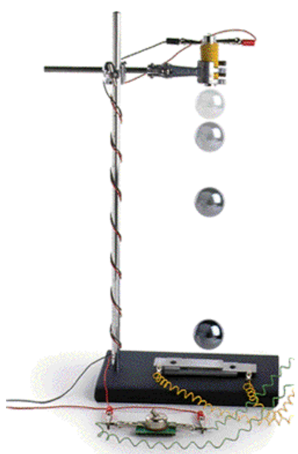
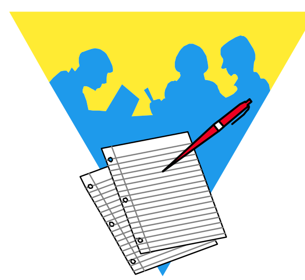
Chapter 3

Teaching a Laboratory Section





I. Cooperative Problem Solving Labs in Operation

The Cooperative Problem Solving (CPS) labs at the University of Minnesota are different from any labs you have experienced. This section describes the goals of the labs, the structure of the labs, and the structure of individual lab problems.

Goal of University of Minnesota Labs

Joe Redish (2003, page 162) describes a variety of different possible goals for a laboratory, from confirmation (demonstrating the correctness of theoretical results presented in the lecture) through inquiry (empiricism) (to help students understand the empirical basis of science) to attitude goals (to help students gain an appreciation of the role independent thought and coherence in scientific thinking). It is impossible to satisfy all of these goals with a single laboratory design. Because University of Minnesota courses follow the traditional structure of learning physics through solving problems, **the goal of the laboratory is to provide students with practice and coaching in using a logical, organized problem solving process to solve problems.** IN OTHER WORDS, THE GOAL OF THE LABS IS THE *SAME* AS THE GOAL OF THE DISCUSSION SECTION -- to help students slowly abandon their novice problem-solving strategies (e.g., plug-and-chug or pattern matching) and adopt a more logical, organized problem-solving procedure that includes the qualitative analysis of the problem. Since one reason that our students cannot solve physics problems is that they have misconceptions about the physics, a second goal is to confront some of those misconceptions in the laboratory.

Instructions for problem-solving labs are different from the instructions for other labs with different goals. A comparison of problem-solving labs with traditional confirmation and inquiry labs is shown in Figure 1 on the next page. You will not find a detailed discussion of the principles explored by the lab; you will not find any algebraic derivations of the equation to be used in the lab; and you will not find step-by-step instructions telling the students what to do. Instead, our labs allow students to practice solving problems (making decisions) based on the physics presented in the other parts of the class: the lecture and the text.

What Are Problem Solving Labs

The student lab manuals are divided into about 5-7 two-to-three-week topics, called *Labs*. For example, part of the Table of Contents from the lab manual for the course for scientists and engineers (Physic 1301) is shown in Figure 2 on page 55. The labs/topics for the first 9-10 weeks of the course are: Laboratory I: Description of Motion in One Dimension, Laboratory II: Description of Motion in Two Dimensions, Laboratory III: Forces, and Laboratory IV: Conservation of Energy. The manual also includes an technique and equipment appendices. For example, the appendices for Physics 1301 are:

Appendix A: Significant Figures
Appendix B: Accuracy, Precision, and Uncertainty
Appendix C: Graphing
Appendix D: Video Analysis of Motion
Appendix E: Sample Laboratory Reports
Appendix F: Simulation Programs.

Figure 1. Comparison of Different Types of Labs

TRADITIONAL CONFIRMATION LABS	U OF MN PROBLEM-SOLVING LABS	INDUCTIVE OR "INQUIRY" LABS
MAJOR GOAL: To illustrate, support what is being learned in the course and teach experimental techniques	**MAJOR GOAL:** To illustrate, support a logical, organized problem-solving process	**MAJOR GOAL:** To learn the process of doing science
INTRODUCTION: • Students are given quantity to compare with measurement. • Students are given theory and how to apply it to the lab. • Students are given the prediction (value measurement should yield).	**INTRODUCTION:** • Students are given a problem to solve. • Students must apply theory from text/lecture. • Students predict what their measurements should yield.	**INTRODUCTION:** • Students are given a question to answer. • Sometimes students are given related theory. • Sometimes students are asked for a prediction.
METHODS: • Students are told *what* to measure. • Students are told *how* to make the measurements.	**METHODS:** • Students are told *what* to measure. • Students decide in groups *how* to make the measurements (guided qualitative exploration).	**METHODS:** • Students decide *what* to measure. • Students decide *how* to make the measurements (open-ended qualitative exploration).
ANALYSIS: • Students usually given analysis technique(s). • Emphasis is on precision and experimental errors.	**ANALYSIS:** • Students decide in groups details of analysis. • Emphasis is on concepts (quantitatively).	**ANALYSIS:** • Students must determine analysis techniques. • Emphasis is on concepts (qualitatively).
CONCLUSION: Students determine how well their measurement matches the accepted value.	**CONCLUSION:** Students determine if their own ideas (prediction) match their measurement.	**CONCLUSION:** Students construct an hypothesis to explain their results.

Figure 2. First Page of Phys 1301 Table of Contents

The Labs themselves are comprised of an introduction page and several lab problems. ***Notice that we do not do experiments in our "laboratory."*** Students typically use the same equipment for a Lab topic. There are more problems than can be taught in the available time. The teaching team for each course section selects a preferred order of problems and the minimum number of problems to be completed *to match the emphasis of the lectures*. In addition, the extra problems allow you the flexibility to select the problems that meet the needs of each particular group. Some of your groups may understand the material and need to be challenged with more-difficult problems to deepen their knowledge and problem solving skills. [This also keeps these groups from becoming bored.] On the other hand, some groups will have difficulty applying their knowledge to solve the problems, and may need to concentrate on a specific difficulty by doing a second, very similar problem.

Structure of the Lab Problems

Skim the two lab problems for the calculus-based course for scientists and engineers (Physics 1301) at the end of this section: Lab I Problem #3: Motion Up and Down an Incline (page 61), and Lab III Problem #1: Forces and Motion (page65). Notice that each lab problem has eight sections (the problem, Equipment, Prediction, Method Questions, Exploration, Measurement, Analysis, and Conclusion). Students read the first four sections of the assigned lab problems (the problem, *Equipment*, Prediction, and *Method Questions*) **before** class. These sections are designed to help students solve the problem. They hand in their problem solutions one or two days before the lab session. During the lab sessions, students collect and analyze data to check their solution (that is, to see if they solved the problem correctly). The *Exploration*, *Measurement*, *Analysis and Conclusion* sections guide students through the process of checking their solution. Typically, it takes students less than an hour to check their solution for one lab problem (if they have done their homework). They should analyze all the data and reach a conclusion in class before starting to discuss and work on the next assigned problem.

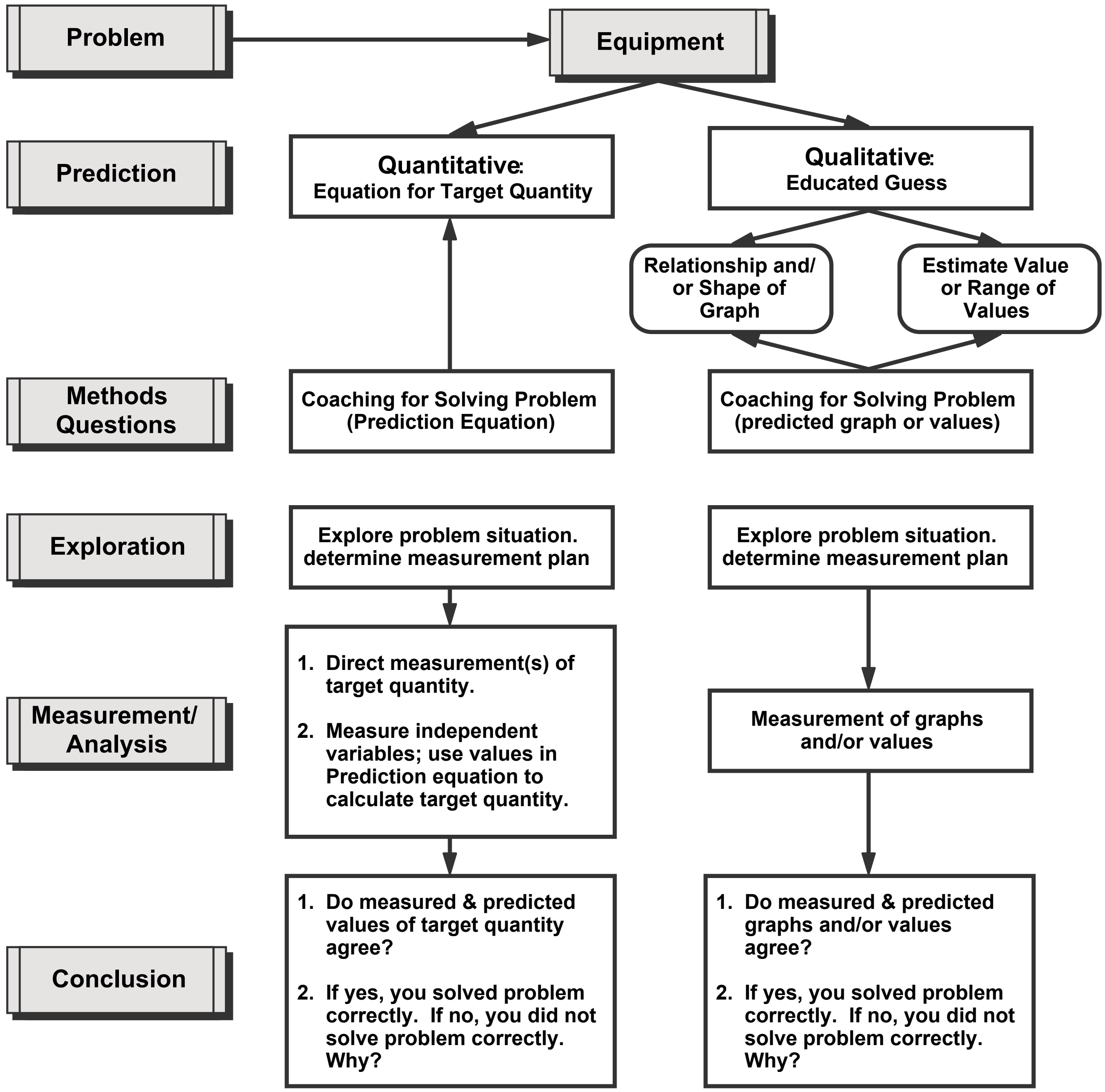
Before a Lab Session

The lab problems are similar to the ones found at the end of a textbook chapter or in a discussion session. There are two different types of lab problems, as shown in Figure 3 on the next page. That is, the problem may require a **qualitative** solution (educated guess) or a **quantitative** (algebraic or calculus) solution. There are two types of qualitative problems. Students may be asked to predict a relationship and/or the shape of a graph. Lab I Problem #1 (page 61) is an example of this type of qualitative problem. For the second type of qualitative problem, students usually predict the value (or range of values) of a physical quantity, such as the coefficient of sliding friction for different surfaces.

After Lab I, qualitative problems are usually found only at the beginning of a Lab. The majority of the problems are quantitative. Lab III Problem #1 (page 65) is an example of a quantitative problem. Students solve the problem for a target quantity (e.g., velocity). The physical quantities on the right side of the prediction equation (e.g., mass of the object A, the mass of the cart, and the distance object A falls) are called the *independent* variables. To check their algebraic solution (prediction equation) during lab, students:

1. measure the target quantity
2. measure the independent variables and substitute these values into their prediction equation to calculate the target variable.

Figure 3. Types of Laboratory Problems



This allows students to determine if they solved the problem correctly (see Figure 3 above).

Look at the ***Method Questions*** for Lab I Problem #1 (page 61) and Lab III Problem #1 (page 66). Method questions are designed to coach students through a logical, organized problem-solving process to arrive at the problem solution. The method questions are the only *individual* "coaching" students receive for solving problems in our introductory courses. Notice that each method question corresponds to a specific part of the problem-solving framework that you designed for students to use during discussion sessions.

Look at the ***Prediction*** sections for Lab I Problem #3 and Lab III Problem #1. Notice that this section restates of the problem question *in terms of the lab equipment and measurements*. In the course for scientists and engineers (Physics 1301), the prediction section changes at beginning in Lab 5 (Conservation of Momentum). At this point, students are required to restate or reformulate the problem themselves. Some examples of the *Prediction* section, starting in Lab 5, are shown below.

> Example Prediction A. "Restate the problem to identify your target and get the relationships useful for the three cases considered in the problem."
>
> Example Prediction B. "What are you trying to calculate? Restate the problem to clearly identify your objective."
>
> Example Prediction C. Reformulate the problem in your own words to understand its target. What do you need to calculate?

At his point, solving a lab problem is analogous to solving a problem in a discussion session or for homework. Good problem solving requires informed decision-making. The first decisions students must make are: What is the question? What physical quantity (target quantity) do I need to calculate to solve the problem?

The *Prediction* section comes before the *Method Questions* section so that students will understand the language of the method questions. But students tend to do things in the order presented, so you will have to remind students to follow the problem-solving framework outlined in the method questions to solve the problem (complete the prediction). Of course, if a student can solve the problem in a logical and organized manner, the *Method Questions* serve as a check of their problem solving process.

During a Lab Session

Unlike a confirmation or inquiry lab, the **purpose of collecting data in problem-solving labs is to allow students to check their problem solution** (answers to Method Questions and Prediction**)**. Examine the *Exploration*, *Measurement*, and *Analysis* sections for Lab I Problem #3 (page 62) and Lab III Problem #1 (page 67). Notice that these sections provide students with minimal guidance -- they are not the step-by-step instructions found in confirmation laboratories. As with any problem, there are usually several correct paths. Discussing the possible choices within the group gives each student the opportunity to solidify correct concepts and dispel alternative conceptions. This freedom also allows groups to make incorrect choices. It is another true cliché that "we learn from our mistakes."

The ***Exploration*** section encourages the students to become familiar with the experimental set-up so they will understand the range over which valid measurements can be made. This is the most important section of the lab, and the one that students tend to skip. **Don't let them.** This is where students develop a "feel" for the real world that is a crucial guide in solving problems. This is also where students can qualitatively test their alternative conceptions about the physical process occurring. The outcome of the *Exploration* should be an organized plan for making the measurements.

The ***Measurement*** section asks the students to collect the data needed to check their problem solution. This usually involves collecting the data necessary to determine the values of a target quantity (e.g., velocity) and/or make one or more graphs. During the first semester, students use a camera and computer program called VideoRECORDER to make one or more digital movie(s) of the motion of an object. For quantitative problems (like Lab I Problem #3), students collect additional data -- they measure the independent variables (e.g., mass of the object A, the mass of the cart, and the distance object A falls) on the right side of their prediction equation (problem solution).

In the ***Analysis*** section, students analyze the data so it is in a form that will allow them to compare experimental results with their prediction. In the first semester, the computer program called VideoTOOL is used for part of the analysis. For quantitative problems (like Lab III Problem #1, students also use their measurements of the independent variables to calculate the value of the target quantity using their prediction equation (problem solution).

Examine the ***Conclusion*** sections for Lab I Problem #3 (page 64) and Lab III Problem #1 (page 68). Notice that there are usually two or three parts of the conclusion. In the first part, students compare their results with their predicted problem solution. If their results do not match their predicted problem solution, then they know that their solution was incorrect. Students are asked to explain why their solution was incorrect.

> Lab I Problem #3. How do your position-versus-time, velocity-versus-time, and acceleration-versus-time graphs compare with your answers to the method questions and the prediction? …If there are any differences between your predictions and your experimental results, describe them and explain why they occurred.
>
> Lab III Problem #1. How does the velocity from your prediction equation in each case compare with the two *measured* velocities (measured with video analysis, and also with stopwatch / meterstick measurements)? Did your measurements agree with your initial prediction? If not, why?

For some problems, the second set of questions are designed to have students think about the solution of the original problem:

> Lab I Problem #3. Did the cart have the same acceleration throughout its motion? Did the acceleration change direction? Was the acceleration zero at the top of its motion? Describe the acceleration of the cart through its entire motion **after** the initial push. Justify your answer with kinematics arguments and experimental results.
>
> Lab III Problem #1. Does the launch velocity of the car depend on its mass? The mass of the block? The distance the block falls?

Finally, students answer a set of question designed to help them address common alternative conceptions:

> Lab I Problem #3. Did the cart have the same acceleration throughout its motion? Did the acceleration change direction? Was the acceleration zero at the top of its motion? Describe the acceleration of the cart through its entire motion **after** the initial push. Justify your answer with kinematics arguments and experimental results.
>
> Lab III Problem #1. If the same block falls through the same distance, but you change the mass of the cart, does the force the string exerts on the cart change? Is the force of

the string on object A *always* equal to the weight of object A? Is it *ever* equal to the weight of object A? Explain your reasoning.

Notice that in Lab I Problem #3, the same set of questions serves two purposes – to think about the answer to the original problem AND address common alternative conceptions.

Pre-lab Computer Quiz

For some courses, students are required to pass a pre-lab quiz before every lab session (your professor will decide whether this quiz is required). The quiz questions are designed to make sure that students have read the relevant sections of the text ***before*** the lab. There is nothing more wasteful of both your time and that of your students than their having to read the text during the laboratory period for the first time.

The questions require minimal understanding of the concepts in the text and are a good preparation for the lectures as well as the laboratory. If a student misses a question, the test is expanded to give them another chance to answer a similar question correctly. The more questions that the student misses, the longer the test. Students can use their textbook, their notes, and consult with other students when they take the quiz. The important thing is that they come to lab prepared.

When a student keeps getting the same question wrong even though they are sure they put in the right answer, it is almost never a computer glitch -- usually the student has an alternative conception. This is an excellent opportunity for instruction. Each student's score is recorded in a report file for your use. A student who has read the material with some understanding should pass the quiz in less than 15 minutes. Of course, this rarely happens. Typically students read their text *for the first time* while they are taking the quiz, so they can take from 30 - 45 minutes to learn the information. If a student is taking more than 60 minutes to pass the check out, this is probably too much time and you should discuss the difficulty with the student. See Chapter 5 for details of how to access the quiz and the quiz report.

LABORATORY I. DESCRIPTION OF MOTION IN ONE DIMENSION

Problem #3. Motion Up And Down an Incline

A proposed ride at the Valley Fair amusement park launches a roller coaster car up an inclined track. Near the top of the track, the car reverses direction and rolls backwards into the station. As a member of the safety committee, you have been asked to describe the acceleration of the car throughout the ride. (The launching mechanism has been well tested. You are only concerned with the roller coaster's trip up and back down.) To test your expectations, you decide to build a laboratory model of the ride.

EQUIPMENT

For this problem, you will have a stopwatch, a meter stick, an end stop, a wood block, a video camera and a computer with a video analysis application written in LabVIEW™ (VideoRECORDER and VideoTOOL applications). You will also have a cart to roll up an inclined track.

PREDICTION

Make a rough sketch of how you expect the acceleration vs. time graph to look for a cart with the conditions discussed in the problem. The graph should be for the entire motion of going up the track, reaching the highest point, and then coming down the track.

Do you think the acceleration of the cart moving up an inclined track will be ***greater than****,* ***less than****, or* ***the same as*** *the acceleration of the cart moving down the track? What is the acceleration of the cart at its highest point? Explain your reasoning.*

METHOD QUESTIONS

The following questions should help you examine the consequences of your prediction.

Read: Fishbane Chapter 2, Sections 2.1-2.4

1. Sketch a graph of the *instantaneous acceleration vs. time graph* you expect for the cart as it rolls up and then back down the track **after** an initial push. Sketch a second *instantaneous acceleration vs. time graph* for a cart moving up and then down the track with the direction of a constant acceleration always down along the track **after** an initial push. On each graph, label the instant where the cart reverses its motion near the top of the track. Explain your reasoning for each graph. Write down the

equation(s) that best represents each graph. If there are constants in your equations, what kinematic quantities do they represent? How would you determine these constants from your graphs?

2. Write down the relationship between the acceleration and the velocity of the cart. Use that relationship to construct an *instantaneous velocity vs. time graph* just below each of acceleration vs. time graph from question 1, with the same scale for each time axis. (The connection between the derivative of a function and the slope of its graph will be useful.) On each graph, label the instant where the cart reverses its motion near the top of the track. Write an equation for each graph. If there are constants in your equations, what kinematic quantities do they represent? How would you determine these constants from your graphs? Can any of the constants be determined from the constants in the equation representing the acceleration vs. time graphs?

3. Write down the relationship between the velocity and the position of the cart. Use that relationship to construct an *instantaneous position vs. time graph* just below each of your velocity vs. time graphs from question 2, with the same scale for each time axis. (The connection between the derivative of a function and the slope of its graph will be useful.) On each graph, label the instant where the cart reverses its motion near the top of the track. Write down an equation for each graph. If there are constants in your equations, what kinematic quantities do they represent? How would you determine these constants from your graphs? Can any of the constants be determined from the constants in the equations representing velocity vs. time graphs?

4. Which graph do you think best represents how position of the cart will change with time? Adjust your prediction if necessary and explain your reasoning.

EXPLORATION

What is the best way to change the angle of the inclined track in a reproducible way? How are you going to measure this angle with respect to the table? (Think about trigonometry.)

Start the cart up the track with a gentle push. **BE SURE TO CATCH THE CART BEFORE IT HITS THE END STOP ON ITS WAY DOWN!** Observe the cart as it moves up the inclined track. At the instant the cart reverses direction, what is its velocity? Its acceleration? Observe the cart as it moves down the inclined track. Do your observations agree with your prediction? If not, discuss it with your group.

Where is the best place to put the camera? Which part of the motion do you wish to capture?

Try different angles. **Be sure to catch the cart before it collides with the end stop at the bottom of the track.** If the angle is too large, the cart may not go up very far and will give you too few video frames for the measurement. If the angle is too small, it will be difficult to measure the acceleration. Take a practice video and play it back to make sure you have captured the motion you want (see the "Exploration" section in Problem 1, and appendix D, for hints about using the camera and VideoRECORDER / VideoTOOL). *Hint: To analyze motion in only one dimension (like in the previous problem) rather than two dimensions, it could be useful to rotate the camera!*

What is the total distance through which the cart rolls? How much time does it take? These measurements will help you set up the graphs for your computer data taking, and can provide for a check on your video analysis of the cart's motion.

Write down your measurement plan.

MEASUREMENT

Follow your measurement plan to make a video of the cart moving up and then down the track at your chosen angle. Record the time duration of the cart's trip, and the distance traveled. Make sure you get enough points for each part of the motion to determine the behavior of the acceleration. *Don't forget to measure and record the angle (with estimated uncertainty).*

Work through the complete set of calibration, prediction equations, and fit equations for a single (good) video before making another video.

Make sure everyone in your group gets the chance to operate the computer.

ANALYSIS

From the time given by the stopwatch and the distance traveled by the cart, calculate its average acceleration. Estimate the uncertainty.

Look at your graphs and rewrite all of the equations in a table, but now matching the *dummy letters* with the appropriate kinematic quantities. If you have constant values, assign them the correct units, and explain their meaning.

Can you tell from your graph where the cart reaches its highest point?

From the velocity vs. time *graph,* determine if the acceleration changes as the cart goes up and then down the ramp. Use the *function* representing the velocity vs. time graph to calculate the acceleration of the cart as a function of time. Make a graph of that function. Can you tell from this *instantaneous acceleration-versus-time graph* where the cart reaches its highest point? Is the average acceleration of the cart equal to its instantaneous acceleration in this case?

Compare the acceleration function you just graphed with the average acceleration you calculated from the time on the stopwatch and the distance the cart traveled.

CONCLUSION

How do your position-versus-time, velocity-versus-time, and acceleration-versus-time graphs compare with your answers to the method questions and the prediction? What are the limitations on the accuracy of your measurements and analysis?

Did the cart have the same acceleration throughout its motion? Did the acceleration change direction? Was the acceleration zero at the top of its motion? Describe the acceleration of the cart through its entire motion **after** the initial push. Justify your answer with kinematic arguments and experimental results. If there are any differences between your predictions and your experimental results, describe them and explain why they occurred.

SIMULATION

If your data did not match your expectations, you may use the simulation to explore what could have happened. A scheme for doing so is outlined at the end of Problem 2 in this lab.

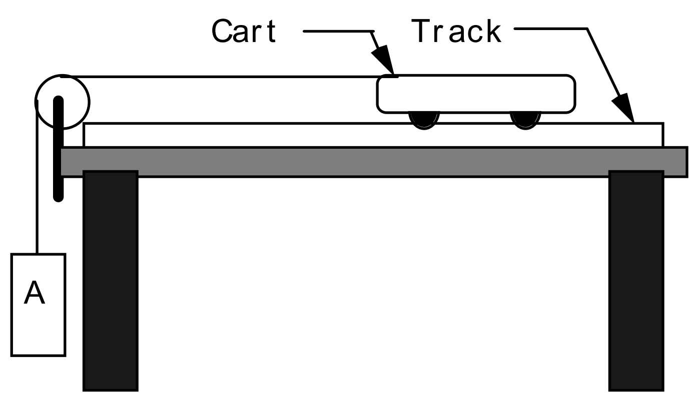
LABORATORY III. FORCES

Problem #1: Force And Motion

You are a volunteer in the city's children's summer program. In one activity, the children build and race model cars along a level surface. To give each car a fair start, another volunteer builds a special launcher with a string attached to the car at one end. The string passes over a pulley and from its other end hangs a block. The car starts from rest when the block is allowed to fall. After the block hits the ground, the string no longer exerts a force on the car and it continues along the track. You decide to calculate how the launch velocity of the car depends on the mass of the car, the mass of the block, and the distance the block falls. You hope to use the calculation to impress other volunteers by predicting the winner of each race.

EQUIPMENT

Released from rest, a cart is pulled along a level track by a hanging object as shown below:



You can vary the mass of Object A and the Cart. A light string connects them. Object A falls from a height shorter than the track's length. You will have a meter stick, a stopwatch, a mass hanger, a mass set, cart masses, a pulley, a pulley clamp, a piece of string and the video analysis equipment.

PREDICTION

Calculate the cart's velocity <u>after object A has hit the floor. Express it as an equation, in terms of quantities mentioned in the problem, and draw graphs to show how the velocity changes with each variable.</u>

METHOD QUESTIONS

Read: Fishbane Chapter 4. Read carefully Sections 4-5 and 4-6 and Examples 4-9 and 4-12.

To figure out your prediction, it is useful to have an organized problem-solving strategy such as the one outlined in the following questions. You might also find the Problem Solving techniques in the Competent Problem Solver useful.

1. Make three sketches of the problem situation, one for each of three instants: when the cart starts from rest, just before object A hits the floor, and just after object A hits the floor. Draw vectors to show the directions and relative magnitudes of the two objects' velocities and accelerations at each instant. Draw vectors to show all of the forces on object A and the cart at each instant. Assign appropriate symbols to all of the quantities describing the motion and the forces. If two quantities have the same magnitude, use the same symbol but write down your justification for doing so. (For example, the cart and object A have the same magnitude of velocity when the string pulls the cart. Explain why.) Decide on your coordinate system and draw it.

2. The "known" quantities in this problem are the mass of object A, the mass of the cart, and the height above the floor where object A is released. Assign a symbol to each known quantity. Identify all the unknown quantities. What is the relationship between what you really want to know (the velocity of the cart after object A hits the floor) and what you can calculate (the velocity of the cart just before object A hits the floor)?

3. Identify and write the physics principles you will use to solve the problem. (Hint: forces determine the objects' accelerations, so Newton's 2nd Law may be useful. You need to relate the magnitudes of forces on different objects to one another, so Newton's 3rd Law is probably also useful. Will you need any kinematics principles?) Write down any assumptions you have made which are necessary to solve the problem and justified by the physical situation. (For example, why will it be reasonable to ignore frictional forces in this situation?)

4. Draw one free-body diagram for object A, and a separate one for the cart after they start accelerating. Check to see if any of these forces are related by Newton's 3rd Law (Third Law Pairs). Draw the acceleration vector for the object next to its free-body diagram. Next, draw two separate coordinate systems; place vectors to represent each force acting on the cart on one coordinate system, and those acting on Object A on the second one (force diagrams). [The origin (tail) of each vector should be the origin of the coordinate system.] For each force diagram, write down Newton's 2nd law along each axis of the coordinate system. Make sure all of your signs are correct in the Newton's 2^{nd} law equations. (For example, if the acceleration of the cart is in the + direction, is the acceleration of object A + or -? Your answer will depend on how you define your coordinate system.)

5. You are interested in the final velocity of the cart, but Newton's 2nd Law only gives you an acceleration; write down any kinematics equations, which are appropriate to this situation. Is the acceleration of each object constant, or does it vary while object A falls?

6. Write down an equation, from those you have collected in steps 4 and 5 above, which relates what you want to know (the velocity of the cart just before object A hits the ground) to a quantity you either know or can find out (the acceleration of the cart and the time from the start until just before object A hits the floor). Now you have two new unknowns (acceleration and time). Choose one of these unknowns (for example, time) and write down a new equation (again from those collected in steps 4 and 5), which relates it to another quantity you either know or can find out (distance object A falls). If you have generated no additional unknowns, go back to determine the other original unknown (acceleration). Write down a new equation that relates the acceleration of the cart to other quantities you either know or can find (forces on the cart). Continue this process until you generate no new unknowns. At that time, you should have as many equations as unknowns.

7. Solve your mathematics to give the prediction.

Make a graph of the cart's velocity after object A has hit the floor as a function of the mass of object A, keeping constant the cart mass and the height through which object A falls.

Make a graph of the cart's velocity after object A has hit the floor as a function of the mass of the cart, keeping constant the mass of object A and the height through which object A falls.

Make a graph of the cart's velocity after object A has hit the floor as a function of the distance object A falls, keeping constant the cart mass and the mass of object A.

8. Does the shape of each graph make sense to you? Explain your reasoning.

EXPLORATION

Adjust the length of the string such that object A hits the floor well before the cart runs out of track. You will be analyzing a video of the cart *after* object A has hit the floor. Adjust the string length to give you a video that is long enough to allow you to analyze several frames of motion.

Choose a mass for the cart and find a useful range of masses for object A that allows the cart to achieve a reliably measurable velocity before object A hits the floor. Practice catching the cart before it hits the end stop on the track. Make sure that the assumptions for your prediction are good for the situation in which you are making the measurement. Use your prediction to determine if your choice of masses will allow you to measure the effect that you are looking for. If not, choose different masses.

Choose a mass for object A and find a useful range of masses for the cart.

Now choose a mass for object A and one for the cart and find a useful range of falling distances for object A.

Write down your measurement plan. (Hint: What do you need to measure with video analysis? Do you need video of the cart? Do you need video of object A?)

MEASUREMENT

Carry out the measurement plan you determined in the Exploration section.

Complete the entire analysis of one case before making videos and measurements of the next case. *A different group member should operate the computer for each case.*

Make sure you measure and record the masses of the cart and object A (with uncertainties). Record the height through which object A falls and the time it takes to fall (measured with the stopwatch).

ANALYSIS

*Make sure a **different** person in your group operates the computer for each case you are analyzing.*

Determine the cart's velocity just after object A hits the floor from your video.

From the time and distance object A fell in each trial, calculate the cart's velocity just after object A hits the floor (assuming constant acceleration). Compare this value to the velocity you measured from the video. Are they consistent with each other?

What are the limitations on the accuracy of your measurements and analysis?

CONCLUSION

How does the velocity from your prediction equation in each case compare with the two *measured* velocities (measured with video analysis, and also with stopwatch / meterstick measurements)? Did your measurements agree with your initial prediction? If not, why?

Does the launch velocity of the car depend on its mass? The mass of the block? The distance the block falls?

If the same block falls through the same distance, but you change the mass of the cart, does the force the string exerts on the cart change? Is the force of the string on object A *always* equal to the weight of object A? Is it *ever* equal to the weight of object A? Explain your reasoning.

SIMULATION

Use the simulation "Lab4Sim" (See *Appendix F* for a brief explanation of how to use the simulations) to explore the effects of a very wide range of masses for the hanging object and the cart. When the hanging object is *much more massive* than the cart, does the system have the acceleration you would expect? When the hanging object is *much less massive* than the cart, does the system have the acceleration you would expect? Explain.

If your results did not completely match your expectations, you may use the simulation to explore what might have happened. First, set the simulation to approximate the conditions of your experiment. Can you get the behavior, and the graphs of position and velocity, that you expect?

If you believe friction may have affected your results, explore its effects with the simulation. Does it affect the behavior, and the graphs of position and velocity, in the ways you expect? Explain

If you believe that your prediction was incorrect because it did not take into account the effects of the mass of the string or the mass of the pulley, explore their effects with the simulation. Do they affect the behavior, and the graphs of position and velocity, in the ways you expect? Explain.

If you believe uncertainty in position measurements may have affected your results, use the simulation to compare the results with and without error. Can you more easily see the effect in the position vs. time graph or in the velocity vs. time graph? Did you see the effects of measurement uncertainty in your VideoTOOL measurements?

NOTES:

II. Grading the Labs

At the end of each Lab topic (2-3 weeks), students will receive a grade for that lab. There are three ways students are graded.

1. About 1 - 2 days before each lab session, your students will give you their journals with their answers to Method Questions and Prediction for the assigned lab problem(s). The Method Questions are graded quickly as either 0 points or the maximum points (usually 3).
2. Each student is also graded once on his or her lab procedure during the 2 - 3 session of a Lab topic.
3. At the end of a Lab topic, you randomly assign *a different lab problem for each student in a group* to write a Lab Report. (You will grade only about 4 lab reports per semester.) Students should never know ahead of time which Lab problem they will write up as a report.

Each of the three grading procedures is described below.

Grading the Method Questions

About 1 - 2 days before each lab session, your students will give you their journals with their answers to the Method Questions for the assigned lab problem(s).

- **The Method Questions are graded for REASONABLE EFFORT, and *not* for the correct answers**.
- **Never indicate in the students' journal whether their answers are right or wrong.** This would spoil the whole purpose of the labs.

One of the purposes of solving the problem *before* the lab is for students to learn how to figure out for themselves *at what location in the problem they get stuck and why*. This metacognitive problem-solving skill is very difficult for most students. So what does reasonable effort mean?

Students receive the maximum number of points if they:

- answer all the questions correctly;
- answer all the questions, *even if some of answers are incorrect*;
- answer some of the method questions, ***and clearly indicate where they got stuck and why***.

Students receive no points (0) if they:

- did not attempt to answer the method questions (even if they solved the problem); or
- answer some of the method questions, *but do not indicate why they did not finish (why they got stuck)*.

Guidelines for Grading Method Questions

Before you grade students' *Method Questions*, solve the problem yourself by answering the questions. Then read the ***Instructor's Laboratory Guide***. You should have a good idea of students' alternative conceptions and what aspects of the qualitative analysis of the problem are the most important for students to learn in the lab.

1. Don't spend more than 30 - 60 seconds looking at a student's answers to the methods questions.
2. Look at the student's work *in general*: Are they using the correct physics concept(s) and principles? Have they made a reasonable effort to answer the questions? If they did not answer all the questions, did they explain why they got stuck?
   - It is usually quicker to look first at the questions that require students to draw a physics diagram (e.g., motion or free-body force diagram) or generate a graph,.
   - Then look at the first equations students write to apply the fundamental principles (e.g., kinematics, Newton's 2^{nd} Laws). Look only at the first equation(s) they write down.
3. Decide on the number of points to give the student. Do not mark anything as "wrong" on the students' papers. Give "hints" if you feel information would be helpful for students, or if it might spark discussion among group members.

When you have finished the grading a section, you will have enough information to decide on the learning focus of the lab session for this section. [See VI. Preparations for Teaching a Lab Session, page 85.]

Grading Lab Procedures

Grade each students' lab procedure and journal *at least once* during the 2 – 3 sessions of a Lab topic. Observe whether:

- students spend adequate time completing the Exploration;
- a measurement plan is recorded in the journal **before** students begin making measurements;
- observations/measurements are written in the journal;
- data tables and graphs are made in the journal **as the data is collected**;
- analysis is completed before students discuss conclusions;
- conclusion includes answers to all questions AND a correct solution to the problem (if they did not answer the Method Questions correctly).

Grading the Written Laboratory Report

The written laboratory report is one of your most important tools in coaching the student in physics. From a student's writing, you can usually tell if they have a firm grasp of the concepts being taught in the class, are confused about the concepts, or still have important misconceptions. After all, a student writing a laboratory report has time to think and can use the textbook, notes, or advice from other students. This truly represents the student's best expression of their knowledge on the subject matter. Based on your reading of the lab report, you may want to talk to that student during the next laboratory period or schedule an appointment with them. At the very least you should communicate forcefully to the student if there is a difficulty in physics understanding. Errors in understanding concepts of physics, problem solving, or measurement will seriously affect a student's ability to succeed in the course as time goes on. It is unfair to lull the student with a good grade on a lab report only to have them get a bad grade on the exams.

Because this course satisfies the University's Writing Intensive requirement, the grading of student laboratory reports takes on added significance. To be acceptable, a laboratory report must always be a coherent technical communication. It must be mechanically correct in spelling, grammar, and punctuation. It must be well organized with a logical presentation and purpose that is communicated clearly. It must have a content supported appropriately with neat and clearly labeled pictures, diagrams, equations, graphs, and tables. It must be expressed in a manner appropriate to a technical report written to an audience of the student's peers. Most importantly, the content must be correct.

You can help your students achieve better writing by insisting on it. Students with serious communications problems can be referred to a central web-based writing center. An added benefit is that a well-communicated laboratory report is easier for you to grade and enables you to give a student focused coaching on specific physics weaknesses. To meet the Writing Intensive requirement, students must be allowed to rewrite their lab report at least once.

Each student is required to write an individual lab report for one problem per laboratory topic (usually two weeks). You will assign each member of a group a different problem at the end of the two-to-three week lab period. ***Assigning the problem at the end of the laboratory period assures that all members of the group attend to every problem.*** Make your problem assignments based on your knowledge of the individual students. This is one of your opportunities to tailor the course to the needs of each individual student. Some students may need the challenge of the most difficult problem and some may need the consolidation offered by an easier problem. You might assign a student needing encouragement a problem you are confident they understand. On the other hand, you might assign a problem to a student because you suspect that they were not adequately involved in the data acquisition or did not understand its point.

The grading criteria are briefly given on the laboratory cover sheet in the laboratory manual. This sheet is to accompany every laboratory report. Students are graded on a total point scale, but you need not accept a report that is not adequately communicated. Each week students receive points for having a logically written *Prediction* and the answers to the *Method Questions*. Also, each week students receive points for keeping a competent lab journal. The report should be a concise and self-contained technical report that is essentially an elaboration of the student's lab journal. It should only be about four pages in length, including graphs, tables, and figures. If you make sure that the students leave the laboratory with a well organized and complete laboratory journal, the laboratory report should not take them long to write.

When the students turn in their Problem Report, they should attach the Laboratory Report Form that is included in their lab manuals. The Checklist from this form is shown on the next page. You fill out this form and return it to students with their graded Problem Report

GRADING CHECKLIST	Points
LABORATORY JOURNAL:	
METHOD QUESTIONS AND PREDICTIONS (individually completed before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL (incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the Points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

To encourage students to use the powerful tool of peer learning, award bonus points if everyone in a group does well on the report. Typically, this has been defined as better than eighty percent. You may want to generate a little peer pressure for preparation by giving a bonus point if everyone in a group comes to lab with a complete set of answers for the prediction and method questions.

III. Overview of Teaching a Lab Session

The usual Cooperative Problem Solving (CPS) routine, like a game of chess, has three parts -- Opening Moves, a Middle Game, and an End Game. As in chess, both the opening moves and the end game are simple, and can be planned ahead of time. The middle game – checking the problem solution -- has many possible variations.

Opening Moves (~ 20 minutes)

Opening moves determine the mind-set that students should have during the Middle Game – checking their problem solution. The purpose of the opening moves is to answer the following questions for students.

- What should we be learning while discussing and checking our solution?
- How much time will we have to check our solution?

Typically, your opening moves begin when you ask the members of each group to arrive at a consensus about one or two of the *Method Questions*. You will know which method question(s) to have students discuss and put on the board from your examination of the answers your students turned in before lab (see the Grading section, pages 71). Make sure to give an explicit time limit for this group discussion. The discussion of for straightforward lab problems should take no more than 5 - 10 minutes. [The discussion for the more difficult problems may take longer. See Section VI, pp. 87.]

At the end of the group discussion time, have one representative from each group put their group's answers to the assigned method question(s) on the board. Ask each group to give their reasons for their answers. Then conduct a class discussion comparing and contrasting the answers and reasons. Remember that one purpose of the opening moves is to increase students' active engagement in the lab [see Redish, 2003, page 163]. ***The discussion need not arrive at the correct answers to the questions.*** In fact, more learning occurs in a lab session when there are unresolved disagreements. Wait to resolve the disagreement in the closing discussion, after students have completed checking their solution.

Finally, discuss *briefly* the measurements they will make to check their solution. For quantitative problems, discuss the direct measurement(s) of the target quantity as well as the measurements of the independent variables in the Prediction equation. The Instructor's Lab Manual often includes suggestions for what to discuss at this point.

Middle Game (~ 35 minutes)

The purpose of collecting and analyzing data in problem-solving labs is to allow students to check their problem solution (answers to the Method Questions and Prediction). The

Exploration, Measurement, and Analysis sections give minimal guidance (they are not the step-by-step instructions) and require the group to make several decisions).

During this time, your role is one of observer, listener and coach. You circulate around the room, observing what the groups are doing, listening to what students are saying, and observing what the groups are writing in their lab journals. Observing groups' incorrect decisions allows you to coach each group when they need it. You intervene when a group needs to be coached on an aspect of physics or the Exploration, Measurement, or Analysis procedure.

At the end of the allotted time, have a representative from each group put their group's *corrected* answers to the method questions on the board (if possible, below their original answers).

End Game (~ 10 - 20 minutes)

The end game determines the mind-set students have when they leave the class -- do they think they learned something or do they think it was it a waste of their time (see Redish, 2003, page 163). The purpose of the end game is to help students answer the following questions.

- ♦ What have I learned that I didn't know before?
- ♦ What did other students learn?
- ♦ What should I concentrate on learning next?

A good end game helps students consolidate their ideas about the qualitative analysis of a problem and produces discrepancies that stimulate further thinking and learning.

Give students a few minutes to examine what other groups wrote on the board. Then lead a whole-class discussion of the results. You may decide to discuss some of the answers to the other methods questions. The time for this discussion depends on:

- the scheduled time of your lab session.
- whether the lab session is the first or second in a Lab topic;
- the type of lab problem (qualitative or quantitative)
- the difficulty of the problem; and
- the learning focus of the lab session (see Section VI, page 85).

We will also discuss leading lab discussions in the TA Orientation and the seminars.

IV. Outline for Teaching a CPS Lab Session

This outline, which is described in more detail in the following pages, is your "lesson plan" for each lab session you teach.

- ❑ assign new roles (and groups when appropriate)
- ❑ answer *Method Questions* to solve the problem
- ❑ grade students' *Method Questions*
- ❑ decide which Method Questions to have students put on board and the learning focus of the session
- ❑ review comments and suggestions in *Lab Instructor's Guide*
- ❑ check pre-lab quiz scores (if appropriate)

	Instructor Actions	What the Students Do
Opening Moves ~15 min.	⓪ Be at the classroom early ① Prepare students for group work by showing group/role assignments. ② Prepare students for lab by: a) diagnosing difficulties while groups discuss and come to consensus on answers to *Method Questions*. b) selecting one person from each group to write/draw on board answers to your selected *Method Questions*. c) leading a class discussion about the group answers (without giving correct answer). d) leading a class discussion about measurements for prediction equation and measurements for checking the prediction. e) telling students how much time they have to check their predictions.	• Students move into their groups. • Work cooperatively. • Write on board. • Participate in class discussion. • Participate in class discussion.
Middle Game (depends on problem)	③ Coach groups in problem solving (making decisions) by: a) monitoring (diagnosing) progress of all groups b) coaching groups with the most need. ④ Grade Lab Procedure (journal). ⑤ Prepare students for class discussion by: a) giving students a "10-minute warning." b) selecting one person from each group to put corrected Method Questions on board.	• Check their group prediction: - explore equipment - decide on measurement plan - execute measurement plan - analyze data as they go along - discuss conclusions . . . • Finish work on lab problem; discussing their group effectiveness • Write on board
End Game ~10 min.	⑥ Lead a class discussion focusing on what you wanted students to learn from solving the lab problem. ⑦ Lead a class discussion of group functioning (as necessary). ⑧ Start next lab problem (repeat Steps 1 – 7) ⑧ At end of session, assign next lab problems; assign Problem Reports (if last week of lab)	• Participate in class discussion • Participate in class discussion

NOTES:

V. Detailed Advice About Teaching a Lab

You should notice a lot of repetition of the same advise given for teaching a discussion session (page 97) because the goal of the labs and discussion sessions are the same – for students to improve their problem solving skills.

Opening Moves

Step ⓪ Be at the Classroom Early

When you get to the classroom, go in and lock the door, leaving your early students outside. The best time for informal talks with students is after the lab!

- Prepare the classroom by checking to see that there is no garbage around the room and that the proper equipment is on student tables and on the front table. On the blackboards, provide space for each group to write their answers to the Method Questions you selected. If you have changed groups, list or project the new groups and roles. (Remember to follow the guidelines for forming groups and rotating roles (page 27).
- Let your students into the classroom when you are prepared to teach the lab. To keep the students from collecting data before they discuss their answers to the *Method Questions*, set aside a small but necessary piece of equipment. Pass this out only after the discussion is finished. [After the students are used to the lab routine, you will not need set aside a piece of equipment.]

Step ① Prepare Students for Group Work (~ 1 minute)

If students are working in the same groups, remind them to rotate roles.

Step ② Prepare Students for Lab (~ 15 - 20 minute)

a) ***Focus on what students should learn (~ 1 minute).*** Tell your students which Method Question(s) they should discuss and put on the board, and what aspect of problems solving they should learn in the lab.

b) ***Diagnose student difficulties (~ 5 minutes).*** While the students are discussing the assigned Method Questions, circulate around the class and ***observe/listen to*** all groups. [Do not intervene with any group unless they have a simple clarification question.] Try to diagnose the difficulties your groups are having coming to consensus on the answers to the method question(s). This is easier to do for some lab problems than others.

No matter how severe students' conceptual difficulties seem to be, **DO NOT LECTURE** about the physics concepts of the problem. They have an opportunity to see the theory of physics in their lectures and textbooks, but lab gives them an opportunity to find out for themselves whether they are right about the way the world works.

Even if the lecturer has not yet covered the material (which happens occasionally), **do not lecture** the students about the concepts or lab procedures. Some lab problems serve as good introductions to a topic, and need only minimal reading from the text for students to be able to complete the method questions before the lab. In other cases, you can treat the beginning of the lab like a discussion session (see Section VI: Preparation for Teaching a Lab Session, page 85).

c) ***Posting group answers (~ 2 minutes).*** Select one person from each group to write their group answers to the method question(s) on the board.

d) ***Lead a class discussion (~ 10 minutes).*** Many students can come up with reasonable looking graphs or a correct prediction equation for strange reasons that do not follow the accepted laws of physics. If you do not discuss these reasons, your students will never realize later that their reasoning is incorrect. The method questions on the board give you an easy way to have students discuss the physics involved in solving the problem

(i) Give students a few minutes to read all the answers on the board. Then ask the representatives of each group to give their reasons for each of their answers. Ask questions about the similarities and differences in what's on the board. Do the differences reflect different physics, or different ways or representing the same physics?

DO NOT TELL THE STUDENTS WHETHER THEIR ANSWERS ARE CORRECT! This would spoil the whole purpose of the labs. Tell the students that at the end of the lab, they will be asked to write on the board any corrections to their method questions.

(i) Discuss briefly the measurements they will make to check their prediction. For quantitative problems, discuss the more direct measurement(s) of the target quantity as well as the measurements of the independent variables in the prediction equation.

e) ***How Much Time (~ 1 minute).*** Tell students how much time they have to check their prediction. If you see from the class discussion that there are prevalent or varied alternative conceptions shown in students' group answers to the method question(s), you will want to stop students earlier so that you can have a longer discussion of their ideas at the end of the lab problem. If, on the other hand, students seem to understand the relevant physics reasonably well before they begin their laboratory problem, you will not need as much time for discussion. The students should then be able to check their prediction very quickly.

Middle Game

There are three instructor actions during the middle game: coaching students in problem solving, grading journals, and preparing students for a whole class discussion. You will spend most of this time coaching groups.

Step ③. Coach Groups in Problem Solving

Below is a brief outline of coaching groups. For detailed suggestions for coaching and intervening techniques, see pages 12 – 15 and 18 - 20.

a) ***Diagnose initial difficulties with the Exploration.*** Once the groups have settled into their task, spend about five minutes circulating and ***observing*** all groups. Try not to explain anything (except trivial clarification) until you have observed all groups at least once. This will allow you to determine if a whole-class intervention is necessary to clarify the task (e.g., "I noticed that very few groups are exploring the range of values for . . . What do you think . . .").

b) ***Monitor groups and intervene to coach when necessary.*** Establish a circulation pattern around the room. Stop and observe each group to see what decisions they are making. Don't spend a long time with any one group. Keep well back from students' line of sight so they don't focus on you. Make a mental note about which group needs the most help. Intervene and coach the group that needs the most help. If you spend a long time with this group, then circulate around the room again, noting which group needs the most help. Keep repeating the cycle of (a) circulate and diagnose, (b) intervene and coach the group that needs the most help.

   If a group finishes early, check their conclusions before you let them start to work on the next assigned lab problem.

Step ④. Grade Lab Procedure

This should be easy and quick to do. Check to see that your students are:

- students spend adequate time completing the Exploration;
- a measurement plan is recorded in the journal **before** students begin making measurements;
- observations/measurements are written in the journal;
- data tables and graphs are made in the journal **as the data is collected**;
- analysis is completed before students discuss conclusions;
- conclusion includes answers to all questions AND a correct solution to the problem (if they did not answer the Method Questions correctly).

If, after a few reminders, a student (or group) is not following these procedures, then tell the student(s) that they have lost their journal point(s). Losing a point *once* will prompt almost any student to improve his or her journal keeping. [Losing one point will not jeopardize a student's final lab grade for the course.]

In computer labs, not all analysis is completed on the computer. Students should be taking data and writing down coefficients and equations ***as they analyze their data***.

Step ⑤ Prepare Students for Class Discussion (~ 10 minutes)

a) ***Ten-minute Warning.*** Ten minutes before you want them to stop, tell students to find a good stopping place and clean up their area. Make sure you have finished grading journals. Also, pass out group-functioning forms at this time (as necessary, about every 2 - 3 weeks).

   When you were an undergraduate, your laboratory instructor probably did not stop you to have a class discussion. Doing this is one of the hardest things you will have to do as a TA. You may be tempted to either let students keep working so that they can get as much done as possible, or to let them go home early so that they like you better. But students do not learn from their laboratory experiences unless they are actively engaged in figuring out what they have learned (see Redish, 2003, page 163).

   In the beginning, a few students may try to keep working. If it is necessary, you can make obstinate students stop working by removing a small but essential piece of equipment (i.e., a battery or a connecting cable) so that they are forced to stop taking data. You are in charge of the class, and if you make it clear that you want the students to stop, they will.

b) ***Posting Corrected Method Questions.*** Tell one person in each group to write their corrected answers to the method questions on the board.

End Game (~ 10 - 20 minutes)

Step ⑥ Lead a Class Discussion (~10 minutes)

The whole-class discussion is always based on the groups, with individuals only acting as representatives of a group. This avoids putting one student "on the spot." The trick is to conduct a discussion about a specific aspect of problem solving without (a) **telling** the students the "right" answers or becoming the final "authority" for the right answers, and (b) without focusing on the "wrong" results of one group and making them feel stupid or resentful. To avoid these pitfalls, start with general, open-ended questions.

- ♦ What is similar about the position versus time graphs?
- ♦ Which part represents the cart slowing down? How can you tell that the cart is slowing down?

In the beginning of a course, students naturally do not want to answer questions. They unconsciously play the *waiting game:* "If we wait long enough, the instructors will answer his/her own question and we won't have to think." Try counting silently up to at least 30 after you have asked a question. Usually students get so uncomfortable with the silence that somebody speaks out. If not, call on a group by number and role: "Group 2 Skeptic, what do you think?"

After the general questions, you can become more specific. Of course, the specific question you ask will depend on what your groups write/draw on the board. For the rolling up and down an incline:

- What function represents how the position changes with time while the cart is slowing down?
- How can you estimate the constants in this function from the graph?

Remember to count silently up to 30, then call on a group if necessary. Always encourage an individual to get help from other group members if he or she is "stuck."

Encourage groups to talk to each other by redirecting the discussion back to the groups. For example, when a group reports their answer to a question, ask the rest of the class to comment: "What do the rest of you think about that?" This helps avoid the problem of you becoming the final "authority" for the right answer.

Step ⑦. Group Processing *(as necessary, ~ 5 minutes)*

An occasional whole-class discussion of group functioning is essential. Students need to *hear* the difficulties other groups are having, *discuss* different ways to solve these difficulties, and receive *feedback* from you (see pages 38-39). Randomly call on one member of from each group to report their group answer to the following questions:

- What is one difficulty your group encountered working together?
- What specific action did your group decide would help you work together better next time?

After each answer, ask the class for additional suggestions about ways to handle the difficulties. Then add your own feedback from observing your groups (e.g., "I noticed that in some groups, one person is doing most of the work. What might you do in your groups to avoid this?")

Step ⑧ Start Next Lab Problem

If there is time, have students start the next assigned lab problem. Repeat Steps 1 through 7.

Step ⑨. End of Lab Session

a) ***Tell students what lab problem(s) to solve for next week.*** You will decide what lab problems all students should solve in your team meetings.

b) ***Assign students problems to write up (if last session of Lab/topic).*** Each student will write a lab report for one problem from each Lab/topic. If there is one student in a group who was not participating as well as you would like in a particular problem, you might consider assigning that problem to the student. This way either the group will help the student catch up with the important information, or the student will learn to participate in the future. [A lower grade on one written lab report will not jeopardize a student's lab grade for the course.]

c) ***Leaving the Lab.*** Leave a neat lab room for the next class. Do NOT let the next group of students into the classroom. Write down the comments on the lab-room sheet (e.g. which equipment did not work). The sheet is on the wall near the door.

VI. Preparation for Teaching a Lab Session

The overall goal of the CPS labs is to help students slowly abandon their novice problem-solving strategies (e.g., plug-and-chug or pattern matching) and adopt a more logical, organized problem-solving procedure that includes the qualitative analysis of the problem. The *Method Questions* (MQs) are designed to "coach" students through the qualitative analysis of the lab problem. *The learning focus of a particular lab session will* ***always*** *be on some aspect of the analysis of the problem and/or the application of the fundamental principles.*

The learning focus of a lab session is established and carried out in your opening moves and end game (see Section III, page 75). So before you teach a lab session, there are several (at least six) decisions you need to make.

Opening Moves

1. Which MQs should I have the groups answer on the board?
2. Do groups need extra time to solve the problem before they begin to check their solution?
3. If so, then how much extra time do groups need and what do I tell my groups to do during this time?
4. What should I discuss/tell students, before they start, about the equipment and measurements for checking their solution?

End Game

5. Besides the discussion of the corrected MQs, should we spend extra time discussing how to solve the problem?
6. If so, then how much extra time should we spend and what should we discuss (what questions should I ask)?

You can plan the opening moves and the end game for a lab session when you have finished grading the *Methods Questions* for the section and read the *Lab Instructor's Guide* for the lab problem. Guidelines for planning are given below. An outline of the planning procedure is on page 91. [Note: This planning procedure is repeated a second time if you teach two lab sessions. For example, if you teach one lab session Monday afternoon and a second lab session Thursday afternoon, your plan for the two lab sessions may be very different.]

I. Background Questions to Answer

Your decisions about how to focus a lab session on problem solving are based on your answers to seven background questions.

❶ When is session scheduled?	❷ Which session is it in the Lab topic sequence?	❸ What is the lab problem type?	❹ How difficult is the lab problem?
☐ Early in Week ☐ Later in Week	☐ 1st Lab Session ☐ 2nd or 3rd Lab session	☐ Qualitative ☐ Quantitative	☐ Easy/Medium ☐ Difficult

❺ Which of the MQs did your students have the most difficulty answering? Common alternative conceptions? Which ones?	Method Questions: ______________________
❻ Count the number of students who were able to solve the problem (even if the solution was incorrect). Is this the majority of the students?	____ students solved the problem out of ____.
❼ Look at the students' final solution (Prediction). How many students got the right answer for the wrong reasons? That is, how many students arrived at a correct (or almost correct) prediction, but had several alternative conceptions in their answers to the MQs.	____ students got the right (or close to right) answer for the wrong reasons.

You will probably find that the *majority* of your students get the right answer for the wrong reasons. There are several explanations for this:

- Many students persist in their plug-and-chug or pattern-matching strategies for solving problems. They will solve the problem first using these novice strategies, and then try to answer the *Method Questions*.
- Sometimes the students' textbook has an example solution to a similar problem (or even the same problem). Some students can arrive at a correct prediction from pattern-matching these example solutions, with very little understanding of the physics concepts or principles.
- For some students, you may notice that the correct prediction seems to appear from nowhere – with very few answers to the MQs. In this case, the student may have gotten the answer (graph/function or algebraic solution) from a friend who did the lab earlier in the week or took the course last year.

II. Decisions About How to Focus a Lab Session on Problem Solving

The following decisions are based on your answers to Questions ❶ – ❼ above.

Opening Moves

1. Which Method Questions should I assign groups to answer on the board?

Your answer to background question ❺ will tell you which MQs to have your groups answer on the board -- the parts of the qualitative analysis of the problem that were the most difficult for your students.

- Qualitative Problem. Usually a few graphs and/or a function.
- Quantitative Problem. Usually the physics diagram(s) [e.g., motion diagram(s) and/or free-body force diagram(s)].

2. Do groups need extra time to solve the problem before they start checking their solution?

Base your decision (YES or NO) on your answer to background question ❻, taking into consideration your answers to questions ❶ through ❹. Here are four examples of how these factors can influence your decision.

Example 1: NO**.** The problem is an easy/medium difficulty quantitative problem, but in 3rd session of the Lab session. The majority of your students were able to arrive at a prediction (although many were incorrect).

Example 2: NO**.** The problem is an easy/medium difficulty qualitative problem, and is the first in the sequence of a new Lab topic. The *majority* of your students did not get very far in the methods questions, and did not arrive at a prediction. On the other hand, the lab problem is a very good conceptual introduction to the topic. You decide that having students discover the answers to the MQs and prediction in lab is a better learning experience than you coaching them through the answers.

Example 3: YES**.** The problem is a difficult quantitative problem, and is the first in the sequence of new Lab topic (e.g., Forces in Motion). The students have had only a few lectures on the topic, and have done no homework problems or had any practice solving this type of problem in a discussion session. So the *majority* of your students did very far in the qualitative analysis of the problem, and most did not arrive at a prediction equation. Without a prediction equation (even a wrong one), they cannot check their solution in lab.

Example 4: YES. The problem is a difficult quantitative problem, and is in the 2nd session in the Lab topic sequence. The *majority* of your students did not get very far in the qualitative analysis of the problem, and most did not arrive at a prediction equation. Without a prediction equation (even a wrong one), they cannot check their solution in lab.

3. If YES, then how much extra time do groups need and what do I tell my groups to do during this time?

Use your answers to background questions ❶ – ❹ to help you decide how much extra time and how much structure your students will need. Two examples are given below.

Example 1**.** The problem is a difficult quantitative problem, and is in the 2nd session of the Lab sequence. Your lab session is on Wednesday afternoon. You decide that your students should have sufficient physics background (collectively, as a group) to solve the problem. You decide to give students enough time to solve the problem in groups, like in discussion sessions. You plan to tell your students:

a) They can NOT start checking their solution until they have solved the problem.

b) They should follow the problem-solving framework outlined in the *Method Questions* to solve the problem as a team, just like they do in discussion sessions; and

c) When they think they have a problem solution, you will randomly check group member's solution (written in journal). If the solution is adequate (not necessarily correct), they can start checking their solution.

Note: An alternative to this last step is to have one student from each group put on the board physics diagram(s) and a list of the equations they used to solve the problem. Then lead a whole-class discussion.

Example 2. The problem is a difficult quantitative problem, and is in the 1st session of a new Lab topic. Your lab session is early in the week. You decide that your students do **not** have sufficient physics background (collectively, as a group) to solve the problem. You decide that you will need to spend a lot of time doing a combination of combination of modeling and coaching *of the whole class*. [Remember, students should have read the textbook before the lab! You can NOT start from ground zero.]

a) Have the groups work on the first method question (or first few method questions). Randomly call one student from each group to write/draw their answers on the board.

   Discuss similarities and differences. You may need to show students how to do something (model). For example, you may need to model how to draw vector components on their motion diagrams, or how to determine what forces are acting on an object, how to label the forces, how to draw a free-body diagram, the meaning of Newton's 2nd Law, how to draw an energy diagram, and so on.

b) Repeat Step a) for the next Method Question (or next few method questions). Call on different students in each group to put answers on board. Discuss and model-coach as necessary.

c) Keep repeating this procedure until the students have arrived at an answer.

4. What should I discuss/tell students about checking their solution before they start?

The *Lab Instructor's Guide* and your own experience with the lab equipment (TA Orientation and TA seminars) will help you decide what to discuss/tell your students about the equipment, measurements and analysis for checking their solution.

End Game

5. Besides the groups' corrected answers to the assigned MQs, do we need to spend more time discussing how to solve this problem?

Base your decision (YES or NO) on your answer to background question ❼ ***and*** your Decisions 2 and 3.

YES. About one-half or more of your students arrived at the correct (or close to the correct) solution *for the wrong reasons* AND you did not spend time coaching students on how to solve the problem in the Opening Moves.

NO. Either the majority of your students had only a few difficulties answering the MQs OR you spent extra time coaching the students on how to solve the problem in the opening moves.

6. If YES, then how much time and how should I structure this extra time?

There are different ways to structure this discussion. One suggestion is given below.

After you have discussed the methods questions on the board, have a different student from each group put their answers to the next Method Question (or few method questions) on the board. Discuss the similarities and differences in the answers. Hopefully, students recognize the best answers. If not, you may need to model (show) students an easy or efficient way to answer one of the MQs. **Stop short of solving the problem**. Get far enough so students recognize what they did wrong in their initial solution.

NOTES:

Lab Preparation

Name ______________________________________ Date: _____________.

Lab Problem: _________________________ Section _________

I. Solve the problem yourself by answering the method questions. Then read the ***Lab Instructor's Manual***. Finally, grade the Method Questions for this section.

II. Answer the following background questions.

❶ When is session scheduled?	❷ Which session is it in the Lab topic sequence?	❸ What is the lab problem type?	❹ How difficult is the lab problem?
☐ Early in Week ☐ Later in Week	☐ 1st Lab Session ☐ 2nd or 3rd Lab session	☐ Qualitative ☐ Quantitative	☐ Easy/Medium ☐ Difficult

❺ Which of the MQs did your students have the most difficulty answering? Common alternative conceptions? Which ones?	Method Questions: _____________________
❻ Count the number of students who were able to solve the problem (even if the solution was incorrect). Is this the majority of the students?	____ students solved the problem out of ____.
❼ Look at the students' final solution (Prediction). How many students got the right answer for the wrong reasons?	____ students got the right (or close to right) answer for the wrong reasons.

III. Based on the answers to these questions, make the following decisions about opening moves and the end game for the lab session.

Opening Moves		
1. Which MQs should I assign groups answer on board?	Use answer to Question ❺:	Method Questions: _____________________
2. Do groups need extra time to solve the problem before they start collecting data?	Use answer to Question ❻, taking into account Questions ❶ to ❹	☐ YES ☐ NO because:
3. If YES, then how much time extra time and how should I structure this extra time?	Use answers to Questions ❶ to ❹	Plan:
4. What do I need to discuss/tell students about how to check their solution before they start?	Use information in *Lab Instructor's Guide* and your own experience	Discuss:

End Game		
5. (Besides corrected answers to assigned MQs), do we need to spend extra time discussing how to solve the problem?	Use answer to Question ❼ and your previous decisions 2 & 3	☐ YES ☐ NO because:
6. If YES, then how much time and how should I structure this extra time?		Plan:

IV. List some possible questions to ask groups during whole-class discussion (opening moves and/or end game) that you think would promote a discussion.

a.
b.
c.
d.
e.
f.
g.