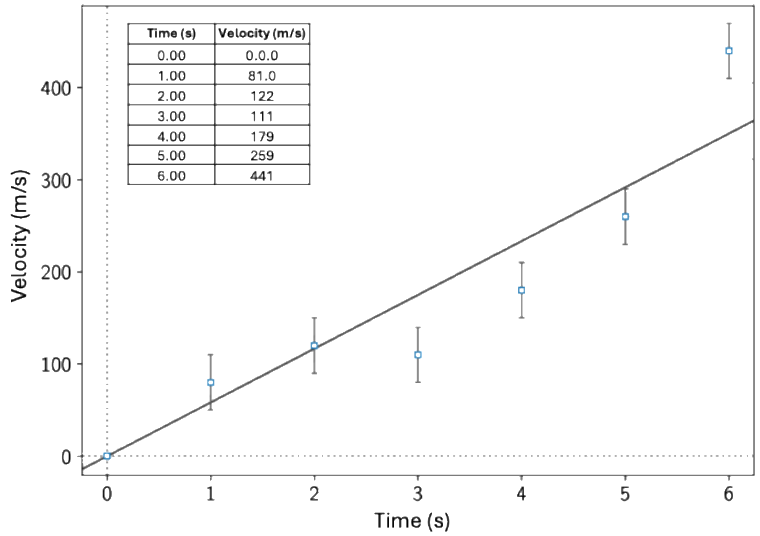
- Learn how to use linear regression techniques in Excel
- Learn how to use data to test the validity of a model

PART 1: Introducing linear regression









https://phet.colorado.edu/en/simulations/curve-fitting

What is the slope and intercept of the line of best fit?
How can their uncertainties be estimated?

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Week 3: Evaluating scientific models

- Learn how to use linear regression techniques in Excel
- Learn how to use data to test the validity of a model

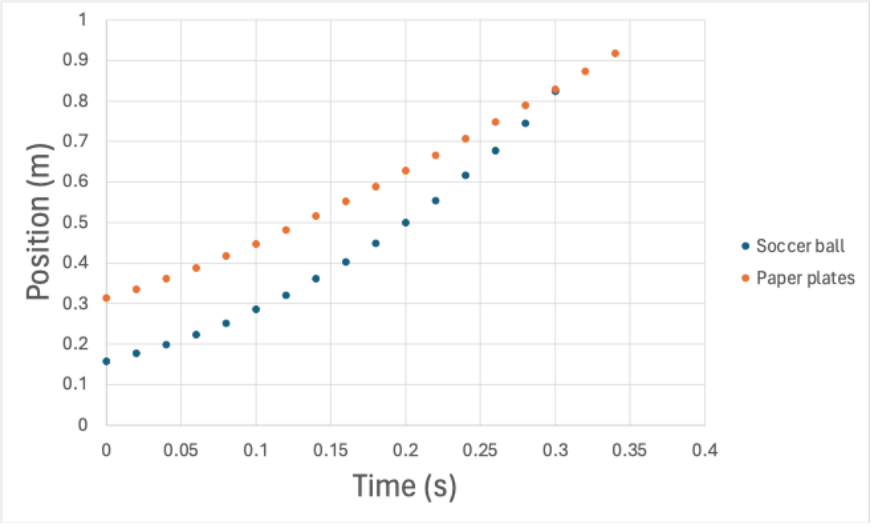
PART 2: Linear regression with real data

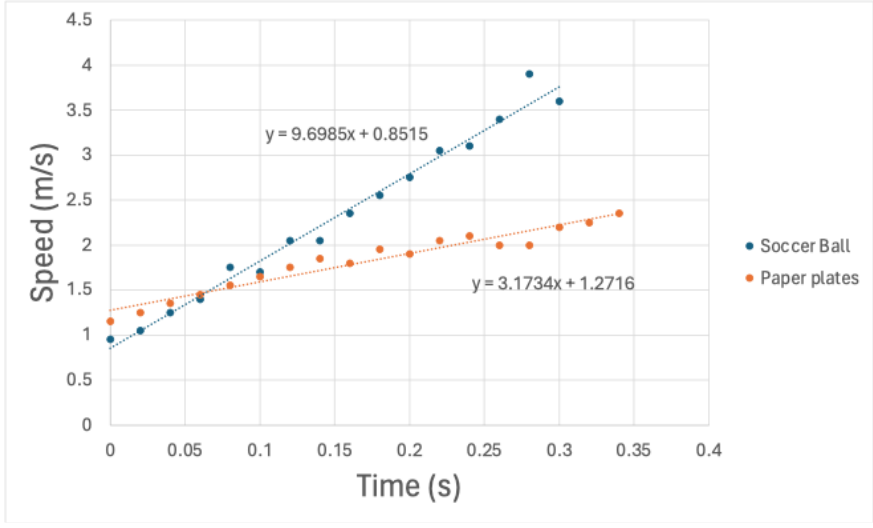
Plot position vs time data
- Introduction to data visualization

Plot velocity vs time data
- Introduction to using formulas in Excel

Linear regression
- Introduction to using Excel to do linear regression

Data Interpretation
- How do we compare experimental results to theoretical ones?
- Is the free fall model valid for both objects?





Students struggled with Excel. Is this the best tool to teach linear regression?

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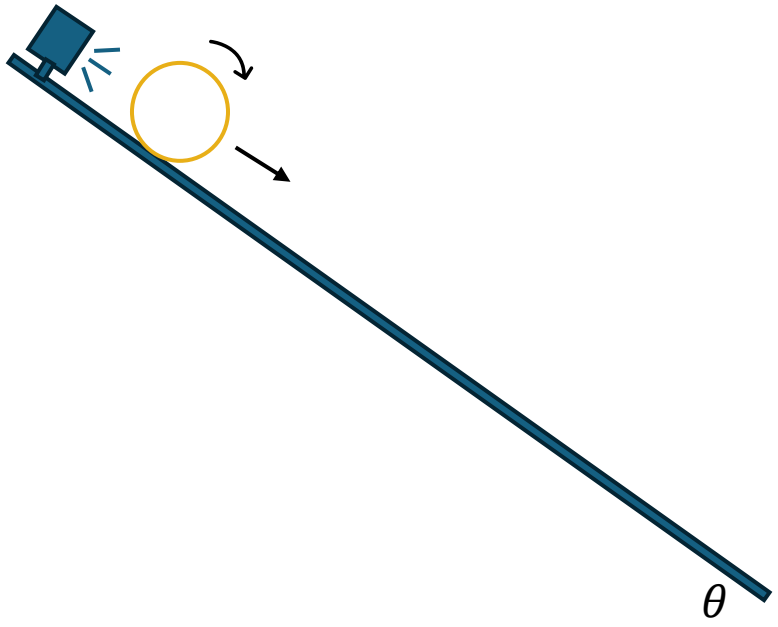
Week 10: Project

- Experiment: Rolling *with* slipping
- Practice experimental and data analysis skills learned throughout the semester



Decide what to measure

- Question: What happens as motion transitions from rolling without slipping to rolling with slipping?

Design experiment

- Identify the most significant sources of uncertainty
- Determine the critical angle at which slipping begins

Collect data

- Most (all?) groups used PASCO motion sensors

Plot as a function of angle

- Focus on identifying trends rather than curve fitting *(this is will be done in a later semester)*

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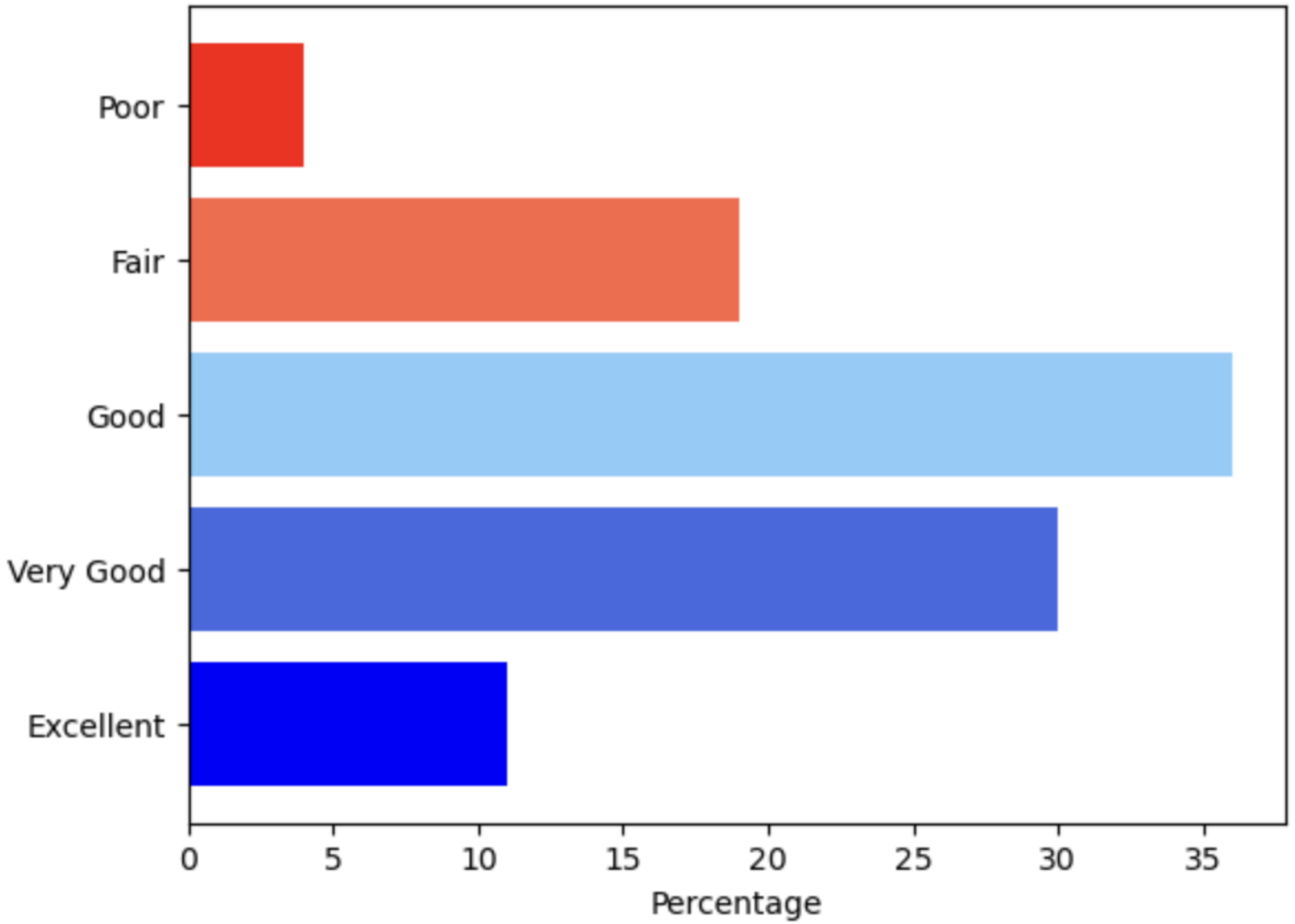
Were there opportunities to develop skills to use in other courses?

- Collecting data
- Analyzing data
- Interpreting results
- Microsoft Excel
- Collaboration
- Scientific reasoning
- Scientific communication (written)



Data obtained from university-run course surveys

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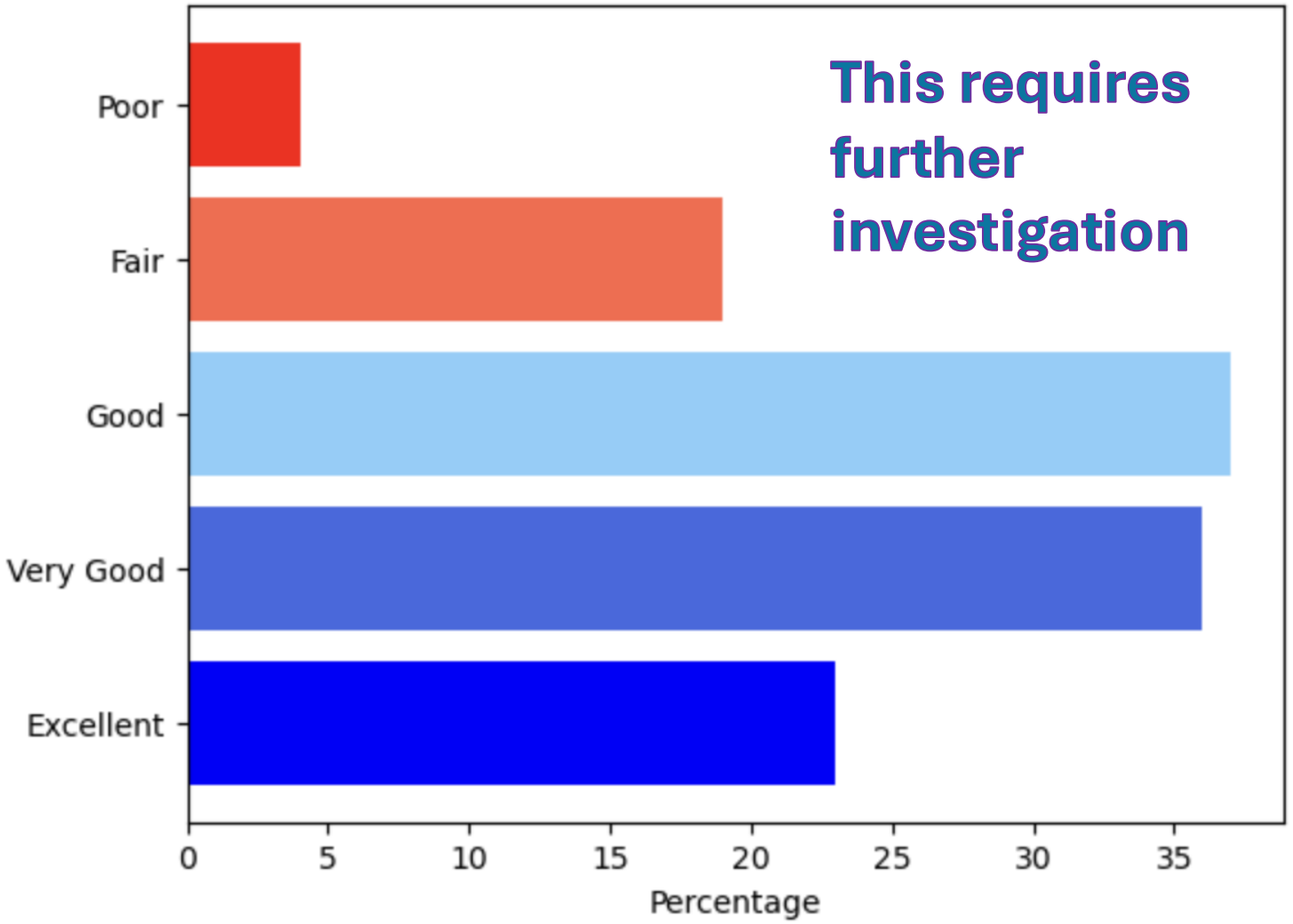
Did you feel that the lab sessions improved your understanding of the course material?



Note: studio physics courses have been shown to have significant learning gains

Data obtained from university-run course surveys

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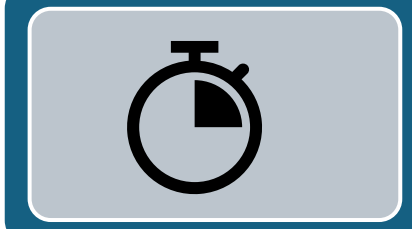
Shaping student understanding of experimentation

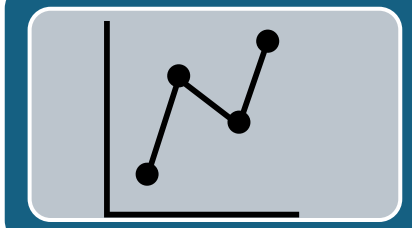
- Experimentation (and especially uncertainty) is a key part of physics
- Designing experiments is challenging, but it is an important skill
- Recognizing good data can be difficult and interpreting its meaning can be difficult

Key Challenges



Time

- Is 2 hours for each session long-enough?
- Uncertainties take a while to properly think about and propagate.



Excel

- Most students have never used it before

Instructions

- Open-ended tasks caused lots of uncertainty/confusion

Expectations

- Students were unsure about what counts as “correct”

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What are the key takeaways?

- Focus on the big picture skills over procedures
- Use real, messy data
- Microsoft Excel makes the analysis more quantitative, but plotting values on graph paper might be quicker
  - Emphasis on reasoning over computation
- Ideal group sizes of 2-3 students

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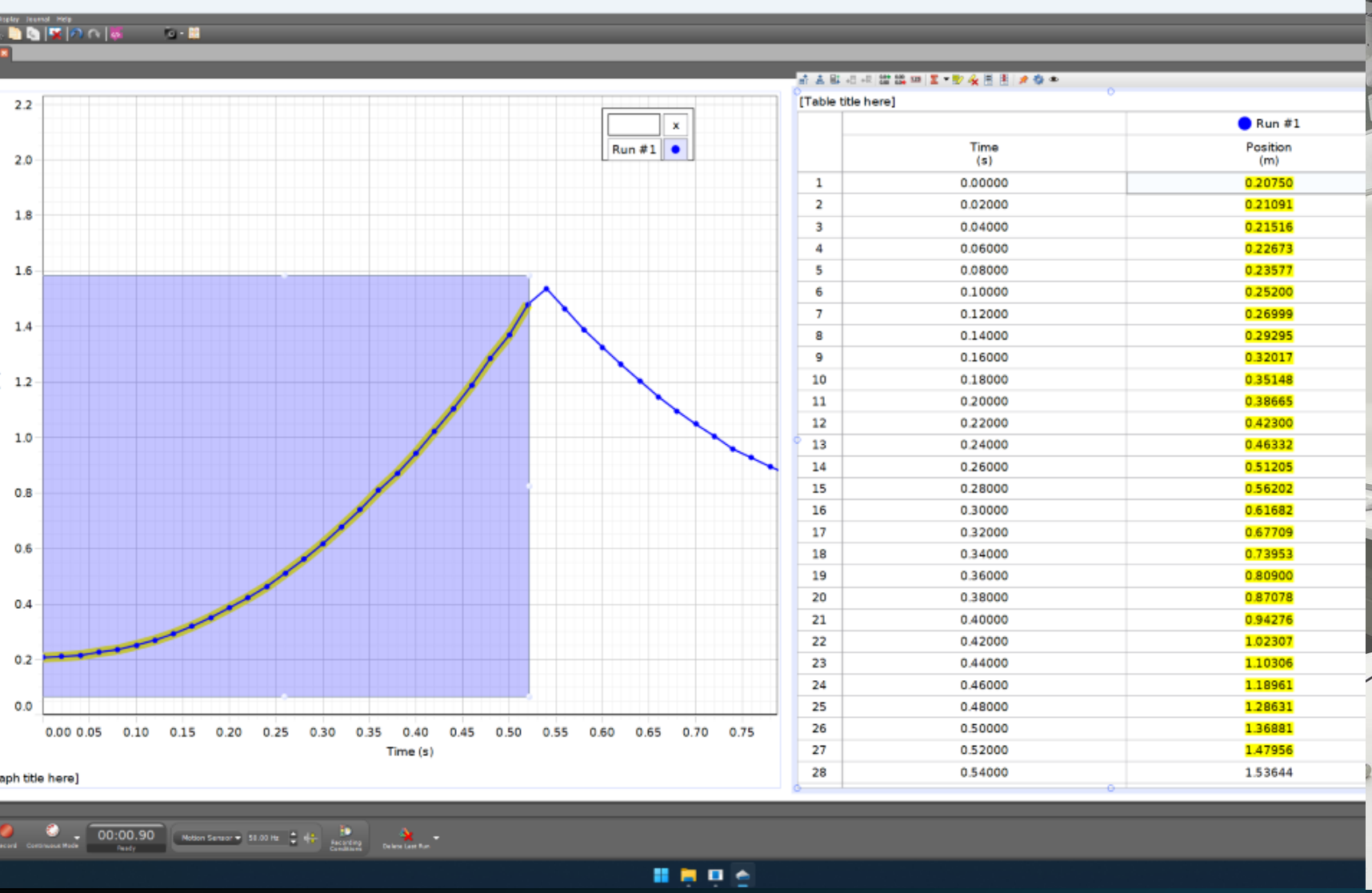
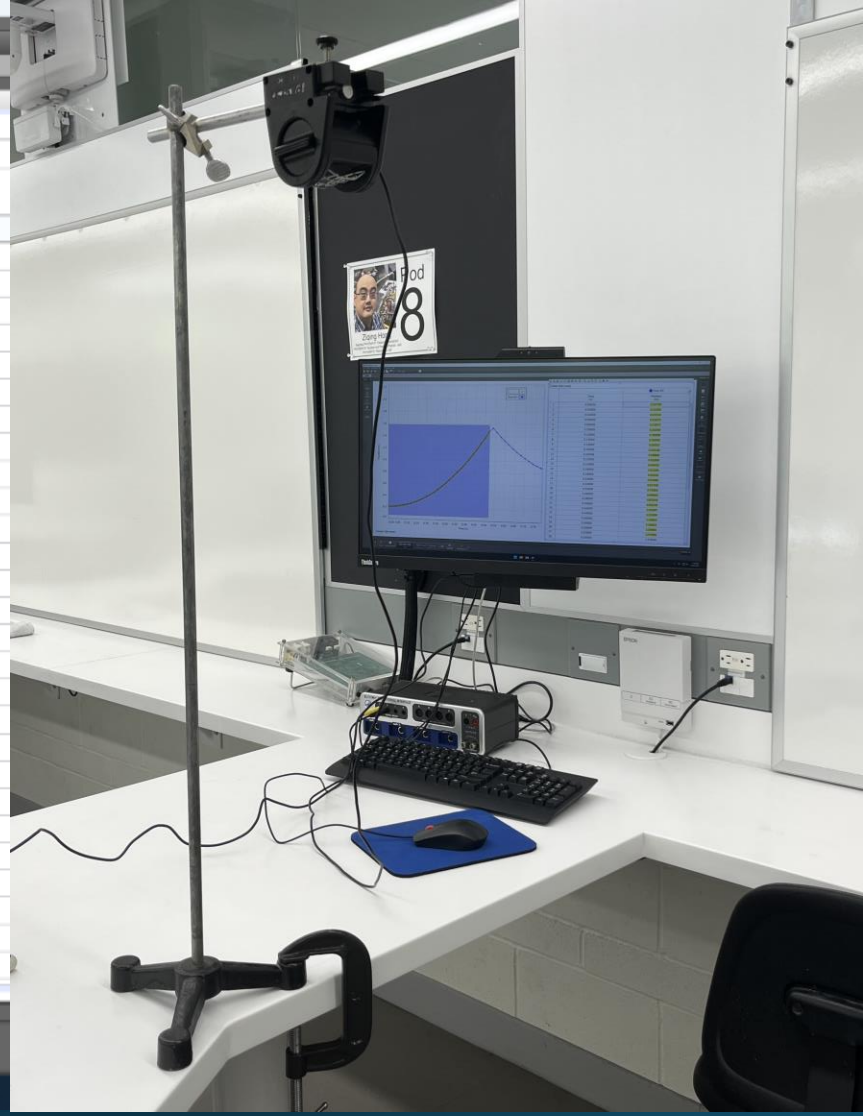


[Table title here]

	Time (s)	Run #1 Position (m)
1	0.00000	0.20750
2	0.02000	0.21091
3	0.04000	0.21516
4	0.06000	0.22673
5	0.08000	0.23577
6	0.10000	0.25200
7	0.12000	0.26999
8	0.14000	0.29295
9	0.16000	0.32017
10	0.18000	0.35148
11	0.20000	0.38665
12	0.22000	0.42300
13	0.24000	0.46332
14	0.26000	0.51205
15	0.28000	0.56202
16	0.30000	0.61682
17	0.32000	0.67709
18	0.34000	0.73953
19	0.36000	0.80900
20	0.38000	0.87078
21	0.40000	0.94276
22	0.42000	1.02307
23	0.44000	1.10306
24	0.46000	1.18961
25	0.48000	1.28631
26	0.50000	1.36881
27	0.52000	1.47956
28	0.54000	1.53644



Not enough motion sensors? No problem!

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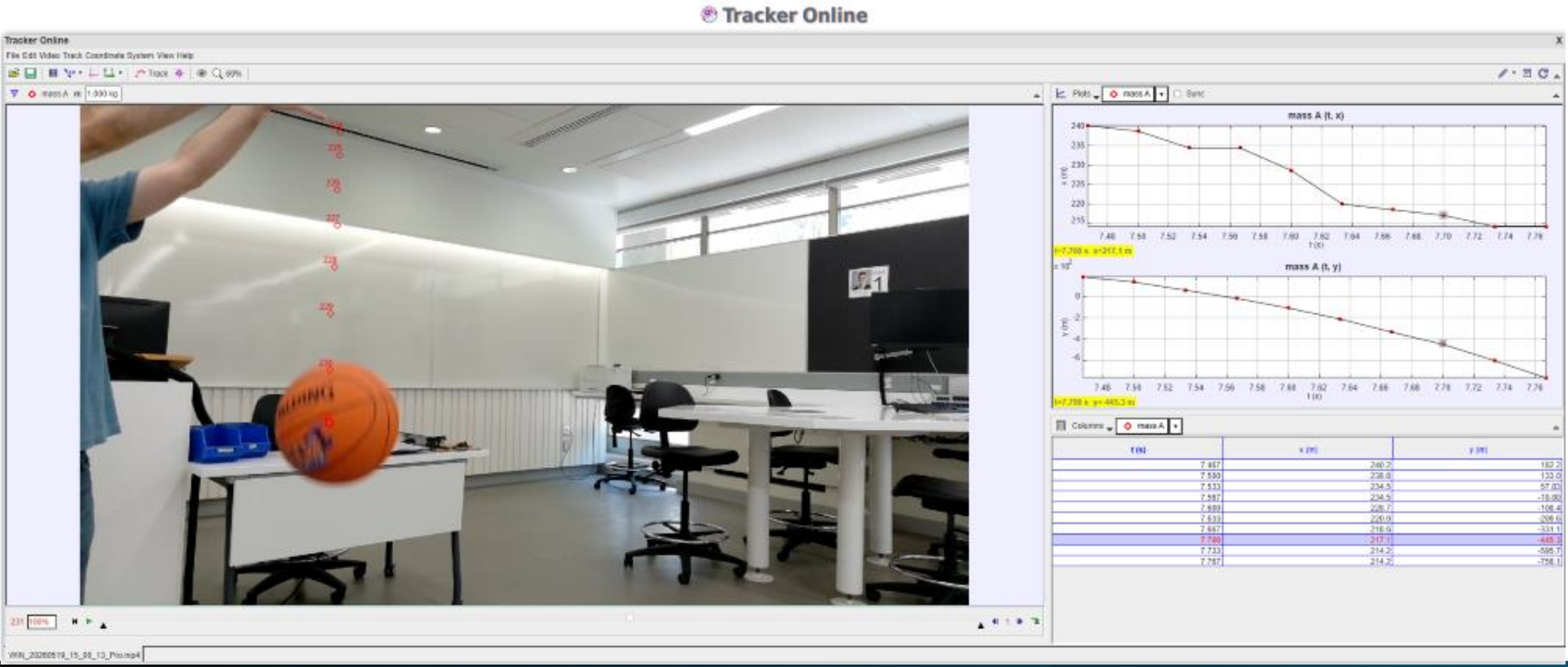

Not enough motion sensors? No problem!

https://opensourcephysics.github.io/tracker-website/
https://opensourcephysics.github.io/tracker-online/

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What comes next?

- Collaborate with Ania Harlick (University of Toronto) to develop a uniform structure for the first-year algebra-based classical mechanics and electromagnetism courses
  - Develop modular activities
  - Decouple data-analysis from specific experiments

- Use research-based tools (like the Physics Lab Inventory of Critical thinking) to more rigorously assess impact

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