Learning Science by Doing Science: Designing, Executing, and Analyzing Experiments in Physics 100 Labs

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Abstract

The goal of the Physics 100 labs is to help students learn how to do science. To achieve that, we have asked students design, execute, and analyze their own experiments. Guidance focused on data collection and analysis, rather than on domain knowledge. In fact, in several weeks the labs preceded the instruction.
To support learning, we treated the labs as data that students should learn from. That is, students analyzed their own experimental design, and tried to improve during the following labs.
Pre- and post-tests show that students indeed learned many of the target concepts. The bigger question, of whether students transfer these skills to other contexts, remains to be known.

List of labs

Lab 1: reaction time
1.1 Individual differences
1.2 Effect of distractors

Lab 2: Mechanical energy
2.1 What factors determine bouncing height?
2.2 Making predictions

Lab 3: Terminal velocity
3.1 How accurately can the terminal velocity be determined?
3.2 Comparing data and theory
3.3 Identifying patterns, generating and reading graphs

Lab 4: Friction
4.1 What factors affect friction?
4.2 Comparing alternative methodologies

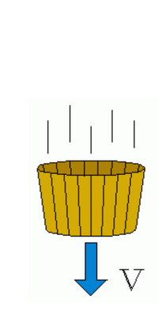
Example lab

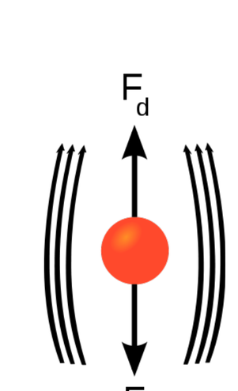
Terminal Velocity: A Company Competition

Major goal: To gain confidence and skill in planning measurements, analyzing data and communicating results. Comparing predictions to data and taking challenging measurements.

Last week: You measured the terminal velocity of different numbers of coffee filters. **This week** you are challenged to make a prediction based on your data. Atmospheric Data Corp (aka ADC) is recruiting a design team to design parachutes for their atmospheric balloons. You will be competing with other design teams to show your skill in analyzing coffee filter terminal velocities as an analog to parachute terminal velocities. One group of you will be chosen to be the company evaluation team.

Question for the Company Competition:
For the design teams: How accurately can your design team predict the terminal velocity of a large number of stacked coffee filters (10 and 15) based on measurements of a small number of filters stacked together?
For the company evaluation team: How well can you obtain reliable data on a large number of stacked filters (10 and 15) to make a convincing argument for selecting the best design team?

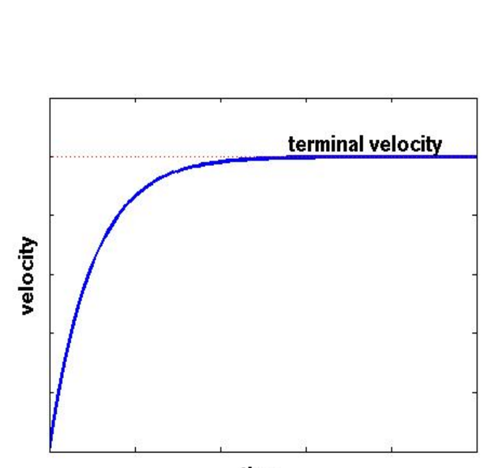




I. Introduction **5 min** **Whole class**
TAs will present the format for the "company competition" and discuss the rules of the competition.

II.a Design Teams **40 min** **6 groups of 6 (by table)**
Looking at the data you have from all of you from last week what does it say about the question?
What does a graph of all your data for terminal velocity versus number of filters look like?
Does it make sense to take a more data? How reliable are your results?
Think about how to present your prediction: Who is going to talk? Who will answer questions? How will you explain the process that you chose? Everyone should think of questions to ask other design teams.

II.b Company Evaluation Team **40 min** **2 groups of 6 (by table)**
Company Team takes data on a large number of stacked filters to compare to predictions of the design teams. The team prepares data to make a convincing case to evaluate predictions. How can you measure the terminal velocity of 10 and 15 stacked filters? You can leave the room, if you need more height, but you will not have the motion detectors. Is there another way to determine velocity? 40 minutes is very little time – make sure you reach your conclusions within this time frame (experimental design, data collection, analysis).
The team prepares questions for design teams.



III. Design Team Presentations **30 min** **6 Groups of 6**
Each Design Team puts their prediction on the board and explains their process, followed by questions from the other teams (5 min overall)
Company Evaluation Teams should not yet write their answer, but instead should ask questions and take notes.

IV. Company Evaluation **10 min** **Group of 12**
Company Evaluation Teams present their findings, and explain how they took the measurements. Then, jointly, they assess predictions and gives analysis relative to its measurements. Finally the company teams chooses the winning design team.

V. Summary **5 min** **Whole Class**

Structure of Labs

Given:
- Research question
- Basic equipment

Part 1:
- Design an experiment to address research question (2 students)

Part 2:
- Carry out experiment and analyze resluts

Part 3:
- Analyze experiment design in larger groups (6 students)

Part 4:
- Reflect on the experiment. How could the experiment be improved?

Grading

Students received pass, fail, or conditional pass.
The most important component was identifying their errors, not theirs strengths

Lab Reports

This page describing your individual work is to be handed with your Part 1 work.

PHYS 100 EXPERIMENT 3 (Part 2)
Terminal Velocity: A Company Competition

Date 10/26/10 Lab section L01

Your Name Lauren [illegible] Your student number 54466107

II. Your analysis of how your data from last week fits the big picture in your group, or your measurement plan (depends on the group you are in).

We plan on putting all of our data on the same graph. So, since we have 3 groups coming together as one today, there will be 3 lines of data on our graph (axis will be Terminal velocity vs. number of filters). Then we will draw a line of best fit for each group, then take the average all the group's predicted terminal velocities for 10 and 15 filter papers. These values will be our prediction.

example of graph we drew via Logger Pro.

Any new data and comments on your group's measurements USE THE REVERSE SIDE OF THIS PAGE

We were a "theory" group, so we did not take any additional measurements, but we did analyze each others data. Please see reverse of page.

III. What did you learn from the presentations?

- One grouped discussed drag, and used their data to see if their data seemed reasonable. This was the most reasonable measurement plan (after ours) since it incorporated drag, which was a main determining factor of the terminal velocity
- Another group compared their data on a graph to a square root function. I did not see what the correlation was with Terminal velocity.
- The third group used a line of best fit to predict their results, which was more/less similar to our group's approach

IV. What are you comments about the company data and decision?

- 1st group assumed average velocity was terminal velocity, which is not true. is it close?
- 2nd group did the same. I disagree with both assumptions. Terminal velocity is the point where an object stops accelerating. Also, this group only used 1 timer, which leaves room for error (because one person may have slower/faster RXN time).

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Assessment

Experimental Design

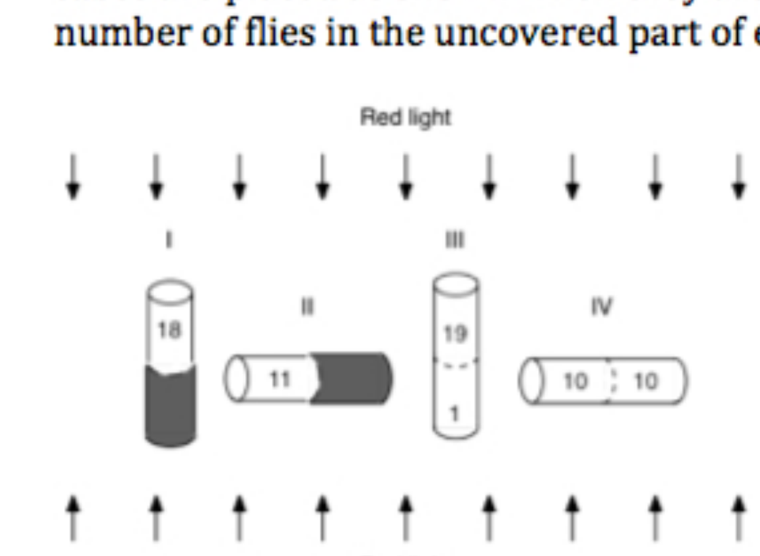
1. Three environmentalists want to evaluate whether summers in Vancouver got warmer during the 20th century (1900-2000). They can choose one of the following data sets. Which data set should they analyze:
   a. 1980, 1985, 1990, 1995, 2000
   b. 1920, 1940, 1960, 1980
   c. 1906, 1907, 1908, 1909, 1999
   d. 1900, 2000

   Answer: B
   Topic: experimental design
   Week 1: 85%
   Final: 94%

6. A shoe store owner wants to find out whether the color of the shoe affects sales. He has 4 shoes in stock: cheap brown, expensive brown, cheap black, and expensive black. Which of the following comparisons can best answer his question?
   a. Comparing the sales of cheap brown with expensive black
   b. Comparing the sales of cheap brown with expensive brown
   c. Comparing the sales of expensive brown with expensive black
   d. Comparing the sales of expensive brown with cheap black

   Answer: C
   Topic: Experimental design
   Week 1: 75%
   Final: 90%

12. Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.



This experiment shows that flies respond to (*respond* means move to or away from):
   a. Red light but not gravity
   b. Gravity but not red light
   c. Both red light and gravity
   d. Neither red light nor gravity

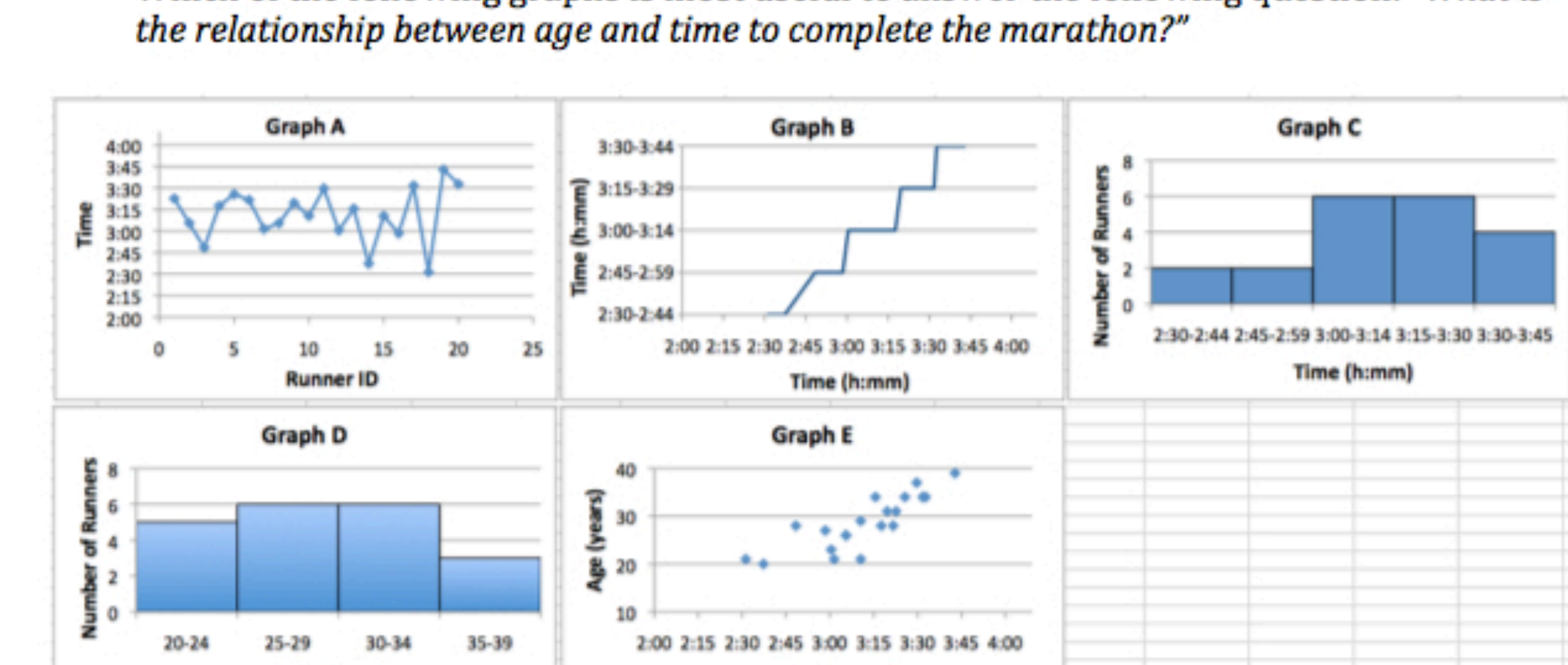
   Answer: B
   Topic: Experimental design
   Week 1: 41%
   Final: 71%

Graphing

4. The following data shows the time it took 20 runners to complete the recent Vancouver marathon:

Runner ID	Time (h:mm)	Age (years)	Runner ID	Time (h:mm)	Age (years)
1	3:23	31	11	3:30	37
2	3:06	26	12	3:01	23
3	2:49	40	13	3:16	34
4	3:18	28	14	2:28	20
5	3:26	34	15	3:11	21
6	3:22	28	16	2:59	27
7	3:02	21	17	3:32	34
8	3:06	26	18	2:32	21
9	3:20	31	19	3:43	40
10	3:11	29	20	3:33	34

Which of the following graphs is most useful to answer the following question: *"What is the relationship between age and time to complete the marathon?"*



   Answer: E
   Topic: graphing
   Week 1: 90%
   Final: 97%

5. The following question uses the same data from the previous one. Which of the graphs above is most useful to answer the following question: "How many runners have arrived each 15 minutes?"

   Answer: C
   Topic: graphing
   Week 1: 88%
   Final: 98%

Weighted uncertainty

3. John and Lesley measured the distance between two buildings. Each of them measured the distance three times:
   John measured: 46m, 64m, 55m.
   Lesley measured: 50m, 52m, 51m.
   What is a reasonable range for the actual distance?
   a. 46-64m
   b. 51-55m
   c. 50-52m
   d. 48-58m

   Answer: C
   Topic: weighted variability
   Week 1: 23%
   Final: 24%

10. Bill measured the flow rate of water coming from a tap and reported it to be (90 ± 20) millilitres per second. Meghan followed a different measurement procedure and reported the flow rate to be (110 ± 1) millilitres per second. How much water will approximately flow from the tap over 10 seconds?
   a. 900 ml
   b. 1,000 ml
   c. 1,100 ml
   d. Cannot be determined

   Answer: C
   Topic: Weighted average
   Week 1: 37%
   Final: 55%