University of Minnesota, Crookston

Analyzing Student Written Communications: *the good, the bad, and (maybe) the ugly**

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http://groups.physics.umn.edu/physed/

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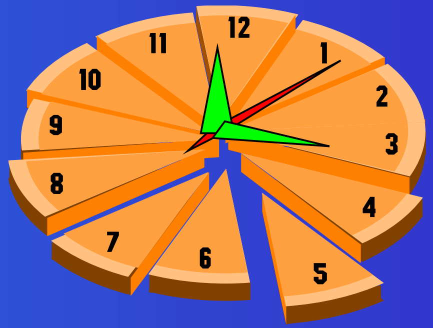
AGENDA: A Guide for Discussion

1) Writing
   - UMN's Writing Across the Curriculum
   - Writing and Problem Solving
2) UMN Instructional Framework
3) Lab Reports
   - What is a Physics Lab?
   - What goes in a lab report?
   - Evaluating lab reports
4) Trials and Tribulations
   - What was good?
   - What was bad?
   - What was somewhat ugly?



What do you want to discuss that is not here?

Teaching with Writing

At the University of Minnesota, instructors from across the disciplines are incorporating writing into their courses. Doing so has affirmed the enhancing role that writing activities can play in student learning. It has also allowed faculty and students alike to recognize that language use and text production take place within disciplinary language communities; writing in Law, for instance, looks different, is directed at a different audiences and is produced for a series of different purposes than is writing in Computer Science

Mission of the Writing Requirement at the University

- Learning to write is a **life-long task … refined through** an individual's personal, social, and professional **experiences**
- Principal means by which all scholars … **conduct inquiries** and **communicate their learning**
- Learning to write effectively can be one of the most **intellectually empowering** components of a university education
- University regards the teaching of writing as a **responsibility shared by all departments**

Thus, the University has established a "*writing across the curriculum*" program

Writing Across the Curriculum:
complementary objectives

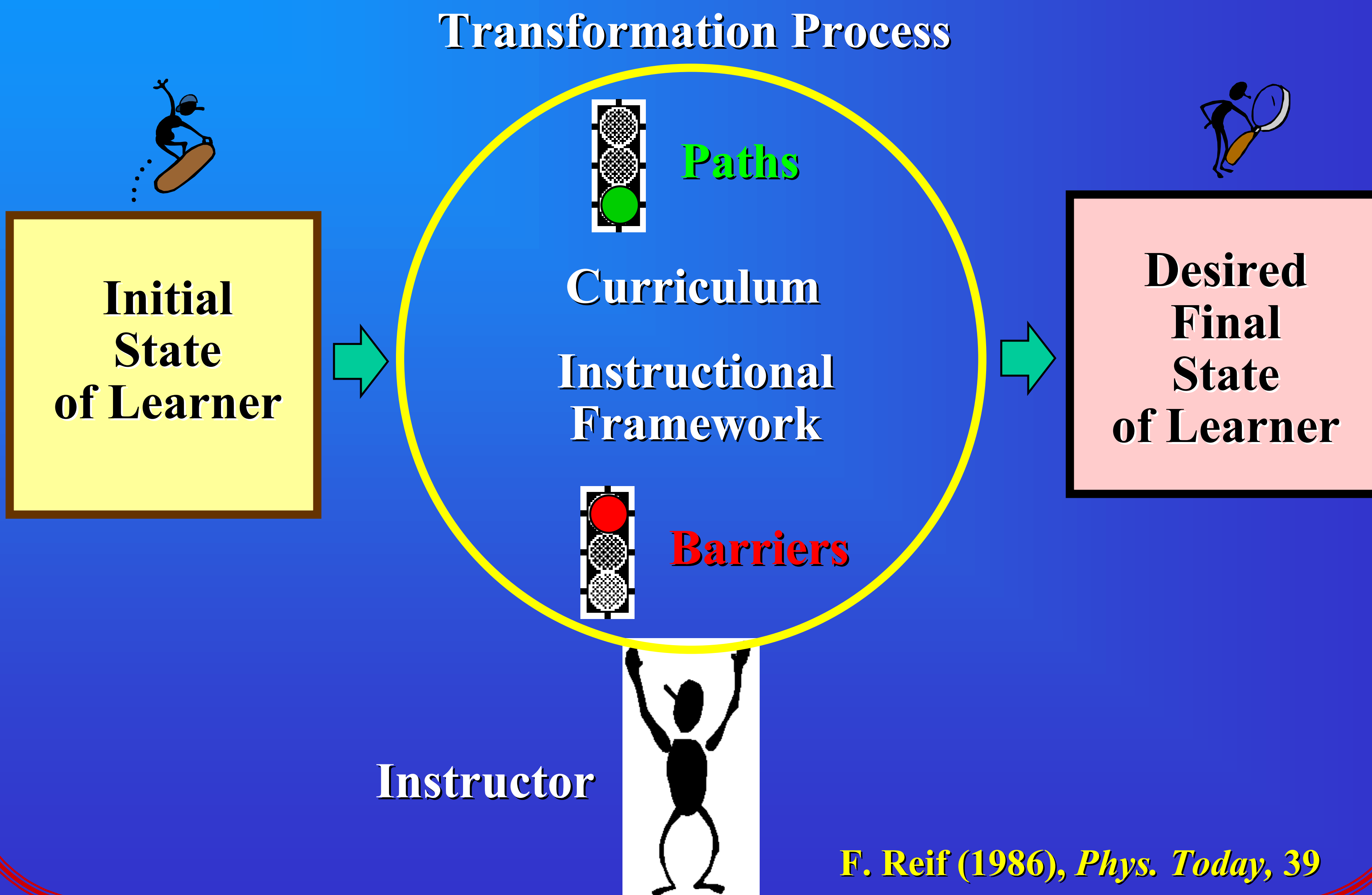
Good writers:

1) practice on a continuing basis, so one of the goals of writing-intensive courses is to offer **ongoing writing practice**
2) are able to write for a variety of audiences; they understand that effective writing depends on context. For this reason, students should **write in many different kinds of courses, to audiences ranging from their peers to senior scholars and scientists**
3) are able to produce a range of different kinds of writing. So the **nature of the writing** done in "writing-intensive" courses **should vary considerably**
4) Because no one course can meet all these goals, the **collective goal** of all these writing-intensive courses is to **prepare students to communicate effectively in a variety of situations** at the University, in their future employment, and in their roles as citizens

Writing Intensive Coursework

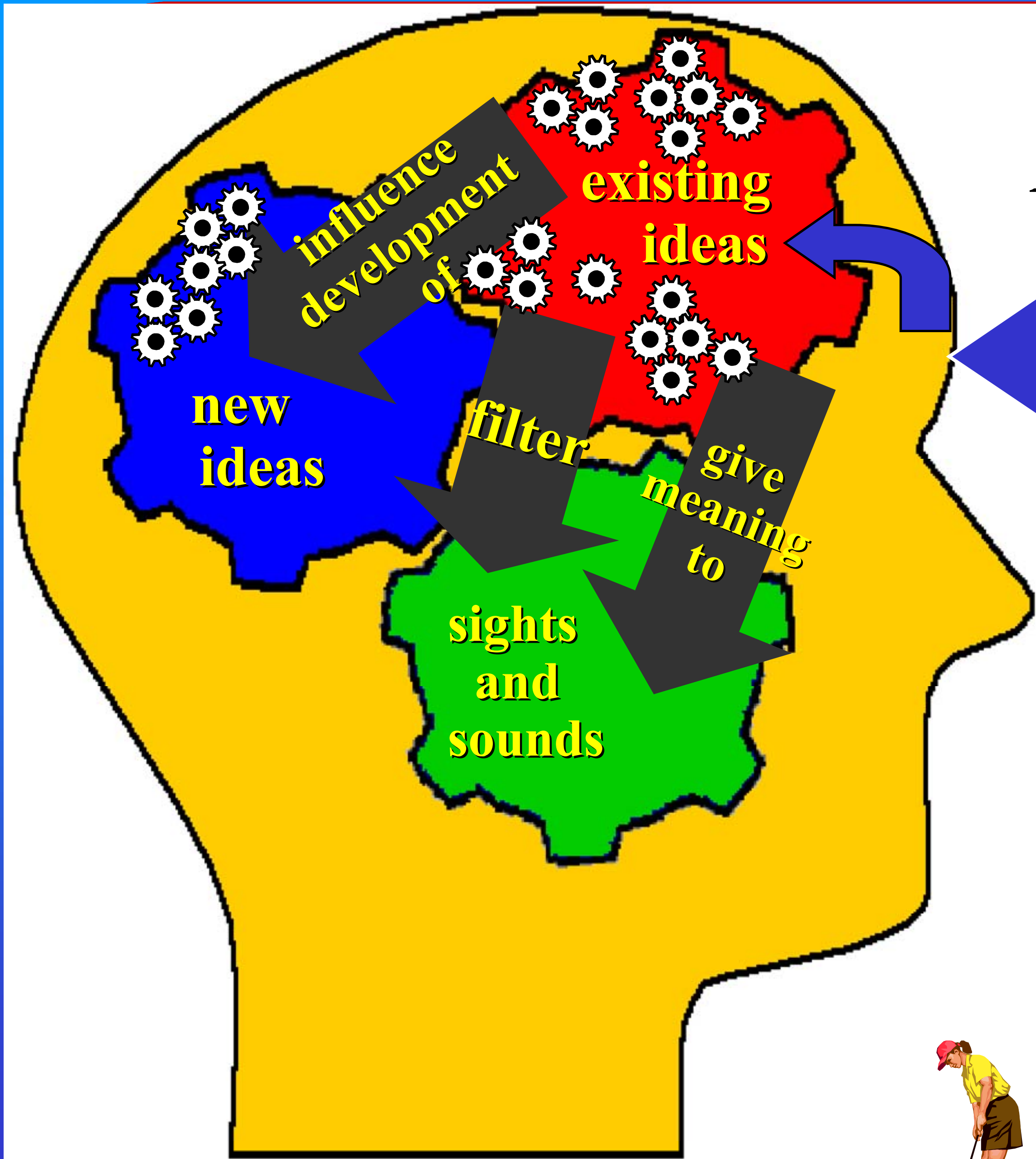
1) Course grade is directly tied to the quality of the student's writing as well as to knowledge of the subject matter, so that **students cannot pass the course who do not meet minimal standards** of writing competence
2) Courses requiring a significant amount of writing -- **minimally ten to fifteen finished pages** beyond informal writing and any in-class examinations. Note that the page guidelines may be met with an assortment of short assignments that add up to the total
3) Courses in which **students are given instruction on the writing** aspect of the assignments
4) Courses in which **assignments include at least one for which students are required to revise a draft and resubmit** after receiving feedback from the course instructor or graduate teaching assistant. Otherwise, writing assignments may be of various kinds and have various purposes, as appropriate to the discipline

Procedure for Change



F. Reif (1986), *Phys. Today*, 39

Cognitive Apprenticeship Instruction



INSTRUCTION

Learning in the environment of expert practice

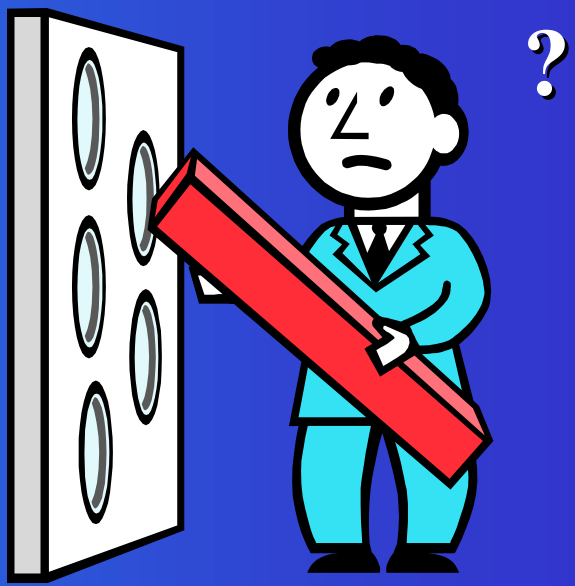
model

coach

fade

Collins, Brown, & Newman (1990)

Initial State of the Learner



Students have Misconceptions about

A Field of Knowledge

The Process of Learning

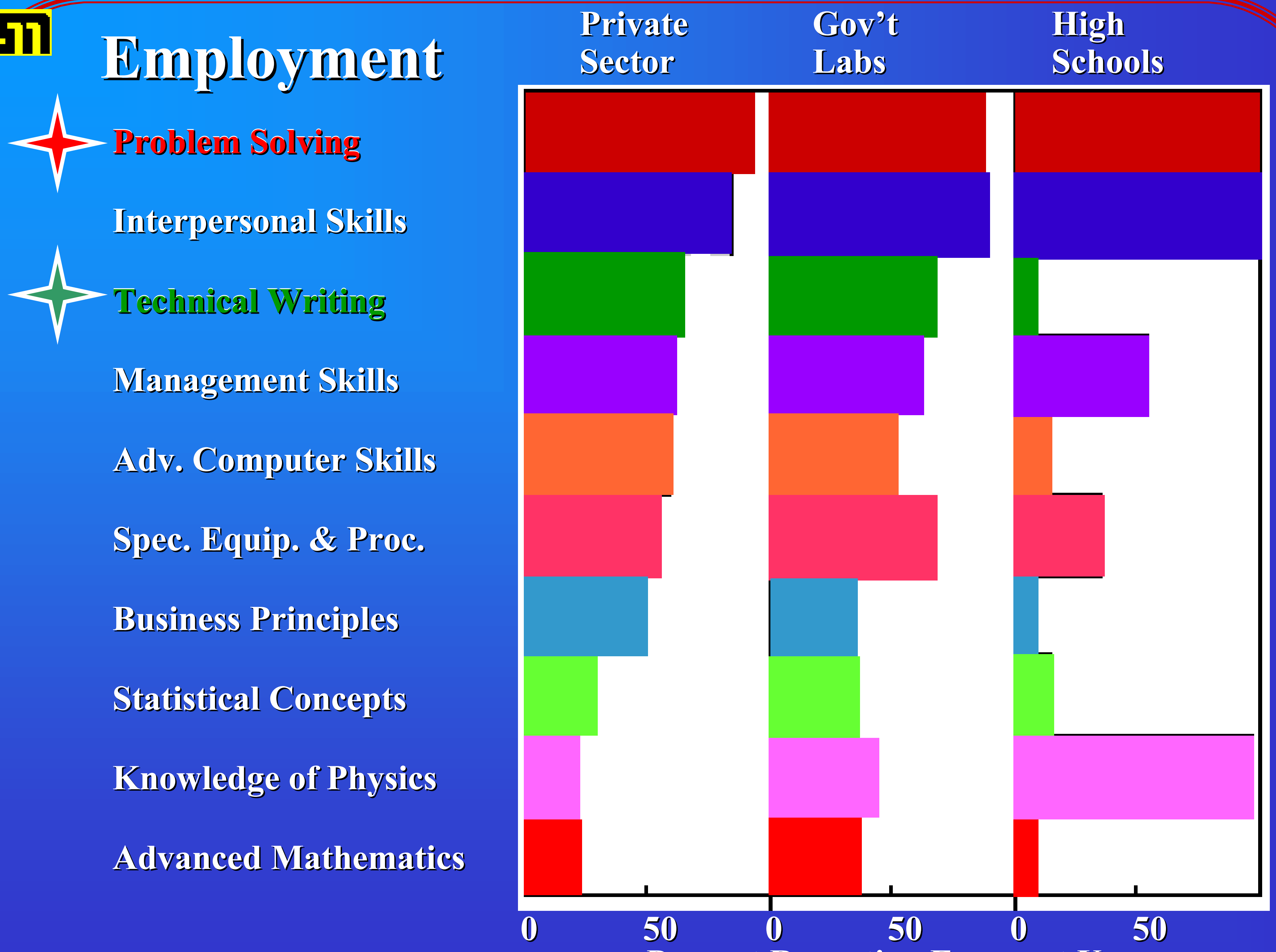
The Process of Problem-solving

The Content of Your Field

All combine to make it difficult for students to solve problems

Not the same as "getting a problem right"

Employment



Survey of Physics Batchelors, 1994-AIP

Teaching Students to Solve Problems

Solving Problems Requires Conceptual Knowledge:

From Situations to Decisions

- Visualize situation
- Determine goal
- Choose applicable physics principles
- Choose relevant information
- Construct a plan
- Arrive at an answer
- Evaluate the solution

Students must be able to communicate these actions in writing

- English
- Organization
- Pictures

Explicit Problem-solving Framework

Used by experts in all fields

STEP 1 — **Recognize the Problem**

What's going on?

STEP 2 — **Describe the problem in terms of the field**

What does this have to do with ...... ?

STEP 3 — **Plan a solution**

How do I get out of this?

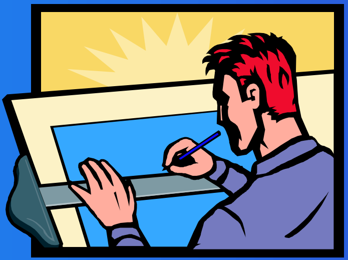
STEP 4 — **Execute the plan**

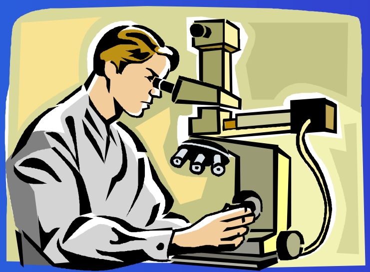
Let's get an answer

STEP 5 — **Evaluate the solution**

Can this be true?

Calculus-Based Physics
1200 students/term





Majors

Engineering	75%
Physics/Astro	5%
Chemistry	6%
Mathematics	5%
Biology	9%

Male	79%
Had Calculus	80%
Had HS Physics	87%

Freshman	64%
Sophomores	22%
Juniors	10%

Expect A	61%
Work	53%
Work more than 10 hrs/wk	25%

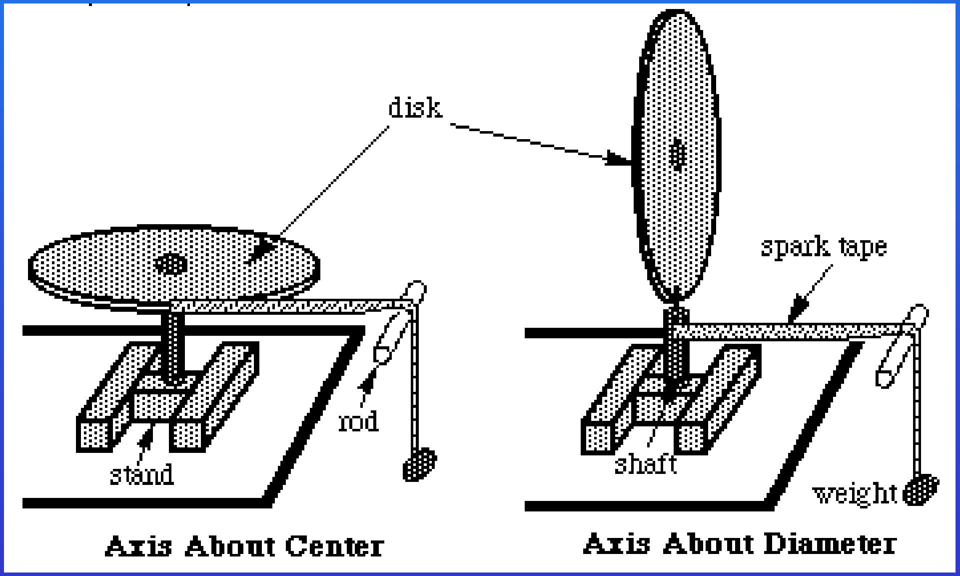
Course Structure

LECTURES	Three hours each week. (200 students)
RECITATION SECTION	One hour each week – solving a problem in 3 person cooperative groups. Peer coaching, TA coaching. (15 students)
LABORATORY	Two hours each week -- *same* groups solve experimental problems. *Same* TA. Peer coaching, TA coaching. (15 students) Written lab reports every 2 weeks.
TESTS	Problem-solving quiz & conceptual questions (usually multiple choice) every three weeks.

Problem Solving Laboratories

- Closely integrated with lecture & recitation
- Always context-rich problems
- Emphasize modeling real systems
- Work in Cooperative Groups
- Lab reports are short technical memos

- Each student hands in an individual laboratory report about every two weeks
- Each group member reports on a different problem
- TA assigns each student a problem at the end of each unit
- Student does not knows which problem will be assigned.
- Report is due in 2 days.



Importance of Laboratory Reports

- **Learning through synthesis of information**
  - Students write reports to communicate to themselves and their instructor their understanding of:
    - Logical reasoning
    - Physics concepts
    - Data analysis choices
    - What they've learned
    - What they've not learned

- **Clear & Concise technical communication**
  - Necessary for upper level courses in all majors
  - Sought-after skills by employers
    - What is the decision
    - Basis for the decision
    - Consequences of the decision

Sample laboratory Report

Appendix E: Sample Laboratory Report

There is no set length for a problem report but experience shows the good reports are typically three pages long. Graphs and photocopies of your lab journal make up additional pages. Complete reports will include the terminology and the mathematics relevant to the problem at hand. Your report should be a clear, concise, logical, and honest interpretation of your experience. You will be graded based on how well you demonstrate your understanding of the physics. Because technical communication is so important, neatness, and correct grammar and spelling are required and will be reflected on your grade.

Note: As with Problem 1 of Lab 1, the double vertical bars indicate an explanation of that part of the report. These comments are not part of the actual report.

Statement of the problem

In a complete sentence or two, state the problem you are trying to solve. List the equipment you will use and the reasons for selecting such equipment.

The problem was to determine the dependence of the time of flight of a projectile on its initial horizontal velocity. We rolled an aluminum ball down a ramp and off the edge of a table starting from rest at two different positions along the ramp. Starting from the greater height up the ramp meant the ball had a larger horizontal velocity when it rolled along the table. Since the table was horizontal, that was the horizontal velocity when it entered the air. See Figure 1 from my lab journal for a picture of the set-up.

We made two movies with the video equipment provided, one for a fast rolling ball and one for a slower one. These movies were analyzed with LabVIEW to study the projectile's motion in the horizontal and vertical directions.

Prediction

Next comes your prediction. Notice that the physical reason for choosing the prediction is given. In this case there is a theoretical relationship between Δt and v_0. There is a reference to real life experience: the example of the bullets. Also, **note that this prediction is wrong**. That is all right. The prediction does not need to be correct; it needs to be what you really thought before doing the lab; that is why it is called a prediction. The prediction is supposed to be a complete and reasonable attempt by your group to determine the outcome of the problem.

Our group predicted that the time the ball took to hit the floor once it left the table would be greater if the horizontal velocity were greater. We have observed that the faster a projectile goes initially, the longer its trajectory. Since the gravitational acceleration is constant, we reasoned that the ball would take more time to travel a larger distance.

Mathematically, we start from the definition of acceleration:

$$a = \frac{d}{dt}\left(\frac{dy}{dt}\right)$$

and integrate twice with respect to time to see how a change in time might be related to initial velocity. We found that:

$$y - y_0 = v_0\Delta t + 0.5a\Delta t^2 \quad (1)$$

With the y-axis vertical and the positive direction up, we know the acceleration is -g. We also know that v_0 is the initial velocity, and $y_0 - y$ is h, the height of the table. Solving for Δt one finds:

$$\Delta t = \frac{v_0 \pm \sqrt{(v_0^2 + 2hg)}}{g} \quad (2)$$

Faced with a choice in sign, our group chose the solution with the positive sign, deciding that a possible negative value for elapsed time does not correspond with our physical situation. From equation (2), we deduced that if v_0 increased, then the time of fall also increases. This coincided with our prediction that a projectile with fastest horizontal velocity would take the most time to fall to the ground. For a graph of our predicted time of flight versus initial horizontal velocity, see Graph A from the lab journal.

LabVIEW generated graphs of x and y positions as functions of time. Our prediction for the vertical direction was equation (1). Since the ball only has one acceleration, we predicted that equation (1) would also be true for the horizontal motion:

$$x - x_0 = v_0\Delta t + 0.5a\Delta t^2$$

The dotted lines on the printed graphs represent these predictions.

The Example of Two Bullets

Our TA asked us to compare a bullet fired horizontally from a gun to a bullet dropped vertically. Our group decided the bullet that is fired horizontally will take longer to hit the ground than the one that is simply dropped from the same height.

Data and results

This section describes your experimental method, the data that you collected, any problems in gathering the data, and any crucial decisions you made. Your actual results should show you if your prediction was correct or not.

Statement of the Problem

Prediction

Data & Results

Sample laboratory Report

To ensure the ball's velocity was completely horizontal, we attached a flat plank at the end of the ramp. The ball rolls down the ramp and then goes onto the horizontal plank. After going a distance (75 cm) along the plank, the ball leaves the edge of the table and enters projectile motion.

We measured the time of flight by simply counting the number of video frames that the ball was in the air. The time between frames is 1/30 of a second since this is the rate a video camera takes data. This also corresponds to the time scale on the LabVIEW graphs. We decided to compare the times of flight between a ball with a fast initial velocity and one with a slow initial velocity. To get a fast velocity we started the ball at the top of the ramp. A slower velocity was achieved by starting the ball almost at the bottom of the ramp.

During the time the ball was in the air, the horizontal velocity was a constant, as shown by the velocity in the x-direction graphs for slow and fast rolling balls. From these graphs, the slowest velocity we used was 1.30 m/s, and the fastest was 2.51 m/s.

After making four measurements of the time of flight for these two situations, we could not see any correspondence between time of flight and initial horizontal velocity (see table 1 from lab journal). As a final check, we measured the time of flight for a ball that was started approximately halfway up the ramp and found it was similar to the times of flight for both the fast and the slow horizontal velocities (see table 2 from lab journal).

A discussion of uncertainty should follow all measurements. No measurement is exact. Uncertainty must be included to indicate the reliability of your data.

Most of the uncertainty in recording time of flight came from deciding the time for the first data point when the ball is in the air and the last data point before it hit the ground. We estimated that we could be off by one frame, which is 1/30 of a second. To get a better estimate of this uncertainty, we repeated each measurement four times. The average deviation served as our experimental uncertainty (see Table 1 from lab journal). This uncertainty matched our estimate of how well we could determine the first and the last frame of the projectile trajectory.

Conclusions

This section summarizes your results. In the most concise manner possible, it answers the original question of the lab.

Our graph indicates that the time of flight is independent of the ball's initial horizontal velocity (see lab journal, Graph A). We conclude that there is no relationship between these two quantities.

A good conclusion will always compare actual results with the predictions. If your prediction was incorrect, then you must discuss where your reasoning went wrong. If your prediction was correct, then you

Conclusions

should review your reasoning and discuss how this lab served to confirm your knowledge of the basic physical concepts.

Our prediction is contradicted by the apparent independence of the time of flight and initial horizontal velocity. We thought that the ball would take longer to fall to the floor if it had a greater initial horizontal velocity. After some discussion, we determined the error in our prediction. We did not understand that the vertical motion is completely independent of the horizontal motion. Thus, in the vertical direction the equation

$$y - y_o = v_o\Delta t + 0.5a\Delta t^2$$

means that the v_o is the only the y-component of initial velocity. Since the ball rolls horizontally at the start of its flight, v_o in this equation always equals zero.

The correct equation for the time of flight, with no initial vertical component of velocity, is actually:

$$y - y_o = 0.5a\Delta t^2$$

In this equation, there is no relationship between time of flight and initial horizontal velocity.

Furthermore, the graphs we generated with LabVIEW showed us that velocity in the y-direction did not change when the initial horizontal velocity changed. Velocity in the y-direction is always approximately zero at the beginning of the trajectory. It is not exactly zero because of the difficulty our camera had determining the position when the projectile motion begins. We observed that the y-velocity changed at the same rate (slope of v_y plots, graphs 1 and 2) regardless of the horizontal velocity. In other words, the acceleration in the y-direction is constant, a fact that confirms the independence of vertical and horizontal motion.

After you have compared your predictions to your measured results, it is helpful to use an alternative measurement to check your theory with the actual data. This should be a short exercise demonstrating to yourself and to your TA that you understand the basic physics behind the problem. Most of the problems in this lab are written to include alternative measurements. In this case, using the time of fall and the gravitational constant, you can calculate the height of the table.

The correct equation for the horizontal motion is

$$x - x_o = v_o\Delta t$$

The horizontal acceleration is always zero, but the horizontal distance that the ball covers before striking the ground does depend on initial velocity.

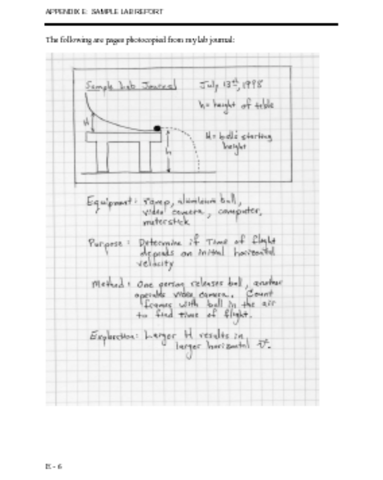
Alternative Analysis

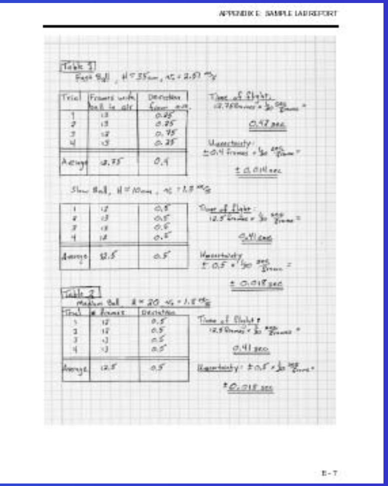
Sample laboratory Report

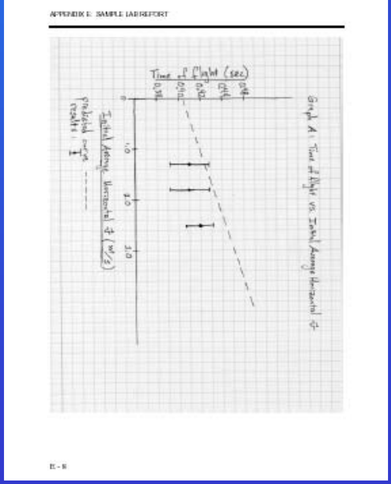
Since $y_0 - y = h$ and $a = -g$ we can check to see if our measured time of flight gives us the height of the table. From our graph, we see that the data overlaps in a region of about 0.41 sec. With this as our time of flight, the height of the table is calculated to be 82.3 cm. Using a meter stick, we found the height of the table to be 80.25 cm. This helped convince us that our final reasoning was correct.

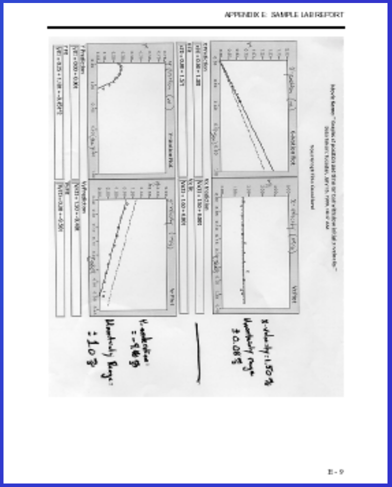
The example of the two bullets discussed in the Prediction section was interpreted incorrectly by our group. Actually, both bullets hit the ground at the same time. One bullet travels at a greater speed, but both have the same time of flight. Although this seems to violate "common sense" it is an example of the independence of the horizontal and vertical components of motion.

Copies from Laboratory Journal









Guideline for grading laboratory reports

Problem Report:	Score
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)	

Given to TAs & Students in Lab Manual

General Criteria for evaluating technical Reports

(Dr. Lee-Ann K. Breuch, Dept. Of Rhetoric, U of MN)

- **Content:** What is the subject? What information needs to be included?
- **Context:** What is expected in the discipline for this type of document?
- **Audience:** To whom is the document written? How will it be used?
- **Organization:** How can the information be best organized? Can the information be divided into sections?
- **Support:** What details, facts, and evidence can be used to illustrate main points?

Example of quality levels - Content

	Satisfactory	Adequate	Poor
Addresses content accurately and thoroughly	Accurate and complete technical information, including formulas, explanations, theory, and data.	Accurate technical information, but has missed some important information.	Does not include accurate or complete information.
Score	3	2	1

Example of quality levels - Context

	Satisfactory	Adequate	Poor
The format is as suitable for a short technical document.	Meets the requirements of the assignment; includes proper format & sections that assignment requires.	Adequately meets requirements of the assignment; does not always display proper format.	Does not meet the requirements of the assignment as specified.
Score	3	2	1

Example of quality levels - Audience

	Satisfactory	Adequate	Poor
The paper can be understood by classmates in this physics class.	Writes appropriately for classmates, including proper terms, explanations of concepts, formal register.	Does not always include proper terms, concepts, or register (perhaps is too informal).	Does not include proper terms, concepts, or register to effectively address audience.
Score	3	2	1

Example of quality levels - Organization

	Satisfactory	Adequate	Poor
The paper is logically organized	Has complete, concise, paragraphs; includes strong topic sentences that indicate focus of paragraph or section; includes strong forecasting statements; includes appropriate headings & subheadings; demonstrates coherence throughout report.	Adequate overall format; does not display concise paragraph or topic sentences; does not have all appropriate headings & subheadings; paragraphs are not clearly coherent.	Does not use appropriate headings or subheading; paragraphs do not logically connect nor are they concise; topic sentences are not effective.
Score	3	2	1

Example of quality levels - Support

	Satisfactory	Adequate	Poor
The paper has adequate support for statements	Has necessary illustrations or figures. Refers to appropriate readings, theories, & relevant background information; includes relevant graphs & tables; with proper labeling & cross-references figures, tables, & graphs.	Has appropriate readings & background information, but does not use clear logic; has tables & graphs but they are not always labeled or cross-referenced.	Does not include necessary support in the form of logic, background information, tables, or graphs. No labeling, & cross-references.
Score	3	2	1

Example – Content & Support

Satisfactory:

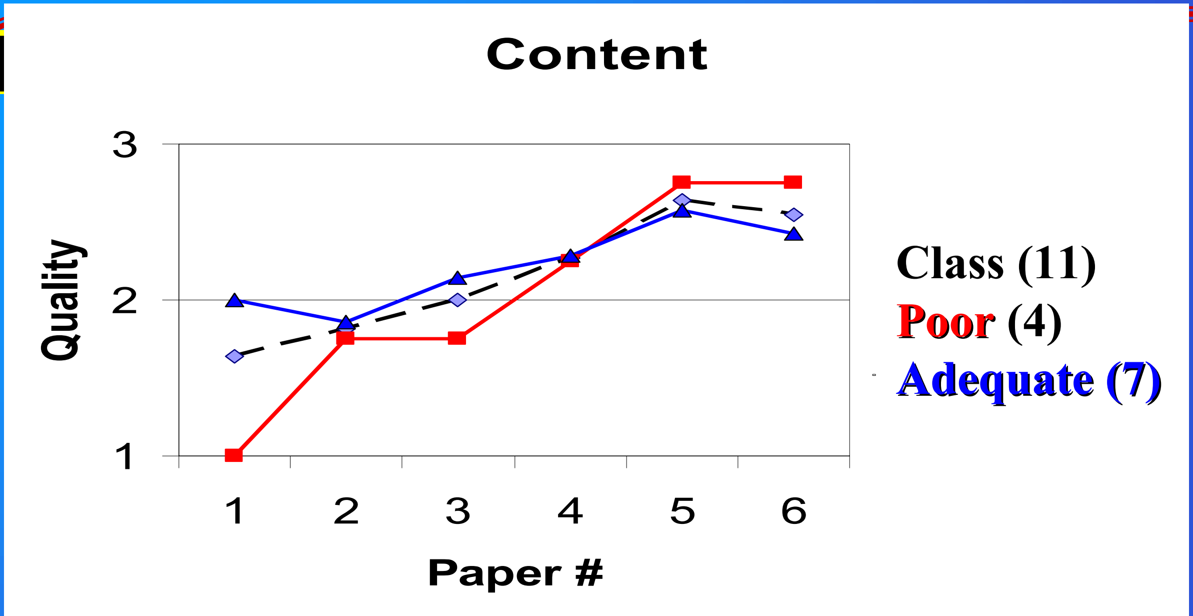
- While the beam was rotating we timed how long it took to make five revolutions. We did this to determine the angular velocity, w. Once we knew w we plugged that value into the equation v = Rw, where R is the radius. Our group and I concluded that the linear velocity (v) of a point on the beam increases when the radius increases with a constant angular velocity. There is a graph at the end of the report that shows this relationship for easier understanding.

Poor:

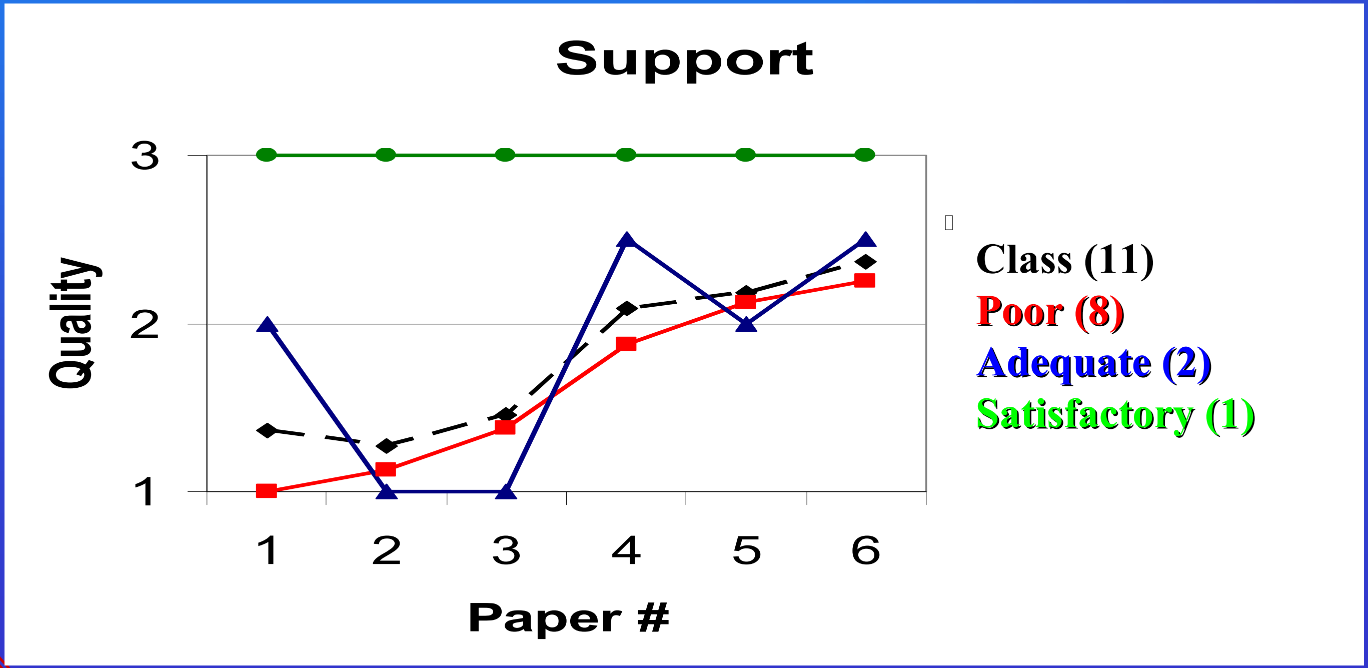
- I observed that the acceleration is zero at the time where the cart switches from going up the track to down the track. This is what we predicted to happen. Our group ... The graph is a constant slope from left to right because the acceleration is always negative and this is why the graph is an upside down parabola. This lab has helped me understand ... The acceleration is always negative (in this respect) which is a little hard to comprehend at first but it was nice to observe this in lab.

A Lab Section

- One class of 15 students
  - 11 of which had all 6 laboratory reports from the entire 15-week semester ($n = 11$)
- Each student is placed into one of three groups based on the grade of the first report
  - Poor
  - Adequate
  - Satisfactory



Content: What information needs to be included?



Support: What details, facts, and evidence are used?

Topic of paper number:

1) 1-D Kinematics

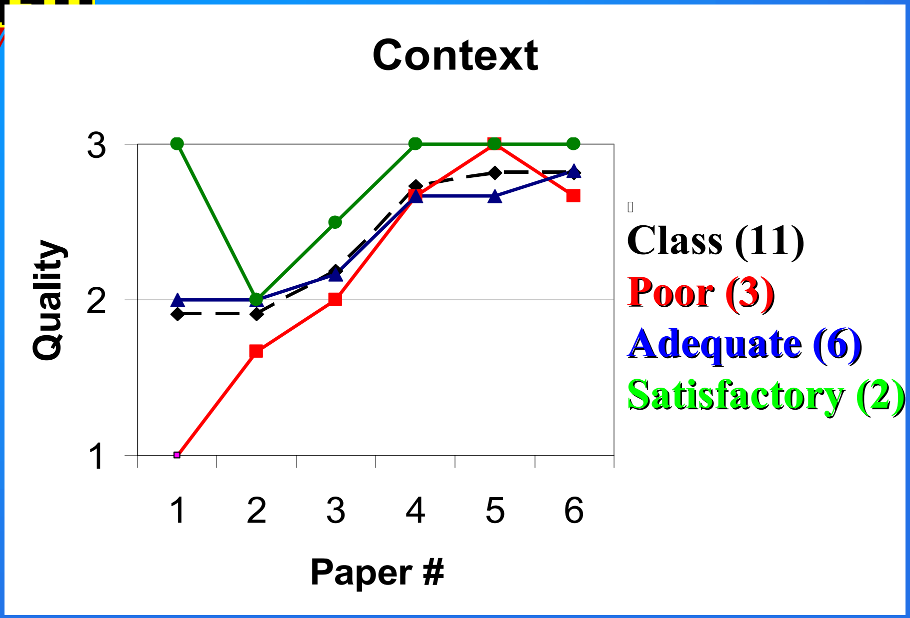
2) 2-D Kinematics

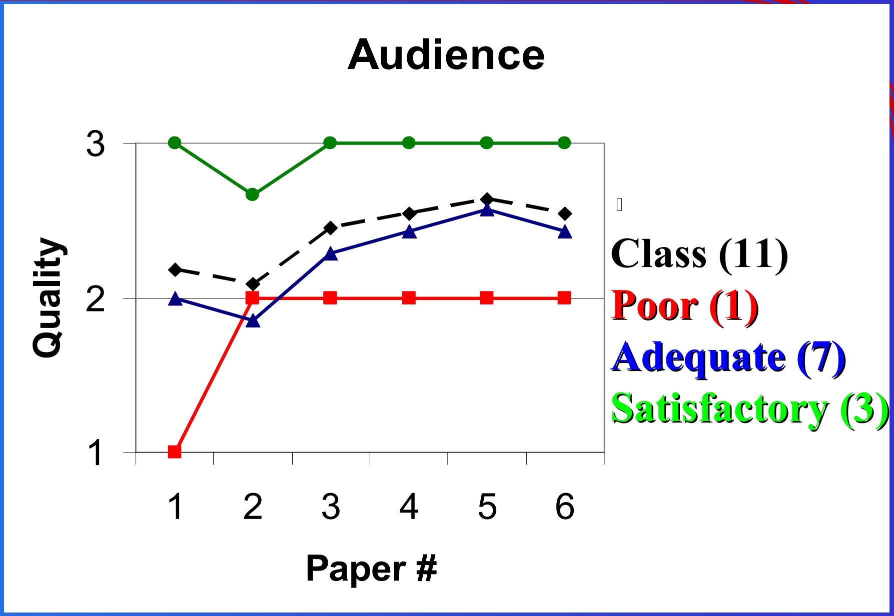
3) Forces

4) Conservation of Energy and Momentum

5) Rotational Kinematics

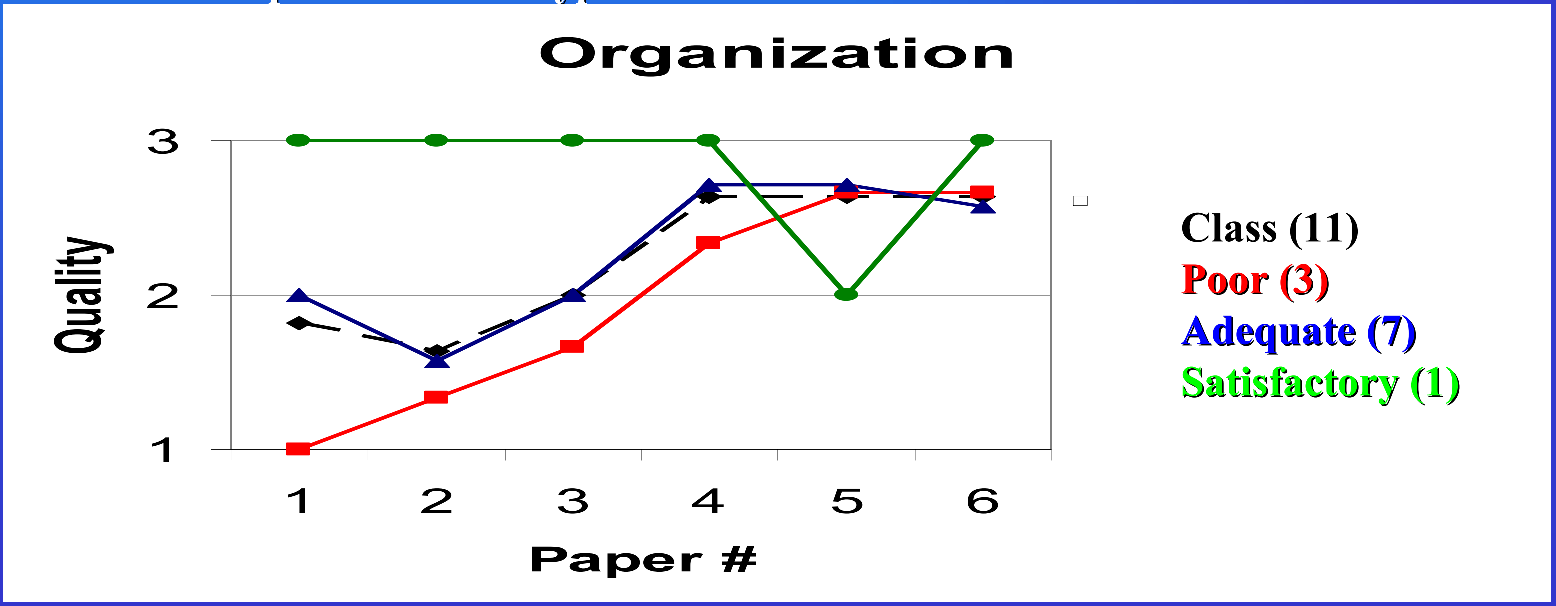
6) Rotational Dynamics





Audience: To whom is the document written?

Context: What is expected for this type of document?



Organization: Is the logic evident in the presentation?

The “Good”

- Students at all starting levels showed improvement in each of the criteria
  - Except for those students that were initially satisfactory, average rating of each group reached approximately the same quality by the end of the 15-week semester

The "Good"

- Identifiable increases in quality apparent by 3rd or 4th report
  – content, context, audience, & organization
- Slower increases in quality of support
  – majority of students only slightly higher than "adequate"

The “Good”

- Similar increases identifiable in grading by the TA
  - Identifiable correlation between TA grading (rubric) and independent analysis (writing criteria)

Now the questions is …

Does this have any relationship with anything else students are doing in the course?

As teachers, we frequently attempt to measure what students learn, and although this is relatively difficult, it is our belief that somehow it may reflect aspects of student knowledge

Some ways of measuring student knowledge in our physics courses:

1. Expository – Written Laboratory Reports
2. Qualitative (Conceptual) – Multiple Choice Questions (FCI, MBT, etc …)
3. Quantitative – Problem Solving

So we decided to take an initial look at the 3 measurements together

Data

- ~ 700 Students in 4 lecture sections
- Each section required a number of reports (4 to 8)
- Students are otherwise not significantly different as indicated by the average post FCI results

Analysis

- Calculate R of Final MC Score vs. Total Laboratory Report Score
- Calculate R of Final PS Score vs. Total Laboratory Report Score

Both calculations done within each lecture section

What might be expect when comparing final exam scores with written lab report scores?

Besides the machine-graded MC …

Grading on lab reports and exam problems generates significant amount of noise

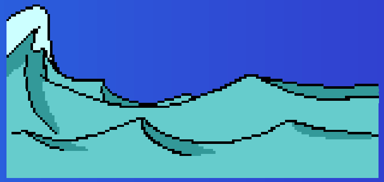
TAs are given significant guidance in grading:

~ 3 hours for each during orientation and the in-service training

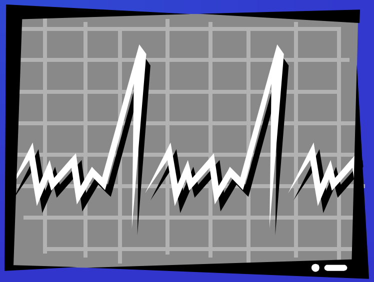
TAs come from a variety of backgrounds and countries … so despite the training, we can expect different criteria

In terms of noise:

The TAs that grade the lab reports also grade the exams

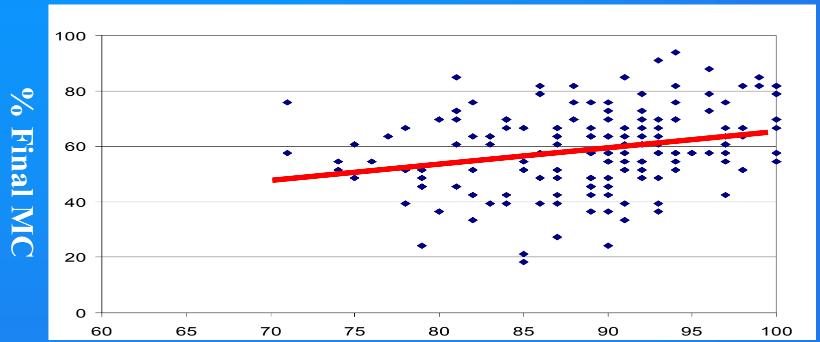


Each exam problem graded by a different person



Final Multiple Choice vs. Lab Reports

Sec A (N = 186)

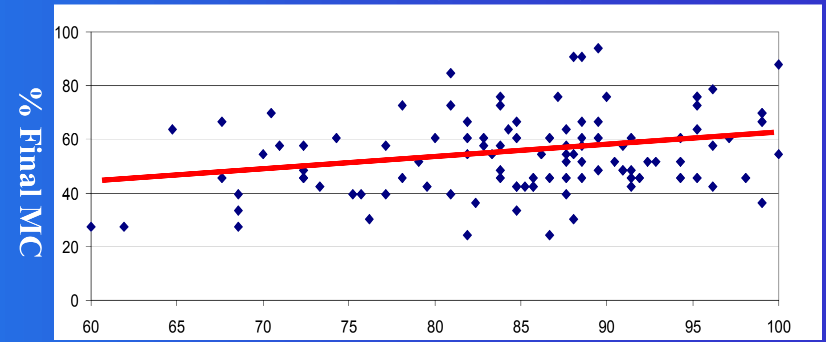


% Lab R = 0.26

6 written lab reports Post FCI = 70%

Final Probs = 47% MC = 59%

Sec B (N = 124)

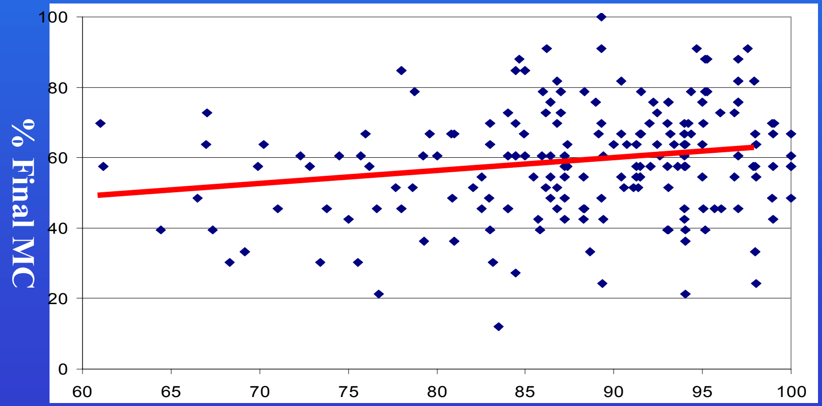


% Lab R = 0.30

7 written lab reports Post FCI = 71%

Final Probs = 47% MC = 50%

Sec C (N = 210)

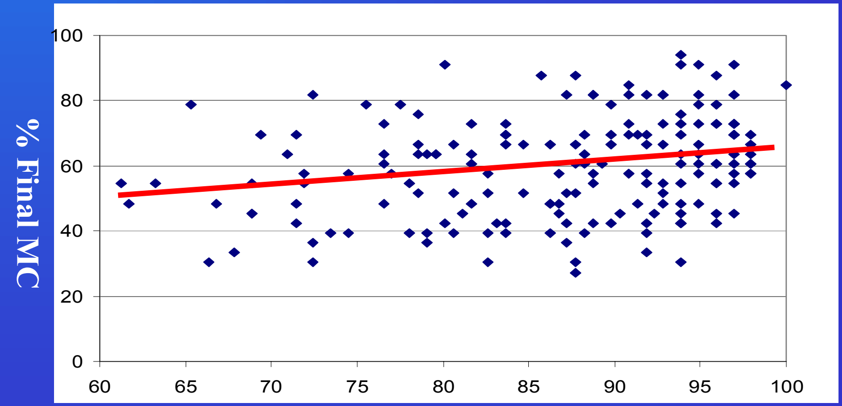


% Lab R = 0.21

4 written lab reports Post FCI = 72 %

Final Probs = 52 % MC = 59%

Sec D (N = 180)



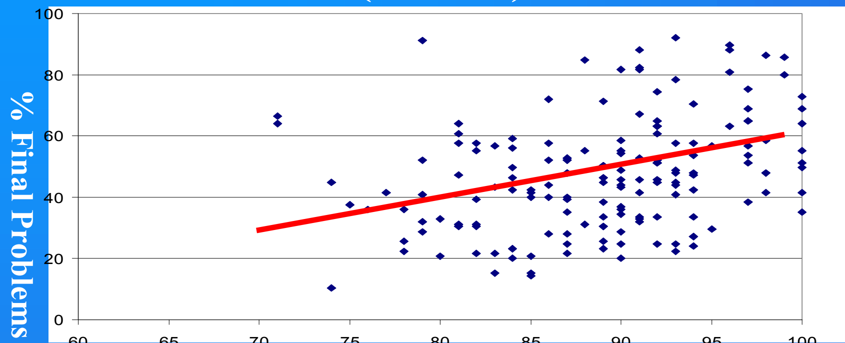
% Lab R = 0.28

8 written lab reports Post FCI = 71 %

Final Probs = 42 % MC = 59%

Final Problems vs. Lab Reports

Sec A (N = 186)

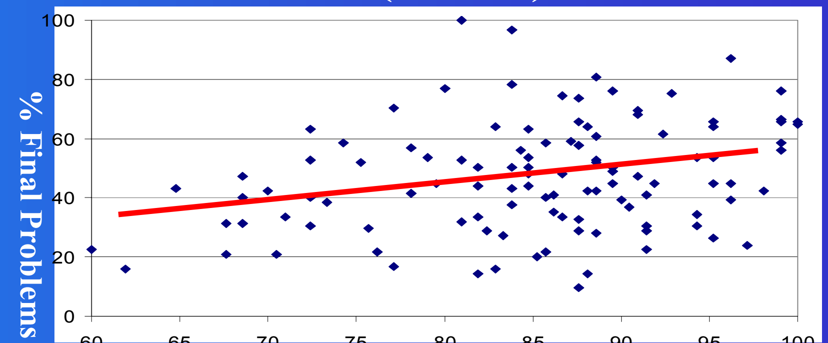


% Lab R = 0.33

6 written lab reports Post FCI = 70%

Final Probs = 47% MC = 59%

Sec B (N = 124)

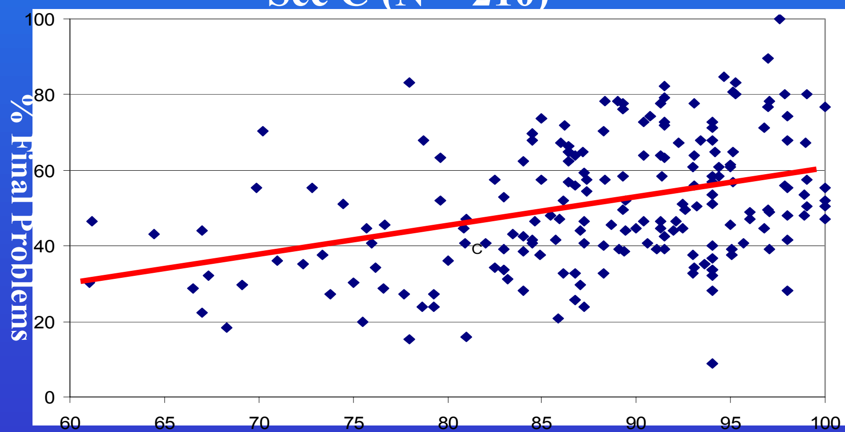


% Lab R = 0.38

7 written lab reports Post FCI = 71%

Final Probs = 47% MC = 50%

Sec C (N = 210)

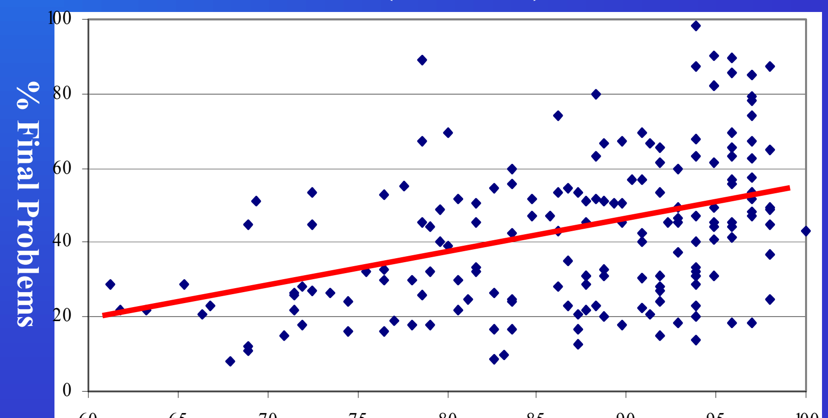


% Lab R = 0.43

4 written lab reports Post FCI = 72 %

Final Probs = 52 % MC = 59%

Sec D (N = 180)



% Lab R = 0.45

8 written lab reports Post FCI = 71 %

Final Probs = 42 % MC = 59%

Correlations

R	Final MC		Final PS	
Lab Report	0.26	0.30	0.33	0.38
	0.21	0.28	0.43	0.45

The "Bad"

- Measures on the laboratory reports seems to have some correlation with the other comprehensive measures in the course
  - Correlations are, however, not necessarily educationally significant for the most part

The "Bad"

- So, from this simple-minded analysis, we cannot say whether writing laboratory reports, as we've implemented so far, has any effect on student learning as shown by their performances on various other measures in the course

The “Bad”

- As we suspected, the measures are very **noisy**
  - The effect, if it exists, may be masked by the noises in the measurement
  - More difficult to tease out then can be done using simple measures

The “Bad”

- Despite efforts to somewhat “level the playing field”
  - Format implementations differ between lecture sections
  - Regulation enforcements differ in scope and emphasis

(anecdotal evidence)

Next

We need to do a refined analysis, of problems and lab reports, to attempt to reduce the **Noise**

A refined analysis could involve one person evaluating the laboratory reports and problems using carefully followed criteria

The “somewhat ugly”

Data Collection

- Collection of the data has been painfully gruesome
  – Hard copies of laboratory reports needed to be digitized for archival purposes (~ 2.5 GB)
- TA’s became somewhat troubled by the extra work, without understanding the purposes of the data collection
  – Led to incomplete sets

The "somewhat ugly"

Data Analysis

- We now have collected 300 complete sets of written laboratory reports from introductory physics
  - Each set contains from 4 to 8 reports (depending on the section requirements)
- Matching set of 300 Final Exams
  - Each set contains 5 problems and multiple choice questions
- Matching set of 300 Conceptual Exams
  - Each set contains pre- & post-instruction results
- Matching set of 300 Locus of Control Surveys

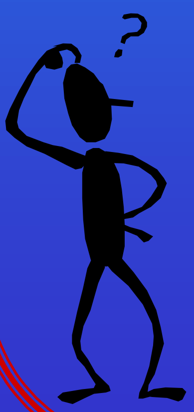
The "somewhat ugly"
Implementation

- Having a fast turn-around is important for feedback
  - Fast pace of course makes it difficult for re-writes
  - May be possible to implement a peer review structure, but that also affects the turn-around time
  - So …?

Importance of Laboratory Reports

- Learning through synthesis of information
  - Students write reports to communicate to themselves and their instructor their understanding of:
    - Logical reasoning
    - Physics concepts
    - Data analysis choices
    - What they've learned
    - What they've not learned

- Clear & Concise technical communication
  - Necessary for upper level courses in all majors
  - Sought-after skills by employers
    - What is the decision
    - Basis for the decision
    - Consequences of the decision



The End

Please visit our website
for more information:

http://groups.physics.umn.edu/physed/

or visit
The Center for Interdisciplinary Studies of Writing at:

http://cisw.cla.umn.edu/

A Lab Problem:

Forces in Equilibrium

Mechanics Lab III, Problem #2

You have a summer job with a research group studying the ecology of a rain forest in South America. To avoid walking on the delicate rain forest floor, the team members walk along a rope walkway that the local inhabitants have strung from tree to tree through the forest canopy. Your supervisor is concerned about the maximum amount of equipment each team member should carry to safely walk from tree to tree. If the walkway sags too much, the team member could be in danger, not to mention possible damage to the rain forest floor. You are assigned to set the load standards.

Appendix p. i

The Problem

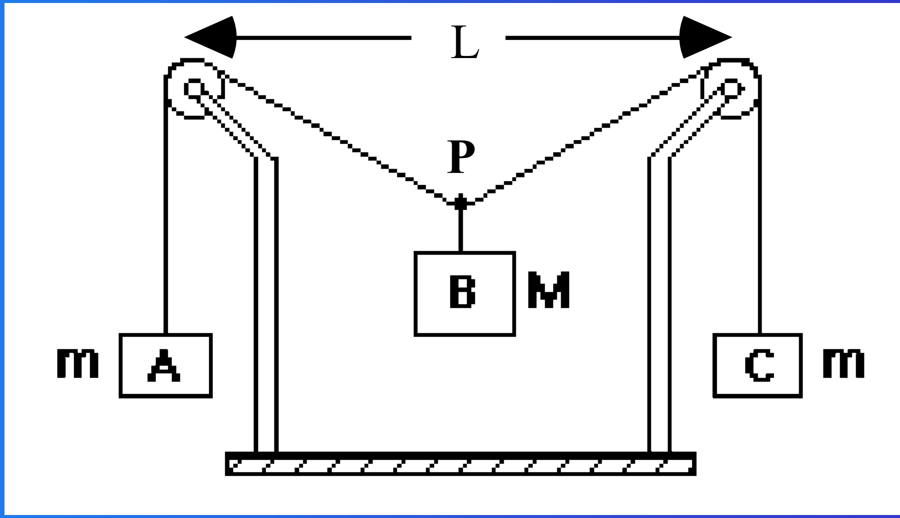
Each end of the rope supporting the walkway goes over a branch and then is attached to a large weight hanging down. You need to determine how the sag of the walkway is related to the mass of a team member plus equipment when they are at the center of the walkway between two trees. To check your calculation, you decide to model the situation using the equipment shown below.

?

How does the vertical displacement of an object suspended on a string halfway between two branches, depend on the mass of that object?

Appendix p. ii

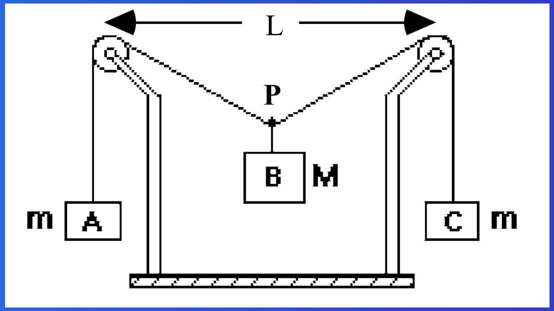
Equipment



The system consists of a central object, B, suspended halfway between two pulleys by strings. The picture above is similar to the situation with which you will work. The objects A and C, which have the same mass (m), allow you to determine the force exerted on the central object by the string. You do need to make some assumptions about what you can neglect. For this investigation, you will also need a meter stick and weights to vary the mass of B.

Appendix p. iii

Prediction

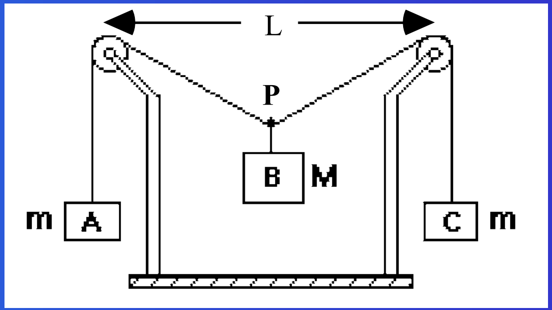


Calculate the change in the vertical displacement of the central object (B) as you increase its mass. You should obtain an equation that predicts how the vertical displacement of central object B depends on its mass, the mass of objects A and C, and the horizontal distance between the two pulleys.

Use your equation to make a graph of the vertical displacement of object B as a function of its mass.

Appendix p. iv

Methods Questions
(Coaching Problem Solving)



1. **Draw a sketch** like the one in the Equipment section. **Use trigonometry** to show how the vertical displacement of object B is related to the angle that the string between the two pulleys sags below the horizontal.

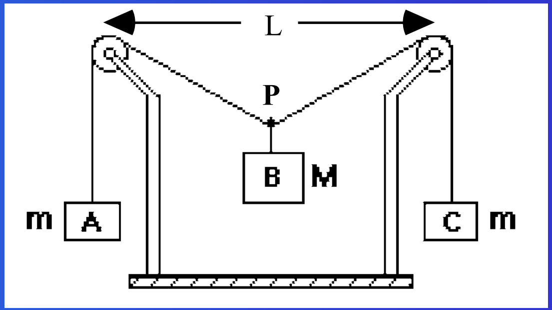
2. **Identify** the "known" (measurable) **quantities** (L, m and M) and the unknown quantity (the vertical displacement of object B).

3. **Use Newton's laws**. Write down the acceleration and draw separate **force diagrams** for objects A, B, C and for point P. For each force diagram, write Newton's second law along each **coordinate axis**.

4. **Solve your equations** to predict how the vertical displacement of object B depends on its mass (M), the mass (m) of objects A and C, and the horizontal distance between the two pulleys (L). Use this resulting equation to make a graph of how the vertical displacement changes as a function of the mass of object B.

Appendix p. v

Exploration



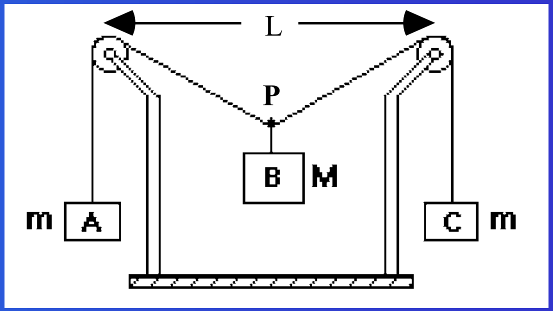
Start with just the string suspended between the pulleys (no central object), so that the string looks horizontal. Attach a central object and observe how the string sags. Decide on the origin from which you will measure the vertical position of the object.

Do the pulleys behave in a frictionless way for the entire range of weights you will use? How can you determine if the assumption of frictionless pulleys is a good one?

Add mass to the central object to decide what increments of mass will give a good range of values for the measurement. Decide how many measurements you will need to make.

Appendix p. vi

Measurement



Measure the vertical position of the central object as you increase its mass. Make a table and record your measurements.

Analysis

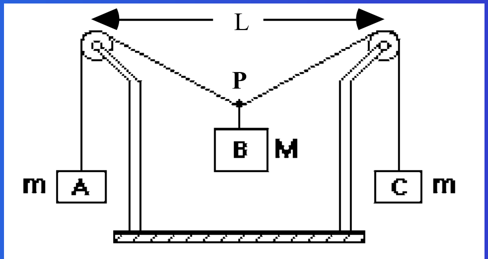
Make a graph of the vertical displacement of the central object as a function of its mass based on your measurements. On the same graph, plot your predicted equation.

Where do the two curves match? Where do the two curves start to diverge from one another? What does this tell you about the system?

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

Appendix p. vii

Conclusion



What will you report to your supervisor? How does the vertical displacement of an object suspended on a string between two pulleys depend on the mass of that object? **Did your measurements** of the vertical displacement of object B **agree with your initial predictions**? If not, why? State your result in the most general terms supported by your analysis.

What information would you need to apply your calculation to the walkway through the rain forest?

Estimate reasonable values for the information you need, and solve the problem for the walkway over the rain forest.

Appendix p. viii