Appendix A: Laboratory Handouts

Handouts for the Scientific Community Lab

A Guide to Physics 121 Labs

In Lab:

- You will not be given step by step instructions, but instead a short description of the question you will be investigating
- You will be given a challenging goal that will require collaboration with others to achieve. Together you will learn how to proceed when no answer is immediately available.
- You may choose to use available equipment, modify it, ask for other, bring or make your own
- You will hand in a group log for a group grade.
- You will be encouraged to evaluate the effectiveness of any aspect of lab in helping you reach the laboratory goal.
- You will not be graded on how close your results are to some standard. In fact, a standard answer may not exist, and if it does, you will not always know what it is.
- The whole class will be a scientific community, synthesizing results to come up with experimental designs and conclusions.

Things to bring:

- A three ring binder with graph paper and lined ruled paper.
- This will be your research journal
- A scientific calculator and digital watch with stopwatch (if you own one)

Preparing for lab:

The lab handout will be posted on the class website a week early. You are responsible for reading it and brainstorming how you will answer the question before you come to lab. As you will see, the lab time is limited, and you need to come prepared in order to finish. This also gives you a chance to request special equipment ahead of time if what you want is not normally available.

Weekly Log:

As a group, you will write a weekly log of your activities in lab; this will be due at the end of the lab period. There is a strict limit of three pages (not including data tables, graphs, and other representations) to encourage you to be succinct. You may wish to use tables, lists, and bullets in your write up.

The group log will be graded out of 10 points as follows:

3 pts: Journal. Could an absent student understand what you did by reading the log? Could they follow the route you took toward making sense – the dead-ends you tried, reasons for ditching ideas, reasons for selecting ideas, problems you ran across? Did you use vocabulary as the class has defined it?
3 pts: Persuasiveness. Does your data support your conclusion? Did you determine and take into consideration your limitations in measurement and how well you know your data?
3 pts: Evaluation: Do you have concrete suggestions for how you could improve each section of the lab? Did your evaluation build on information from other groups in the class discussion?
1 pt: Consistency: Do the sections of your weekly log agree? Did you communicate and organize the log as a group?

Each member of the group will be responsible for writing up one section, and must sign their name by that section. You may wish to include the following sections: Intro, Method Description, Data, Calculations, Conclusion, and Evaluation. Each group member must write up each section at least twice over the semester. The front page of the log should have each member's name and the section, lab, and group number.

Research journal:

Your TA will grade, photocopy, and hand back your weekly log, so everyone will have a copy. This should be kept in your research journal. You may also wish to take personal notes in addition to the log. It is not possible to remember completely all the information that goes into planning, executing, and analyzing an experiment, and you will need information from your research journals for future homework assignments, future labs, and the lab quizzes.

Lab quizzes:

There will be two lab quizzes a semester, the weeks of October 21 and December 2. You will be allowed to use anything in your research journal, and will have an hour to take the quiz. As opposed to other lab activities, the quiz will be taken individually. It will ask you to critique or further develop a lab, to apply techniques or debate concepts we've discussed in lab.

Attendance:

The labs are an integral part of this physics course, so missing a lab will affect your comprehension of the course material and impair your progress through both the lab and the lecture part of this course. There are no make-up labs.

If you will miss or have missed a lab:

- immediately talk to your TA.
- go to another section that week. (students in a Thursday lab will need to know ahead of time if they will miss a lab).

If you miss a lab and fail to make it up:

- if you have a VALID WRITTEN excuse (for missing and failing to make up), you will not be penalized.
- If you miss and fail to make up a lab without a valid written excuse, you will get zero for that lab.

If you are more than ten minutes late to lab, you will be counted as absent, and need to make up the lab in another section
If you are less than ten minutes late, please wait outside for the TA to let you in.

If you miss more than one lab, even with a valid excuse, you will fail the entire course, by departmental policy.

Grades:

The lab grade is 20% of your total course grade. Your grade in lab will be based on your participation during lab, weekly logs, and lab quizzes. During lab we expect every student to take an active role in planning the lab, setting up equipment, taking and analyzing data, and especially asking and answering questions during class discussion.

Safety:

You are not allowed to eat in lab because we may be dealing with harmful substances, and any crumbs increase our already bad roach problem. You may drink from closed bottles inside the lab room, and may eat outside in the hallway during break. Always wash your hands after lab.

Lab 1: Impeccable Timing

Stopwatches are frequently used by sports coaches, athletes, and physics students to measure a time interval. However, someone must stop and start them. How well can a person actually measure time? How does their reaction time affect their measurement? Are certain people better at measuring time than others?

During this lab, we will do everything as a whole class in order to introduce you to this new type of lab. However, this lab is slightly reversed in that the TA will show you a method (usually you will have to come up with a method yourself) and as a class you will decide on a question to answer (usually the question will be given to you).

Question:

As a class, decide on a question to investigate.

I. Brainstorming and Planning Meeting:

How will you answer your question?
Who will take what data?
How will you organize the data people take?
What will you do to the data to form conclusions?
How will you present the data to clearly show your conclusions?

II. Carrying out the Experiment

III. Class Discussion

What conclusions can you draw from your data?
What information can you take from this that will help you in future labs?

IV. Evaluate and Reconsider:

How can you make your argument more convincing?
Do you need a new experimental design? New data?
New ways to analyze and present the data you took?
New arguments in support of your conclusions?

Lab 2: Grandfather Clock

You have come across an old grandfather clock that someone has discarded. It has a big pendulum that swings back and forth, making the clock tick forward once per swing. You are a group of artists and decide to build a new housing for the clock, decorate the face, and build a new pendulum out of materials from your studio. However, when you assemble the clock with the new pendulum, which is lighter and longer, you notice that the clock no longer keeps the correct time. Before you rebuild the pendulum, you decide to figure out how the mass and length of the swing affect the time it takes to complete a swing (the period.) Then you can be sure you can build both an interesting and accurate clock.

Questions:

1. Does changing the length change the period?
2. Does changing the mass change the period?

I. Introduction: 10 min Whole Class

Discuss the bus stop question

II. Brainstorming and Planning Meeting: 15 min Groups of 4

Brainstorm ideas for answering these questions. Discuss them, choose a method.
Plan your experiment.
Call the TA over when you feel you are ready to start taking data,
and give him/her a description of what you physically will be doing to gather data.
You may start gathering equipment while waiting for the TA.

III. Carrying out the Experiment 40 min

Make sure you will be ready at the beginning of the second hour to present your experimental method, your data, and your conclusions about whether changing the length and mass affects the period. *The goal of the presentation is to convince other students that your conclusions are correct.* So, please put some thought into your presentation; it's the main point of this lab. For instance, how will you convince a group whose measurements turned out very different from yours to believe your data? How will you convince a group that took similar data but still disagreed with your conclusions? During the Class Discussion, other students will have the opportunity to argue with your conclusions, so you'd better be ready for them!

IV. Class Discussion Whole Class

Each group will present their method and results.
Can the whole class come to a consensus on the effect of mass and length?
Can you trust one group's results more than another's? Why or why not?
If two group's results contradict, how can you resolve that?
If you had to do this again, how would you combine everyone's methods?

V. Evaluate and Reconsider: Groups of 4

How can you make your argument more convincing? Plan your revision.
Do you need a new experimental design? New data?
New ways to analyze and present the data you took?
New arguments in support of your conclusions?

Lab 3: Grandfather Clock cont.

Now that you've spent so much time investigating clock pendula, you decide to go full time into the clock building business. But in order to make clocks of all different sizes you need to know specifically how the period depends on the length of the pendulum. Is it a linear relationship? Inverse? Quadratic? Cubic? Square root? Some other power? Sinusoidal?

Question:

How does the period of a pendulum depend on its length?
Test at least three functions.

I. Introduction: Whole class

Discuss your answers to the function fitting homework question.

II. Brainstorming and Planning Meeting:

Brainstorm ideas for answering this question. Discuss them, choose a method.
Plan your experiment.
Call the TA over when you feel you are ready to start taking data,
and give him/her a description of what you physically will be doing to gather data.
You may start gathering equipment while waiting for the TA

III. Carrying out the Experiment

Make sure you will be ready at the beginning of the second hour to present your experimental method, your data, and your conclusions about how changing the length affects the period.

IV. Class Discussion Whole Class

Each group will present their method and results.
Can the whole class come to a consensus on the dependence?
Can you trust one group's results more than another's? Why or why not?
If two group's results contradict, how can you resolve that?

V. Evaluate and Reconsider:

How can you make your argument more convincing? Plan your revision.
Do you need a new experimental design? New data?
New ways to analyze and present the data you took?
New arguments in support of your conclusions?
Call the TA over when your revised plan is ready.

Lab 4: The wheels on the car

A child you know is entering the pinewood derby in her club. She has to design and build a small wooden car for racing down a ramp, and needs help deciding what kind of wheels to order. They come with a lot of options for wheel design – you get to choose the material, shape, and size of the wheel rim. You wonder if any of these things will affect how quickly the wheels accelerate down the ramp, and thus if the car will win the race.

Question:

What affects the acceleration of a rolling object? Choose one property to investigate.

I. Introduction: 10 min Whole Class

Evaluate two experimental designs.

II. Brainstorming and Planning Meeting: 15 min Groups of 4

Brainstorm ideas for answering the lab question.
What things might affect your results, obscuring the effects you want to see?
How can you design your experiment to make the strongest possible conclusion?
Plan your experiment.
⇨ Call the TA over when you feel you are ready to start taking data,
and give him/her a description of what you physically will be doing to gather data
and how you will analyze that data to make a conclusion.
You may start gathering equipment while waiting for the TA.

III. Carrying out the Experiment 40 min

Make sure you will be ready at the beginning of the second hour to present your experimental method, your data, and your conclusions about whether your property affects the acceleration.

IV. Class Discussion Whole Class

Each group will present their method and results.
Can the whole class come to a consensus about each property?
Can you trust one group's results more than another's? Why or why not?
If two group's results contradict, how can you resolve that?
When you do something similar next week, how will you combine everyone's methods?

V. Evaluate and Reconsider: Groups of 4

How can you make your argument more convincing? Plan your revision.
How would you improve your experimental design? Your data?
What are better ways to analyze and present the data you took?
What new arguments do you have in support of your conclusions?

Lab 5: The Rolling of the Cylindroid

You have just been allowed a marvelous chance to study the actual finches that Darwin collected. You discover, hidden at the bottom of an old box, a collection of new creatures. These 'cylindroids', as you call them, all have round, silver colored bodies, travel primarily by rolling, and have the same mass. There are two different species of cylindroid, but you don't know which species a certain cylindroid belongs in.

In this lab each group of students will test two cylindroids and determine if they belong to the same species or a different species. These are very fragile endangered creatures, so you must be extremely careful with them.

Question:

Do your two cylindroids belong to the same species or to different species?
One point of your weekly log will depend on your answer.

I. Introduction: 10 min Groups of 4

Discuss the homework question on representations.

II. Brainstorming and Planning Meeting: 15 min Groups of 4

Brainstorm ideas for answering the lab question.
What things might mess up your results and how can you minimize their effects?
How can you design your experiment to make the strongest possible conclusion?
Plan your experiment.
Call the TA over when you feel you are ready to start taking data,
and give him/her a description of what you physically will be doing to gather data
and how you will analyze that data to make a conclusion.
You may start gathering equipment while waiting for the TA.

III. Carrying out the Experiment 40 min

Make sure you will be ready at the beginning of the second hour to present your experimental method, your data, and your conclusions about whether your cylindroids are the same species or not.

IV. Class Discussion Whole Class

Each group will present their method and results.
Can any information from other groups help you decide about your cylindroids?
If two group's results contradict, how can you resolve that?
If you had to do this again, how would you combine everyone's methods?

V. Evaluate and Reconsider: Groups of 4

Now that you know the species of your cylindroids, evaluate your conclusions.
How can you make your argument more convincing? Plan your revision.
How would you improve your experimental design? Your data?
What are better ways to analyze and present the data you took?
What new arguments do you have in support of your conclusions?

Lab 6: Friction

You are at the hardware store to get some of those little discs you can put under furniture legs so you can slide your couch across the hardwood floor of your living room. They have several sizes and you are trying to decide if you should get the smallest size that fits your couch legs or a larger size. You remember learning in lecture that the force of friction depends on the surfaces and the normal force, $f = \mu N$. Does it depend on the area of contact between the two surfaces? Will a certain size disc make it easier to slide your couch around the room?

Questions:

1. Does friction depend on the contact area between two surfaces?
2. In your experiment, what things besides surface area might be causing a difference in your data? Which has the largest effect? What can you change to reduce its effect and thus see only the effect of changing the surface area?

I. Introduction: Whole class

The BMW convertible

II. Brainstorming and Planning Meeting:

Brainstorm ideas for answering this question. Discuss them, choose a method.
Plan your experiment.
Call the TA over when you feel you are ready to start taking data,
and give him/her a description of what you physically will be doing to gather data.
You may start gathering equipment while waiting for the TA

III. Carrying out the Experiment

After you have taken some data, consider again question 2. Improve upon your experimental design to improve your conclusion.
Make sure you will be ready at the beginning of the second hour to present your experimental method, your data, what you changed to improve your results and your conclusions about whether friction depends on surface area.

IV. Class Discussion Whole Class

Each group will present their method and results.
Can the whole class come to a consensus about friction?
Can you trust one group's results more than another's? Why or why not?
If two group's results contradict, how can you resolve that?

V. Evaluate and Reconsider:

How can you improve your ability to measure friction? Plan your revision.
Do you need a new experimental design? New data?
New ways to analyze and present the data you took?
New arguments in support of your conclusions?
Call the TA over when your revised plan is ready.

Lab 7: Rescue Mission

A certain town in Alaska is inaccessible by road, and the weather has not allowed any planes or boats to reach the town, so the people living there are running out of food. You have been asked to design a system to launch bags of food from a cliff above the town into a field near the town. However, you will not be allowed to randomly launch containers of food off the cliff. You must be able to predict where the containers will land using measurements performed on the cliff itself.
Your first step is to design and test a system that will launch a marble from a table. You must be able to predict roughly where the marble will land based on measurements made on the floor or on the table. You may not launch the marble through the air.

You do not have to write a weekly log for this lab. However, your log for next week will include this information, so you will want to take notes for yourself.

Question:

How will you predict where your marble will land?

I. Introduction

II. Brainstorming and Planning Meeting:

Brainstorm ideas for answering this question. Discuss them, choose a method.
Plan your experiment.
Call the TA over when you feel you are ready to start taking data,
and give him/her a description of what you physically will be doing to gather data,
and how you will predict where your marble will land from this data.
You may want to use an experimental design chart.
You may start gathering equipment while waiting for the TA

III. Carrying out the Experiment

When you are finished, tape an x where you predict the marble will land.

IV. Class Discussion

Each group will test their prediction.
What can you take from each group's method that will improve your experiment next week?

Lab 8: Minimization

Consider the following design problem:

> You are designing a new booth for a traveling carnival. People will use a catapult to toss a penny at a plate. If it lands on the plate, they win a prize. If no one ever wins a prize, people will stop playing. If too many people win a prize, you will lose money. So you want to make your plate large enough to catch a small fraction of pennies, but not large enough to catch them all.

Two of the main things we have been working on in previous labs are how to design an experiment to answer a question, and how to think about the spread in the data you take. To focus on these issues, consider the following task.

> Design a method for launching an object horizontally from the table onto the floor. The goal is to launch the object onto a paper target on the floor so that in 10 launches it hits the target more than 5 times but less than 10. As in last week's lab, you may take measurements on the floor or on the table, but may only launch your marble through the air once (before the 10 trials), with TA in attendance.

Question:

How will you know how large to make your target so that the marble hits it more than five times but less than ten times?

One point of your weekly log will depend on your success.

I. Introduction:

Why miss?

II. Brainstorming and Planning Meeting:

Brainstorm ideas for answering this question. Discuss them, choose a method.
Plan your experiment.
Call the TA over when you feel you are ready to start taking data,
and give him/her a description of what you physically will be doing to gather data.
You may start gathering equipment while waiting for the TA

III. Carrying out the Experiment

Get a white and yellow paper from the TA and draw your target on it. Write the names of everyone in your group on it.
Make sure you will be ready before the beginning of the second hour to run your 10 trials. This means you need to have the TA watch your one 'free trial' and 10 trials before the class discussion.

IV. Class Discussion — Whole Class

Each group will present their method, results and target.

V. Evaluate and Reconsider:

How can you improve your ability to predict the landing area? Plan your revision.
Do you need a new experimental design? New data? New ways to analyze and present the data you took? New arguments in support of your conclusions?

Lab 9: Roller Coaster

You have just been hired to design a roller coaster with a loop in it. However, the budget for this project is very tight (the amusement park hasn't been doing very well financially) and cannot build you a full track with which to experiment. You have to figure out how high to make the track so the car will make it around the loop using only a section of the track.

Question:

What is the minimum height at which you can release the ball in order for the ball to just make it around the loop?

I. Introduction:

Come to a consensus on the loop homework question.

II. Brainstorming and Planning Meeting:

Brainstorm ideas for answering this question. Discuss them, plan your experiment.
Each team may experiment on a piece of track.

- You may NOT form a loop with this track, or permanently harm it in any way.
- Do not make sharp bends in it, cut or scratch it.
- You may gently bend it in a reversible manner.

Call the TA over when you feel you are ready to start taking data,
and give him/her a description of what you physically will be doing to gather data.

III. Carrying out the Experiment

After you have decided on a height, put a piece of tape marking a line beside the loop track with your group number on it. You may use your group's marble for the final roll.

IV. Class Discussion — Whole Class

Each group will present their method and results. After everyone has presented, we will start at the top height and test them all.

V. Evaluate and Reconsider:

How can you improve your ability to determine the lowest release height?
Plan your revision.
Do you need a new experimental design? New data?
New ways to analyze and present the data you took?
New arguments in support of your conclusions?

Lab 10: Gravity

In order to determine whether to drill for oil in certain locations, geologists will measure the local gravitational strength, g, in that and surrounding locations. Very small variations in g (a difference of 10^{-5} N/kg or .000l percent) will tell them if there are caves, dense rocks, or lighter porous rocks under the surface. You have been given the task of measuring g in the basement of the physics building well enough that you could tell if g changed by 1 percent or less. .

Questions:

How well can you measure g?
What is g in room 0220 in the physics building?

I. Introduction:

Discuss the car homework question.

II. Brainstorming and Planning Meeting:

Brainstorm ideas for answering this question. Discuss them, choose a method.
Plan your experiment.
Estimate quantitatively how well you will be able to measure g.
You must give this number to your TA before you can start taking data.
What outside factors may affect your data? How can you reduce those factors?

III. Carrying out the Experiment

IV. Class Discussion **Whole Class**

Each group will present their method and results.
- How did you make your estimation?
- How close was your estimation to your actual measurements?

V. Evaluate and Reconsider:

How can you improve your ability to measure g?
How can better predict your ability to measure g?
Plan your revision.
Do you need a new experimental design? New data?
New ways to analyze and present the data you took?
New arguments in support of your conclusions?

Lab 11: A Massful Spring

In lecture we developed the theory for a mass oscillating on a spring, assuming that the spring was ‘massless’, or weighed much less than the oscillating mass. Unfortunately, massless springs are very expensive (that’s a joke), and we often have to make do with springs that have some mass. Does the theory need to be revised to agree with experimental data taken using massful springs?

Question:

How can one revise the theory to include the idea that springs have mass?

I. Introduction:

Discuss the homework question.

II. Brainstorming and Planning Meeting:

Brainstorm ideas for answering this question. Discuss them, choose a method.
Plan your experiment.

Call the TA over when you feel you are ready to start taking data,
and give him/her a description of what you physically will be doing to gather data.

III. Carrying out the Experiment

IV. Class Discussion — Whole Class

Each group will present their method and results.

V. Evaluate and Reconsider:

How can you improve your ability to revise the theory?
Do you need a new experimental design? New data?
New ways to analyze and present the data you took?
New arguments in support of your conclusions?
Call the TA over when your revised plan is ready.

Handout for Cookbook+Explanation Lab B

Lab IX: Interference

1. Start with the single slit. In order for our approximations to hold, the slits need to be far away from the screen.
2. Look at the pattern formed by the different slits. Explain why such a pattern is formed by light going through one slit.
3. Describe what happens to the pattern as the slit width changes. Explain why this happens, using your answer to number 2. Draw a picture.
4. We know that for a minima to occur on the screen $a\sin\theta = m\lambda$ where a is the slit width, m is 1, 2, 3, etc., and λ is the wavelength of light coming out of the laser. Use this equation to derive how far apart on the screen your 1st, 2nd, 3rd, 4th, and 5th minima will be. Draw a picture.
5. Choose a slit wisely. (Which slit gives you the best picture of the first five minima?) Use your data from the first five minima and your equation from number 4 to find the wavelength of laser light. Compare your calculated wavelength to the accepted value (p. 96 in lab book). (It is easiest to do this by taping a piece of paper to the screen and drawing the pattern on there and measuring from your drawing.)
6. Now take a human hair, tape it to the empty slide mount and look at the pattern formed. Make up some plausible reason why this happens.
7. Look at the patterns formed by the double slits. What happens when the slit separation changes? What happens when the slit width changes?
8. Using your answer from number 2 and the modified prelab, explain why this happens. (If you didn't do the prelab, you need to now explain the pictures on p. 97) Draw a picture.
9. Look at the pattern formed by the multiple slits, only 2 and 3 slits. BEFORE looking at the 4 and 5 slit patterns, predict what you think they will look like. Draw a picture of the 3 slit pattern, and then a picture of your predictions for the 4 and 5 slit patterns. Check to see if you were right. Explain why this happens.
10. Predict what the pattern would look like if you had 2000 slits. Draw a picture.
11. A diffraction grating is basically a slide with a large number of slits in it. If d is the density of slits (number of slits per meter), L is the distance to the screen, and y is the distance between the first maxima, then $d = y/(\lambda L)$
12. Considering d, λ, and L, what happens to the distance between the maxima in the pattern (y) when they increase or decrease? Do these trends make sense?
13. Determine the density of slits on your diffraction grating. Compare this to the accepted value (roughly 7500 lines per inch). Will it decrease or increase your error to shine the pattern across 10 meters instead of just 1?
14. Play with the pattern formed by the mesh. Isn't it pretty? Sketch the patterns.
15. See if you can make a pretty pattern by trying different combinations of your slits in different directions. Join with another pair to do this.

Appendix B: TA Handouts
for the Scientific Community Lab

A TA Guide to Physics 121 Labs

Semester Goals:

Measurement and Certainty:

Understand uncertainty in an experiment
- What is the mechanism causing a range in data
- Is it inside or outside variation
- What kind of range will that mechanism cause
- Which mechanism causes most outside variation
- Predict certainty

Experimental Design
- Minimize sources of outside variability
- Stacking

Interpret Data
- Information gleaned from taking multiple measurements
- What average, range means
- Range overlap
- Histogram, peak overlap
- Low probability data
- Range propagation

Point vs. Set (Ensemble)
- Understand difference between a past question and a predictive question
- It doesn’t mean something is wrong if you have a range in your data

Epistemology/knowledge tools
- Range
- Average
- Graphs/Histograms/Other Representations

Physics Concepts

Group Work

Presentation, Communication Skills

Methods to achieve goals:

'Design your own' lab:

This encourages students to think and to understand their method. Students need to understand what they are doing to be able to critique it or other group's methods. Also in general a good skill to have for bioscience and architecture majors.

Develop a class vocabulary:

Students need to be able to communicate with each other, which may be difficult if one group uses range to mean max-min and another to mean standard deviation. Also, once these terms are defined, it will be easier to encourage everyone to use them and hopefully be thinking about them. Each section will have its own board with terms and tools written down.

Class Discussion: Developing a scientific community

We need to change how students view social interactions during lab. We want them discussing and debating ideas and defending their work.

While designing and performing their experiment and interpreting data, students know that they will have to be able to defend their conclusions to other students. This puts them in the right 'mode' to analyze their data effectively to make strong arguments and also to care more about what they are doing.

Science is a community. The class as a whole will produce the strongest conclusion. It is not cheating to get help from classmates.
The class discussion also gives students a chance to ask the community for help, and as a class to come to a consensus on what methods work well, how to interpret data, and perhaps agree on a solution to the posed question.

Weekly Log Grading Policy

Students are **not** penalized for not being able to come to a conclusion because of a faulty design or a faulty interpretation of data. They **are** penalized for not realizing what their problem was or suggesting improvements. This gives them a chance to explore and try out ideas during lab, and also encourages them to use the class discussion time.

The group log will be graded out of 10 points as follows:

3 pts: **Journal**. Could an absent student understand what you did by reading the log? Could they follow the route you took toward making sense – the dead-ends you tried, reasons for ditching ideas, reasons for selecting ideas, problems you ran across? Did you use vocabulary as the class has defined it?

3 pts: **Persuasiveness**. Does your data support your conclusion? Did you determine and take into consideration your limitations in measurement and how well you know your data?

3 pts: **Evaluation**: Do you have concrete suggestions for how you could improve each section of the lab? Did your evaluation build on information from other groups in the class discussion?

1 pt: **Consistency**: Do the sections of your weekly log agree? Did you communicate and organize the log as a group?

You will grade the log, make four photocopies, hand back the photocopies to the students, and keep the original for data. Last week's log should be returned at the end of the following lab.

Lab quizzes and lab homework

These are both open-book. This is to give a reason for students to be writing down information from lab, and re-reading their lab reports.

It also is a chance for certain things to be graded right or wrong. Students can easily decide that all this stuff is very subjective and there is no right or wrong answer, which for some things is not true. For example, some students believed that two sets of data with different averages agreed as long as the range was the same size. They were treating range size as giving the same information on a set of data as the average does.

Students frequently don't know what we want. In the solutions and examples we can communicate to students what we are looking for, if they read them.

Real life examples

Students already are able to do a lot of what we want of them. They just don't use those resources during physics lab. Real life examples are a way of getting students to think using the resources they have, and of showing that physics has applicability.

Format of two hours:

Introduction (10 min)

Real life example introducing main measurement issue of the lab, run as a mini ILD

Brainstorming (15 min)

Hand out lab question, groups start planning. TA helping with equipment, and ok-ing procedures of groups.

Carrying out experiment (30 min)

TA listening in to groups, occasionally interrupting.

Flex Time (10 min)

TA trying to get all groups ready for class discussion.

Presentations and Class Discussion (30 min)

Each group presents. Rest of groups listen and ask questions.

Conclusions (5 min)

Have students sum up main points of class discussion, any new vocab defined, tools used, etc

End (10 min)

Groups finish writing lab reports, hand back homework, leave.

Physics 121 Homework Schedule

#	Pre-hw	Intro disc.	Lab	Post-hw
1			Introduction and reaction time	
2		Bus stop	Pendulum Investigations	
3	Math modeling	Math modeling	Pendulum Investigations II	Linear fit to math modeling
4	Accel on ramp	Expt design eval	Rolling Objects I – known objects	
5	Invent representation	Discuss representations	Rolling Objects II – mystery cylinders	Low probability data
6	Drive car mileage on auto or man?	Ext vs int effects	Surface Area Friction	
7	Calc x distance	2 group's exptl design	Lab Quiz Rescue Mission I	
8	Calc propagated range	Why miss?	Minimization II	
9	Loop question	Loop solution	Roller Coaster Loop	
10	Toy car estimate range		Measure g	
11	Change T = equation	Change T = equation	Massful springs	
			Lab quiz	

Lab 1: Impeccable Timing

Stopwatches are frequently used by sports coaches, athletes, and physics students to measure a time interval. However, someone must stop and start them. How well can a person actually measure time? How does their reaction time affect their measurement? Are certain people better at measuring time than others?

Goals:

Framing: For students to understand what exactly we want them to do in this crazy lab. They need to be thinking and working. We will not give them answers, but will help them along. The process is more important than the end answer. (Though here, the end answer will help in future labs)
Vocabulary: students have to define any word they're using so that groups can communicate.
Work together: As a class this time, instead of a group, they need to organize who will do what and how to compile all their data easily.
Time measuring: In answering their question, they will hopefully learn about measuring time, how to make it more consistent, which person in their group has the best reaction time, things that will help them in the future with using a stopwatch.
Tools: How flow charts can help in planning a lab.
Set Paradigm: The question we're asking is a predictive question, it is answered by taking multiple trials, looking at the set of data, using the range, etc.

During this lab, we will do everything as a whole class in order to introduce you to this new type of lab. However, this lab is slightly reversed in that the TA will show you a method (usually you will have to come up with a method yourself) and as a class you will decide on a question to answer (usually the question will be given to you)

Possible Questions:

Does age affect reaction time? Type of ruler? Person doing the holding? Year in college? Sight vs sound: (see ruler dropping, or have person say 'drop' when they let go)
Have the class choose a question and then make them elaborate, narrow down that question.
Don't let them convert length to seconds, or get stuck on distance not being time.

I. Brainstorming and Planning Meeting: 15 min?

Introduce flow charts.
How will you answer your question?
Who will take what data?
How will you organize the data people take?
What will you do to the data to form conclusions?
How will you present the data to clearly show your conclusions?

After you're done, ask for a student to summarize what the class decided.

II. Carrying out the Experiment 30 min?

Ask for a student volunteer to be 'master of ceremony' and keep everyone on schedule. You can participate in the data taking

III. Class Discussion 15 min?

This is where the whole class should look at the data and come up with some kind of conclusion. If they're having a hard time doing this as a large group, ask them to talk in small groups for a while, come up with something, then call on those who haven't gotten a chance to talk.

Possible questions:

- What exactly in the data can you use to answer the question?
- Do we need any more data to fully answer this question?
- Should we 'throw out' any data?

Critical questions:

- Suppose I told you Sam got 14 cm and Jamie got 13 cm. What information does that give you? Why do we take multiple trials?

IV. Evaluate and Reconsider:

Lead the class in a discussion. See if they're able to come up with something for the typical questions:

- How can you make your argument more convincing? Plan your revision. Do you need a new experimental design? New data? New ways to analyze and present the data you took?
- New arguments in support of your conclusions?

Then have a higher level discussion:

- What is the purpose of this week's lab? (if no one volunteers, make each group discuss and then contribute something)
- Of this semester's labs in general?
- Suppose I told you that a country-wide experiment found that juniors and seniors have a faster reaction time than freshman and sophomores. What would that add to your learning? What use would that be to you? Would you use that result or your own?

The purpose of this is partly to introduce meta-discussions, and show such things are a valid topic of discussion.

Lab 2: Grandfather Clock

You have come across an old grandfather clock that someone has discarded. It has a big pendulum that swings back and forth, making the clock tick forward once per swing. You are a group of artists and decide to build a new housing for the clock, decorate the face, and build a new pendulum out of materials from your studio. However, when you assemble the clock with the new pendulum, which is lighter and longer, you notice that the clock no longer keeps the correct time. Before you rebuild the pendulum, you decide to figure out how the mass and length of the swing affect the time it takes to complete a swing (the period.) Then you can be sure you can build both an interesting and accurate clock.

Questions:

1. Does changing the length change the period?
2. Does changing the mass change the period?

Goals:

Framing: What is the student's role? What is the TA's role?
Design experiment: How many data points should I take? Over what range should I take data?
Measuring time: What exactly will the 'human error' do to the data and how to minimize its effect. Should one person time all? Two people time and average? They will be timing pendula again next week, and should come up with a good method to minimize outside variation.
Interpret data: Are these numbers the same or different? Looking at the range in data, using data to tell uncertainty.
Vocabulary: Period, average, range
Tools: Stacking (measure stack of 20, divide by twenty)

Tools and Terms board

I. Introduction: 10 min Whole class

Students are supposed to be reading the lab handout before they get to class. Ask how many actually did. Remind them to do this. If anyone complains about 'not enough time', ask if they actually read and planned ahead of time.

Run intro question as an ILD. "To start out with, I have a question for everyone. I'm going to read it, then I want you to talk about it in your groups for a minute, then I'll ask each group to briefly give their conclusion."

One morning a bus arrives at 9:03. The sign on the bus is broken, so she doesn't know which bus it is. Is this bus her bus, or another bus?

Run this QUICKLY. Possible responses: 'we can't know unless we have more data', 'it's 15 minutes early, I know from experience buses are never early', 'they say expect 3 minutes on each side, so this is outside that range.'

A student takes the 9:18 bus every morning. According to her watch, in the last two weeks it has arrived at 9:12, 9:21, 9:17, 9:08, 9:07, 9:28, 9:19, 9:16, 9:23, 9:10. A bus arrives at 9:03. Is this her bus, or another bus?

Write these numbers on the board, just a list, in the order they're written. Some groups might say we need more info about when the neighboring buses usually show up, or make an arbitrary judgment not looking at the range in data. Hopefully some groups will look at the range in data. That's what we want – to get them realizing what multiple data points can do.

Then have a meta-discussion. Ask 'who thinks these questions are a waste of time, stupid, or don't belong in a physics lab?" Hopefully some students will volunteer that they do. If they don't, say something like "well, if you won't agree to these being dumb, what about the intro paragraph to the lab. Obviously you guys aren't clock designers. Isn't that rather ridiculous?" Have groups (for brief period) talk about why we do this stuff. Then group discussion. At end, give your reason why. What we do is based on research, but the students can still argue with whether this works for them or not.

II. Brainstorming and Planning Meeting: 15 min Groups of 4

You should check out all groups' plans before they start doing the experiment.
Possible questions:

How are you going to build your pendulum? How will that help your conclusion?
What are you going to change between measurements? What are you going to keep the same?
How many measurements are you going to take? Why? (It's ok to answer 'we'll see')
Who is going to do what? How have you planned your time so you will be finished and ready? Who will write up what section? Remind them of the three page limit.

III. Carrying out the Experiment 40 min Groups of 4

You should either be standing nearby and listening to a group or talking to a group. Please do not get them off task – if you start talking to them about the game, you have just stolen a lot of time from them. If they have time, talk to them about how best to measure the period: start/stop at edges of swing or through middle. (Not pushing to a right answer, just alerting them to things to think about, they could also bring this up in the discussion, good seeding question)
Ten minutes before you want to start the class discussion, hand out white boards and give them a warning. Five minutes before force them to actually write something down. At the time take away their markers. Be consistent about keeping the schedule.

CHANGE TAPES

IV. Class Discussion Whole Class

The whole group should stand up with the whiteboard, but one main speaker should be chosen. First ask the class if people understand what the group did. Then ask for questions or critiques – the presenting group can also ask questions of the audience. If they don't have any questions, think of one and ask if anyone was wondering this. Then make them ask it. Lead applause when the group is finished. Audience should only be writing if they're taking notes on the discussion. I prefer they don't write. They need to be paying attention.
Main point is does the period change or doesn't it. They need to use data to prove their results. The discussion should be set up as a time for the whole class to come up with a conclusion, on good methods or good results. Cooperative, not competitive.

Questions:

What is good about each group's timing method, what can we use to come up with the best method of timing?

Four data sets, same averages, two overlap and two don't.

						average:
data1:	18	14	17	12	15	15
data2:	16	22	19	18	17	18
data3:	18	20	19	18	17	18
data4:	14	16	15	16	14	15

If you wanted to measure the width of a nickel with a ruler, would it be better to stack twenty, measure that, and divide by twenty? What is similar here? (The cougar homework question might help.)

Did we define any new terms or tools that we should put on the board?

V. Evaluate and Reconsider: Groups of 4

Listen in, and see if the groups understand what they're supposed to be doing. This is the first lab, you can help them out, model what we want here. Make sure their area is clean before they leave.

Remember to tape the whiteboards

Possible Problems:

Groups run out of time. If they don't get to both questions, remind them to read and plan ahead next time.

It might take them a while to start, to build a pendulum. Encourage them along. You can make suggestions – tie over pipe, shelf, etc.

Groups think they need to build a pendulum that makes one swing a second, or build one that looks like a clock's pendulum. It's just an introduction to start them thinking about the question.

Groups will probably need encouragement to take a lot of data and look at a wide range. If they're finished early make them try a longer pendulum (2 meters) or take more data, or whatever they can think of that will improve their argument.

Lab 3: Grandfather Clock cont.

Now that you've spent so much time investigating clock pendula, you decide to go full time into the clock building business. But in order to make clocks of all different sizes you need to know specifically how the period depends on the length of the pendulum. Is it a linear relationship? Inverse? Quadratic? Cubic? Square root? Some other power? Sinusoidal?

Question:

How does the period of a pendulum depend on its length?

Goals:

Design experiment: How many data points should I take? Over what range should I take data? What's the point of taking many trials when trying to fit a function?
Tools: Mathematical modeling. How do I fit a function?
Interpret data: Not just to tell if a function is better than another, but if the function actually fits within uncertainty. Use range of multiple trials.
Presentation skills: Present just enough information so audience understands.

Possible Problems:

Mathematical modeling is a difficult topic. Groups may have no idea what to do. Understanding what the proportionality constant means is a lot more difficult than one would expect.

Students do not understand functional dependence. Spend time with the groups having them explain to you how they are analyzing their data. Listen to their issues.

Just because 2 or 3 students in a class understand this stuff and dominate the discussion does not mean the class gets it. Don't let people dominate – either the class discussion or the group of four.

I. Introduction: 10 min Whole class

Ask again how many students actually read the lab handout ahead of time. Let me know if they tried and weren't able to see it.

Have everyone get out the homework question and come to a group consensus on #1. (5 min) Pick two groups to present another function and how well it fit, from #2. This is their first introduction to using prop. constants to fit a function. Main points are that the constant should be constant, and that multiple trials of the same length give you the range for the constant.

Handout the continued part of the homework question, have groups discuss for 5 min. Ask a couple groups to present their solution to the problem posed. Main point is look at the percent of variation.

There will be a post homework leading them to fit a line to this data, just so you know. The groups will need to be thinking about these issues during this lab.

II. Brainstorming and Planning Meeting: 15 min Groups of 4

You should check out all groups' plans before they start doing the experiment.

How many measurements are you going to take?
What functions are you going to try out? How are you going to tell if they fit?
Who is going to do what? How have you planned your time so you will be finished and ready? Who will write up what section?

III. Carrying out the Experiment 40 min Groups of 4

Groups will probably need a lot of time to analyze their data. Make them start doing this while they're taking data – it doesn't take four people to time.

IV. Class Discussion Whole Class

Probably everyone took data in a very similar way. Learning to present in a concise yet understandable way is important – tell them they can just say 'we did what group x did to time, and then....'

Students, if they even get to the proportionality constant, will not see the use of multiple trials. The purpose of the homework question was to bring up the idea that you know what the overall spread of the constant should be from multiple trials of the same length.

The other issue is they like to choose the constant with the smallest range, not taking into account the magnitude of the constant. That was the point of the additional section.

V. Evaluate and Reconsider: Groups of 4

They should have a concrete suggestion for each of those questions – data taking, data analysis, and conclusions.

Lab 4: The wheels on the car

A child you know is entering the pinewood derby in her club. She has to design and build a small wooden car for racing down a ramp, and needs help deciding what kind of wheels to order. They come with a lot of options for wheel design – you get to choose the material, shape, and size of the wheel rim. You wonder if any of these things will affect how quickly the wheels accelerate down the ramp, and thus if the car will win the race.

Question:

What affects the acceleration of a rolling object? Choose one property to investigate.

Goals:

Framing: Groups need be aiming toward the strongest argument possible. Everything they do should make their conclusion more convincing to others.
Data Analysis: What to do with data, when to throw out points. How to present data.
⇨ **Measuring acceleration**: How to start, how to stop, how to time, to be as consistent as possible. They will be doing this again next week, and should come up with a good method to get better data.
⇨ **Interpret data**: Are these numbers the same or different? Looking at the range in data, using data to tell certainty.
Mechanism: Difference between random or systematic error. What causes what effect in your data.
⇨ **Tool**: Synthesis table. How can the class come up with the best answer?

I. Introduction: 10 min Whole class

Discuss in groups: (1 handout per group)
Two groups measure the acceleration of an object down a ramp with different methods. Evaluate their methods – which will give better results and why?

1. Group A built a short, steep ramp. They roll their object down the ramp and let it roll onto the floor. They have 3 meters marked out on the floor, and they measure the time it takes the object to roll that distance. Then they calculate the final velocity, and from that find the acceleration of the object down the ramp.

2. Group B built a long shallow ramp about a meter long. They roll their object down the ramp and time how long it takes to roll down the ramp. From this they calculate the average velocity and then the acceleration.

Have a short discussion of their conclusions. They should be backing up their answers with specific things: "I think measuring on the floor is better because it's a longer distance, and so it's easier to time" or "I think measuring on the ramp is better because then you don't have the friction from the floor"
It might be productive to use a flow chart to clearly show where certainty is limited – templates are available.
We will be using rolling again next week, and also building on our conclusions from this week.

II. Brainstorming and Planning Meeting: 15 min Groups of 4

Feel free to tell them, if they want a long flat ramp, to ramp their tables.

What property of rolling objects are you investigating? What are you going to measure? How are you going to get the acceleration from these measurements? Will you be seeing just the effects of different objects? Or will other things be affecting your results? Who is going to do what? How have you planned your time so you will be finished and ready?

III. Carrying out the Experiment 45 min Groups of 4

IV. Class Discussion 25 min Whole Class

The whole class hopefully will be able to come to a conclusion. Also, there will be a homework question using this data later.

After the first presentation, ask the class how we can synthesize every group's results to come to a conclusion. Draw a table on the board, ask for what is useful to put in it. This is often done with medical studies.

Students should be paying attention to how the group measured the acceleration - which methods are better, and also how they drew their conclusions. Did the groups control variables properly to make their conclusion?

Which group got the best acceleration measurements? What do we do if two groups contradict? Do we need to throw out any groups results? They should be using the 'scientific community', and actually getting useful stuff from other groups.

V. Evaluate and Reconsider: 15 min Groups of 4

Possible Problems:

If groups want to use the time it rolling on the floor method, they may have a really difficult time with the kinematics equation. I would recommend the use of an experimental design chart, and perhaps have them say 'greater is greater, but we don't know exactly how' in the middle box.

Control of variables

Lab 5: The Rolling of the Cylindroid

You have just been allowed a marvelous chance to study the actual finches that Darwin collected. You discover, hidden at the bottom of an old box, a collection of new creatures. These 'cylindroids', as you call them, all have round, silver colored bodies, travel primarily by rolling, and have the same mass. There are two different species of cylindroid, but you don't know which species a certain cylindroid belongs in.

In this lab each group of students will test two cylindroids and determine if they belong to the same species or a different species. These are very fragile endangered creatures, so you must be extremely careful with them.

Question:

Do your three cylindroids belong to the same species or to different species?
One point of your weekly log will depend on your answer.

Goals:

Framing: Spend effort in lab, care about your results. Take as much data as you can.
Data Analysis: What to do with data, when to throw out points. How to present data.
Group Work: Use data from other groups to tell if your cylinders are different or same.
Interpret data: Looking at the histogram of data, using data to tell uncertainty. What to do with low probability data points.
Tool: Histogram, Various Representations.

Possible Problems:

Sometimes it seems groups get data that they have interpreted correctly, but gives them the wrong conclusion. This might be the can construction, or it might be that they slightly changed data taking method. You may not want to press any groups on one or the other answer, because you may be wrong. The group may have changed their measurement method slightly the second time around. Perhaps encourage them to go back to the first cylinder again after the second and see.

Racing two cans down a ramp almost always gives the wrong answer. Two cans made the same way do not roll exactly the same way. They need to see the range and compare to other groups to make a conclusion. You can argue with them about making a convincing argument in their weekly log or in the class discussion.

I. Introduction: 10 min Whole class

Have each group pick a representation they consider the best, and draw it on the board. Have a brief discussion about which of these communicate what things. Stress it's not that one's better than the other, it's that different representations are useful for saying different things. Explain the "species difference" to them. Half have more mass in the middle, half have more mass toward the edge. [One eats gravel, one has denser bones] They have to decide which of their three cylindroids are from the same or different species. Biologists actually do things like this, though with finches beak size, not rolling.

II. Brainstorming and Planning Meeting: 15 min Groups of 4

You should check out all groups' plans before they start doing the experiment. They've done this before, so they should have a good plan and reasons thought out for why.

Why are you going to do this? How will it help make a strong conclusion? How many measurements are you going to take? Could another group's data on different cylinders be helpful to you?

III. Carrying out the Experiment 45 min Groups of 4

Encourage them to use a representation to communicate their conclusion clearly in the discussion.

IV. Class Discussion 25 min Whole Class

Probably every group will do very similar things. They don't need to explain it all out again. Here is where groups may want to ask the rest of the class for help if they're having a hard time deciding. After every group has gone, ask the whole class to come up with a conclusion for each, an attempt to make it more cooperative. After discussion, have every pair hand in a piece of paper with their names, their cylinder numbers and same or different. Then tell them if they're right or not.

V. Evaluate and Reconsider: 15 min Groups of 4

Here, they have a 'right' answer. If they got it right, they can evaluate how to make their conclusions even more convincing. If they got it wrong, how they went wrong, what could have happened.

Lab 6: Friction

You are at the hardware store to get some of those little discs you can put under furniture legs so you can slide your couch across the hardwood floor of your living room. They have several sizes and you are trying to decide if you should get the smallest size that fits your couch legs or a larger size. You remember learning in lecture that the force of friction depends on the surfaces and the normal force, $f = \mu N$. Does it depend on the area of contact between the two surfaces? Will a certain size disc make it easier to slide your couch around the room?

Questions:

3. Does friction depend on the contact area between two surfaces?
4. In your experiment, what things besides surface area might be causing a difference in your data?
   Which has the largest effect? What can you change to reduce its effect and thus see only the effect of changing the surface area?

Goals:

Framing: Groups need be aiming toward the strongest argument possible. Groups will hopefully get contradictory results, and will have something to argue about.
Experimental Design: What you need to be careful about, what you don't need to be careful about. (temperature of the room or dust in the air probably won't matter, but pulling the spring quickly or slowly or scratches in the surface or wood block irregularities may matter)
Interpret data: Are these numbers the same or different? What happened to my results when I started being more careful taking data?
Tool: Minimize sources of outside variation. Mechanism.

Possible Problems:

It is hard to figure out how to measure friction. You can help groups brainstorm ideas. But bug them about not reading the handout and thinking about this ahead of time.
Groups may falsify data to get the answer they want, or to make their spread seem much lower after they make changes. This means we haven't communicated to them that their grade does not depend on their 'right result' but on their thinking and evaluation. If they don't have time to think of and carry out an improvement, their improvement can be written in their report.

I. Introduction: 10 min Whole class

Students like to think that only an 'error' in the experiment would cause a range in data, you have to do something wrong for it not to be the same thing every time. If you just had a lot of money and time you could fix the problem and have no range in your data. They don't know quantum, so we cannot go into that. But try to stress that the range is caused by the system, that's the way things are, and that's what we're measuring. It's not an 'error'.
Ask groups to give their answers to the question. Compile them on the board, and ask them to discuss which one may be largest, which smallest. These things need to have a word describing them, perhaps 'outside effects' or 'multiple effects' something like that. Not 'error' or anything like that. If that comes up, have a discussion about if there's something 'wrong' that's causing it. Maybe bring up tossing pennies, heads or tails.

II. Brainstorming and Planning Meeting: 15 min Groups of 4

You should check out all groups' plans before they start doing the experiment.

How are you going to measure friction?

What are you going to change between measurements? What are you going to keep the same?

How will you decide whether surface area matters?

They don't need to know their answers to Q2 at this time, they can figure that out after they get a little bit of data.

Flow charts may help some groups.

III. Carrying out the Experiment 45 min Groups of 4

When you see a group with a method, having taken a little bit of data, ask them if they'll be able to see the difference that surface area may cause. If they can't, then does that mean that it's not causing a difference? What may be causing that range, and how can they design their experiment to reduce that?

IV. Class Discussion 25 min Whole Class

Groups should be critiquing student's measuring methods, their improvement on their method, and their conclusion from their data. This should be a good class discussion, they have a lot to argue about. A synthesis table may be useful here.

V. Evaluate and Reconsider: 15 min Groups of 4

Lab 7: Rescue Mission

A certain town in Alaska is inaccessible by road, and the weather has not allowed any planes or boats to reach the town, so the people living there are running out of food. You have been asked to design a system to launch bags of food from a cliff above the town into a field near the town. However, you will not be allowed to randomly launch containers of food off the cliff. You must be able to predict where the containers will land using measurements performed on the cliff itself.

Your first step is to design and test a system that will launch a marble from a table. You must be able to predict roughly where the marble will land based on measurements made on the floor or on the table. You may not launch the marble through the air.

You do not have to write a weekly log for this lab. However, your log for next week will include this information, so you will want to take notes for yourself.

Question:

How will you predict where your marble will land?

Possible Problems:

Students method of launching should be non-reproducible enough so that they will get a spread that is measurable in the next lab. Perhaps we can encourage that by making springs available?

When students are measuring time, they may get a range more from their stopwatch than from the launching device. They want to see the launching device's, not the stopwatches, range.

Motivation. They have just taken a lab quiz. Remind them that they need this for next week.

Goals:

Design experiment: How can I build something to launch with the limited materials available? What is the best way to determine where the marble will land?

Physics concepts: velocity, accel, kinematics

Interpret data: The range in distance isn't the result of something going 'wrong', it's how the equipment behaves.

I. Introduction: 10 min Whole class

Launch a rubber band across the room. Have someone put a foot where it lands. Ask for predictions about another one. Shoot another one. Ask 'is there some error that made the second rubber band not land exactly with the first, if so, what is it, if not, why didn't it land in the same spot?'

Discuss in small groups, discuss in whole class.

II. Brainstorming and Planning Meeting: 15 min Groups of 4

This lab takes a much longer time to physically set up equipment than other labs. Make sure they actually have a plan of what to measure and what to calculate, or they might spend the whole time building.

What are you going to measure? How?

How are you going to calculate where it lands?

III. Carrying out the Experiment 40 min Groups of 4

IV. Class Discussion Whole Class

Have each group tape an x where they think the marble will land. With everyone watching, test each group's method.

V. Evaluate and Reconsider Groups of 4

Lab 8: Minimization

Consider the following design problem:

> You are designing a new booth for a traveling carnival. People will use a catapult to toss a penny at a plate. If it lands on the plate, they win a prize. If no one ever wins a prize, people will stop playing. If too many people win a prize, you will lose money. So you want to make your plate large enough to catch a small fraction of pennies, but not large enough to catch them all.

Two of the main things we have been working on in previous labs are how to design an experiment to answer a question, and how to think about the spread in the data you take. To focus on these issues, consider the following task.

> Design a method for launching an object horizontally from the table onto the floor. The goal is to launch the object onto a paper target on the floor so that in 10 launches it hits the target more than 5 times but less than 10. As in last week's lab, you may take measurements on the floor or on the table, but may only launch your marble through the air once (before the 10 trials), with TA in attendance.

Question:

How will you know how large to make your target so that the marble hits it more than five times but less than ten times?

One point of your weekly log will depend on your success.

Possible Problems:

Students method of launching should be non-reproducible enough so that they will get a spread that is measurable. When students are measuring time, they may get a range more from their stopwatch using than from the launching device. They may want to think about how large their stopwatch range is and compare that to the range they're getting. If they're comparable, perhaps their range is a lot smaller than they think. Or maybe they can think of a way to measure the range without using a stopwatch.

Groups may get $5 < x < 10$ because their target is half on, half off the actual range. This means they could have made a smaller target.

If the target paper isn't white on top, yellow on bottom, correct sides together, it will not make a mark. Test it first to make sure. Have students draw their target instead of cutting it, so you can see where the 'misses' landed.

The person launching may adjust their method if they need some 'misses'. Have a person from a different group doing the launching. This is motivated by the carnival scenario – all different kinds of people will be using the launcher. Let students know this ahead of time.

If groups make the challenge, they may have trouble evaluating, saying that 'we did it perfectly'. How to solve this problem?

Goals:

Design experiment: How will I take data to see the launching range and not something else?
Interpret data: propagation of error

I. Introduction: 5 min Whole class

Make sure the task is understood. Ask students to think of reasons why you might design something on purpose to fail some of the time.

II. Brainstorming and Planning Meeting: 15 min Groups of 4

This should be largely done from the previous lab. However, they have to figure out how to propagate error, and build on the strengths seen in last week.

What are you going to measure? How?
How will you know your range is coming from the launching equipment and not from your method of measuring?
How will you calculate your target area?

III. Carrying out the Experiment 40 min Groups of 4

Each group should have their target made and have done their trials before the class discussion. Make sure you supervise their practice shot, this is just to make sure their target is centered. They may not want to move their target – that particular launch may have been on the edge. Then have them run the 10 trials. Have a member of the group count the trials, and another person watch the target just in case the paper fails to mark, and a member of another group using the launcher.

IV. Class Discussion 35 min Whole Class

Each group presents their method, and then their target.
Discuss good points of several targets. Who made it the smallest possible? Whose is well centered?

V. Evaluate and Reconsider: 15 min Groups of 4

In this lab, groups have a clear result – did they make it or not? If they did, they may have trouble evaluating, saying that 'we did it perfectly'.

Lab 9: Roller Coaster

You have just been hired to design a roller coaster with a loop in it. However, the budget for this project is very tight (the amusement park hasn't been doing very well financially) and cannot build you a full track with which to experiment. You have to figure out how high to make the track so the car will make it around the loop using only a section of the track.

Question:

What is the minimum height at which you can release the ball in order for the ball to just make it around the loop?

Possible Problems:

Last year students had a hard time calculating the theoretical value. They then stopped thinking, and had to be forced to take measurements. This year they still may think 'I have the answer here, why do I have to measure anything?'. Ask them if they really believe that will work in real life.

It's hard to tell exactly where the marble leaves the track.

The group that 'wins' may have trouble evaluating, saying that 'we did it perfectly'. Is it possible to make it around going any lower?

Goals:

Design experiment: It's a difficult question to answer. Experimental design charts may help.

Interpret data: How to use your range to decide on a minimum height?

I. Introduction: 5 min Whole class

Ask a group to volunteer to go over the homework question. Make sure everyone understands what they can and can't do with their track. Demonstrate failure on the loop. (Make sure it will fail)

II. Brainstorming and Planning Meeting: 15 min Groups of 4

Groups may have a tenuous link between what they measure and how much additional height they need.

What are you going to measure? How?

How will this tell you how much additional height you need?

III. Carrying out the Experiment 40 min Groups of 4

Don't let students write on the track, their marks should always be on masking tape so it can be removed. Please do not move the track from its location, it is set to be at the proper angle. Each group should have their line taped beside the loop before the class discussion.

IV. Class Discussion 35 min Whole Class

Start with the highest group, and have them present. After everyone has presented, ask the whole class to predict what they think is the lowest mark that will work. See if they can predict by judging from the design of the experiment. Then test them, highest to lowest.

Have students carefully watching the top of the loop and listening to see if it leaves the track.
This can be hard to tell.
Then have another discussion, evaluating the whole class.

V. Evaluate and Reconsider: 15 min Groups of 4

Lab 10: Gravity

In order to determine whether to drill for oil in certain locations, geologists will measure the local gravitational strength, g, in that and surrounding locations. Very small variations in g (a difference of 10^{-5} N/kg or .000l percent) will tell them if there are caves, dense rocks, or lighter porous rocks under the surface. You have been given the task of measuring g in the basement of the physics building well enough that you could tell if g changed by 1 percent or less. .

Question:

What is g in room 0220 in the physics building?

Possible Problems:

Last year students didn't estimate their certainty first to see if their measurement will actually be what they need

They had a hard time thinking of a way to measure g.

Goals:

Design experiment: How will I design something to get the certainty I want?

Interpret data: propagation of error

I. Introduction: 5 min Whole class

Ask groups to present their solutions to the homework question.

> A group of students has decided to measure the speed of a battery powered toy car. It takes the car an average of 6.34 seconds to travel 1 meter, so they report a speed of 15.8 cm/sec. Another group measures the speed of the same car to be 14.6 cm/sec. Do the results of these two groups agree or disagree? (Hint: Use your experience from lab to estimate the range of each group's measurements)

Define a term for propagation of error from an estimate. (might be different from your term for propagation of error from the target lab)

Ask students to have their estimation of certainty finished when they talk to you about their design. They cannot take data until they have that estimate.

II. Brainstorming and Planning Meeting: 15 min Groups of 4

> What are you going to measure? How?
> What will your certainty be?

III. Carrying out the Experiment 40 min Groups of 4

IV. Class Discussion 35 min Whole Class

V. Evaluate and Reconsider: 15 min Groups of 4

Lab 11: A Massful Spring

In lecture we developed the theory for a mass oscillating on a spring, assuming that the spring was 'massless', or weighed much less than the oscillating mass. Unfortunately, massless springs are very expensive (that's a joke), and we often have to make do with springs that have some mass. Does the theory need to be revised to agree with experimental data taken using massful springs?

Question:

How can one revise the theory to include the idea that springs have mass?

Possible Problems:

They have to measure the k of the spring and then the period of oscillation and calculate c. There are a lot of variables and calculations and it's easy to get confused. Students may think the un-revised equation is still valid and try to use them both.

Goals:

Design experiment: design a more complicated experiment
Expand on theory: use data to revise theory
Data Analysis: What to present as final answer from data. (one number, range, etc)
Interpret data: Do the group's results agree or disagree?

I. Introduction: 10 min Whole class

Go over the homework question. Ask tables to present. Use unit arguments, and sense-making to merge them to get to $T_{revised} = 2\pi\sqrt{\frac{m + cm_s}{k}}$ but we don't know what the c is, so have to find that with experiment. Tell them the question really is: what is c?

II. Brainstorming and Planning Meeting: 15 min Groups of 4

This may be difficult. They have a lot to measure, so it would be nice to have this finished quickly.

What are you going to measure? How?
How will you get c?

III. Carrying out the Experiment 40 min Groups of 4

IV. Class Discussion 35 min Whole Class

Hypothetically, if our proposed equation is a good model, each group should get the same c. Do any groups agree? Which methods worked better? Should c be less than 1?

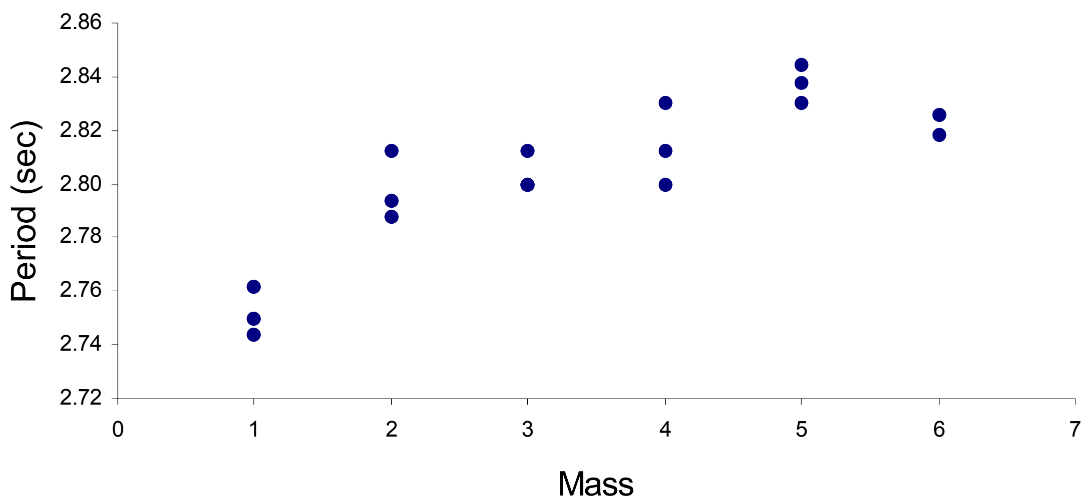
V. Evaluate and Reconsider: 15 min Groups of 4

Appendix C: Laboratory homework, anonymous survey, and lab quiz

Lab 3 pre-homework

You need to bring a copy of this completed question to Lab 3.

Elizabeth and Lydia have just finished the pendulum lab, where they measured the period of a pendulum with different masses. They made a two meter long pendulum, used six different masses and measured the period three times for each mass. Though they had a wonderful time measuring the period, they aren't happy with just knowing whether or not the period depends on the mass. They want to know what function describes the dependence.



Lizzie: I think the graph looks like a square root function,. $T = C_1\sqrt{m}$

Lydia: How do you know? It could just as easily be a cube root, $T = C_2\sqrt[3]{m}$

Lizzie: Well, if either function fits, then C_1 or C_2 must be constant for all of our data.

Lydia: Hmm?

Lizzie: If we use each of our data points to calculate the constant, then, if our data fits a function perfectly, we'll get the same constant for all our data.
Let's see, so $C_1 = T / \sqrt{m}$ and $C_2 = T / \sqrt[3]{m}$.

Mass (g)	Period (sec)	$C_1 = T / \sqrt{m}$	$C_2 = T / \sqrt[3]{m}$
1.34	2.75	3.18	3.03
1.34	2.74	3.18	3.03
1.34	2.76	3.20	3.05
2.68	2.79	4.57	3.88
2.68	2.81	4.60	3.91
2.68	2.79	4.56	3.87
4.02	2.80	5.61	4.45
4.02	2.80	5.61	4.45
4.02	2.81	5.64	4.47
5.36	2.83	6.55	4.95
5.36	2.81	6.51	4.92
5.36	2.80	6.48	4.90
6.70	2.84	7.35	5.35
6.70	2.83	7.33	5.34
6.70	2.84	7.36	5.36
8.04	2.83	8.01	5.66
8.04	2.83	8.01	5.66
8.04	2.82	7.99	5.65

Lydia: Look – the cube root only varies from 3.03 to 5.66, but the square root varies from 3.18 to 8.01. I think the square root fits the data.

Lizzie: But they're supposed to be constant. That's not constant.

Lydia: Nothing's going to be perfect in real life. That's as close to constant as we're going to get – we had to time these by hand with stopwatches.

Lizzie: No – look, we measured each period three times, so we know how scattered the data is going to be. For mass 2, our period was from 2.79 to 2.81 seconds. This made C_1 go from 4.57 to 4.60 and C_2 go from 3.87 to 3.91. So our range from timing can only cause a range in the constants of about 0.04. The constants have a lot larger range than that, so they aren't constant.

Lydia: What?

Lizzie: In an ideal world, we'd get the same thing every time we measured the period, and the function that fit would have exactly the same constant for all the data.

Lydia: Yeah, that's what I was saying, it's not an ideal world. The constants are not going to be perfectly the same, so the function that has the smallest range of constants is the one that fits the best.

Lizzie: Right, but we know how 'un-ideal' we are because we measured the period three times for each mass. This range in periods tells us how much the constant can vary and still be judged 'constant' because of the variation in periods. We need to find a function whose constants have a range that is just as big as the range caused by the three different periods for one mass.

Answer the following questions:

1. Which function, if either, fits? Elaborate on arguments made in the discussion above to make your point.

2. Guess another function that might fit this data. Use this method to see if it fits the data. Include your calculations and reasoning. Does it fit? If not, is it a better or worse fitting function than the two tried earlier? (If you use a spreadsheet program to answer this question, please print out and attach all relevant pages)

Lab 3 post-homework

What Function?

You've now spent a lot of time fitting functions to data. Let's look again at the data you had in the first homework question on function fitting.
Graph the data, putting the period on the y axis going from 0 sec to 3 sec.
According to theory, T = **Error! Objects cannot be created from editing field codes.**.
Changing the mass should not change the period, so the data should be constant, all in a horizontal straight line. Write the function for a horizontal line and define your symbols.
Try fitting this function to the data. How well does it fit?

Mass (g)	Period (sec)
1.34	2.75
1.34	2.74
1.34	2.76
2.68	2.79
2.68	2.81
2.68	2.79
4.02	2.80
4.02	2.80
4.02	2.81
5.36	2.83
5.36	2.81
5.36	2.80
6.70	2.84
6.70	2.83
6.70	2.84
8.04	2.83
8.04	2.83
8.04	2.82

Lab 4 pre-homework

A matchbox car mass M rolls down a ramp, starting from rest. It takes a time T to roll a distance L on the ramp. What is the car's acceleration on the ramp?

Lab 5 pre-homework

In last week's lab, a group of students measured the acceleration of two cylinders with the same size but different masses. They measured each five times:

Brass cylinder: (m/s^2)	0.303	0.315	0.294	0.300	0.298
Aluminum cylinder: (m/s^2)	0.310	0.298	0.291	0.315	0.312

Another group measured the accelerations of cylinders with two different radii. They measured each 20 times, and then placed them in bins according to the first two significant figures:

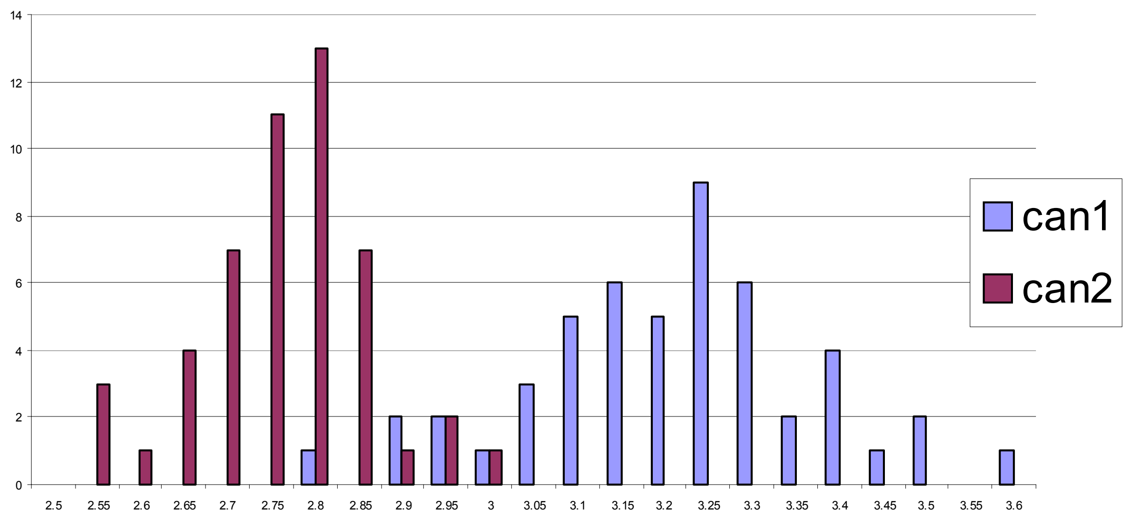
Large cylinder:		Small cylinder:	
# times measured	Acceleration (m/s^2)	# times measured	Acceleration (m/s^2)
4	.41	1	.45
6	.42	1	.46
4	.43	3	.47
3	.44	5	.48
1	.45	6	.49
2	.46	4	.50

Both groups want to present their data as a picture – some kind of representation that presents clearly their data's useful information.

Make up two representations – one for each group, that they could use in their class discussion. Draw them, and explain in 2-3 sentences how each representation communicates useful information clearly.

Lab 5 post-homework

A group times how long it takes two cans to roll down a ramp fifty times for each can. They then count up all their data and make a histogram.



As part of their conclusion in their weekly log, they write:

> "The max to min ranges for the times for each can are 2.8 to 3.6 seconds and 2.5 to 3.0 seconds. Since the ranges overlap, we must conclude that the cans are the same. However, the histogram seems to show two different peaks. We don't know exactly what to make of that."

Write a response to this group, including

- What you think their conclusion should be, and why
- What information the max to min range gives them
- A suggestion for another type of range besides max to min that they should think about using.

Lab 6 pre-homework

A certain physics professor bought a BMW convertible that has an option to drive it in automatic, where the car shifts gears, or manually, where you tell it when to shift. This professor wants to know which is more efficient – that is, in what mode he will get better gas mileage. He decides to run an experiment. As much as possible, he wants his data to show only the difference in gas mileage caused by automatic or manual mode. What other things may cause differences in his data, so that he should be careful to keep those the same? Name at least four things, and give details about how each one will affect the gas mileage – a large or small effect, cause better or worse mileage, etc. How can he design the experiment so these things will not cloud his results?

Lab 7 pre-homework

If a marble rolls off the edge of a table going with a horizontal velocity v_0, where will it land? Define, using letters, any information you might need. (For example, you might use T_r for the temperature in the room.)

Lab 8 pre-homework

A group of students designed a spring marble launcher to launch a marble off of a table 0.9 m tall. They measured the velocity of the marble leaving the launcher twenty times. They found:

Velocity (cm/sec)

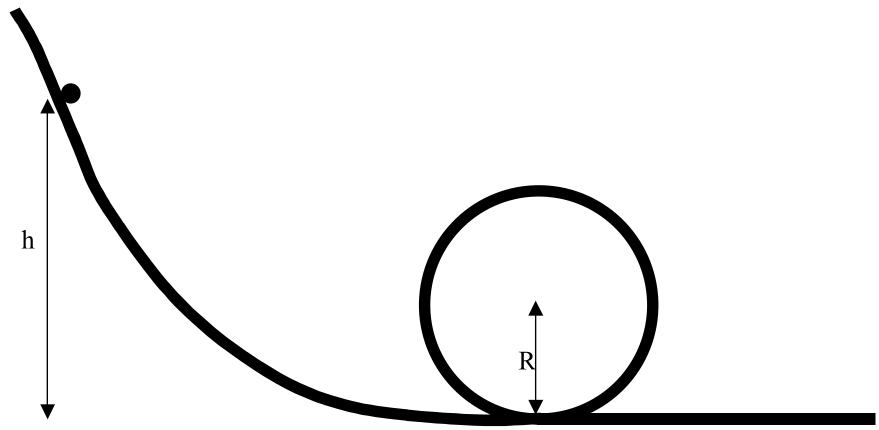
36.4	38.0	36.4	39.6	34.1	35.1	33.5	37.2	39.0	35.7
34.1	37.6	39.3	38.0	39.2	37.2	38.3	38.2	37.9	38.7

1. They want to build a box for the marble to land in. How large should the box be?

2. They have a box 2 cm long, and place it where the marbles are landing. If they launch the marble twenty times, how many times will the marble land in the box? Explain, showing your calculations.

Lab 9 pre-homework

In next week's lab, you will be using a track for a marble shaped into a loop.



The following parts lead you through calculating the minimum height at which a marble must be released in order for it to make it around a loop-de-loop track without falling off the track.

1. Draw a free body diagram for the ball when it is at the top of the loop, having rolled down the track.

2. What, if anything, will happen to the forces on your diagram if the ball is just about to fall off the track? In other words, it is going so slowly that it is just making it around the top of the loop, and any slower it would fall off.

3. Since the ball is going in a circle, the net force on the ball must be equal to mv^2/R. Use this to calculate the velocity, and then the kinetic energy of the ball when it is just about to fall off the top of the loop.

4. We want to solve for the initial height of the ball using energy conservation. When one uses energy conservation to find a value, one finds the energy of the object at two different points and sets them equal. What should be the two points here? Explain why you chose those points.

5. Find the total energy of the ball at these two points and set them equal. Solve for the minimum height at which the ball must be released to just make it around the loop.

6. The height you just found is the value that theory predicts will allow the ball to just go around the track. When we do this in the laboratory, do you think the ball will have to be let go at a higher, lower, or the same height? Explain why.

Lab 10 pre-homework

A group of students has decided to measure the speed of a battery powered toy car. It takes the car an average of 6.34 seconds to travel 1 meter, so they report a speed of 15.8 cm/sec. Another group measures the speed of the same car to be 14.6 cm/sec. Do the results of these two groups agree or disagree? (Hint: Use your experience from lab to estimate the range of each group's measurements)

Lab 11 pre-homework

Ankur and Prithvi have measured the period of a mass oscillating on a spring. Here is their data:

Mass of spring: 12.5 g

Hanging mass: 20 g

Average period: .493 s

Spring constant (k): 4.9 N/m

When they use the equation T = $2\pi\sqrt{\frac{m}{k}}$, they find that their measured period, 0.493 sec, does not agree with their calculated period, 0.401 sec. Here is their discussion:

Ankur: Maybe that equation doesn't hold for this case.

Prithvi: But it's right here in the book, "A mass oscillating on a spring has the period…"

Ankur: Yeah, but this is the real world. Nothing in the real world works like it's supposed to.

Prithvi: But what specifically could be going wrong? It's a rather simple measurement. And we're way off.

Ankur: Look – the book says "the springiness is entirely in the spring, which we assume to be massless, and the inertia is entirely in the block". Is our spring massless?

Prithvi: No, but we always assume things are massless and it's fine.

Ankur: Maybe it's not fine here. But what can we do? I guess the equation doesn't hold.

Prithvi: Could we change the equation? Maybe add the mass of the spring to the mass of the block, and use that as the mass in the equation?

What can they do to solve this problem? Suggest a solution and explain why it would work. Then use the student's data to calculate the period using your revised equation, and compare it to the measured period. Now do they agree?

Scientific community lab anonymous survey

What did you get out of lab that will help you in your future career?

____

What was our (Prof. Redish and TA's) main purpose in lab?

____

____

If you could change anything, what would you do to change lab?

____

____

TEAR OUT

How valuable were each of the following in helping you learn physics, compared to a typical science course? Rate each by circling your choice. Please comment on your choice in the space provided.

Lecture	Very Useful	Somewhat Useful	Not Useful

Comments:

Homework	Very Useful	Somewhat Useful	Not Useful

Comments:

Course Center	Very Useful	Somewhat Useful	Not Useful

Comments:

How many hours a week did you spend in the course center? ______________

Tutorial	Very Useful	Somewhat Useful	Not Useful

Comments:

How many of the11 tutorials did you attend? ______________

Laboratory	Very Useful	Somewhat Useful	Not Useful

Comments:

Traditional lab anonymous survey

Anonymous Laboratory Feedback

This survey helps us learn your ideas about the introductory physics laboratory. The results will help us to design materials to make this a better course. Your responses will have no impact on your grade in this course in any way. We appreciate your cooperation and help.

This survey is ANONYMOUS. Please answer each question fully.

What did you get out of lab that will help you in your future career?

____

What was the lab designer's main purpose for the labs?

____

____

If you could change anything, what would you do to change lab?

____

____

____

How valuable were labs in helping you learn physics, compared to labs in a typical science course?
Circle your choice and comment on your choice below.

Physics Labs	Very Useful	Somewhat Useful	Not Useful

____

____

Lab Quiz

I. Short Answer. (2 points each, 18 pts total)

Answer each question in a succinct manner, 1-3 sentences.

A. Which battery lasts longer, Energizer or Duracell? A student performs an experiment measuring the number of hours two AA batteries from each brand will run a tape player. Her data is below.

	Trial 1:	Trial 2:	Trial 3:	Trial 4:	Trial 5:	Average:
Duracell (hours)	11.4	12.2	7.8	5.3	10.3	9.4
Energizer (hours)	11.6	7.0	10.6	11.9	9.0	10.0

1. Which battery lasts longer? Explain.

B. A group of students is measuring how long it takes a coffee filter to fall 2 meters. One person is standing on a chair dropping the filters, and two people are timing how long it takes the filter to fall. They start timing when they see the filter start to fall, and stop timing when they see it hit the ground. After taking some data, the person dropping makes a comment: "I think we should tape a ruler so it sticks out of the wall. Then I can line the coffee filter up with the ruler and know exactly where to drop it."

Below is their data table, before they improved their method.

Trial #	1	2	3	4	5	6	7	8	9	10
Time (sec)	2.81	2.75	2.49	2.36	2.45	2.31	2.98	2.64	2.57	2.96

average:	max:	min:	max-min:
2.632	2.98	2.31	0.67

1. They take another 10 trials after they tape the ruler to the wall. How would you expect their average to change? Explain.

2. How would you expect the max, min, and max-min to change? Explain.

A. A group of students uses a force probe to measure the force between two magnets. They measure the force when the magnets are separated by different distances, three times for each distance. They are trying to find how force and distance are related for two magnets, so they calculate the proportionality constants (*A, B, C*) for four functions.

$$F(r) = \frac{A}{r^2} \qquad F(r) = \frac{B}{r^3}$$

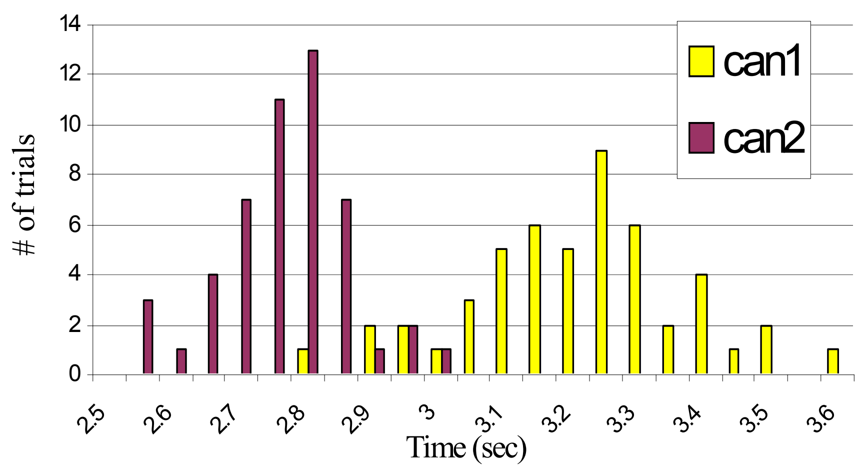
$$F(r) = \frac{C}{r^4}$$

dist(mm)	Force(N)	$A=F*r^2$	$B=F*r^3$	$C = F*r^4$
5	46.2	1160	5800	29000
5	45.7	1142	5710	28551
5	45.2	1131	5655	28273
10	6.23	623	6227	62275
10	4.70	470	4696	46958
10	6.04	604	6038	60382
15	2.39	537	8057	120858
15	1.64	369	5531	82970
15	1.49	336	5038	75567
20	1.02	409	8186	163712
20	0.69	277	5547	110938
20	0.52	207	4149	82990
	Average:	605	5886	74373
	Max:	1160	8186	163712
	Min:	207	4149	28273

1. What information does the three trials with the same distance give the students? (For example, what information does 163712, 110938, and 82990 give that just one trial, 110938, would not?) Explain.

2. Which function, if any, fits the data? Explain.

B. A group times how long it takes two cans to roll down a ramp fifty times for each can. They then count up all their data and make a histogram.



As part of their conclusion in their weekly log, they write:

"The max to min ranges for the times for each can are 2.8 to 3.6 seconds and 2.5 to 3.0 seconds. Since the ranges overlap, we must conclude that the cans are the same. However, the histogram seems to show two different peaks. We don't know exactly what to make of that."

1. What information does the max to min range give them? Explain

2. Suggest another type of "range" besides max to min that they should think about using. Explain why it is useful.

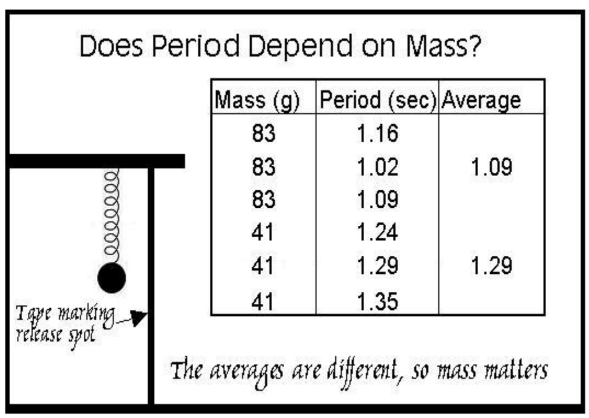
3. What conclusion would you make from this data? Explain.

4. Pick something from your section's Tools and Terms board, and explain how it is useful in this situation.

II. (15 points) Write the evaluation section of the following group's weekly log. You will be graded on the quality and quantity of your points, and how well you demonstrate that you were listening and thinking during the discussions in Labs 1-6.

During a hypothetical lab a group of students is measuring the period of a mass bouncing up and down at the end of a spring. They want to determine if the period depends on the mass. Below is their presentation.

"We hung the spring from the table and tested two different masses. One was almost double the other, so we had a good variation to test. We pulled it down to the same spot every time, a mark on the table leg, and then we timed one period, starting and ending at the lowest point. We had the same person time and the same person let go every time. We took three trials and averaged them, so our results would be more precise. The averages were 1.09 seconds and 1.29 seconds, which are different, so mass does matter."



Mass (g)	Period (sec)	Average
83	1.16	
83	1.02	1.09
83	1.09	
41	1.24	
41	1.29	1.29
41	1.35	

You may want to consider the following questions in planning your evaluation:

- Is their presentation convincing?
- How could the group improve their experimental design? Their data?
- What are better ways to analyze and present the data they took?
- What better arguments could they use in support of their conclusion?

Appendix D: Interview protocols and transcript excerpts

Mechanics 2000 Interview protocol

11/8/00-11/28/00
10 students mid semester

Why are you taking this course?	
Why do you think it's required?	How is this different from your chemistry class?
In what way do the labs/homework/lecture/recitation help you (or not help you) learn physics?	What was helpful for chemistry?
Are there any previous experiences you had that are helping you with this course? If not, what could have helped you?	
In two years, when you're out of college, will you remember anything from this class? Will you be using anything from this course?	Do you think chemistry will be more useful? How is this different from chemistry?
How do you go about doing the homework? If you're stuck on a problem, what do you do? What is the hardest part of a problem?	How is this different from chemistry?
How do you study for exams? Are you happy with how you did on the last exam? What could you have done better?	How is this different from chemistry? How is this different from chemistry?
What do you do during lecture?	
How well do you think you're doing in the class? If you had unlimited time, what would you do to improve?	What does it mean to understand chemistry?
What does it mean to understand physics? How could you tell if someone else understood some concept in physics, say Newton's third law?	

Electricity+Magnetism 2001 interview protocol

5/9/01-5/31/01
13 students post semester

Looking back over the year (semester) what stands out for you?

Why are you taking this class? Why do you think this class is required?

In two years, when you're (in medical school, working in a lab, etc) will you remember anything from this semester? Will you be using anything from this semester? (not just content)

Has this class affected anything else you've done this year?

Do you think this class taught you anything besides the physics? Are you getting anything out of if besides the specific subject?

What was most helpful in this class? (what did you think of the ILD's) Why do you think that helped? (Do you think you learned more in the lecture, office hours, tutorials, labs, or while doing homework and why?)

How would you design this physics course? (homework, lecture time, recitation time, lab time)

What was different about this semester vs. last semester? (content and other) Do you think you'll get a better or worse grade? Why?

What advice would you give to a student taking this course next semester who wants to do well? Did you follow this advice? Why or why not?

Did you work with other people on homework? How was that?

Roy and Theo are working on a homework problem.

Roy: **"I remember in the book it said that anything moving in a circle has to have a centripetal acceleration."**

Theo: **"But if the particle's velocity is constant, how can it be accelerating? That doesn't make sense."**

Roy: **"Look, right here, under 'Uniform Circular Motion' – here's the equation, a=v2/r. That's what we need for this problem."**

Theo: **"But I know that to have an acceleration, we need a change in velocity. I don't see how the velocity is changing. That equation doesn't seem right to me."**

> When working on your lecture homework, which person do you think would be more helpful to work with? What would be the advantages of working with Roy? What would be the advantages of working with Theo?

What is the purpose of the labs?

When you are doing an experiment, what is important to keep in mind?

Think of a lab you found useful. How did it help? What made it useful, what was different about it compared to other labs?

Did you go to tutorial regularly? How was working in your group?

Some professors assign roles for group work, for example, one role would be to question agreement, to make sure everyone is really agreeing and not just wanting to move on. Would this have been useful in your group?

Do you think the exams really assessed your learning? What would be better?

A professor gave a quiz question to her students one week and found only half of them got the question right. After spending some more class time on that topic, she gave the same quiz question (although with a slightly different context) to the students. When she graded them, she found that a number of students that hadn't answered right the first time now got the question correct, but some who had been right the previous week now gave incorrect answers. What should she conclude? (Leave open-ended and then offer choices?)

a) Some of the students learned the material in that week, but some forgot .
b) The students who were right then wrong never really understood the material.
c) The context matters. A problem may seem easy or obvious in one context but not in another.
d) Only the students who got it right both times really understand the topic.
e) This question is not a good question for assessing students' understanding.
f) Other

Electricity+Magnetism 2002 interview protocol

5/8/02-5/21/02
6 students post semester

Looking back over the year (semester) what stands out for you?

Why are you taking this class? Why do you think this class is required?

What was different about this semester vs. last semester? (content and other)

Do you think you'll get a better or worse grade? Why?

In two years, when you're (in medical school, working in a lab, etc) will you remember anything from this semester? Will you be using anything from this semester? (not just content)

Has this class affected anything else you've done this year?

Do you think this class taught you anything besides the physics? Are you getting anything out of if besides the specific subject?

What was most helpful in this class? Why do you think that helped?

How would you design this physics course? (homework, lecture time, recitation time, lab time)

What advice would you give to a student taking this course next semester who wants to do well? Did you follow this advice? Why or why not?

Do you think the exams really assessed your learning? What would be better?

What is the purpose of the labs? The way Redish designed, what was he trying to teach you?

How well did the labs coincide with lecture?

When you are doing an experiment, what is important to keep in mind?

Think of a lab you found useful. How did it help? What made it useful, what was different about it compared to other labs?

Interview Subject Information

Code Name	Major	Interview Date	Professor
Beach	Dietetics	11/00	Prof. A
Bill	Biological Sciences	11/00	Prof. B
Bart	Biological Sciences	11/00	Prof. B
Christie	Cell Biology	11/00	Prof. A
Iris	Economics	11/00	Prof. B
Liz	Biological Sciences	11/00	Prof. A
Mark	Architecture	11/00	Prof. A
Steve	Biological Sciences	11/00	Prof. A
Uta	Biological Sciences	11/00	Prof. B
Arnold	Genetics	5/01	Redish both
Brian	Neurobiology and Physiology	5/01	Redish second
David	Microbiology	5/01	Redish both
Henry	Neuroscience	5/01	Redish second
Jacob	Cell Bio and Molecular Genetics	5/01	Redish both
Joshua	Biological Sciences	5/01	Redish second
Lisa	Biological Sciences	5/01	Redish both
Maggie	Biological Sciences	5/01	Redish second
Sally	Biological Sciences	5/01	Redish both
Sarah	Physiology	5/01	Redish both
Sharon	Cell Biology and Molecular Genetics and Business	5/01	Redish both
Tara	Biological Sciences	5/01	Redish both
Thomas	Biological Sciences	5/01	Redish second
Clara	Architecture	5/02	Redish second
Jessica	Biological Sciences	5/02	Redish first
Malachi	Biological Sciences	5/02	Redish second
Martha	Biological Sciences	5/02	Redish second
Mitch	Biological Sciences	5/02	Redish first
Nate	Biological Sciences	5/02	Redish first

Professor column explanation:
Prof. A teaches in a very traditional manner, and is known for giving clear lectures and receiving good student evaluations.
Prof. B teaches in a very traditional manner, and does not receive good student evaluations.
Prof. Redish teaches the modified, meta-learning course. Students are allowed to switch sections between semesters, so they could have Prof. Redish for first semester only, second semester only, or both semesters.

Excerpt from Liz

I: means interviewer comment
S: means student comment

I: Are you a pre-med, or biology?

S: Yeah, I'm biology. I'm kind of like pre-graduate school. I want to go into biochemistry and stuff like that…

I: Just to start off with, how is the class going? You said you got 100 on your first exam?

S: I got 100 on my exam, but that was no part in thanks AT ALL to the professor or my discussion leader. That might sound really bad, it might really sound horrible, but our professor, I have not learned a thing from him, I am so, I go to the class and I sit there and I'm like, 'oh my god, I'm so confused, I am SO confused'. My discussion leader is pretty good; actually, he's ok. Like it took me a lot to get over the language barrier, but once I got past that and I could understand what he was saying, then he has been a little bit helpful, but everything has basically been self taught, and I had to ask my Dad, my Dad's an electrical engineer, so I asked my dad for help on a couple of things but it was basically I did every single problem in the book and every single problem in the study manual and that's why I think I did ok.

I: So, when you're sitting in lecture, you're not getting anything out of it?

S: Pretty much, no. Like he basically delineates every single section in the book, he'll be like, 'section 9.1' and he'll say exactly what it says in the book and nothing else. He'll do a couple of demonstrations, but they usually go wrong, and then everyone laughs but it's like a farce. I feel like it's not even worth my time to go sit in the class, like I do my homework in the class. I should probably not be saying this, but I do my homework in the class because at least I'm doing physics. I don't know, it's really, I feel like it's very inefficient, I guess, and very like, nobody's getting anything out of it. Like the quiz averages are three out of ten, something has to be wrong if everyone is getting a three out of ten. Like if I got a hundred percent on my organic chemistry final, and that's a really hard class and I got a hundred percent on it, why am I getting a 2 out of 10 in physics? That doesn't make any sense.

I: So, do you get more out of reading the book on your own than lecture, or is the same?

S: I guess I get more out of doing it on my own. I am definitely the kind of person who learns really well from a good professor. Like my biochemistry professor is amazing, and I feel like the book supplements my learning that she has taught. Like she teaches it and the book supplements it. In this class, it's like the book is what I'm learning and once in a while, maybe the lecture will supplement it, maybe, if I'm lucky, on a good day. So it's like reversed of how I think almost all my other classes have been.

I: So, your other classes you go to lecture, you learn something, and then the book helps build on that?

S: Exactly, Exactly. And this way is basically the opposite, like the lecture might help supplement the book. It's bad, it really is. And the book is really confusing, like the book isn't that good either. Like if it was a good book, I don't know, I get really frustrated. This is the only class I have ever taken that has made me feel severely dumb. It really makes me feel like I am stupid. And I am NOT a stupid person, I am really not, I swear to god. Like I understand stuff most of the time, and I don't know if it's the teaching, or the material, maybe I'm not physically minded, but I think I am, I think that I can be a very logical mathematical person, it's just that, I don't know. I leave the class being like, I'm so dumb. It's like, lowered my self esteem to be in physics, it's so bad. It really makes me feel stupid. Like, I call my mom, I'm like 'mom, I think I failed another quiz', and I don't know, I feel like if he went over how to do – like if he went over more examples and he went through them very thoroughly, I think that we would be ok. It just seems like he wants us to fail. Like our TA told us that he was mad because the average was higher than what he thought it should be and so this exam is going to be way harder because our average should not be that high. Like if I was the professor, I would take such delight in the fact that my kids were doing well. That's just me, though. I don't know, yeah, I don't really feel that I've gained very much from lecture.

I: So when you're studying on your own, you're reading the book?

S: Yes, and doing problems, just problems and problems and more problems and more problems, pretty much. Going over the old quizzes, what I got wrong on all of them, and trying to figure out. The other thing too is I feel, we'll do a problem and we'll do it in discussion. It will take us the whole period to go over the problem, so that's like an hour, and he expects us to do the same amount in fifteen minutes on a quiz. We just can't. It's stressful and you can't think that fast. If you sit, like I sit near the front, so that's good, I get it toward the beginning of the fifteen minutes, but it takes them five minutes to pass them out. I don't know, I don't know what would be more beneficial, or how you judge the fairness of it, but I don't really feel like it's fair. If my TA discussion leader has a problem figuring out how to do the problem, and really takes a long time to think about it, to process it, and realize what formula's you're supposed to use, how are we, as introductory physics students, ones who don't really have the background, or the knowledge, supposed to do it in a quarter of the time? The quizzes are what get to me. The homework, not as much because I can do that at my own pace. And the test, somehow by the grace of god, I don't know, I did ok. But I think it's because I did like every single problem in the book. It was ridiculous. Like, chapter 1-5? Yup, I've done them all. My schedule, like I'm taking biochemistry, statistics, I'm taking all these classes and they don't overwhelm me. Physics, it's not even the hard physics, it's not even the calculus based physics, like dumb physics is completely stressing me out. And I don't know what to do, I really don't know.

I: So, you're doing tons of problems on your own, you're doing all of them, that's how you're mainly going about studying for this.

S: Yup, absolutely.

I: How do you go about doing them, like if you get stuck on a problem, what do you do?

S: I work it. I try to do the odd ones are in the back of the book, the odd answers, so basically I do all the odd problems and I work at it and work at it and work at it until I get the right answer, and if I get really really stuck then I will ask my friend or I will ask my dad or something like that. I just keep going. And usually I eventually figure it out, but it takes a long time sometimes. And the student solutions manual, I have that, and that goes through how to do a lot of the problems. And they do kind of correlate, so you can kind of extrapolate what they did in one problem to another problem, and so it definitely helps to have that. Like if I didn't have the student solutions manual, I'd be lost. Like that definitely does help, I'd definitely recommend that to anybody.

I: Is there, usually you get stuck in the middle, or you're able to get through but you have the wrong answer, what is usually the hardest?

S: More recently it's been figuring out what exactly I'm supposed to be doing. Like what am I trying to find and what formula should I use to find it. And then once I have the formula, then usually I can plug and chug, like I can get through it. It's the concepts, to be honest, I think a lot of times is where I get stuck. And then once I get the concept, and what I'm supposed to do with it, then I'm fine. It's just the main, grasping the main idea. Which is really bad, because if it was just that I was mathematical errors, that wouldn't be a big deal. But I'm not even understanding where I'm supposed to go in the beginning.

I: So it's kind of the first step.

S: The first step is where…If I can get past that initial hump, past the first step, then I'm usually home free. It's getting over that initial hump, and trying to figure out what I'm supposed to be doing.

I: Can you tell when you're first reading a problem if you think you're going to be able to do it or not?

S: Yup, umhum. Pretty much.

I: So you sit at the exam, look at the problem, and you're like, ohhh.

S: Right, I look at the quiz, I'm like, 'nope, not going to be able to do this one today'. I should list a few formulas and see, maybe, but nooooooo. It's hard for me to visualize a lot of times like what forces are coming out of what part and where they're centered and just different stuff like that. Like torque and I do not agree. We do not get along, we are not friends. Like I made friends with work and all that stuff, I kind of understand it. Torque, don't even, I don't get it. And he did a horrible job. And somebody said that there are a couple of different ways to measure torque but they said that our professor did the absolute hardest way. But now that that's the way I kind of started learning it, I can't learn the other way. I don't like torque, I really don't like torque. I'm starting to understand a little bit better because I've been going through the problems and stuff, but it's still really confusing to me.

I: How is this different? When you were working on organic, how did you go about learning that?

S: I mean, essentially, I guess a lot of the same. The thing with organic, I felt my lectures gave me a strong enough basis to go and try the problems on my own. I could do the problems. Same with biochem. She gives us the problems, and I do the problems based on what I learned in class. And she goes over plenty of examples, like I know how to do the problems because she has led me by example. Same as in organic, like they would show example after example after example after example. And in a class like that that's what you need to do. If that's what you're being tested on, if you're being tested on problems, go through the problems. He's not testing us on concepts, he's testing us on concrete problems. So they'll go through them and then I can go home and use the examples they gave to do the set of problems. Whereas in physics, it's like he goes through a few things, maybe, gives us lots of definitions, and mumbo-jumbo that noone really cares about because, whatever, and then we're left on our own to go and tackle these things that honestly no one really understands how to do. The difference is the examples and just how thoroughly they were explained. Like if you explain something really really thoroughly, then usually I can understand it, and I can go and do it on my own. And also, explain it to other people. Because I tutor in chemistry and I tutor in biology and biochemistry because I understand the concepts well enough to go and teach it to other people. Whereas in physics, I don't understand this at all. This is ridiculous. That's the difference I guess. The teacher is teaching, and then I can go and do problems. Like I always do problems, regardless, because that's how I learn. Like if I do the math problems and I look at the answers and I see where I did something wrong or if I do my organic and I see that I got the wrong answer then I know where I went wrong. Same with physics, it is essentially I'm doing problems like I would do in any other class. But I feel like in the other classes I at least had a jumping off point to know how to even tackle the problems, whereas in physics it's like luck of the draw. Maybe I'll pick the right formula, maybe I won't, say a little prayer.

I: He hasn't given you enough examples to know how to do that?

S: Not at all. Examples, I think, would be great. Like if he went through…To his credit, I think he tries once and a while. But then, he'll go and he'll be like, oh wait, I did this wrong. So you go through the whole thing thinking you're going to do it this one way and then you take it all back.

I: Very frustrating.

S: Yeah, it is very frustrating. I feel like he doesn't even know how to do the problems, so how am I supposed to know how to do the problems? Yeah, major beef.

I: Just trying to sum up, you do the same mode of attack for all the classes, understand how to do the problems, but in organic you're taught how to do them, you're given more examples, in physics you're not.

S: Yeah, like exactly. I guess I have a very consistent way of learning, and that is, I go to lecture, I learn the lecture, I go and I read, and then it supplements the lecture, and then I do the problems, because they've shown me how to do the problems and then I can go and do them. Whereas with physics it's like, sometimes in class I'll read the paper, do my problems…

I: Do the crossword puzzle…

S: Exactly. I've gotten so good at doing crossword puzzles. Like I feel so bad not going to class so I'll go, hoping that maybe I'll absorb something, maybe, maybe. But I really feel like it is the most fruitless, most inefficient. Like I don't learn anything. I leave physics feeling dumb. And that is a horrible feeling. And it's a general feeling. I do not go home and cry about quizzes in other classes. I cry. I do not understand. He never went over anything like this. None of the problems in the book were anything like this. How am I supposed to know how to do this if he doesn't teach me, the book doesn't teach me, I'm just supposed to what, pull it out of my head? I do not have a strong enough physics background, yet…

Excerpt from Sharon

…[selection from middle of interview]

I: you talked a little bit about the labs that they were kind of helpful, but not as helpful as the tutorials?

S: [our TA] was awesome this semester, he made the labs really fun and he explained them to us and I actually understood them, and he would pick and choose what we would understand, and what we wouldn't understand, so that was helpful. Last semester I felt like I did them and I would rush to finish them, and I had no idea why I was doing them. In this semester he wouldn't totally make us answer all, he would pick and choose which ones to answer, and then we would have to write actually what we did and explain what happened, which was really good for Redish's type of class because that's what you do a lot, you have to write what you did why it's important and how it relates, which made me like, I had to write things, so that was good. They helped a little bit. I mean they are cool. This semester they were cooler than last semester, because last semester is like boring stuff. But this semester there was like electricity and things like that and that was much cooler. I've taken so many labs that it wasn't a big deal, it wasn't bad at all. I liked having to turn them in better, it just felt like you got it done and you didn't have to worry about it all week, because there's so much other things you have to do in physics, it was just better.

I: can you think of a lab that you think helped you with the class?

S: there was one, I want to say it was the flux one. Was there one on flux?

I: we did coils and magnets in and out.

S: that helped a lot. I think all the ones that helped me were all the ones that I was having a hard time understanding. Same with the lens one that helped, too. Because those were the two things that I was, I had a really hard time with flux this semester, for some reason. I don't know why, it was like because you didn't exactly know what it was, there's no real, like what the hell is flux, it's like who knows. So I guess because I didn't have a concrete definition it was hard. But those are the only two that really helped me actually see. I think they all were helpful because you could actually see. I had Andy as my lab partner and he was awesome, he always seemed to understand everything, so it was good.

I: why do you think that flux lab helped you?

S: because I could see it, I could do it myself without reading a problem and actually see okay if I put the magnets this way, this is what happens. Whereas I know in the tutorial homework we did flux I did it all wrong I messed it up because you were predicting what was going to happen, whereas with the lab I could actually see it happen and know it was happening.

I: did you do predictions in the lab?

S: yes.

I: so you could predict it, do it, and then

S: and then, yeah exactly. Yeah we did make a whole list of predictions which were all wrong. I think that's probably why I remember that it helped me a lot because then I could see what was happening, yeah, we did predictions.

I: so kind of the immediate feedback was helpful?

S: it was helpful, right, because then I could understand what was going on better. I'm trying to think what else. I don't know, the only thing maybe about the adjustment is maybe you could do ILD's right at the beginning or something like that. Maybe that would help, do an ILD or maybe give a quiz, and then you could see what questions he was going to ask, just to get them kind of, it's not so scary. Because you go into that first exam and think it's going to be so scary. Especially the exams he puts on the Web, they are scary, because he teaches differently every semester. I don't actually think those practice exams were helpful, I never did them, they never helped me.

I: I think they might have been from the engineering class.

S: maybe that's why. They must have been because they were scary. That's all I can think of.

I: so you're a biology major?

S: I'm cell biology and molecular genetics and business. I'm a double major.

I: so what do you plan to do?

S: I don't know exactly what I want to do. It's more like what's going to be, I'm going to graduate in three and a half years, I'll graduate in December. I really wanted to get into management of a pharmaceutical company, but to get that you have to be a sales rep, which is not what I want to do, but maybe I'm going to look at that a little bit. And then if I really hate that, like I'd never wanted to go to medical school but now I think emergency medicine would be really cool, so. My grades aren't great but they're not horrible, so if I don't like that I may look into medical school, I don't know. I guess it's going to be a lot of what's out there. Right now I have an internship at a small biotech firm doing marketing for them, expanding the customer database and going to conferences and stuff like that. I have no idea what I want to do we will see what comes along.

I: do you think anything you learned this year is going to help you with what you're going to do?

S: not like the actual content of the class, obviously unless I take the MCAT or go to medical school. I think that the way that he made me think, I think being able to write what I think and explain something in writing is going to help me especially in the business world. I think that's definitely going to help. And realizing hey you don't need to memorize something you can figure it out just by the knowledge that you've gained from the difference applications that you’ve done. I think that will definitely help. Because writing is so important in any job that you get, being able to write and explain what you think. So I think that will definitely help me.

I: you said before that you were looking at a question on an exam and freaked out and said I couldn't do that, but then you thought and you could figure it out...

S: you know which one it was that I really freaked out, it was the battery estimation. I totally did it, I kind of did it wrong, not totally. I didn't remember how power was watts per second?

I: well it's in Watts which is joules per second.

S: yeah that's what I mean. But I wrote it down, I just started writing, and I just started being like okay this is what you do this is what you need to do it. And I was like well I know how to do it I just don't remember this one conversion. And it was good because then I could sit there and figure out step-by-step what I had to do. He really stressed that getting your final answer isn't totally important. So it was good because then I could figure out step-by-step what I had to do it and then eventually I got to the final answer but not necessarily a number but I got to a writing one, which you know, at least I knew what I was doing and I could explain it. Because I mean, that's the thing, so many teachers don't understand when you are in the real world you're really going to have to, it's going to be like taking an exam. You're going to have resources to look at, you're going to have things to figure things out. I guess with his class I didn't feel like I need to memorize everything, study so hard, because if I didn't remember one thing I could figure it out from somewhere else, or if I didn't figure it out I could explain it. I don't like when he gives multiple-choice. I did not like the multiple-choice on the final I hated that. Because you think it's so easy and it's like no no it's not that easy.

I: do you think the ILD's were the most helpful?

S: I wouldn't say that any one was most helpful. I think it was probably the ILD's, and the homework was a good way to think for really hard problems. For quick studying I think the tutorial and the ILD was good, because you could realize things like this [snaps fingers] you know, you could see the formulas, you could apply things easily. I think the homework was a good way to apply a lot of what you learned in one problem and bring everything together. That's what he did really well is tie one thing into one another, so you understand how one thing related to another. More first semester than second semester, but second semester you could only do so much. But I think, especially towards the end of the semester, he would tie everything into one problem and that was good, because then you could pull from different areas and answer the problem. Whereas the tutorial homework and the ILD's would just concentrate on one thing and take you through every step of the one thing, so I think they were all helpful.

I: you talked a little bit about the differences between first semester and second semester. Could you talk a little bit more about that?

S: I think last semester is kind of like introduction to physics, you do some of the easier things, the formulas aren't as important, you can get around formulas. It's a lot of concepts, and understanding how things work, and you don't necessarily have to use formulas to figure it out. But second semester it's definitely the content is more difficult, its harder. Because I think first semester you can relate it more to real life than second semester, because I mean how many people really, I mean some you can relate it, but. And you have to use formulas you cannot get around that, you have to, there's just no way, with current and all that, you have to. But at the same time second semester it tied in really well too, when you do current and magnetic fields and electric fields and all that you can tie that in. But first semester it's definitely easier which is weird because I did worse first semester, but I think it was getting used to the class. And I kind of like how we had two exams this semester and quizzes.

I: do you think they really assessed your knowledge?

S: oh, definitely. Yes. I had to put every ounce of effort. I mean, to go to a physics exam, you have to be ready to take that exam, because it is exhausting. After you're done you're just like ohh. After the final, I was like oh my god let me just go home and sleep, because it's hard. You have to really think, you have to really be on your toes. I would take not studying and getting sleep over studying, whereas any other exam I would take the studying over sleep. But for this class I really felt like if on an exam I didn't have sleep I was going to be in so much trouble because my brain would not function right. Because you have to be ready to think, be ready to apply, everything. You're just pulling from so many different things, and you just have to remember so much and think what exactly are you looking for, what he's asking for. Whereas in other classes it's kind of like okay that's the answer. But you have to think and apply, so definitely they assessed how well I understood. And if not them, the homework or the tutorial, something.

…

Appendix E: Selected behavior mode transcripts and coding

Excerpt from Cookbook Lab B

1 and 2 are students working together on an equipotential surfaces lab. They use a masonite board with electrodes of different shapes painted on it. They hook these electrodes up to a power supply and measure the potential difference at different locations on the board with a probe.
B and F are students sitting at the tables behind them and in front of them, respectively.

mode				time (min)
			[beginning of tape]	
1		1:	Well you'd think it would be close to it, considering that is	0.09
		2:	[scraping pointer over flat] well	0.17
		1:	it cant be too far from it, cause the further away you go,	0.17
		2:	Right, the less it's gonna be	0.25
		1:	The less strength it will be. So it should ultimately be right near it, like what it was doing [tries to take pointer]it was like in a circle around it like that. So try to, i mean we should ask her first	0.29
		2:	[Examining pointer] We should ask her cause see, look, look, that's not a meas, there's no measurement there and that's touching it with the plastic, that's as close as you can get until you put metal in contact with it.	0.55
		1:	It seems like it's like right on the edge. You gotta have it like touching it though.	0.73
		2:	And see that's not gonna give us any reading when we start to do that, although then the shape that we actually have, so there's obviously, there's something wrong..	0.88
		1:	We do need to ask her.	1.07
2		TA:	you're gonna get a circle [talking to front table]	1.09
		2:	See, you're talking about circles, we're not getting any circles, we're not getting nothing.	1.22
		1:	[?] yeah, i was just gonna say try changing the	1.28
		2:	[rearranging wires, moving pointer] See it should be going from seven to zero along there	1.37
		1:	Right, at a gradient, and it's not doing anything.	1.56
	M	2:	And it's something, yeah. So that is not doing it's job. I dont know.	1.6
		1:	I'll get her once she turns around.	1.79
		b:	[?]	1.83
		1:	Ours isnt reading anything [to b]	1.95
		2:	Yeah, see theres is working different.	2
		1:	Ours isnt even working, so we tried to tell her.	2.04
		2:	[comparing two setups]	2.08
		1:	Looks the same, lets see what's wrong with ours	2.14

	b:	What did you do?	2.2
	1:	Do you see anything different?	2.23
	2:	No, there's absolutely nothing different than what they're doing.	2.24
	1:	Like we put it here we get seven. We take it and move it, we get zero anywhere.	2.28
	2:	Anywhere else other than directly on the metal	2.34
	1:	On top of the metal.	2.38
	b:	Oh, the other side, the other thing.	2.4
	2:	The other side	2.49
	1:	Oh, ok, thanks. [turn around lower plate]	2.49
	2:	Now that will work. If it doesnt work i'm just gonna throw it.	2.53
	1:	I hope not. Well, that's better. Alright, this is seven. Oh, we want it directly on top of it.	3.03
	2:	No, yeah.	3.21
	1:	Yeah.	3.22
		[changing knobs, reading dials]	3.29
M	2:	Ok, that's as close to seven as it's gonna get. Ok, so what we want to do is find what, now, i'm sorry, i lost the whole stream of thought that we're looking for. [reads papers]	3.48
	TA:	Are you guys ok?	3.66
	2:	We just figured out that you have to use the black side of the board.	3.69
	TA:	Yes.	3.72
	2:	Now, what lines are we supposed to be marking?	3.74
		[TA leaves]	3.81
	1:	Where you get seven reading mark it.	3.84
	2:	Well that's only on the metal.	3.87
	1:	[looks to b] They're getting	3.9
	2:	But see now, where are they getting seven also?	4.02
	1:	[to b] where'd you get seven? Far away from it? Are those your dots for seven?	4.04
	b:	No, no, seven is	4.2
	1:	Right on top, right?	4.24
	b:	Yeah.	4.25
	1:	Ok. It is right on the middle. So mark a point. And then you just go down, 6, 5, 4, draw your dots, right?	4.26
	b:	uhh, we're just doing like 5 all the way around.	4.4
	1:	Right, that's what i mean.	4.47
	2:	Ok.	4.48
	1:	Alright, so where's six?	4.52
	2:	Right, you're at six now.	4.55
	1:	Am i still at six?	4.57
	2:	Yeah	4.74
	1:	I know i'm not moving it very much, but	4.76
	2:	Move it a little more, yeah. Still at six.	4.78
	1:	Still at six.	4.84
	2:	Wait, go closer to it a little bit, there you go.	4.86
		[continue marking dots, closer, more, right on, etc]	4.89
	2:	We can just forget the ones on the top, it's gonna be reflective.	5.12
	1:	No, but, [?] and then one more.	5.35
	2:	Now you're on seven cause the wire underneath is touching it, so just forget about the ones on top, they're gonna be hard to get to the wiring.	5.42

	1:	Ok.	5.55
	2:	So these are six? Ah, here's what we could do, yeah.	5.67
	1:	What?	5.78
	2:	Let's do this, since we dont have any points up there,	5.83
	1:	Draw an arrow?	5.88
	2:	Put an open circle and put a six, so that ring is now 6.	5.92
	1:	Ah, put it there. That makes sense. [labelled the ring]	6.06
	2:	Ok, now you want to go to five?	6.09
	1:	Yep, because that's what it said at some point when i read it. Here it is, "repeat this for each part".	6.13
	2:	Yeah.	6.23
		[closer, right on, etc, marking points]	
		[reach end of paper]	
	1:	It's gonna be off the paper	
	2:	Go out to the edge of the paper, yeah, right there is it.	7.6
	1:	Now what are we gonna, i guess the lines will just go like this. [motions circle off paper]	7.64
	2:	Yeah, you could try doing one up there just for shits and grins.	7.72
	1:	It should be around there.	7.75
	2:	You're really, you're right on it, right now.	7.77
	1:	I'm pretty good.	7.86
	2:	Damn, you are good. You could have an exciting career in the world of electronics.	7.88
	1:	Thanks.	7.97
	2:	Now you need to move closer	7.98
		[continue on]	8.05
	1:	Here's this funky looking circle thing, you get the idea.	8.24
	2:	It's close enough for my government.	8.43
	1:	It looks like straight lines everywhere, you get the idea.	8.45
	2:	Yeah.	8.51
	1:	I can't mark this, it looks like an egg.	8.53
M	2:	yeah that's fine, it's supposed to look kind of like an egg.	8.63
	1:	Alright, 4	8.67
		[start marking 4]	8.69
	1:	Do you want to exchange jobs, or do you want me to keep doing it.	8.87
	2:	doesnt matter...I could care less, as long as we get done.	8.92
		[continue on 4]	8.99
	1:	It's gonna go off the paper.	9.17
	2:	Umhum, so we can just kind of estimate where the other one's-	9.35
	1:	We get the upside too. I'll go up there	9.57
	2:	If you can, i dont know if it will reach.	9.61
	1:	It will.	9.64
		[continue marking]	9.66
	2:	You still need to go further away. See now, what's going on is the metal underneath there is touching that.	9.88
	1:	Touching the ring?	10.1
	2:	Yeah. So let's just guesstimate it. Either that or try to get this point.	10.11
	1:	Which one, this one?	10.16
	TA:	You guys dont have to do exactly 1,2,3,4,5 and 6 potential. Just do enough so you feel you have the picture of it.	10.2
	1:	This is good.	10.29

	2:	Ok, i feel like i have the picture.	10.31
	1:	Right about there?	10.33
		[continue marking]	10.44
M	2:	There, that's it. Good enough for what we're gonna do.	10.55
	TA:	And so it works best if one person is looking at the meter and the other person puts the dots on it. Try to just be as quick as you can.	10.65
	1:	Somewhere like that, oh sorry. Ok, so now what? We're done with that one, now we move onto the next one, right?	10.85
	2:	Right.	10.89
	1:	Alright, i'll lift them, you pull the paper out.	10.91
	2:	Let's turn off the power. Oh, i'm sorry.	10.98
	1:	Just pull the paper out.	11.05
	2:	I said lets turn off the power before we go sticking out fingers underneath the board. [to TA]	11.07
	TA:	Well it's just like, i mean you have a nine volt battery this is seven.	11.15
	1:	It wouldnt be bad.	11.2
	2:	Oh that's true, but i used to work with high voltage neon, and it was a good habit to get into.	11.21
	1:	Does it matter which order we do them in?	11.32
	TA:	Your goal is to predict what this is gonna look like, so you decide.	11.35
	1:	Whichever, we dont have to have one of each?	11.43
	TA:	Now you dont have any over here? [no points on other side] How do you know what it's gonna look like over here?	11.48
	1:	It's symmetric.	11.54
	2:	Alright.	11.57
	1:	Alright, put it under.	11.63
	2:	[?] line it up to our template. Wait, let's see if there's anything over there to record.	11.86
	1:	There is. Yep, see, it's just low.	12.02
	2:	There's just one out there.	12.17
	1:	Yeah but we need to draw it, get the points.	12.32
	2:	Uh, what we need to do, line it up to this	0.01
	1:	It's getting there. There.	12.47
	TA:	If you're getting really funky readings that are waving all over the place, let go, because by touching certain metal parts of it, you can ground it and you can mess it up.	12.66
	2:	Ok. Metal side down.	12.81
	1:	[?]	13.04
	2:	You want to do, what, pick a number, 2? Ok, there's two, right there.	13.08
		[marking 2]	13.15
		[knock off wire]	13.35
	1:	Oh that's good.	13.79
	2:	Oops, that doesnt help. What is this, it's just reading zero now. [joking]	14.23
		[marking 2]	14.31
	2:	See we're getting, that's the belly in the curve that we're talking about, which means we should get in another belly right around here, so it's, there you go.	14.93
		[marking 2]	15.54
	2:	Now you're near that metal, so	15.82
	1:	Cant touch it	16.09

	2:	That's gonna be good.	16.11
	1:	Now, so what does it do, loops?	16.14
	2:	Now then, hold on just a second though, [?]	16.2
	1:	She said if you get weird things you should take it off because it's grounding it, I mean it's screwed up	16.23
	TA:	So what's this? [pointing to curve on paper]	16.33
M	1:	We're trying to figure it out.	16.35
	2:	I dont know.	16.4
	TA:	What number are you at now?	16.43
	2:	That's 2.	16.45
	1:	We're just starting 2.	16.47
	TA:	Ok, so that looks about 2, that looks about 2 [checking points]	16.48
M	1:	We double checked it, we put it back on we were like, ok	16.54
	2:	Yeah	16.6
	TA:	Oh, you know what, you're not, i dont think you're in contact over here, you might want to	16.63
	2:	I dont know, that's still reading 2 there, still reads 2 there, now it's reducing closer to 1.	16.66
	TA:	Ok, so this is where error comes into play, ok? SO if this is about 2 and this is about 2, you cant read if it's 2.01 or 2.03 or whatever, so what do you think, which one do you think you want to draw your line through?	16.79
	2:	Oh, we're gonna just eliminate that one.	17.01
	1:	Yeah, that's what i'd say.	17.06
	TA:	So you just look and you decide, well, it's about, goes like that, and that's good enough.	17.08
	1:	Ok, i got it. Because you cant, it could be 2, but it's 2 point something, so you gotta pick one that's best.	17.15
	TA:	Right, you gotta pick one that's best.	17.28
		[drawing points]	17.3
		[marking 1]	17.69
M	2:	You better check up, oh no, cause we all know what that's gonna be, yeah, ok, i'll buy that for a dollar.	18.09
	1:	And then it will just keep curving around like that, right? Three would be out here, and then there's four, also, do you want to do three to see the?	18.48
	2:	Not really, i'd like to move on and go get a smoke. Something more interesting than two dots, at least. Call me impatient. ah, let's turn off the power first.	18.65
	1:	Done.	18.81
	2:	Move on.	18.83
		[replacing template]	19.06
	f:	What are all the noises?	19.17
	2:	I think someone's playing a game on their cell phone. What is this one?	19.27
	1:	We didnt change it.	19.38
	2:	Haha, no we can change it now, that's ok.	19.41
	1:	Which one, this one or the other one? Skip this one and just do this one? She said we dont have to do all of them. Now we do this right this time.	19.48
		[fastening template]	19.68

	2:	So i got in a car wreck yesterday, it was so totally not my fault. It's great, hopefully it will total my car and i'll get a check for 3 or 4 thousand dollars, i can still drive it, so.	19.83
	1:	Wait, [?]	20.03
	2:	Which one is that?	20.07
	1:	Does it go this way? No, cause you cant hook it up that way, that's too far up. Unless we just tape it. This is not gonna be very accurate. We need to find another template.	20.09
	2:	Obviously this is the wrong template. These are all identical. Da-da-da. [found the right one]	20.5
		[tracing]	20.73
3	2:	I didnt end up going to any classes yesterday, so	20.87
	1:	What time did this happen?	21.02
	2:	On the way into school, [details of accident] ends up on median strip	21.04
2	1:	Ok, so this should be seven again.	21.37
	2:	Close enough for my government, yes, seven. And then check the whole field along there, check that whole bottom.	21.4
	1:	It just did, it was weird.	21.75
	2:	Oops, do we have the right side down.	21.9
	1:	Yeah.	21.94
	2:	Just out like here? Ok, that's seven too, so that whole bar is seven.	21.96
	1:	Oh, i might have been touching that, yeah, seven.	22.09
	2:	Yeah that whole bar is seven, that whole bar is zero, that's fine.	22.14
	1:	Ok, now what, 6?	22.25
	2:	So that whole thing is seven, so lets go to six.	22.28
		[tracing]	22.59
	2:	Gee, and where do you think the next field line's gonna be, [1]?	22.65
	1:	Right beside it.	22.71
		[tracing 6]	22.73
	f:	Is this how, what'd you guys use to trace it?	23.02
	1:	We went over there and got theirs.	23.3
		[tracing]	23.32
	1:	And let's get up here.	23.47
M	2:	Yeah, well it's gonna do the same thing.	23.61
	1:	I know, but [?]	23.62
	2:	Yes maam. Ok, just get like two points.	23.64
	1:	Here too.	23.75
	2:	That's gonna be hard because your wire's going over the contact, so you're gonna have to stay off of that. There you go, babe. You got it. Now you're getting close to your other metals, but [?]	23.78
	TA:	On each picture i want both the equipotential and the field lines.	23.98
	f:	We just share, right, we dont need to each make our own?	24.02
	TA:	You need to trace it over, for the partner, everybody needs to have their own set of these, so it doesnt need to be exact, but just have the person who doesnt have a picture just trace it.	24.05
	1:	We need to draw the field lines.	24.21
	2:	Ok, lets get the equipotentials down and then, well the field lines are just perpendicular to it, which is gonna be a royal mess.	24.28
		[tracing 5]	24.47
	2:	We call that a keeper.	24.62
	1:	Is that good?	24.77

	2:	Yeah, we'll keep that one. Yeah.	25
		[tracing 5]	25.03
		[extrapolate the top area]	25.28
	1:	so it's just a huge circle going around [?]	25.52
	2:	Right. Let's take this as being zero, so let's come over here and start looking for 1. Wait, why is it hitting seven, there's something wrong, we're grounding out something	25.77
	1:	Freaking out.	26.08
	2:	So this is, oh, [finds wire]could be a problem	26.1
	1:	It was pulling out	26.16
M	2:	Hold on for a sec, can i explore for a second?	26.23
	1:	Yeah. Let's do three first.	26.37
	2:	Ok.	26.57
		[tracing three]	26.63

Cookbook+explanation lab B

mode			time (sec)
2	1	Want to get us some paper, [2]?	5.8
	2	Do you have paper, [TA]?	
	1	What's this?	
		[plugging stuff in]	
	1	How do I turn this on? [2 switches it]	
	1	Wait. Things go sideways.	7.2
	2	Yeah.	
	1	I thought they were going to go up and down like in that picture. I feel like this needs to be elevated or something. How do we make ours higher? [to TA]	
	2	Just lower it down. I knew you'd figure it out.	
	TA	What's going to happen to your pattern if the slit is close to your screen?	8
	S	It will shrink.	
	TA	If you want to be measuring distances, where do you want your slit?	
		Far Away	
	TA	As far away from your screen as you can. So very close to your laser. Because, think about what you're doing as you're doing it.	
	1	Oh, there's a good one. You want to use that one? [pattern on screen]	8.4
	F1	How did you guys get it to hit over there? [get pattern on screen]	
	1	You have to keep moving around your little disk	
	2	Play with it a little.	
	1	We need a ruler. We don't have one. Oh, that's not a good one.	
		[setting up paper on screen, drawing dots]	9.8
	F1	Did you have to pick this [pattern]?	11
	2	Yeah.	
	F1	Which one did you use?	
	2	It's the best one. You can see clearly the splits on here. Pick the best one that gives you the splits.	
	F1	Ok	
	2	You want to put the paper up there?	11
	1	No, we can just keep erasing those. [drew directly on screen]	
	1	Oh, wow. [lights off, can see better now]	11
	2	Do we need to draw that?	12
	1	I don't know.	
	2	[TA], should we be looking at other slits as well?	
	TA	These are all your single slits and you want to look at them all and see what happens. You didn't write that, did you? Gotta erase it after.	
	1	We will	

		2	The thing is, I wanted to use the paper	
		TA	And you didn’t want to? As long as you leave it in the same condition you find it.	
		2	Do we need to draw that?	
	M	1	Yeah, what are we doing?	13
		TA	What are you doing?	
		1	I mean, we need to draw every single one?	
		TA	I want you to look at it, explain what’s going on, I want you to describe what happens as the slit width changes, what happens to the pattern.	
		1	I can't read which one’s which, like I don’t know which	
		TA	It’s all labeled what the width is. Just take it out and look at it.	
		1	Our other one’s .8, this one’s .4	
		2	Go back to four?	
1		1	It gets more, well, *obviously* when it gets more narrow, the slits get narrower. As it gets wider, the slits get wider. Wow. [sarcasm]	14
		2	The width of the slit increases with increasing? So, what’s that?	
		1	This is .2, the other one was .4 Or .02	
		2	That’s .02?	
		1	Yeah.	14
		2	Then .8 was narrower. Yeah. We started out with .08 and it was like	
		1	Oh, the *wider* the width the narrower the slits get. Because there’s more room for light interference because there’s more rays of light going through.	15
		2	Right	
			[writing]	
		1	Are the dark spots where they cancel out?	
		2	Yeah.	17
		2	So the angle theta decreases, right?	18
	M	1	I don’t know.	18
		2	Because the…	
		1	The angle theta is just from here to there and there to there….	19
		2	Why?	
		1	… and here to there and here to there.	
			Why? That's the…Why is the, she said why is the space between the spots rising. As theta goes, I guess theta increases the width decreases.	
		1	Between each one, it’s just there’s more light coming through for a wider one so it's more light waves interfere. It’s like the frequency of the light’s greater. Because there’s more light waves coming through, so there’s more overlap.	19
			[writing]	
		1	Ok, are you done? You’re pretty slow.	23
		2	Well, because you gotta draw that. She said draw a picture for three.	
		1	You just go like this. Ok, so go like this. Ready?	

	2	What did you put for #2, why the pattern looks like that?	
	1	I just said,	25
	2	Going through one slit?	
	1	Um, hold on.	
	1	This is what I drew, it's more dense because there's more light coming through, so it's wider and this one's narrower. Ok, I said, 'as the width increases, the distance between the dark and light spots on the screen decreases. Because the slit is wider more light is passing through. This means there are more light waves passing through which means more interference between these waves and therefore more light and dark spots on the screen with smaller distances between them.	26
2	1	Does it matter what slit width we use?	26
	2	I think she said choose.	
	1	Choose one? Which one do you want to do? Well, we might as well use the one I drew on there.	
	1	[measuring pattern] Each one is exactly five centimeters.	
	1	A is the slit width.	28
	1	What's the wavelength of light coming out of the laser?	29
	2	630, It's in the book. 632.8? Yeah, 632.8 nm	
	1	So it's 632.8?	
	1	Oh, it's in nanometers? Oh, so how do we make that meters?	
	2	Nanometers is ten to the negative nine meters.	31
	1	We want centimeters. So we're going to do ten to the negative seven.	
	1	So our theta is… .045 degrees,	31
	1	Uhoh. We have to know how far away the screen is. I have to line this up again. [1 lines up screen and measures distance, 2 writing]	
	1	61.5	34
	1	Awesome. We got it.	36
	1	Don't move it. [2 touched screen]	37
	1	[TA] I have a question. I'm having an issue with units.	37
	TA	Ok, which ones do you want to use?	
	1	Well, I'm using centimeters just because that's the easiest thing that we can measure. So I did, if this is nm?	
	TA	How many nanometers are in a meter first of all?	
	1	10^-9, so in cm is 10^-7, which is what we did. Then I got theta to be .045 degrees.	
	TA	From what? How did you know that was theta?	
	1	From this equation, because we picked m is one. And then .08 was our slit. So I got m1 distance to be .048, but really when I measured it was .5 not .05.	
	TA	What are you trying, which way are we going with this? What are we trying to find at the end?	
	1	The distance. How far apart on the screen the minima are.	38

TA Ok, so I want you to derive that with the letters not the numbers first of all, because then you don't have to worry about units. So go the other way first of all, take this equation, call the distance apart y or something. I want you to give me an equation that has y equals something.

1 Oh. Equal, but it's going to be the same as this, right? 39

TA With letters, not numbers.

1 Ok, so it's going to be the negative tangent of this m, no.

TA So what's your x?

1 Oh, our x would be the tangent of theta.

TA Ok, now let me know you something kind of neat. Since this is so far away, remember theta go- [tape ends] 39

TA -Goes up here?

1 Right.

TA We can assume, since theta is really small, here you got it to be .045, sine of theta is the same as tangent of theta at that small an angle, 39

1 Oh, it is?

TA That's an approximation we're making, so you don't need to go into tangent, you can just say sine of theta is this distance over this distance. 39

1 Ok, so we just insert that into this equation?

TA Yeah. And make sure [2] understands what you're doing. 40

1 [laughs] This simpleton over here.

TA No, I'm not meaning it like that.

2 I know.

1 I know, it just sounded funny.

F1 Can I ask you guys a question? For the second question, are they just asking for when you do one slit? 40

2 You should look at all of them just to see what the pattern looks like.

F1 Like are you talking about for when you have one slit and then you have two slits?

2 Right. The distance between the slits.

F1 Ok, so you're just doing one slit but you're looking at the distance, ok.

1 Can you come check this one? Did you get this? Ok, this is the equation, and the sine of theta is that over that, because it's so small it's the same as tangent or sine, it doesn't really matter. So you use the sine of y over x. So the sine of theta equals y over x, right? So you plug in that to that in this equation. So A y over x equals n. So this distance always equals the m times the wavelength or frequency whatever, times x which is 61.5 cm or however far the screen is, over A, which is .8. So. 42

[writing] 43

F1 For number 3, what kind of picture does she want? 44

2 Just what you saw.

1 Ok, and then for 5 we use the numbers. This is good because we know it's .5. So y1, [reading] 'use your data to find the wavelength of the laser light'. So the wavelength is [solving equation for wavelength]. X is… 44

[calculating]

1 Ok, we got 6.5E-4 cm, and the actual one is what, 623.8? 46

2 632

1 Well, we just want to make sure it's the same units. Um, we wanted to get 6 something to the negative five, we got negative four. Let's ask her if that's ok. A human hair? Alright.

2 We'll have to use yours.

M 1 Ok. Ooh, wow, look. I have no idea why that happens. I don't know how hairs work, you know? 47

2 It's apparently opposite that of slits. [hair makes vertical pattern because it's sideways]

[1 calculating]

M 1 Oohh, it's .08 meters, oh no, mm, that's why our unit's off. Millimeters. So we have to make it .8 cm. Now it's tenths. Perfect, we got an awesome value then. Thank god I figured that one out. Still off. No. No, that didn't work. 49

2 It didn't?

1 No. How do you make millimeters to cm? Oh, it's going to be less centimeters, so it's going to be .008 centimeters. Ok. Yay, 6.5 times 10 to the negative 5. The actual value is 6.3. Oh we're good, look at that. This is the value we found and that is the actual value. Alright, now let's make up about the hair thing. Obviously there's some kind of slits in hair. I don't know.

2 [Reading] "make up some plausible reason" 51

M 1 Let's, you wanna skip that one for a minute? We can come back to it, because we have lots of other stuff to do with double slits. I should probably erase this now. 51

2 Can I copy the equation for number four?

1 We're way ahead of them.

2 .008 is centimeters, right?

1 Yeah, this is all centimeters. First we have the slit separation change. Start with that guy. Ok, now the slit separation is going to change. [looking at patterns from double slits] Alright, [2], what happened? 55

2 I'm sorry, I missed the first one.

1 These are both the same slit width but they're a different slit separation. There's little dark spots within the light spots and they get narrower.

2 Is that what you saw?

1 You don't see that? Look. See those little slits?

2 Yeah, ok.

1 They get narrower because the slit separation got wider. No, the slit space got wider and they got narrower.

[writing] 56

1 Ok, wait, let's just put it in front. This is the same slit separation as that. So the distances between the small dark spots remains the same. 58

2 Because the slit separation is the same, is that what you're saying?

1 Yeah. The distance between…

1 …Dark spots remain the same…Don't move it. 59

2 I'm not moving it. Can you do that again, though?

1 Ok. This one is .4 60

2 .04, right?

1 Yeah, .04, but they're each separated by 500 ml separation between the two slits, ok? I mean, 250. This is .08,

2 With the same s-

1 Slit separation. So the distance between the little small ones is the same. So the little ones stay the same and the big ones get narrower.

2 You're looking at the slits in between the red things, right? 61

1 Yeah, those tiny little slits are the same. See, look, we'll do this one, too. Here's four at 250. See the tiny little slits you can barely see, there, now you see them?

2 Barely. 61

1 They're really thin. It's gonna be just as thin at 8, but the big ones are going to be narrower. See, they're just as thin but the big ones are narrower. Then when you change the slit separation but it's the same width, the big ones stay the same and the little ones get narrower.

2 mmm 61

1 Ok, I'm doing the prelab now. 63

1 [to table across] That's right, [2] knew that too.

2 What?

1 You knew the nanometer conversion. Nah, just kidding a lot of people know that. I had to learn that in chemistry but I just forgot it. 64

1 2 What did we have to do for the prelab? 64

1 You know that picture that looked like this?

2 This one?

1 Yeah, it's like what we're doing here. It's like the two waves are converging. You have this big wave and then a wave with a higher frequency and it's gonna just go in the same pattern as that wave. And that's what it's like here. You have these big overlaps and then you have the little overlaps. And the little overlaps just fall inside the pattern of the big overlaps.

2 What's the question though?

1 The question of the prelab is just why these look the same.

2 Oh. Why the two patterns look the same?

1 Yeah. I'm just going to say, it's basically the superposition of the two waves. 65

1 So the first wave has a smaller period, right.

2 So we're comparing these two, that's all?

1 First wave has a higher frequency but it's a constant. Let's see, you know what I'm saying?

1 It has a higher frequency but the same amplitude each time.

2 I'm still trying to understand 7. 67

[1 writing, 2 looking at patterns for different slits]

1 Ok. This one is the interference between the slits which is always going to be a small dark and light pattern. Ok? 71

1 And the diffraction which is due to the width of each slit is what we first measured which is going to be a large spot here and then small in between each one, you know? So when you put these two together you have two slits and you change the widths it's going to make this kind of pattern. Here is the interference patterns and here is the diffraction. So it's just the superposition of the wave patterns between interference and diffraction. So that's all you really need. I wrote 'just like the picture in the prelab, the two different wave patterns caused by interference between slits and diffraction due to the width of each slit are being combined. The resulting pattern is small and large, dark and light spots is the superposition of these two wave patterns. 71

2 1 Ok, and now we can look at the difference between two and three slits. 72

1 Ok, let's look at the pattern of two slits and three slits and then we have to predict what four and five will look like. Here's two. Here's three. Ok, two slits, three slits. It didn't look any different. Did it look different? 73

2 No.

1 Let's just look. Four. Aaah, I don't think that looks any different.

[writing]

1 Like, is it just us, are we just? I'm seeing no difference, are you? 76

2 Two and three look the same. Do we want to?

1 Ok, that's three

2 That's three.

M 1 [TA]? Are we wrong? They all look the same? 77

Ta They all look the same?

1 Is that right?

2 Two, three, four, five?

1 Two, three, four, five all look the same.

TA Ok. So that.

1 They're not supposed to?

TA Two, three, four five? Wait, what are two three four five?

1 Numbers of slits.

TA Oh! Oh, you're all the way out here already! Good for you.

1 Two and three look the same, so we thought they'd all look the same, and they did.

1 We're having fast day I guess.

2 Because last week was so awful.

TA So that's two, that's three, that's four, that's five.

1		1	It's just basically that multiple slits are going to look different than one slit, but more slits really doesn't make a difference, just cause…	77
		TA	So if we compare five to three,	
		1	No difference. Can we draw our picture like this?	
		TA	Yeah.	
		1	Ok.	
		TA	Now	78
		1	That's hard to explain why that happens. Oh, and the hair? We have no idea why it goes the other way.	
		TA	Ok. When we had a slit	
		1	We're guessing that the slit is this way, but…	
		TA	So the slit is a narrow window like this.	78
		1	Right.	
		TA	And it lets the light through the window and blocks it outside. The hair is like this, so it lets the light through outside and blocks it in the middle.	
		1	Oh, we're supposed to put our hair like this? [vertically]	
		TA	Yeah.	78
		1	Oh, I put it like this. [horizontally] That's why our lines were like that.	
		TA	Now you're comparing this to a slit like this, is what you want to compare.	
		1	Ok, where did my hair go.	
		TA	So that would be putting your slits this way, if you look at this…	
		1	But it looked, that's what our hair looked like.	78
		TA	Exactly, it looks the same, whether you block it, or let it through.	
		1	Oooh. Why?	
		TA	That was part of the question.	
	M	1	But if you block it, how does it get through? That's what I don't understand.	79
		TA	Ok. Are you blocking the whole beam with the hair? If I put a paper in front, would I get any pattern? No. So I've got a thin hair…[interrupted by S] When you put the, you've got this thin hair in the beam, how big is this beam?	79
		1	Bigger than the hair, I guess.	79
		TA	So the beam's going through, so before the slit we looked at the beam, the rays	
		1	Wouldn't we see two strips then?	
		TA	Why?	
		1	If it goes on either side of the hair.	
		TA	Well, it goes either side of the hair then what does it do?	
		1	Converges.	
		TA	Then it's…	
	M	1	Oooh.	80
		TA	So before we had two on either end, then interacting. Now we have two just making it around the hair, and interacting.	

1 Oh, so it's like the same as having two slits?

TA Well, when we had a single slit we said the two rays on either side of the slit are going to interact. 80

M 1 Ooh. So it's the same as going from two sides of the slit it's like going around two sides of the hair and crossing. Oh. That's weird. Interesting. 80

TA It's kind of like making a shadow with a hole or making a shadow with a ball. You can do it with both of them.

1 Ok.

2 Ok, I understand. 80

1 The pattern, if we had two thousand slits would look the same. 81

2 Because if we had a ball…

[writing]

TA How are you guys? 86

1 So, if you have, this is what I think it is. There's more slits, but because they're the same distance apart each time it's not going to change the interference pattern because they're just hitting the same pattern. So it's just like reinforcing the same pattern that was already there.

TA Right. It should be a little brighter, but it may be hard to see. 87

1 Ok.

TA Is this your diffraction grating? No, this is your multiple slits. 87

[writing]

2 Which one was that? 87

1 Nine and ten. Which one are you on? Oh, you're doing nine right now. That's what we were just talking about.

2 What's that? What did you say? More slits?

1 More than one slit just means that it's going to have an interference pattern. Before it was the width changes the diffraction due to each width. But when we change the distance of the slits it changes the little distance, the little interference. But if you have a bunch of slits that are the same distance, it's just going to be the same pattern. It might be brighter, but it's just going to be the same pattern coming through each slit so it's not going to change the light pattern. Because there's no more interference because they're all the same interference pattern. 88

2 [writing] 91

1 [reading] 'What happens to the distance between them'

1 We should get extra credit on this lab because we're doing such a good job. 92

2 Yeah. You done?

1 Yup. Man, I wrote like essays. Look at this.

2 I know.

M 1 I like this lab. This lab makes so much sense to me. More than other labs. 95

2 I think any lab after last week is better.

		1	For me? Yeah. I was on the rag. I was just being a very moody girl. I get like that. I'm sorry. I hate being like that.	
		2	Number nine, ok. Number 6 doesn't make a difference, it doesn't have an affect on the pattern. The pattern may become brighter as you increase the number of slits. Why? We know that the interference…	96
1		1	Because the pattern is being reinforced more by more light getting in. So there's more light but the pattern doesn't change. So it can be brighter but the same pattern.	96
		2	Ok. What does that have to do with interference?	
		1	Because the interference is what makes the pattern. But more slits it's still going to cause the same pattern of interference between all those slits. So it's going to appear the same, it's just. Like, if you look at the, I guess you could have the same thing with waves in water. Like say you have two waves and you go like this. It's going to make the same interference patterns going out. You do like four, you could still have those same interference patterns. It might be higher and lower waves, but it could be the same patterns because they're all in the same, like they're the same wavelength, you know what I mean? And the same distance apart. The same wavelength and same distance apart. That's the important thing I think.	96
		2	Yeah.	97
2		1	If slit separation is wider, … [talking to herself]	99
	M	1	These [trucks?] don't make sense. Oohh, number of slits per meter, that means the slits are getting narrower. Ok.	101
		TA	Ok, I'd like everyone to look at the front of the room for a moment. What I have right here is a diffraction grating which is a bunch of slits all really close together, and we get all these dots. So what is going on is now we've got tons of slits and the light's going through that. So instead of seeing these patterns with dots inside of them, we've gotten so the dots are so small and the lines are so close together that we just get a bunch of spots. So that's your diffraction grating, that's taking the limit to very very many little dots close together. So if you don't get to it, that's what the diffraction grating is going to look like, just a bunch of dots.	105
		F1	Why is that?	
		TA	So instead of seeing spots with spots inside of them, we've gotten so many so close together that you can't see the spots anymore and they spread out a lot. This is coming from over here, so it's spreading out over a long distance. But we've taken it to the almost extreme limit. These things are made very carefully, there's tons of little slits close together, 7500 slits per inch.	
		S	Why don't they make it per square cm or something?	106
		TA	Oh, just to make it annoying.	
1		2	So, 12, the number of slits is proportional to y right, so if one increases, the other increases?	106

	1	It's the same for all of them. When all three of them increase, y increases. And I said, um, it makes sense because when the density of the slits increases, the distance between the slits is narrower.	
	2	Ok, the [???]	107
	1	No, no, no. I'm saying like the density, it means	
	2	There's more slits.	
	1	There's more slits so it means the distance is narrower and we found when that was narrower, these were wider, and that's how we found it. And then I said that when the wavelength and the length increases, the wavelength obviously if it's a bigger wavelength, it's going to be less light coming, like the waves are larger basically and so there's less diffraction patterns between the light waves. Like if you have this wavelength and then this interferes with it, they're going to be farther apart then a higher wavelength so the distance is going to be greater between them.	107
		[interrupted by F1 do you have the multiple slits?]	108
	F1	How are we supposed to know the density and all that stuff?	
2	2	You don't. I'm just recopying the equation, just wrote something for 12.	109
	TA	Alright, if you haven't gotten to see the multiple slits yet, just quick take a look at them and finish your sentence and your picture and hand it in. If you don't get to everything that's alright.	110
	2	And what do you think for the hair thing?	110
	1	We were supposed to actually do the diffraction grating, but we didn't get to it, so that's ok.	
	2	What did you say for six, the hair?	111
	1	I said, …[writing]	111

Scientific community lab C

Mode				time (min)
2		3:	Does someone want to start like right now?	8.722
		4:	Yeah, i know we shouldnt use, but, i'm just	8.767
		1:	Can we just make a bulleted list and then write it up, or do you want to just write it up? Cause were go-	8.905
	M	2:	We should, wait, what are we doing now? I dont know how to do this	8.997
		3:	How, ok	9.019
		2:	Lets start with just like	9.04
		3:	You want to, like discuss the question?	9.078
		2:	discussion	9.157
		1:	Well, ok, let's just, in previous physics classes i have learned that the length affects it and the mass does not.	9.236
		3:	What happened now?	9.321
		1:	Really.	9.372
		2:	[???]do the length [???]	9.423
		1:	The length affects it, the length changes it but the mass doesnt, it doesnt matter if it's heavier, the only thing that affects it is the mass, so we can design an experiment around that.	9.474
		2:	Cause it's just the...	9.524
	M	1:	Ok, that's kind of like cheating, but.	9.573
1		2:	So, basically what we have to do is like make something with different lengths	9.623
		4:	Have a short pendulum, yeah	9.642
		2:	Different lengths	9.66
		1:	A short one with a heavy and a light and a long one with a heavy and a light?	9.715
		3:	Or maybe like some [???] have like a short one with a heavy and a light and then that compares the mass, and then a long one short string the same amount of weight so that way it will compare the mass.	9.974
2		TA:	If everybody can look up here real fast, i do want to remind you this week you will be writing up a log of what you're doing right now, ok, so you want to be sure that your groups you do designate people to write up the different portions of your lab that	10.3
		1:	Alright, well questions we have, hypothesis we have,	10.41
		2:	Should we start writing?	10.46
		3:	Yeah, i think we can start writing, because by the time	10.51
		2:	At least for these parts, and then we'll wait	10.55
		1:	And then by the time we figure out what we're actually going to do, we'll know our materials.	10.61
		2:	Ok, so what are the	10.64
		3:	Who wants to write?	10.67

	2:	Well we all have to write a different part	10.7
	1:	We all have to write a part	10.72
	3:	Oh, ok.	10.75
	2:	Ok, let's look at the good one.	10.78
	4:	So we need an intro and a method.	10.81
	2:	Intro and method	10.92
	3:	Ok, how about I can write up the intro, the questions, and the hypothesis.	11.04
	2:	Ok	11.06
	3:	I mean like	11.09
	2:	Someone else can do the method.	11.12
	1:	I can do that, what we actually do, the procedure, I can do that.	11.22
	2:	I was going to do data analyzing, like calculations, and then there's conclusions.	11.33
	3:	And i'll do data and conclusions, and then you can just do	11.38
	2:	I mean we can all help each other	11.42
	4:	Data is just like, nothing	11.52
	1:	Yeah.	11.61
	4:	So what am i doing? Oh, data. But we dont copy?	11.71
	1:	Well i'm just gonna, i'll rewrite it, we're going to have it on one paper	11.76
	3:	umhum.	11.78
	2:	So it means since the category is a quarter[?] we can like	11.8
	3:	You mean start on this one and then	11.85
	2:	Yeah, and then like pass it	11.9
	1:	[to TA] Do we need to all have copies of what our logs, or?	11.96
	TA:	No, you'll just give us one copy and we'll make copies for you guys and you take it back. But right now, go ahead and be thinking about what you're going to do with your experiment, because you only have a few minutes.	12.13
	1:	Ok, yeah, lets figure out what we're going to	12.18
	TA:	You guys have until 3, 4 o'clock to take data and come up with an answer to these questions, you want to try to convince your classmates that your answer to that question is correct.	12.37
1	4:	So lighter and longer does not, well first of all look, lighter and longer does not keep the correct time, so we know that	12.49
	1:	Obviously, because they changed the length	12.54
	4:	Yeah, so we're trying to find the correct length?	12.59
M	1:	No, these are our questions. Is it because of the length or is it because of the mass.	12.69
	4:	Oh	12.77
	2:	Yeah, we dont have to actually do this. We need like a control. So	12.86
	4:	So, does mass or length affect the time swing of a pendulum.	12.97
	1:	Right.	13
	4:	Ok, so there's our question.	13.03

	3:	We can do maybe like four experiments. You have like a constant string length, two different weight masses, two different things that have different masses, that will tell you ok, well, you do need a control.	13.27
	1:	Those will be the same, those should come out the same because it doesnt matter how much weight you have.	13.35
	3:	Ok, and then you can have two different string lengths, one long, one short, with constant mass	13.42
	1:	With the same weight	13.48
	3:	Right, with the same weight. And then that will tell you whether or not they're the same or different, by how much, whatever.	13.54
2	4:	Let's get some of the equipment	13.57
	2:	Materials [2,4 leave to get stuff]	13.72
M	1:	I think that will work, it's my theory. Once we do it, i think we'll see. So we're going to have	13.87
	3:	Do we need to have, like for the length of the string, do we need to have an intermediate weight or no?	13.99
1	1:	Different weights. Those should come out the same. Then we're going to have two different lengths, same weight. That should come out different. It's going to be hard to actually measure a swing.	14.47
	3:-	Yeah, cause how are we going to measure a swing? A complete swing. It's gonna be [?] I wish there was something that we could compare it to, like see how many swings you'll get with something and then take the different, because we know it's gonna stay	15.1
	1:	Ok, so you mean have like one	15.12
	3:	Have something that we can compare it to that we know that you get this many swings with this, now maybe lets get something that weighs more	15.26
	1:	And lets change the length and then lets change the weight and see compare whether it's different or the same.	15.34
	3:	Like we can have a standard ok let's have a -	15.38
	1:	-ok, standard, that's a good word, that's what i was	15.43
	3:	string that's like this long and a standard weight just to see how many they are and then compare we change the weights higher and lower we change the lengths	15.49
	1:	And then the lengths longer and shorter	15.51
2	3:	Actually we like six?	15.52
	1:	I dont even know	15.55
	2:	Ok [returns with stuff]	15.59
	1:	What are we doing?	15.62
	2:	This gets taped to there	15.69
	1:	We need to decide	15.75
	2:	Only two different lengths or three?	15.8
	1:	We need two weights that are the same.	15.89
	2:	Ok, but then for the weight one, just two different ones right?	15.98
	1:	Ok	16.08

	4:	Can you help me decide what is short and what is long.	16.18
	1:	We have decided that we're going to have one standard, because we were figuring, how are we gonna measure, like what are we gonna measure?	16.31
	3:	Yeah, so we were thinking	16.33
	4:	Like this, stopwatch.	16.34
	1:	Oh	16.4
	3:	I thought we were testing how many periods, how many swings	16.45
	1:	How many swings per time that we'll measure with that.	16.51
	4:	Yeah, we can measure number of swings in like thirty seconds.	16.57
	3:	Yeah, and that would be what we compare the standard to. Or are we even still using the standard?	16.69
	1:	Um.	16.76
	4:	Let me first, i need to go over the experiment, but what's the, do you want it to be like 20 inches is our long	16.84
	1:	Yeah, that's fine. Is that gonna hit the ground?	16.88
	2:	Oh yeah, let's measure how long	16.92
		[measure table]	16.96
	4:	So it's like 34.	17.1
	1:	That's fine. 20 is fine.	17.17
	4:	And do you want to do half of it?	17.24
	2:	Sure, ten? Sure.	17.28
	3:	What happened? I missed it.	17.33
	1:	Our long is going to be 20 and our short is gonna be 10.	17.37
	3:	Oh, as far as length? Ok.	17.4
1	2:	Should we have a bigger?	17.44
M	3:	That's what I was, that's what we would think	17.47
	2:	And then use that middle for the	17.5
	1:	We were thinking of having like a standard, one where we measured and then compared our other ones to.	17.58
	2:	Ok	17.59
	3:	So that we know, what	17.6
	4:	Something in the middle	17.61
	3:	So we have something to compare it to.	17.62
	2:	So like	17.63
	3:	Fifteen.	17.65
	2:	Fifteen.	17.7
	3:	Do we have another size weight?	17.75
	4:	Yeah.	17.79
	3:	Oh good. These can be our middle weights and these can be our light weights.	17.83
	2:	So then these will be our middle and then when we do these two we'll do at 15, and then with this one	17.92
	1:	Right, cause that's what our result is gonna be	17.99
	3:	Yeah, those will be the change in weights, and then, yeah, ok.	18.05

	2:	So that's what we want.	18.1
	3:	Are we cool?	18.12
	4:	So we are going to	18.13
	1:	[laughs]	18.17
	2:	Yeah, come one, go ahead.	18.2
	4:	I just. Three different lengths, one short, one standard, one long. And the short we're gonna test two times, one with the big weight and one with the smaller weight, right?	18.41
	1:	We have to test everything with both weights, right?	18.45
	2:	Ok, yeah.	18.48
	4:	And then the middle one and then the big one.	18.54
M	1:	But what, we're testing it against the fifteen? It will never come out the same because we're changing the length. Like we need to test	18.68
	2:	What?	18.71
	1:	We need to test the fifteen against a fifteen of a different weight.	18.74
	2:	So that's what	18.76
	3:	That's what i'm thinking, yeah.	18.78
	2:	I was thinking we do ok 20, 15, and 10 with this weight. And then, at 15	18.92
	1:	Those will never be the same.	18.93
	2:	They shouldnt. And then at 15-	18.94
	3:	They should be the same.	18.98
	2:	do this, this, and this.	19.01
	1:	oh, ok.	19.06
M	3:	Let me see are we saying the same thing. Ok,	19.1
	2:	So we do like	19.12
	1:	Oh, i see.	19.14
	2:	Ok, let's say so were doing length, we'll have this weight here here and here	19.23
	4:	Well then why cant we just do each one with different weights.	19.26
	2:	I dont think we have to.	19.38
	3:	Cause see i'm thinking like with the standard ok we'll take the 15, the 15 is gonna be whatever it is we'll hook the medium weight on it, we'll get a measurement. Ok, now we'll take it put these two up on it	19.49
	2:	Exactly	19.54
	3:	Then we're gonna compare it. So that's the weight part.	19.58
	2:	That should be the same.	19.66
	3:	And then as far as the length is concerned, we're gonna take, three, we need three the same one, we're going to take the same measurement with this medium one, take it, then we're going to change the length	19.74
	1:	oh	19.75
	4:	A long and a short, that's what i'm saying	19.76
	3:	And a long and a short with the same weight.	19.78
	2:	Excellent.	19.79

		4:	Does it matter, do you think we'll get a different reading if we had this weight at 10 and this weight at 20, will we get a different reading?	19.93
		3:	That's what we're trying to see.	19.96
		2:	Yes, it's the length.	19.97
		1:	Yes, because it's the length that affects it and not the weight.	19.98
		1:	If you put this and that on a 10 it should be the same.	20.08
2		3:-	And like any of it will be know that, that's what we're trying to see. Ok cool, i'm gonna start writing up the introduction, so that, you all want to call her over now? You can call her over and i can explain it to her? Ok, cool, so we can get cracking	20.3
		2:	Yeah. Can we get scissors or something.	20.36
1		4:	Are we, how many swings per?	20.42
		2:	oh.	20.45
		1:	30 seconds.	20.48
		2:	I was thinking like count	20.52
		4:	Well it wont swing that long i think.	20.56
		2:	like pick a certain number of swings and count how long it takes to do 10 swings rather than count how many swings per time you know?	20.75
		4:	That's better.	20.79
		3:	[?] swing all day	20.8
		2:	Swing at [?]	20.82
		4:	Because we're looking for time, so we cant have the time constant, so we have [?]	20.89
		3:	I got another question, how high are we gonna raise it to swing? You know what i'm saying, because?	20.94
		2:	We should have like a line.	20.97
		1:	An exact line that we always start it from.	21.01
		3:	ok	21.05
2		4:	Yeah, put like	21.1
		1:	It's really high	21.16
		4:	That's cool	21.18
		2:	Let's suspend it from this.	21.21
		4:	Maybe like out to right here.	21.27
		2:	I mean we could have somewhere along here where we could line it up.	21.36
		4:	How about we cut it and see, cut it and then pull it and see how far we can make it swing, hit somebody	21.45
		1:	We're gonna need more tape.	21.63
1		4:	Now, how are we gonna, how is this thing gonna be anchored to this.	21.81
	M	1:	See, yeah, that's another problem.	21.97
		4:	They have paper clips there, we could tie the ends to, but then we're adjusting the weight and the length. No, it doesnt work.	22.13
		2:	But if we use the same paper clip every time, then it doesnt matter.	22.26

	1:	Yeah, but it matters how much you tie it.	22.39
2		[setting up equipment]	22.53
	4:	So we need one at ten, i need to cut some slack on it.	22.67
1	2:	Ok, here's another question. Are we gonna count the length of the weight, or?	22.7
	3:	All we're doing is counting the period, counting the swings.	22.72
	2:	No, but i mean like, see this is	22.78
	1:	It's the length of the-	22.84
	4:	Pendulum, and so that would add to it	22.91
	1:	-pendulum, it's not,	22.95
	4:	But that is, like the pendulum is the whole thing	22.99
	1:	Is it the whole thing?	23.09
	4:	Yeah. It says. I think it matters.	23.18
	2:	Because look, between these two when we're measuring times	23.26
	4:	One's going to be higher than another one.	23.29
	2:	Yeah, i think it's part of it.	23.37
	4:	So why dont i just tie the string to that and then measure the whole thing on here and then cut it?	23.45
	2:	ok. And then allow, i guess allow for [?]	23.61
	3:	Would they come out to be the same then? Because i mean as far as the string part is, ok. Ok.	23.77
	2:	I think it should be part of the [?]	23.82
	4:	Because it will, it's gonna alter the	23.86
	2:	It will alter the length.	23.93
	3:	Cause that's not gonna affect the weight soon, if you have something that's shorter and it weighs. I dont know, it's ok.	23.99
	4:	but if you just think about a pendulum, like, it's the whole thing.	24.11
	3:	Yeah, it is, it is the entire thing.	24.14
	2:	The whole thing moves, it's gotta be the same length, so i mean, cause this is a big difference, you know.	24.17
2	TA:	How's it coming over here?	24.5
	2:	um, good.	24.54
	TA:	Have you guys decided what you're gonna do?	24.57
	2:	Alright, we're gonna do, to measure, our standard is a length of 15 cm	24.71
	4:	Inches	24.81
	2:	I mean inches, with this weight. And then we're gonna do, with the same weight we're gonna do one at 10 and one at 15 and then	24.91
	4:	compare them	24.92
	2:	compare them.	24.93
	TA:	Ok, are you gonna measure, how are you going to measure the period?	24.98
	1:	We're gonna measure a certain number of swings how long that took, like ten swings.	25.08
	TA:	Ok, so you're gonna measure the same number of swings each time. Ok, how many times are you gonna do each length? Just once?	25.17

	2:	No, we didnt decide that.	25.26
	1:	I think twice, just once, i dont know.	25.34
	2:	I dont know, i say a couple at least.	25.37
	TA:	Ok, well that's something that you got to think about.	25.4
	3:	I say between two and three depending on how things go.	25.44
	TA:	Keeping in mind, remember, the point at the end is to prove everything to your classmates.	25.5
	2:	So more than that.	25.55
	1:	And then we're going to take a couple of 15 lengths and change the weight.	25.61
	2:	Yeah, use this still as a standard and this.	25.66
	TA:	How high are you gonna, um	25.71
	1:	Yeah, we're gonna make a mark	25.73
	TA:	Ok	25.76
	4:	Run the experiment and see what works.	25.8
	2:	Hang it and pull it and make a mark and see how far.	25.89
	1:	One question is does the weight part count as the length, or is it just the length of the string?	25.98
	TA:	However you guys want to do that, you can make your decision about that.	26.04
	1:	But then in a normal pendulum how does that work?	26.07
	TA:	There is not a normal pendulum, so its, this is entirely up to you.	26.15
	1:	Excellent	26.23
	TA:	However you want to measure your length is fine, just want to be sure that you're consistent the way you do that, so there's not a normal, we're trying to figure out.	26.32
	1:	Yeah.	26.36
1	3:	So we just want to see, we want to say ok, 20 seconds, let's see how many swings its gonna do in that period of time.	26.4
M	2:	No, we're going to do swings.	26.45
	1:	No, we're going to see how long it takes to do 10 swings, because that way we can get-	26.5
	3:	So we're measuring time, we're not measuring the periods, we're not measuring complete swings, we're measuring time.	26.58
	1:	Right, because we're trying to see if it affects, changes the period.	26.64
	3:	I thought the periods was the complete swing.	26.7
	4:	It is.	26.79
	1:	Well if it changes it will have more or less swings in the same amount of time, and if it doesnt change it should have the same amount of swings.	26.87
	4:	So we want to do 20? [length of string]	26.91
	2:	Like, ok, let's say, so you can divide whatever time you get by 10 and figure out how long your period is.	26.94
2	4:	Do we need one at 20?	26.97
	1:	Yeah.	26.99
	2:	Not for the big one.	27.06

	1:	oh yeah, not with the big one.	27.11
M	4:	I'm so confused. How are we gonna	27.17
	2:	Because we're just measuring for weight at 15, and we're gonna do three different ones at 15 and three different ones at 20. And the length, we just use this.	27.39
M	4:	And then for the 10 and the 20 we just use this? [certain mass] Oh, i see, it's just taking me a while.	27.59
	2:	How are we deciding that this should be included in the	27.7
	1:	I dont know.	27.71
	4:	I mean i think it should	27.73
	2:	I think it should just cause otherwise[?]	27.76
	4:	Now how should i cut this off, should i, we could tape it. No, it might fall off.	27.98
	2:	Maybe we could put a hook on the end.	28.22
	3:	What's wrong?	28.27
	2:	Trying to decide how to attach this on the top so that we can still have an accurate measurement.	28.36
	3:	Attach what at the top?	28.45
	1:	Like we have to attach the string to here but it's gonna change the length when we tie it.	28.53
	2:	if we cut it right at 20 and then tie it then some of the 20 is gonna be used up in the knot.	28.66
	3:	I think, i think just give it like	28.82
M	4:	This needs to be farther out, this is gonna be farther out, because if something pushes on it it's gonna get caught on this.	28.88
	2:	Ok. Oh yeah, we need to decide that, i guess same person timing.	29.11
	4:	yeah.	29.13
	2:	I need some more tape.	29.16
	1:	They made a longer one.	29.26
	4:	Alright we need to get going.	29.37
	3:	Yeah, i mean something like that i think it can be negligible, i mean that's one of the things that you can write up and say that	29.44
	1:	The time is gonna come out really close.	29.48
	3:	Yeah,i mean if we do further experimentation	29.53
	1:	Leave a little extra on the end to tie it and try to leave the same amount of extra on the end to tie it.	29.6
	2:	So should we just add an extra inch	29.66
	4:	And cut it here so we have like, or maybe, well that's not enough.	29.76
	2:	No that's not enough. Or should we just tie it and then try to measure? Here, just cut extra and then we'll hang it and try to measure.	29.93
	4:	So this is 15, this is not gonna make a weight difference, is it?	30.1
	2:	The string?	30.11
	3:	What?	30.12
	4:	Because we dont know the weight of this, we cant just say [?]	30.2

	1:	There's a scale up there. Isnt there a weight on it?	30.28
	4:	It says 6, but i dont know	30.32
	TA:	You guys have 15, 20 minutes to take data.	30.37
	3:	I say that's negligible as far as like how far to tie it. That's something that we could say in future experiments to better, get more accurate data we can actually measure, you know.	30.58
	1:	Yeah, i mean we dont have the tools to do this perfectly.	30.63
	3:	Yeah.	30.7
	4:	But all i'm saying is just for when we write it up what are we gonna say, is this the big one, or	30.78
	2:	Yeah, that's the heavy weight, heavy.	30.83
	3:	Or you can say when the mass of the weight is increased, then we got this.	30.94
		[tying pendulum]	31.44
	4:	One swing is going from	31.48
	2:	Ok, someone should start doing this while we make the rest of these things.	31.62
	4:	But one swing is going	31.65
	2:	Up and back	31.67
	4:	All the way to that side and back, right? Ok.	31.73
	2:	Maybe we should do less than	32.3
	3:	How long are we gonna let it swing for?	32.39
	1:	Yeah how many swings are we gonna do? Ten?	32.43
	3:	So how long it takes for ten swings? 1,2, yeah we got 15 minutes.	32.6
	4:	I'll weigh it once we're done.	33.15
	3:	That's fine. Who's gonna write it? I can hold this and do it at the same time.	33.28
M	1:	I dont think it's the right length.	33.4
	2:	It's not 15?	33.45
	1:	I dont think so.	33.47
	4:	It's 14 and a half.	33.71
	3:	I think that's good because we have fifteen minutes to do 6 experiments.	33.8
	2:	Alright, ready?	33.85
		[timing pendulum]	34.59
	1:	Oh no. It started going that way. 13.20	34.7
	2:	It hit the thing didnt it? Let's do it again.	34.76
	3:	How long did it take?	34.78
	1:	13.47	34.83
M	4:	But no, it hit the desk so you cant.	34.87
	1:	Should we do less than 10?	34.97
	2:	Five.	34.98
	1:	It hit after. 6 seconds, 6.5 seconds.	35.15
	2:	Do it again?	35.3
	1:	Let's do it three times.	35.34
	3:	I'm gonna get my hand out of the way. We got till 4 o'clock?	35.85

		[pendulum hits table]	35.89
M	3:	It's not long enough.	35.94
	TA:	So what are you guys seeing is going wrong?	35.96
	1:	It's hitting the table.	35.98
	3:	The setup is bad.	36
	TA:	So is it hitting at the very beginning?	36.04
	1:	No, it's going crooked.	36.07
	3:	Maybe i should set it out right here so that it wont do it, because i'm holding it anyway, so the tape is not doing any good, so that's fine.	36.21
	TA:	Or, i dont see that it's hitting immediately.	36.28
	1:	No, but it's hitting during our count.	36.32
	TA:	Ok, so you guys are counting a lot of trials, and that's why it's happening.	36.4
M	2:	Who knows what we're doing.	36.45
	1:	Alright, ready? 6.47	36.66
	3:	Ok, that's cool.	36.67
	4:	We've done three?	36.69
	3:	That's good, they both were like 6.5	36.75
	1:	Two works nice.	36.78
	4:	So we're only doing two trials.	36.85
	1:	Cant we just change the weight on that? That's the same string.	36.93
	3:	I think two is good.	37.01
	4:	Two works for me.	37.07
	1:	Middle weight is next?	37.12
	3:	Do we have any string left?	37.21
	4:	We can get more.	37.42
	1:	Now which string is this? So we changed the weight, not the length, so it should be the same time.	37.62
	4:	ten inch, we're going to be doing the ten inch with middle, light and heavy.	37.68
	3:	15 with middle light and heavy.	37.76
	4:	The long and the short ones, what are we gonna be using for this? Same weights?	37.88
	3:	All the same weights. The long, short, and medium all the same weight because we're controlling the weight but the length is just varying. Cause with this one they're all the same length but we're changing the weight.	38.23
	1:	Ready?	38.42
	3:	That's not even tied. I'll tie it.	38.54
	1:	No, there's not enough string. Put it back up.	38.66
	3:	Like i said, cause i mean i dont think, you know.	38.71
	TA:	How's it coming guys?	38.75
	2:	You gotta have enough length to time.	38.86
	1:	The problem is the length.	38.88
	4:	Maybe we could, what if you taped it? And then if you hold it?	38.95
	1:	Cant you just hold it?	38.98

		3:	it's not big enough, it's too slippery. We dont have our other one's made, that's gonna hold us up too.	39.15
			[end of 2A1 39:24]	39.15
			[second part tape A]	39.15
			[taking data]	39.35
		1:	6.62, wait that's [?]	39.6
		1:	6.63.	39.85
		2:	Oh, perfect.	39.87
		1:	However, what was the [?] excellent.	39.94
		3:	What different lengths do we need, we need, 10?	39.98
		2:	Oh wait, this is wrong, that's the wrong. It's different string. There's two rolls.	40.32
1		4:	One more question guys. After we do the 10 and the 20 inch	40.47
		1:	The ten is gonna be with the middle weight	40.51
		4:	And the 20 inch will be the middle weight.	40.56
		2:	We only have three more to do.	40.64
		4:	We can choose either one but we'll choose the middle weight?	40.72
		1:	Yeah, just cause it's average. I mean, it doesnt take long to actually do the thing.	40.93
		2:	Yeah, we're fine, we only have three more to do.	40.96
		1:	It's only 10 to.	41
		2:	Ok, but we were working out some kinks in our experiment.	41.07
		1:	So we need a 10 inch with the middle weight but we're adding them in.	41.14
	M	4:	Yeah, next time i'm really gonna sit down and think about how we're gonna do it.	41.18
		1:	I know, so i know what to do, wait i have the plan.	41.25
		2:	But it's hard like, because we didnt know what materials we would have coming into this, you know, you have to kind of wait so you can see	41.39
		1:	Yeah, that is the problem, you dont know	41.41
		2:	Cause you could make up this wonderful thing and not	41.47
2		4:	Alright, we definitely chose wrong string.	41.54
		3:	Yeah, it's some thicker string over there.	41.59
		2:	Yeah, i just thought this stuff was better [?] You dont have to do it exactly because i'm just gonna measure it here and hold it.	41.94
			[tying 10 and 20 with middle weight string]	43.29
			[timing one]	43.71
		1:	6.62	44.13
1	M	4:	So it's pretty much consistent with	44.16
		1:	Yeah, so that's excellent	44.19
		4:	So it means that mass does not matter.	44.23
		2:	Yeah.	44.25
		1:	Right, which is what we thought.	44.28
		2:	Alright, let's do this.	44.3

	1:	So basically it's just the length that we're changing, so as long as the length is different then this will work.	44.53
	4:	So we proved our hypothesis that mass doesnt matter.	44.6
2	4:	Is that the 20?	44.66
	TA:	How's it going over here?	45.02
	4:	We're almost done. We proved one.	45.07
	TA:	What kind of data are you getting?	45.08
	4:	Good data.	45.1
	TA:	Excellent. What'd you get?	45.14
	4:	We're proving that mass doesnt matter.	45.18
	TA:	Ok, that's great.	45.22
		[timing another]	45.56
	1:	7.75	45.89
	2:	Oh yeah.	45.91
	1:	[time second trial] 8. [?]	46.73
	4:	Um, maybe we should do one more.	46.77
	1:	Um, it was different, that's what we wanted to prove	46.85
	2:	That's pretty close, though, it's close enough.	46.88
	4:	Alright, that will be in our discussion how maybe we should have	46.96
	1:	Wait, that's not the same weight as this	46.98
	2:	Yes it is.	47
	1:	Phew	47.02
	4:	They're not the same weights?	47.04
	1:	No, they are, they are. I was like aah.	47.06
	4:	They are, arent they?	47.14
	1:	No.	47.2
	2:	Oh, no. Ok, it's ok, we'll just make this one really short.	47.27
	1:	Just cut the string shorter.	47.29
	4:	Which one did we use?	47.3
	2:	And that will be better anyway, because then we'll really know [that it's the same.]	47.36
	1:	Wait, dont cut it, let's just hold it.	47.43
	4:	Oh, who cares. That's good because now we know there's no discrepancy	47.47
	2:	Because we actually used [the same mass] Now hopefully on that middle one we used.	47.55
	1:	We did.	47.59
	TA:	You guys in about 10 minutes you'll be presenting to the class what you did, what you concluded, that kind of thing, put on here whatever it is you think the class needs to know about your experiment.	47.79
	4:	Ok.	48
		[measuring, timing]	48.22
	1:	5.38	48.54
	4:	Let's do it one more time because then it will be as high as the other one.	48.86

	1:	Are you sure?	48.88
		[timing]	49.39
	1:	5.38	49.91
M	4:	Wow, good.	49.93
	2:	Is that the exact shame?	49.98
	4:	Yeah	49.99
	2:	Holy shit. We're awesome.	50.01
	1:	Yeah baby.	50.03
M	4:	Ok, now how, we need to make sense of all this.	50.08
	2:	Ok, we need to put it in a little chart	50.1
	1:	Yeah, let's make a chart. Let's do a chart girls, there we go.	50.16
		This &#& thing. [microphone in the way]	50.21
	TA:	How are you guys doing over here on your writing?	50.25
	1:	Uh, good.	50.28
	3:	I'm doing the introduction, the introductory stuff	50.3
	2:	And then we're gonna pass it around.	50.32
	4:	Do we have, we have to do the whole writeup by four?	50.38
	1:	Five.	50.41
	TA:	SO i can see it.	50.45
	3:	Oh this is trash, this part right here, it's something i was writing and then my sentence didnt come out right.	50.49
	TA:	Ok, ok, well you could have just crossed it out, i mean you can just cross it out, it doesnt have to be perfect.	50.58
	3:	I dont like scribble scrabble.	50.61
	TA:	Ok, that's fine. But this is all the time you get to write up your lab report.	50.66
	1:	Chart time, chart time.	50.68
	3:	We have until 4?	50.71
	1:	Wait no, we have until 4 to write it?	50.75
	2:	We have until 5 to write on that.	50.78
	TA:	But during the time we're talking, you're not going to be able to write up your lab reports. So from 4 till about 445 we'll be talking. So we'll try to end a little bit early because i dont think people will.	51.05
	1:	Yeah, we didnt know that.	51.06
	2:	How are you supposed to write everything and do the whole experiment at the same time?	51.12
	1:	Supposed to, this is ridiculous.	51.2
	4:	Ok, um, so let's write, do you want to just write the question, write what we think will happen, and then just write our data and write our conclusion.	51.29
M	1:	I think that's too much. Just write our data and write the conclusion because they already know what the questions are.	51.37
	2:	Should we just say, should we write our hypothesis?	51.42
	1:	Yeah sure, whatever.	51.45
	4:	And i'm gonna start	51.57

	1:	See we cant really start until she finishes.	51.63
	2:	Length affects, mass will not [writing it down]	51.86
	4:	Should we include how we, setup	52.08
	1:	We can explain it, i think all we need here is our data.	52.11
	4:	I'm gonna start writing since she says we dont have time.	52.18
	1:	So we wanna write	52.31
	2:	Should we do two charts, one for length, one for mass.	52.4
	1:	Mass, ok.	52.48
	2:	So we're gonna have a ten inch	52.56
	3:	Are we just saying it will or it wont affect it or are we saying we think that the longer string will be more, we just think it will or it wont affect it.	52.88
	2:	We're saying that length	52.91
	1:	mass does not affect it	52.92
	3:	Mass does not, length does, that's all we're saying?	52.96
	1:	Length does	52.97
	3:	Length does, mass doesnt. Ok.	52.99
	1:	And write time [to 4]	53.06
	2:	Well, shorter makes it faster. Wait you guys do we want to say that shorter like put	53.13
	3:	Yeah, that's what i'm saying, do we want to be more specific, or just say that it does or it doesnt.	53.19
	2:	And shorter length will be faster	53.26
	1:	Shorter will be faster	53.28
	4:	I'll make a little n.	53.29
	2:	Oh we didnt measure the, alright, well we'll just go with the um	53.53
	1:	Time to make trial[?]	53.79
M	2:	I'm so confused.	54.3
		[end of tape A]	54.3
		[beginning tape B]	54.3
		[who is doing which part]	54.58
	1:	You put in the question and what we thought?	54.61
	3:	yeah, i put the question and the hypothesis.	54.63
	1:	Excellent.	54.64
	3:	I put that we thought that mass would have no affect on the period or the swinging time and length would be in particular the shorter the length is -	54.9
	1:	Excellent	54.97
	3:	- the faster the swinging period, or the complete period, something like that.	55.05
		[writing]	55.15
	1:	How do you spell scissors?	55.25
	3:	S-c-i-s-s-o-r-s	55.31
	4:	Do we really need to write all that down?	55.35
	1:	I dont know, i just [?] Are you doing ok?	55.51
	4:	Nods.	55.55

3:	You're doing the data, so that's like our calculations, ok, which part were you doing?	55.59
4:	The conclusion	55.63
3:	Conclusion	55.64
4:	Discussion	55.65
3:	Ok, you want me to write that? I could write that.	55.76
4:	I got it.	55.77
3:	You sure?	55.79
4:	Yeah, i'm almost done.	55.8
3:	Ok.	55.81
TA:	I'm gonna take you all's pen in like 30 seconds.	55.85
	[reading off data for white board]	56.28
2:	Just write on the bottom of that one this is all the same, in a different color, like regardless of different weights it's all the same, and this one it's like circle, pretty much our answer is like	56.52
TA:	You guys all done with this? [takes pen]	56.64
3:	Yeah.	56.91
	[writing]	57.19
TA:	Ok, is everybody ready?	57.47
3:	Oh my god	57.49
1:	This is so hard.	57.52
	[class discussion starts]	

Appendix F: Measurement Surveys

Preliminary Survey

This survey was given to 92 students as part of the lab quiz in the middle of the fall semester of 2001. It was administered in paper format, exactly as shown, and graded only for completion, not for reasoning.

Lab Quiz 1A:

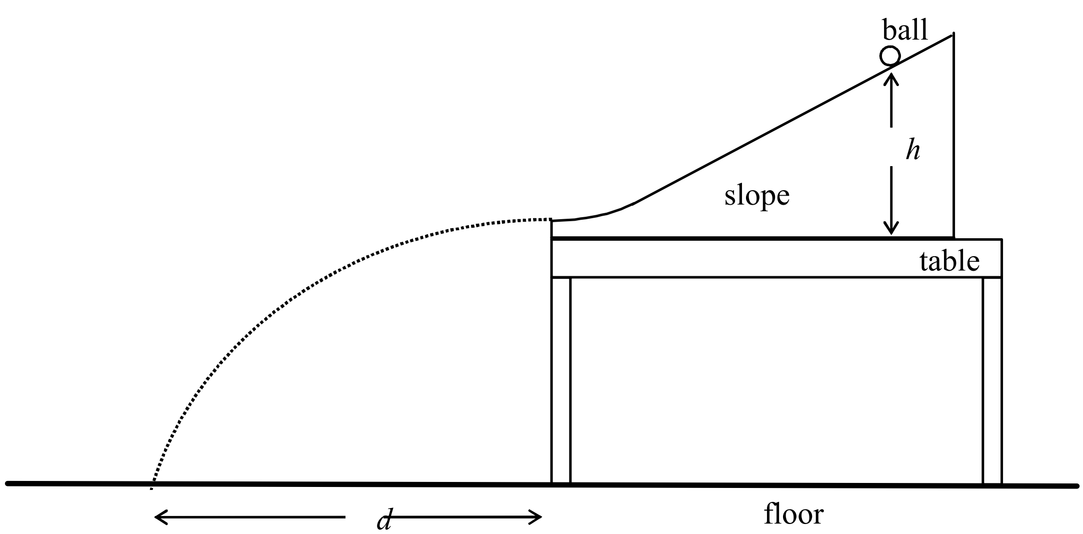
This part of the lab quiz will be graded only on your reasoning. Your answer will not be graded right or wrong, you will get full points for a full, well thought out answer.

It is recommended that you spend at **most 25 minutes** on this part of the quiz. Try to move through it quickly.

It is possible that some answers may be similar or exactly the same as others. Please write out all answers in full, even if you feel that you are repeating yourself.

Context:
An experiment is being performed by students in a physics laboratory. A wooden slope is clamped near the edge of a table. A ball is released from a height *h* above the table as shown in the diagram. The ball leaves the slope horizontally and lands on the floor a distance *d* from the edge of the table. Carbon paper is placed on the floor on which the ball makes a small mark when it lands.

The students have been asked to investigate how the distance *d* on the floor changes when the height *h* is varied. A meter stick is used to measure *d* and *h*.



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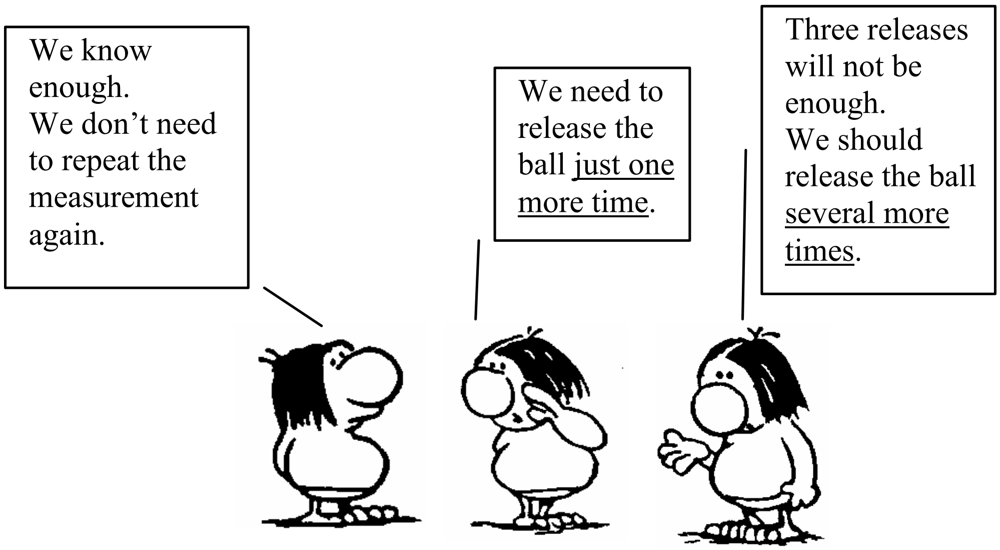
Supported by the National Research Foundation (South Africa)

1. The group of students decide to release the ball twice from $h = 400$ mm.

First release: $h = 400$ mm $d = 436$ mm
Second release: $h = 400$ mm $d = 426$ mm

The following discussion then takes place between the students.



A B C

With whom do you most closely agree? (Circle ONE):

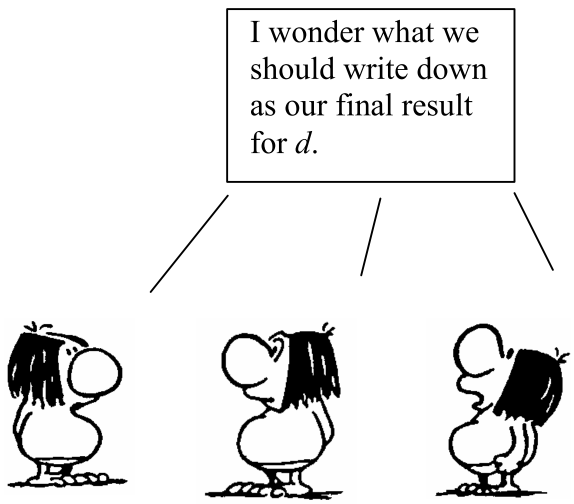
A	B	C

Explain your choice.

2. The students continue to release the ball down the slope at a height $h = 400$ mm. Their results after five releases are:

Release	d (mm)
1	436
2	425
3	440
4	425
5	434

The students then discuss what to write down for d as their final result.

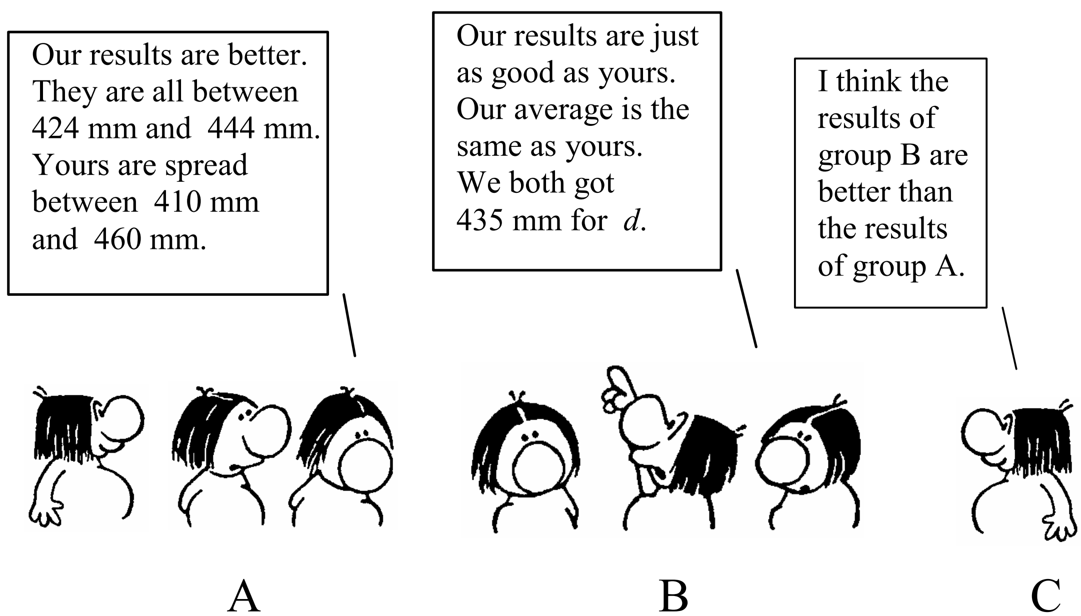


Write down what you think the students should record as their final result for *d*.

Explain your choice.

3. Two groups of students compare their results for d obtained by releasing the ball at h = 400 mm. Their results for five releases are shown below.

Release	Group A d (mm)	Group B d (mm)
1	444	441
2	432	460
3	424	410
4	440	424
5	435	440
Average:	**435**	**435**



With which group do you <u>most closely</u> agree? (Circle ONE):

A	B	C

Explain your choice.

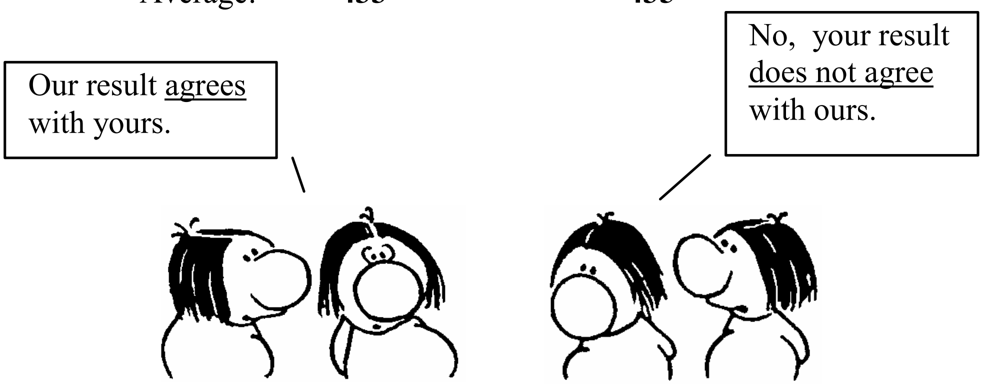
____

____

____

4. Two other groups of students compare their results for d obtained by releasing the ball at $h = 400$ mm. Their results for five releases are shown below.

Release	Group A d (mm)	Group B d (mm)
1	440	432
2	438	444
3	433	426
4	422	433
5	432	440
Average:	**433**	**435**



A   B

With which group do you most closely agree? (Circle ONE): | A | B |

Explain your choice.

____

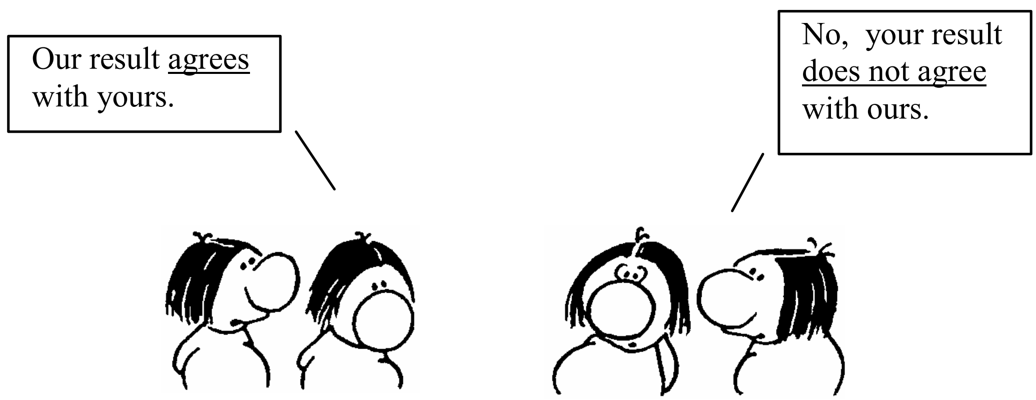
____

____

____

5. Two groups of students compare their results for d obtained by releasing the ball at $h = 400$ mm. Their results for five releases are shown below.

Release	Group A d (mm)	Group B d (mm)
1	444	458
2	435	438
3	424	462
4	440	449
5	432	443
Average:	**435**	**450**



A B

With which group do you most closely agree? (Circle ONE):

A	B

Explain your choice.

____

____

____

____

Free-Response Survey

This survey was administered before and after the spring semester of 2002, the electricity and magnetism second semester algebra-based physics course. Out of the 79 students who took both the pre and post survey, 43 were in the scientific community labs in the previous semester (the “old” students) and 36 were in traditional labs in the previous semester (the “new” students). It was administered in paper format, exactly as shown, and students received participation points for filling out the survey.

Lab Survey:

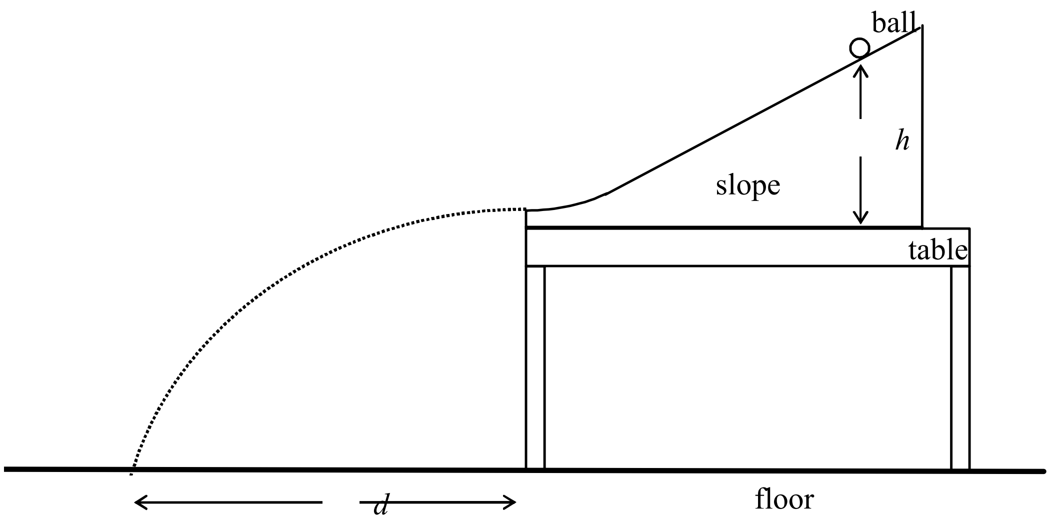
This survey will have no effect on your grade for this course, except for the participation points you will receive.

Try to move through it quickly.
Do not go back to a page after going on to the next question.

It is possible that some answers may be similar or exactly the same as others.
Please write out all answers in full, even if you feel that you are repeating yourself.

Context:
An experiment is being performed by students in a physics laboratory. A wooden slope is clamped near the edge of a table. A ball is released from a height *h* above the table as shown in the diagram. The ball leaves the slope horizontally and lands on the floor a distance *d* from the edge of the table. Carbon paper is placed on the floor on which the ball makes a small mark when it lands.

The students have been asked to investigate how the distance *d* on the floor changes when the height *h* is varied.
A meter stick is used to measure *d* and *h*.



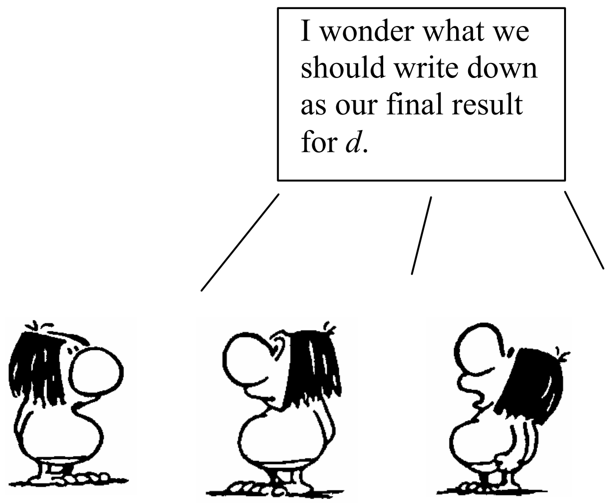
The questions on the following pages involve students performing an experiment with this apparatus.

Selected From
Physics Education Group
Physics Department, University of Cape Town with University of York Science Education Group.

1. The students release the ball down the slope at a height $h = 400$ mm.
Their results after five releases are:

Release	d (mm)
1	436
2	425
3	440
4	425
5	434

The students then discuss what to write down for d as their final result.

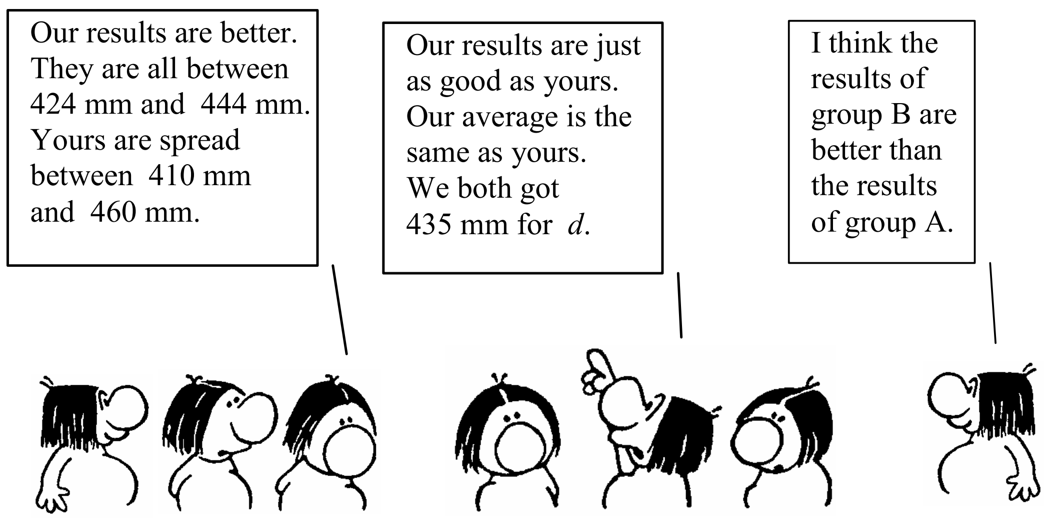


Write down what you think the students should record as their final result for d.

Explain your choice.

2. Two groups of students compare their results for d obtained by releasing the ball at h = 400 mm. Their results for five releases are shown below.

Release	Group A d (mm)	Group B d (mm)
1	444	441
2	432	460
3	424	410
4	440	424
5	435	440
Average:	**435**	**435**



A B C

With which group do you most closely agree (Circle ONE): | A | B | C |

Explain your choice.

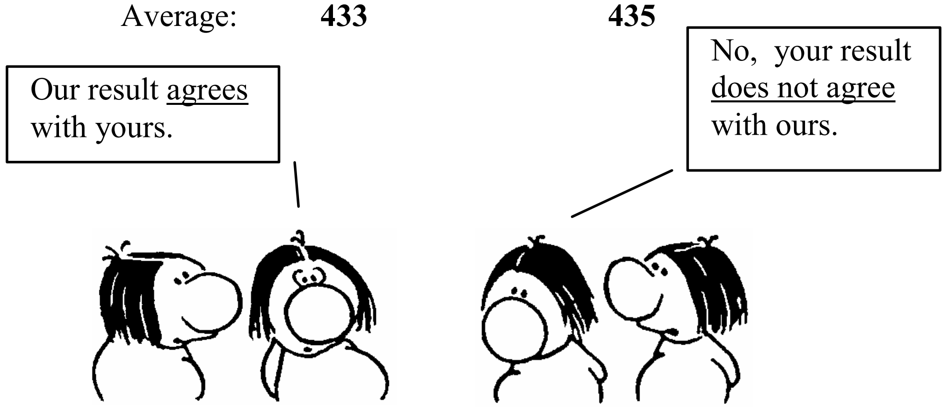
____

____

____

3. Two other groups of students compare their results for *d* obtained by releasing the ball
at *h* = 400 mm. Their results for five releases are shown below.

Release	Group A *d* (mm)	Group B *d* (mm)
1	440	432
2	438	444
3	433	426
4	422	433
5	432	440
Average:	**433**	**435**



A B

With which group do you most closely agree? (Circle ONE): | A | B |

Explain your choice.

____

____

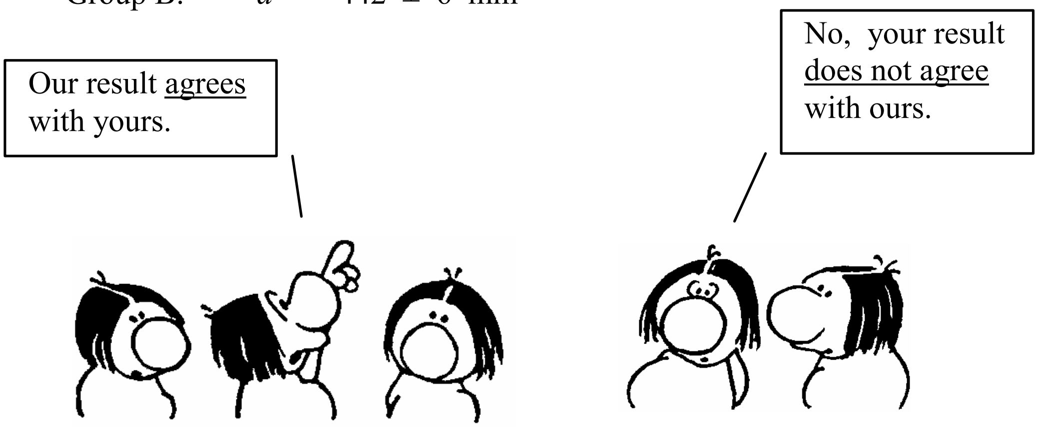
____

____

4. Two other groups of students compare their results for d obtained by releasing the ball at $h = 400$ mm. Their means and standard deviation of the means for their releases are shown below.

Group A: $d = 434 \pm 5$ mm

Group B: $d = 442 \pm 6$ mm



A B

With which group do you most closely agree? (Circle ONE): | A | B |

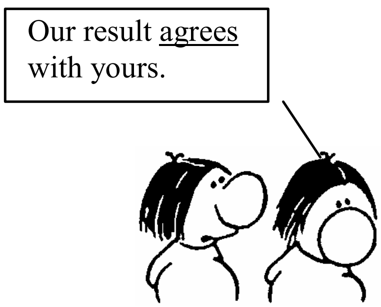
Explain your choice.

The two groups want to combine their results. What should they report as their combined result? Explain.

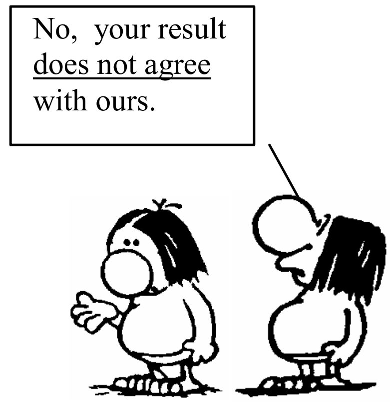
5. Another two groups of students compare their results for d obtained by releasing the ball at $h = 400$ mm. Their means and standard deviation of the means for their releases are shown below.

Group A: $d = 434 \pm 5$ mm

Group B: $d = 448 \pm 5$ mm



A



B

With which group do you most closely agree? (Circle ONE):

A	B

Explain your choice.

___

___

___

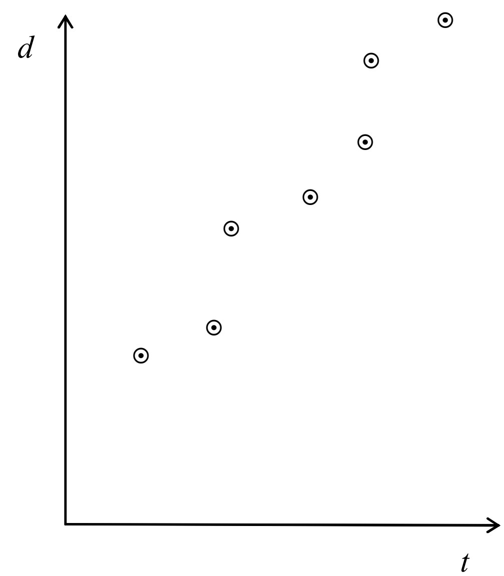
The two groups want to combine their results. What should they report as their combined result? Explain.

___

___

___

6. A group of students collect data at different heights and use it to plot a straight line graph. The data are plotted below. On this graph, draw the line that you think best fits this data.



Explain carefully what you have done and why.

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____

Multiple-Choice Survey

The multiple-choice survey was administered to 120 students before and after the scientific community labs in the fall 2002 semester. Students received participation points for taking the survey online. It was administered using the survey tool of WebCT, with JavaScript programming. The JavaScript is included in the following section.

---

1. The students release the ball down the slope at a height h = 400 mm.
Their results after five releases are:

Release:	1	2	3	4	5
d (mm):	436	425	440	425	434

Write down what you think the students should record as their final result for *d*.

2. Two groups of students compare their results for *d* obtained by releasing the ball at *h* = 400 mm. Their results for five releases are shown below.

	Release	**1**	**2**	**3**	**4**	**5**	**Average**
Group A	**d (mm)**	444	432	424	440	435	435
Group B	**d (mm)**	441	460	410	424	440	435

How do their results compare?

Group A's results are just as good as group B's.

1. Both averages are the same. They both got 435 mm for d.
2. It doesn't really matter what data they got, what matters is that they got the same result.
3. Different groups use different methods, just as long as they come out the same, it's fine.
4. Whatever human error the groups did, they did it routinely to get 435 as an average.
5. other

Group A's results are better.

6. Group A's results are all between 424 mm and 444 mm. Their results are more consistent and have a smaller range. Because A's range is smaller there is less variance in their data which possibly could have resulted from less error.
7. Since group A's results are closer together, their average is more believable.
8. Values that are inconsistent may not be reproducible. It may just be luck that gave both groups the same average.
9. other

3. Two other groups of students compare their results for d obtained by releasing the ball at $h = 400$ mm. Their results for five releases are shown below.

	Release	1	2	3	4	5	Average
Group A	**d (mm)**	440	438	433	422	432	433
Group B	**d (mm)**	432	444	426	433	440	435

Do the results of these two groups agree?

Yes

1. There isn't a significant difference between the two group's results.
2. Everything has error, it's impossible to get exactly the same every time.
3. There's a difference of two millimeters between the two group's averages. Two millimeters is small, and so they pretty much have the same result.
4. Both groups got the values 440, 433, and 432.
5. Group A's range is from 422 to 440, group B's from 426 to 444, so the ranges overlap.
6. Both group A and group B have a range that is 18 mm wide, so their results are the same.
7. Other

No

8. Their averages are different.
9. There is a significant difference between the two group's results.
10. The difference of two millimeters is a large difference compared to the distances they're measuring.
11. Group A's range is from 422 to 440, group B's range from 426 to 444, they only overlap for 4 mm which is not enough.
12. Other

4. Two other groups of students compare their results for d obtained by releasing the ball at $h = 400$ mm. Their results for five releases are shown below.

	Release	1	2	3	4	5	Average
Group A	**d (mm)**	444	435	424	440	432	435
Group B	**d (mm)**	458	438	462	449	443	450

Do the results of these two groups agree?

Yes

1. There isn't a significant difference between the two group's results.
2. Everything has error, it's impossible to get exactly the same every time.
3. There's a difference of 15 millimeters between the two group's averages. Fifteen millimeters is small, and so they pretty much have the same result.
4. Group A's range is from 424 to 444, group B's from 438 to 462, so the ranges overlap.
5. Other

No

6. Their averages are different.
7. There is a significant difference between the two group's results.
8. The difference of fifteen millimeters is a large difference compared to the distances they're measuring.
9. Group A's range has a width of 20 mm, and group B's range has a width of 24 mm, so they have different results.
10. Group A's range is from 424 to 444, group B's range is from 438 to 462, they only overlap for 6 mm which is not enough.
11. Other

5. Two other groups of students compare their results for d obtained by releasing the ball at $h = 400$ mm. Their means and standard deviation of the means for their releases are shown below.

Group A: $d = 434 \pm 5$ mm

Group B: $d = 442 \pm 6$ mm

Do the results of these two groups agree?

Yes

1. There isn't a significant difference between the two group's results.
2. Everything has error, it's impossible to get exactly the same every time.
3. There's a difference of eight millimeters between the two group's averages. Eight millimeters is small, and so they pretty much have the same result.
4. Group A's range is from 429 to 439, group B's from 436 to 448, so the ranges overlap.
5. Other

No

6. Their averages are different.
7. There is a significant difference between the two group's results.
8. The difference of eight millimeters is a large difference compared to the distances they're measuring.
9. Group A's range has a width of 10 mm, group B's range has a width of 12 mm, so they have different results.
10. Group A's range is from 429 to 439, group B's range is from 436 to 448, they only overlap for 3 mm which is not enough.
11. Group A's average of 434 does not fall within the range for group B (436 to 448), and vice versa.
12. Other

6. The two groups want to combine their results. What should they report as their combined result?

1. They cannot combine their results.
2. They shouldn't combine their results, because their results don't agree.
3. They should take the average, 438 ± 5.5
4. They should report the full range of all their data, 429 to 448.
5. They should report the average, 438, with the range of both group's data, 429 to 448.
6. They should put all their data points together and use those to calculate an average and a standard deviation.
7. Other

7. Another two groups of students compare their results for d obtained by releasing the ball at $h = 400$ mm. Their means and standard deviation of the means for their releases are shown below.

Group A: $d = 434 \pm 5$ mm

Group B: $d = 448 \pm 5$ mm

Do the results of these two groups agree?

Yes

1. There isn't a significant difference between the two group's results.
2. Everything has error, it's impossible to get exactly the same every time.
3. Both groups have the same range, a standard deviation of 5 mm.
4. There's a difference of 14 millimeters between the two group's averages. 14 millimeters is small, and so they pretty much have the same result.
5. Group A's range is from 429 to 439, group B's from 443 to 453. They are off by only four millimeters, which is small, so their results agree.
6. Other

No

7. Their averages are different.
8. There is a significant difference between the two group's results.
9. The difference of 14 millimeters is a large difference compared to the distances they're measuring.
10. Group A's range is from 429 to 439, group B's range is from 443 to 453. They do not overlap, so their results contradict.
11. Group A's average of 434 does not fall within the range for group B (443 to 453), and vice versa.
12. Other

8. The two groups want to combine their results. What should they report as their combined result?

1. They cannot combine their results.
2. They should not combine their results, because their results do not agree.
3. They should take the average, 441 ± 5
4. They should report the full range of all their data, 429 to 453.
5. They should report the average, 441, with the range of both group's data, 429 to 453.
6. They should put all their data points together and use those to calculate an average and a standard deviation.
7. Other

JavaScript Programming

The survey was administered using WebCT with JavaScript. The text for question 2, formatted so it could be imported into WebCT, is included below.

```
# Start of question: 2 - Question 2

:TYPE:MC:N:0:C
:TITLE:02 - Question 2
:FEEDBACK

:QUESTION:H
<SCRIPT LANGUAGE="javascript">
var stop = 0;
function LinkUp(number)
{
if(stop == 1)
{
```

```
alert("You have already seen one window of reasons.  Choose an answer below and
move on")
}
if(number == "1"&&stop == "0")
{
window.open ("/_COURSEID_/labsrvy/q1r1.html", "newwindow",
config="height=335,width=400,toolbar=no,menubar=no,scrollbars=no,resizable=yes,loc
ation=no,directories=no,status=no")
stop = 1;
}
if(number == "2" && stop == "0")
{
window.open ("/_COURSEID_/labsrvy/q1r2.html", 'newwindow',
config="height=310,width=400,toolbar=no,menubar=no,scrollbars=no,resizable=yes,loc
ation=no,directories=no,status=no")
stop = 1;
}
if(number == null)
{
alert('Choose reason other')
}
}
</SCRIPT>
<p><b>Question 2\:</b><br>
<LI>Two groups of students compare their results for  d  obtained by releasing the ball at
h=400 mm.  Their results for five releases are shown below.<br> <br>
<table border=0 cellspacing=0 cellpadding=0 >
<tr >
<td width=85 >
<p class=MsoNormal align=center > </p></td>
<td width=85 >
<p class=MsoNormal align=center><b>Release<o\:p></o\:p></b></p></td>
<td width=65 >
<p class=MsoNormal align=center ><b>1<o\:p></o\:p></b></p></td>
<td width=65 >
<p class=MsoNormal align=center ><b>2<o\:p></o\:p></b></p></td>
<td width=65 >
<p class=MsoNormal align=center ><b>3<o\:p></o\:p></b></p></td>
<td width=65 >
<p class=MsoNormal align=center ><b>4<o\:p></o\:p></b></p></td>
<td width=65 >
<p class=MsoNormal align=center ><b>5<o\:p></o\:p></b></p></td>
<td width=102 >
<p class=MsoNormal align=center ><b>Average<o\:p></o\:p></b></p></td>
</tr>
<tr >
```

```
<td width=85 >
<p class=MsoHeader align=center ><b>Group
A<o\:p></o\:p></b></p></td>
<td width=85 >
<p class=MsoNormal align=center ><b>d (mm)<o\:p></o\:p></b></p></td>
<td width=65 >
<p class=MsoNormal align=center >444</p></td>
<td width=65 >
<p class=MsoNormal align=center >432</p></td>
<td width=65 >
<p class=MsoNormal align=center >424</p></td>
<td width=65 >
<p class=MsoNormal align=center >440</p></td>
<td width=65 >
<p class=MsoNormal align=center >435</p></td>
<td width=102 >
<p class=MsoNormal align=center >435</p></td>
</tr>
<tr style='height\:17.0pt'>
<td width=85 >
<p class=MsoNormal align=center ><b>Group B<o\:p></o\:p></b></p></td>
<td width=85 >
<p class=MsoNormal align=center ><b>d (mm)<o\:p></o\:p></b></p></td>
<td width=65 >
<p class=MsoNormal align=center >441</p></td>
<td width=65 >
<p class=MsoNormal align=center >460</p></td>
<td width=65 >
<p class=MsoNormal align=center >410</p></td>
<td width=65 >
<p class=MsoNormal align=center >424</p></td>
<td width=65 >
<p class=MsoNormal align=center >440</p></td>
<td width=102 >
<p class=MsoNormal align=center >435</p></td>
</tr>
</table>
<br>
<b>How do their results compare?</b>
<br> 
<br>
Choose one, and a window will appear with reason choices.<br>
You are only allowed to click once in this drop-down menu <br>
<SELECT NAME="DDlinks" onChange="LinkUp(selectedIndex)" >
<OPTION SELECTED>----pick one-----
<OPTION VALUE="1">They are the same
```

```
<OPTION VALUE="2">Group A's results are better than Group B's
<OPTION VALUE="3">Other
</SELECT>
:IMAGE:
:LAYOUT:vertical
:ANSWER1:10:H
<b>Group A's results are just as good as group B's</b> <br>
    Reason 1
:ANSWER2:10:H
    Reason 2
:ANSWER3:10:H
    Reason 3
:ANSWER4:10:H
    Reason 4
:ANSWER5:10:H
    Reason not mentioned.  <br>
    Please write your reason in the box on the next question.
:ANSWER6:10:H
<b>Group A's results are better.</b><br>     Reason 6
:ANSWER7:10:H
    Reason 7
:ANSWER8:0:H
    Reason 8
:ANSWER9:0:H
    Reason not mentioned.  <br>
    Please write your reason in the box on the next question.
:CAT:prenew
# End of question: 2 - Question 2
```

Multiple-Choice Survey Results

Explanation:
The numbers of students who selected each answer choice are shown for the pre and post survey. The values assigned each answer choice are shown with s or p for set or point, respectively, followed by their number value, with o standing for the “other” option which was not assigned a value.

Q1	pre	post
take an average:	90	98
range:	2	19
units:	15	9
# answered just 425:	7	5
# answered just 440:	5	1
# answered just 430:	6	2

		1	2	3	4	5	6	7	8	9	10	11	12
Q2	**values**	p3	p3	p3	p2	o	s3	s3	s3	o			
	pre	18	4	7	12	1	73	9	10	1			
	post	10	4	5	4	4	83	15	5	0			
Q3													
	values	s1	s1	p3	p3	s3	p3	o	p3	p1	p3	s3	o
	pre	61	24	14	1	14	2	6	14	3	2	6	0
	post	45	11	8	2	52	6	3	2	3	2	6	1
Q4													
	values	s1	s1	p3	p3	s3	o	p3	p1	p3	s3	o	
	pre	11	4	1	5	1	3	20	56	21	19	6	
	post	2	3	5	3	3	2	11	31	12	53	5	
Q5													
	values	s1	s1	p3	s3	o	p3	p1	p3	p3	s3	s3	o
	pre	22	19	8	25	1	14	24	8	1	13	10	2
	post	17	4	8	35	2	3	10	2	3	29	14	1
Q6													
	values	p1	p1	p3	s3	s3	s3	o					
	pre	3	16	11	22	21	58	1					
	post	8	17	14	22	42	24	3					
Q7													
	values	s1	s1	p3	p3	s3	o	p3	p1	p3	s3	s3	o
	pre	5	6	4	1	2	2	16	34	13	39	22	3
	post	2	4	1	4	3	0	8	17	5	69	24	1
Q8													
	values	p1	s1	p3	s3	s3	s3	o					
	pre	10	35	6	10	19	46	2					
	post	20	54	6	8	20	19	0					

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