Transforming Introductory Physics Labs: Implementing Scientific Reasoning Instruction

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Traditional Physics Lab

Questions

1. A ramp is placed on a table top so that the bottom is hanging over the edge. A marble and a golf ball are released from rest at the same time on the ramp, at the same height. (The contact point for each is at the same height.) Assuming they roll straight down the ramp without slipping, following parallel paths, which reaches the bottom first? Or do they both reach the bottom at the same time? Why?
2. A filled cylindrical can and an empty can the same size are released from rest on the same ramp at the same height. Assuming they roll straight down the ramp without slipping, following parallel paths, which reaches the bottom first? Or do they both reach the bottom at the same time? Why?

- Attempt to synchronize with lecture (topics always addressed first in lecture).
- Summary of pertinent topics.
- Goal: verify equations and concepts.
- Cookbook approach:
  - What data to take and how to take it.
  - What to analyze and how to analyze it.
- Answers given.
- Full lab report expected for each experiment in term.

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Promote *Scientific Reasoning* (*SR*) as a Filter for Students

- Domains:
  - Control of variables
  - Proportional reasoning
  - Correlations
  - Integrated hypothesis testing
  - Hypothetical deductive
  - Statistical reasoning
  - Causation reasoning
- Skills measured with iSTAR assessment (extension of CTSR).

Subset of critical thinking

Foundation of SR skills

istarassessment.org

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COV Progression

Presented with a scenario, students must…	Bloom's Taxonomy
Decide if experimental design is valid with two testable variables.	Understand-Interpret
Design a controlled experiment if there are more than two variables.	Apply-Implement
Decide if a variable is testable when it is actually testable (more than two variables present).	
Decide if a variable is influential when it is testable & influential.	Analyze-Differentiate
Decide if a variable is testable when it is testable (two variables present).	
Decide if a variable is testable when it is not testable.	
Decide if several variables are testable when some are influential & hidden relations exist.	Create- Putting elements together to generate prediction
Decide if several variables are influential when some are influential & hidden relations exist	
Predict outcome by deciding if a variable is influential when it is influential.	

Wood, K. E. (2015). *Evolution of Scientific Reasoning in Control of Variables for Undergraduate Physics Lab*. Dissertation.

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First Semester Physics Labs Developed to Instill…

- Thinking like a scientist.
- Exploring and predicting.
- Posing a testable question.
- Designing experiments.
- Collecting data to answer a question.
- Interpreting data through graphs, identifying patterns.
- Sharing data as a *research community* (whiteboards).
- Engaging in evidence-based reasoning & argumentation when writing lab reports.

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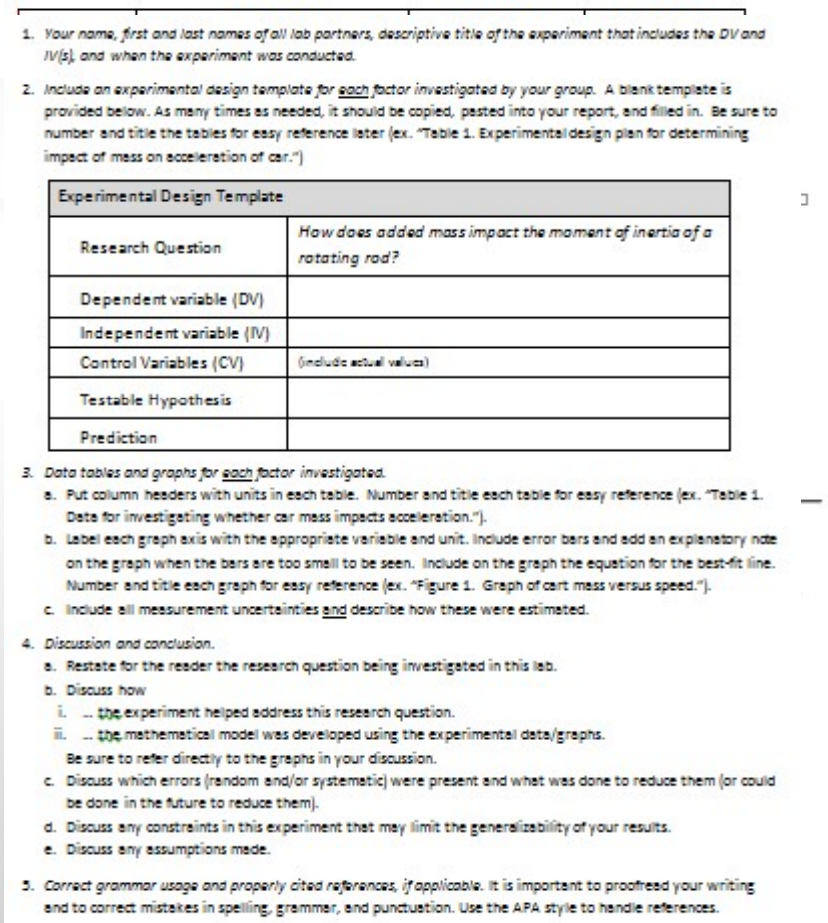
iSTAR Physics Lab



1. *Your name, first and last names of all lab partners, descriptive title of the experiment that includes the DV and IV(s), and when the experiment was conducted.*

2. *Include an experimental design template for <u>each</u> factor investigated by your group.* A blank template is provided below. As many times as needed, it should be copied, pasted into your report, and filled in. Be sure to number and title the tables for easy reference later (ex. "Table 1. Experimental design plan for determining impact of mass on acceleration of car.")

Experimental Design Template	
Research Question	*How does added mass impact the moment of inertia of a rotating rod?*
Dependent variable (DV)	
Independent variable (IV)	
Control Variables (CV)	(include actual values)
Testable Hypothesis	
Prediction	

3. *Data tables and graphs for <u>each</u> factor investigated.*
   a. Put column headers with units in each table. Number and title each table for easy reference (ex. "Table 1. Data for investigating whether car mass impacts acceleration.").
   b. Label each graph axis with the appropriate variable and unit. Include error bars and add an explanatory note on the graph when the bars are too small to be seen. Include on the graph the equation for the best-fit line. Number and title each graph for easy reference (ex. "Figure 1. Graph of cart mass versus speed.").
   c. Include all measurement uncertainties <u>and</u> describe how these were estimated.

4. *Discussion and conclusion.*
   a. Restate for the reader the research question being investigated in this lab.
   b. Discuss how
      i. ... the experiment helped address this research question.
      ii. ... the mathematical model was developed using the experimental data/graphs.
      Be sure to refer directly to the graphs in your discussion.
   c. Discuss which errors (random and/or systematic) were present and what was done to reduce them (or could be done in the future to reduce them).
   d. Discuss any constraints in this experiment that may limit the generalizability of your results.
   e. Discuss any assumptions made.

5. *Correct grammar usage and properly cited references, if applicable.* It is important to proofread your writing and to correct mistakes in spelling, grammar, and punctuation. Use the APA style to handle references.

- Flipped classroom, structured/guided inquiry-based.
- Pre-lab reading material and online quiz.
- In lab student groups of three or four, instructor engages Socratically, checkpoints.
- Handwritten Lab Records graded with rubric.
- Four lab reports over term.

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Group Whiteboard Results

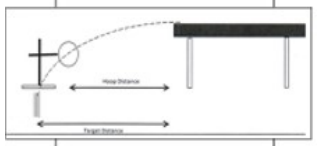
Week 1 Pendulum
- RQ: *What impacts the period of a pendulum?*
- Identification of variables (DV,IV,CV)
- Write a *testable* hypothesis
- Experimental design
- Graphical analysis
- Making and supporting a claim with evidence

Week 2 Pendulum
- RQ: *What impacts the period of a pendulum?*
- Uncertainties due to measurement tool and technique
- Use of error bars and equivalency criterion
- Systematic and random errors

Week 3 Pendulum
- RQ: *What impacts the period of a pendulum?*
- Reduce error
- Create mathematical model from experimental data
- Write a **Lab Report** (justify a claim using evidence)

Lab Report

Week 4 Projectile Motion
- Application of mathematical model to make predictions
- Propagation of uncertainties



Challenge Lab

Week 5 Newton's 2nd Law
- RQ: *How is acceleration of a system related to the force applied?*
- Design and conduct controlled experiment to determine mathematical model from experimental data
- Compare to theoretical model

Week 6 Newton's 2nd Law
- Apply experimental mathematical model to create outcome
- **Challenge Lab:** Given a larger cart, predict the hanging mass needed to cause the cart to accelerate at a specified value.
- Write a **Lab Report** (justify claim using evidence)

Lab Report

Week 7 SHM
- RQ: *What affects the period of an oscillating spring/ mass system?*
- Design and conduct controlled experiment to determine mathematical model from experimental data

Week 8 SHM
- **Challenge Lab:** Use SHM set-up and mathematical model to determine mass of an unknown

Group Whiteboard Results

Lab Report

Week 9 Cons. Momentum & Energy
- **Lab Challenge 1:** Collect *enough* data to demonstrate that momentum and energy of a system is conserved in an **elastic** collision (using carts on air track)
- **Lab Challenge 2:** Determine mass of unknown cart

Challenge Lab

Week 10 Rotation
- RQ: *How does amount and location of mass impact moment of inertia of rotating rod?*
- Design and conduct controlled experiment to determine mathematical model from experimental data
- Lab Report

Lab Report

Week 11/12 Windmill
- RQ: *What factors impact the speed of a windmill blade system?*
- *Design Challenge Lab:* Build the fastest rotating windmill blade system

Challenge Lab

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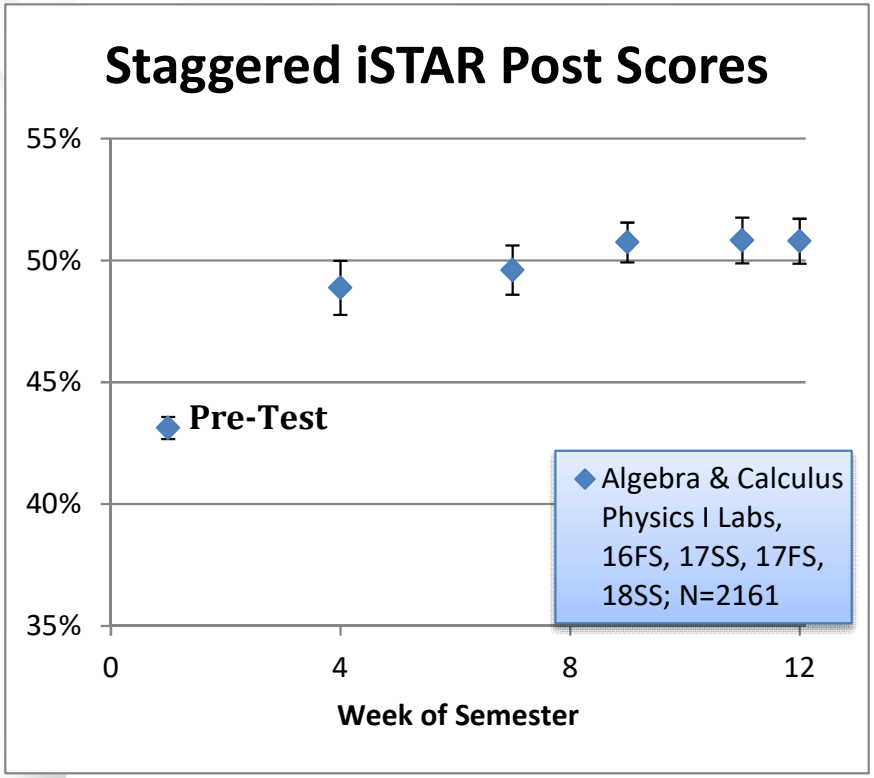
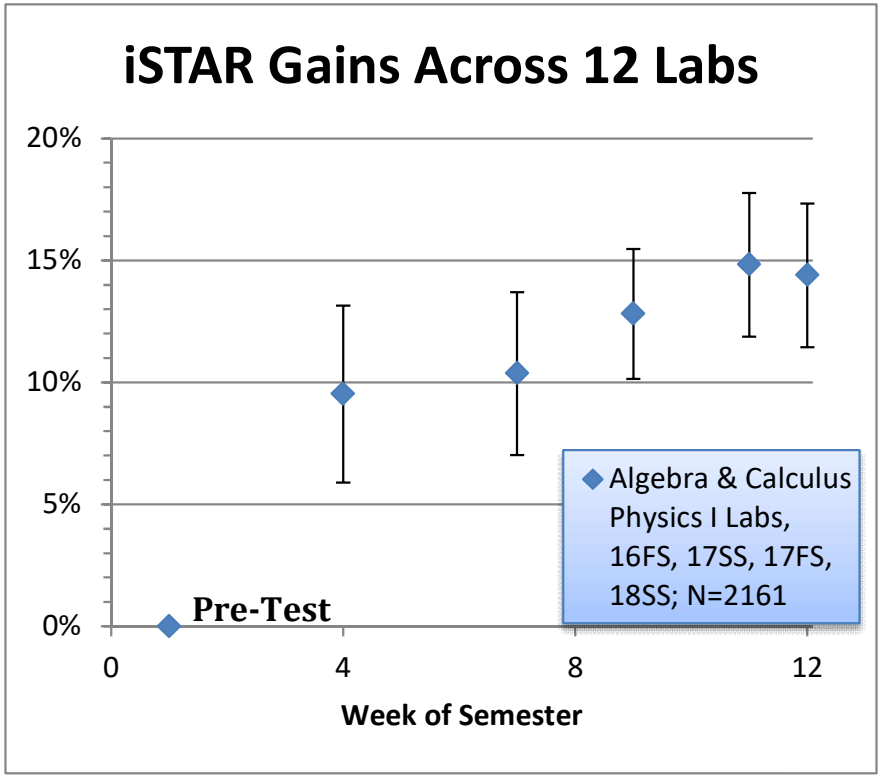
Results at UC





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Current Status

- Concentration has been on Control of Variables skills.
- Working to expand statistical and causal reasoning scaffolding and instruction.
- Looking to share SR curricular framework.
  - We will work with you to adapt your labs.

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Thank You! Time to Wake Up!

Questions?

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