Teaching Physics Through Problem Solving
Risks and Benefits

"The Thrill of Victory

And the Agony of Defeat"

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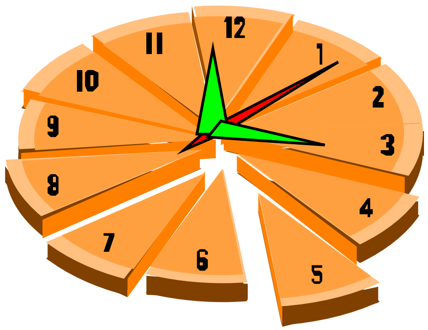
15 year continuing project to improve undergraduate education with contributions by:
Many faculty and graduate students of U of M Physics Department
In collaboration with U of M Physics Education Group

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

Supported in part by Department of Education (FIPSE), NSF, and the University of Minnesota

AGENDA
A Guide for Discussion



- ✓ **Who**
  are the Students
- ✓ **Why**
  teach Physics through Problem Solving
- ✓ **What**
  are Problems
  is Problem Solving
- ✓ **How**
  to Teach It
- ✓ **Does It Work**
  Data

Where We Started
The Introductory Physics Course

4 lectures/week
- **50 minutes**
- **200 students/class**

Disconnected lab
- **2 hours/week**
- **16 students**

No recitation sections

Not a popular course to teach or take!

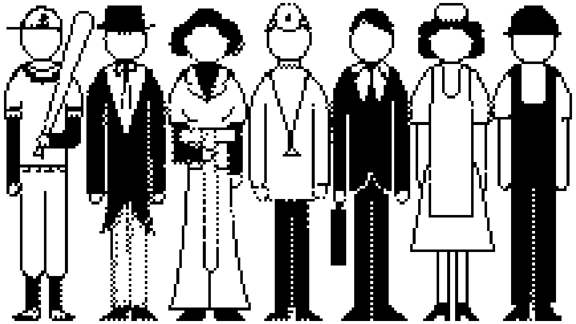
Algebra Based Physics Students
300 students/term

Interest

Architecture	45%
Paramedical	26%

- Physical therapy
- dentistry
- pharmacy
- chiropractic
- medical tech
- veterinary

Agriculture / ecology 9%



equal female / male

50 % had calculus

40 % had chemistry

50% had high school physics

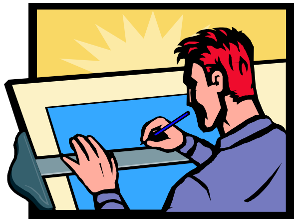
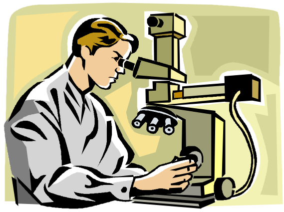
30% freshman

30% sophomore

30% junior

10% senior

Calculus Based Physics
1200 students/term

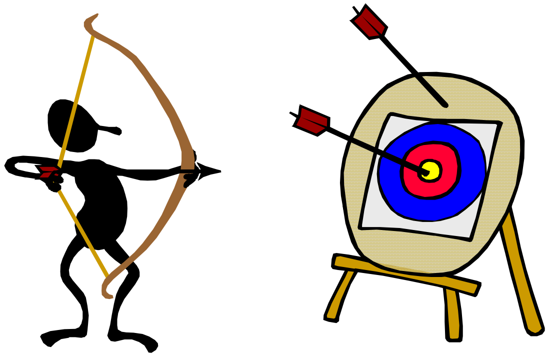

Majors	
Engineering	75%
Physics/Astro	5%
Chemistry	6%
Mathematics	5%
Biology	9%

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%

Should Teaching Problem Solving be an Aim of Introductory Physics?



- What do Other Departments Want?
- What is Useful?
- Is it Needed?
- Is it Physics?

Many different goals could be addressed through this course. Would you please rate each of the following possible goals in relation to its importance for your students on a scale of 1 to 5?

1 = unimportant	2 = slightly important	3 = somewhat important	4 = important	5 = very important

Know the basic principles behind all physics (e.g. forces, conservation of energy, ...)

Know the range of applicability of the principles of physics (e.g. conservation of energy applied to fluid flow, heat transfer, plasmas…)

Be familiar with a wide range of physics topics (e.g. specific heat, AC circuits, rotational motion, geometrical optics,...)

Solve problems using general quantitative problem solving skills within the context of physics

Solve problems using general qualitative logical reasoning within the context of physics

Formulate and carry out experiments

Analyze data from physical measurements

Use modern measurement tools for physical measurements
(e.g.. oscilloscopes, computer data acquisition, timing techniques,...)

Program computers to solve problems within the context of physics.

Overcome misconceptions about the behavior of the physical world

Understand and appreciate 'modern physics'
(e.g. solid state, quantum optics, cosmology, quantum mechanics, nuclei, particles)

Understand and appreciate the historical development and
intellectual organization of physics.

Express, verbally and in writing, logical, qualitative thought
in the context of physics.

Use with confidence the physics topics covered.

Apply the physics topics covered to new situations
not explicitly taught by the course.

Other goal. Please specify here

What Do Departments Want?

Goals: **Calculus-based Course (75% engineering majors)**

- **4.5** **Basic principles behind all physics**
- **4.5** **General qualitative problem solving skills**
- **4.4** **General quantitative problem solving skills**
- **4.2** **Apply physics topics covered to new situations**
- **4.2** ***Use with confidence***

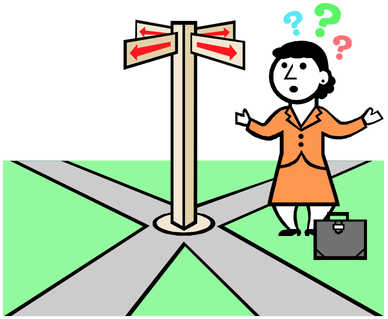
Goals: **Algebra-based Course (24 different majors)**

- **4.7** **Basic principles behind all physics**
- **4.2** **General qualitative problem solving skills**
- **4.2** ***Overcome misconceptions about physical world***
- **4.0** **General quantitative problem solving skills**
- **4.0** **Apply physics topics covered to new situations**

Solving Problems Requires Conceptual Knowledge:

From Situations to Decisions

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



Students must be taught *explicitly*

The difficulty -- major misconceptions, lack of metacognitive skills, no heuristics

Problem Solving Needs Metacognative Skill

- Managing time and direction
- Determining next step
- Monitoring understanding
- Asking skeptical questions
- Reflecting on own learning process

Some Heuristics

Means - Ends Analysis

identifying goals and subgoals

Working Backwards

step by step planning from desired result

Successive Approximations

range of applicability and evaluation

External Representations

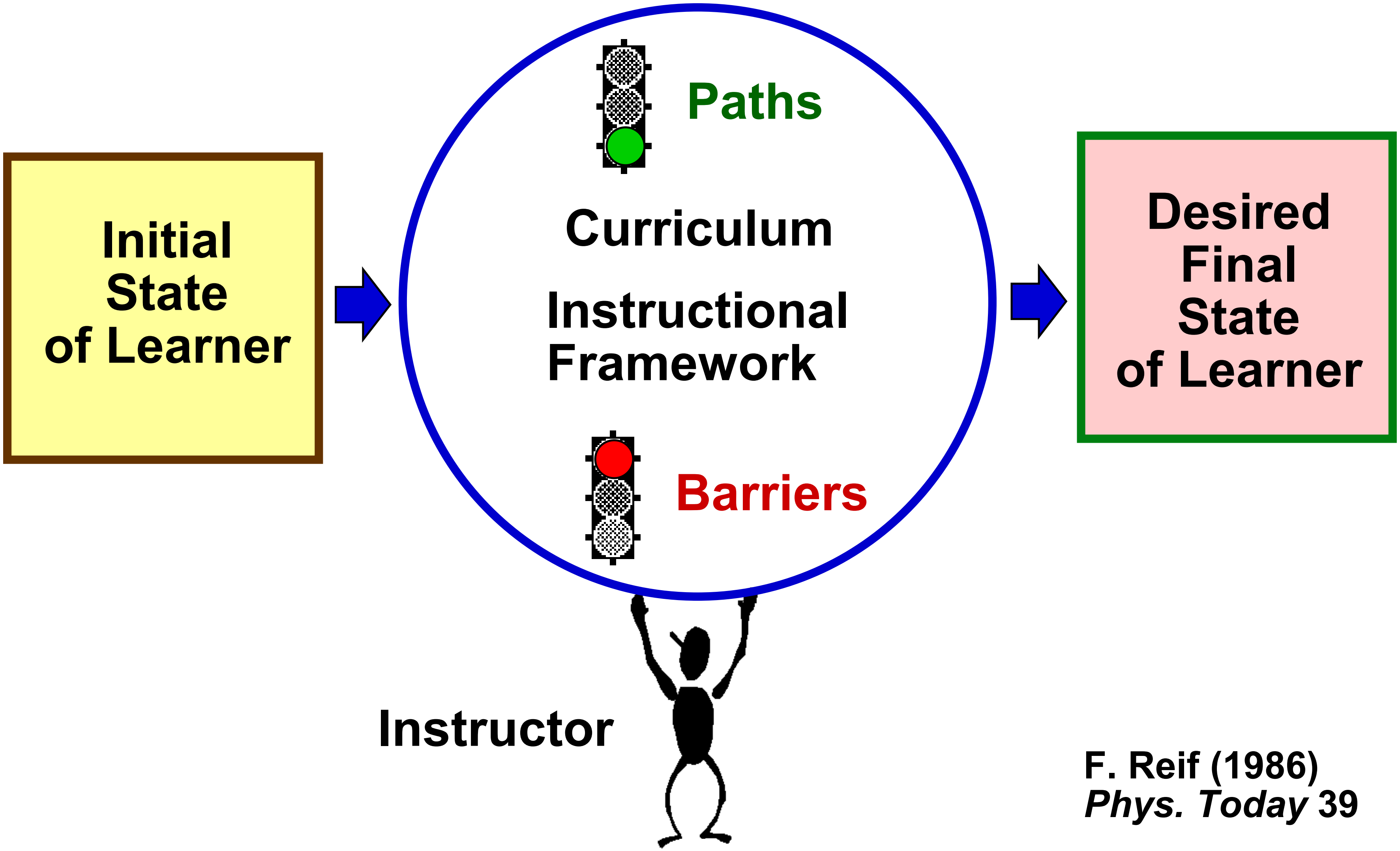
pictures, diagrams, mathematics

General Principles of Physics

Procedure for Change

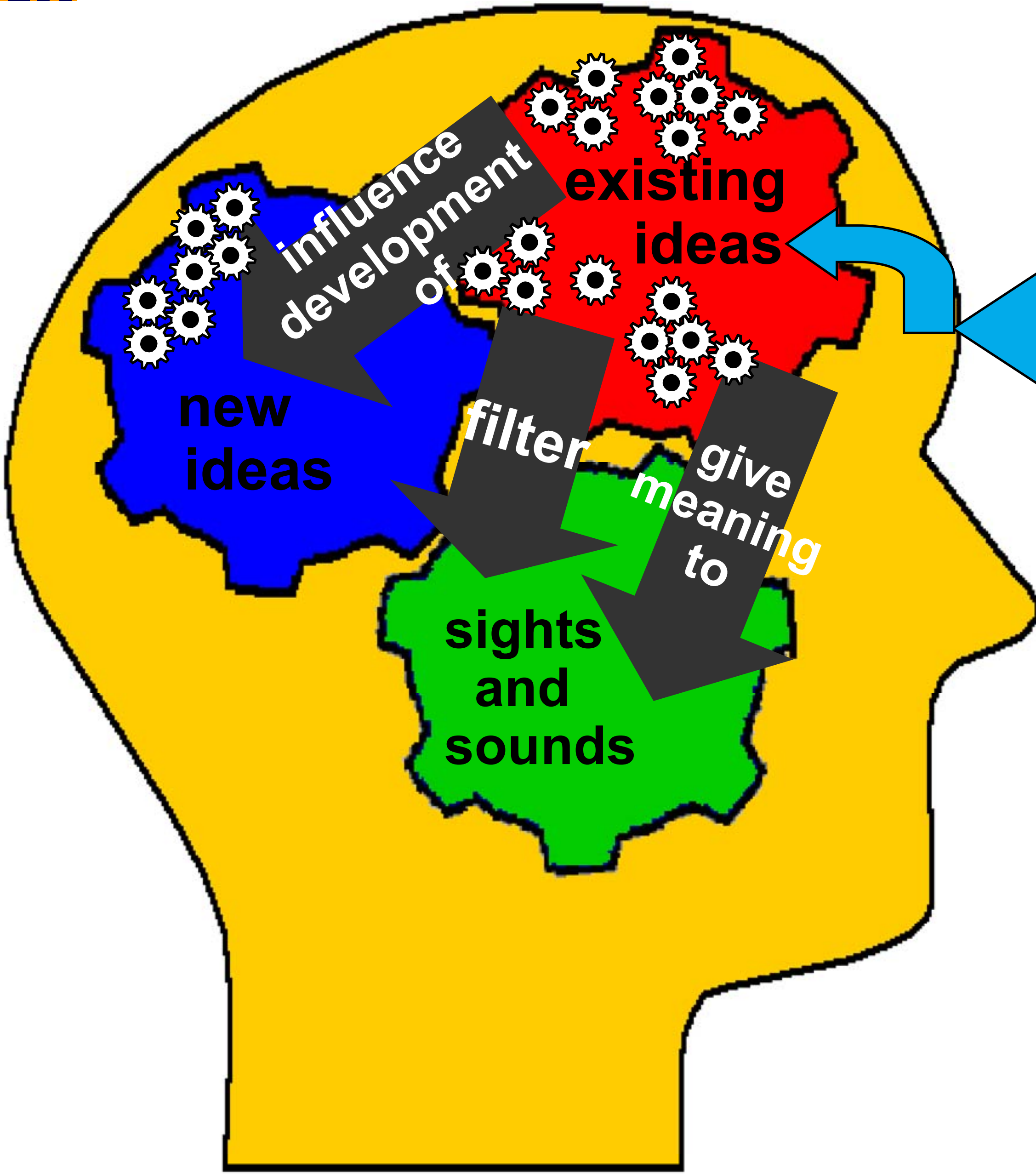
<final | T | initial>

Transformation Process



F. Reif (1986)
Phys. Today 39

Cognitive Apprenticeship Instruction



Learning in the environment of expert practice

model

coach

fade

Collins, Brown, & Newman (1990)

Initial State of the Learner

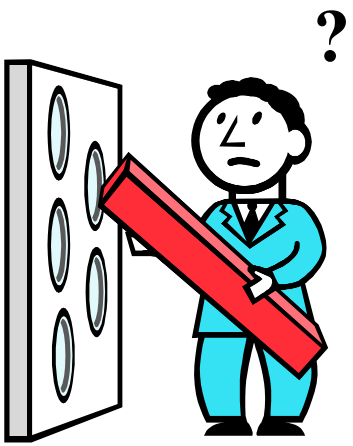
Students have Misconceptions about

The Field of Physics

Learning Physics

Nature

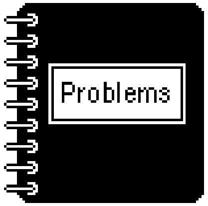
Problem-solving



All combine to make it difficult for students to solve problems.

Not the same as “getting a problem right”.

Students' Misconceptions About Problem Solving



You need to know the right formula to solve a problem:

Memorize formulas

Bring in "crib" sheets

Memorize solution patterns

$$\Sigma F = ma$$
$$T - f = ma$$
$$a = \frac{T - f}{m}$$

It's all in the mathematics:

Manipulate the equations as quickly as possible

Plug-and-chug

Numbers are easier to deal with

Plug in numbers as soon as possible

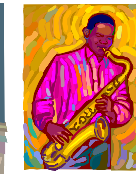
How do YOU solve a problem?

- ✓ Read the next problem
- ✓ Write down how you would go about solving this problem

You are investigating the possibility of producing power from fusion. The device being designed confines a hot gas of positively charged ions, called a plasma, in a very long cylinder with a radius of 2.0 cm. The charge density of the plasma in the cylinder is 6.0×10^{-5} C/m^3. Positively charged Tritium ions are to be injected into the plasma perpendicular to the axis of the cylinder in a direction toward the center of the cylinder. Your job is to determine the speed that a Tritium ion should have when it enters the cylinder so that its velocity is zero when it reaches the axis of the cylinder. Tritium is an isotope of Hydrogen with one proton and two neutrons. You look up the charge of a proton and mass of the tritium in your Physics text and find them to be 1.6×10^{-19} C and 5.0×10^{-27} Kg.

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**

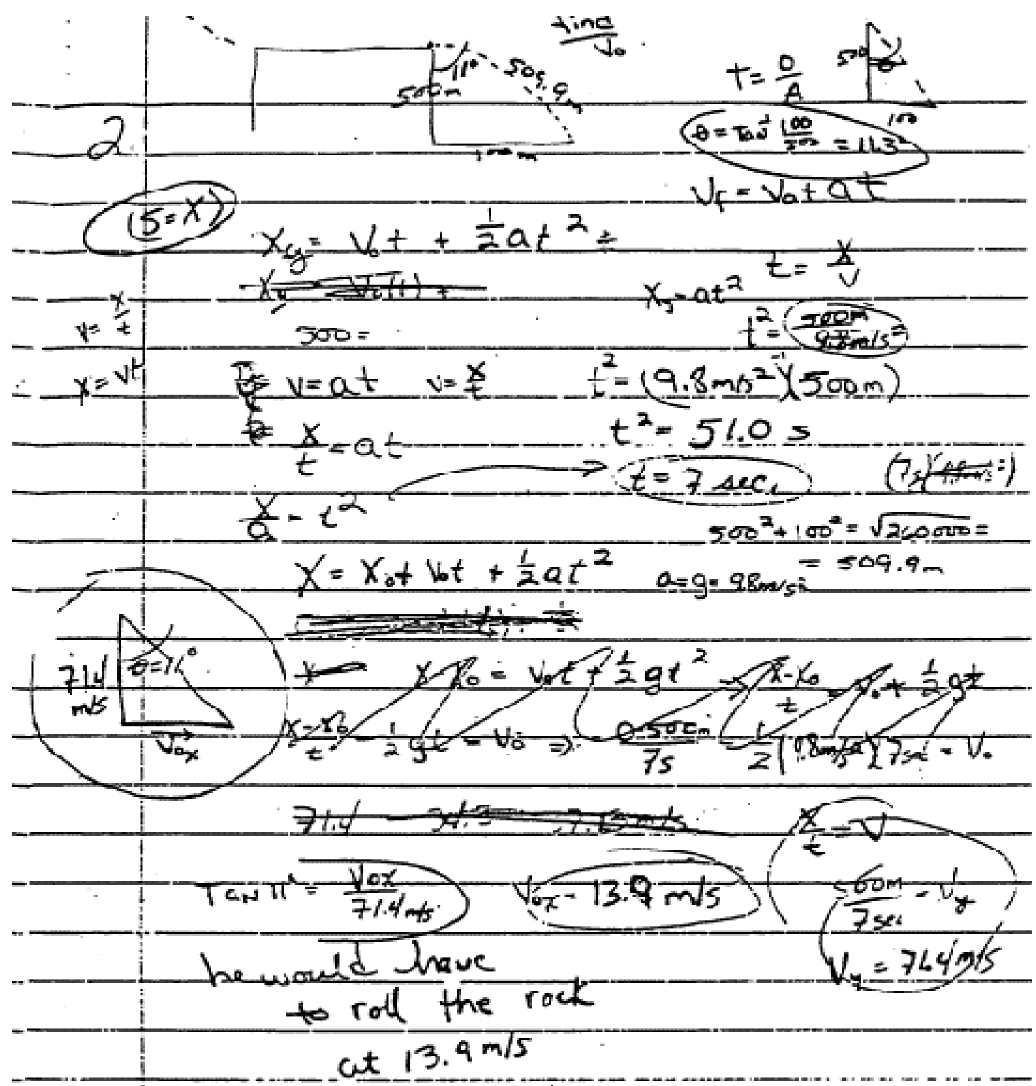
Let's get an answer

STEP 5 — **Evaluate the solution**

Can this be true?

Typical Student Test

Because parents are concerned that children are taught incorrect science in cartoon shows, you have been hired as a technical advisor for the Cowboy Bob show. In this episode, Cowboy Bob is camped on the top of Table Rock. Table Rock has a flat horizontal top, vertical sides, and is 500 meters high. Cowboy Bob sees a band of outlaws at the base of Table Rock 100 meters from the side wall. The outlaws are waiting to rob the stagecoach. Cowboy Bob decides to roll a large boulder over the edge and onto the outlaws. Your boss asks you if it is possible to hit the outlaws with the boulder. Determine how fast Bob will have to roll the boulder to reach the outlaws.



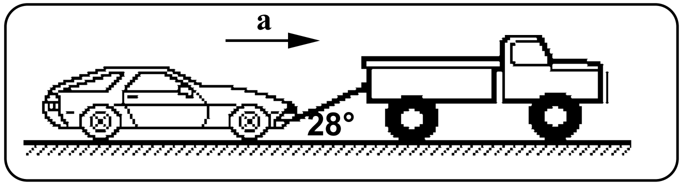
Students need instructional support to solve problems

Competent Problem Solving

Step | **Bridge**

1. Focus on the Problem

Translate the words into an image of the situation.

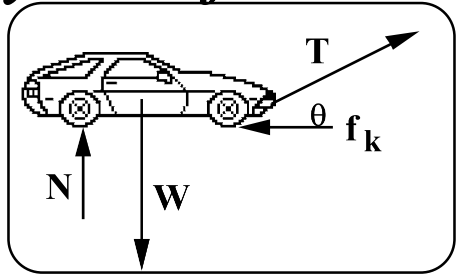


Identify an approach to the problem.

Relate forces on car to acceleration using Newton's Second Law

2. Describe the Physics

Translate the mental image into a physics representation of the problem (e.g., idealized diagram, symbols for knowns and unknowns).



Assemble mathematical tools (equations).

$$\sum F = ma$$
$$f_k = \mu N$$
$$W = mg$$

3. Plan a Solution

Step | Bridge

3. Plan a Solution

Translate the physics description into a mathematical representation of the problem.

Find a:

[1] $\sum F_x = ma_x$

Find $\sum F_x$:

[2] $\sum F_x = T_x - f_k$

Outline the mathematical solution steps.

Solve[3] for T_x and put into [2].

Solve[2] for $\sum F_x$ and put into [1].

Solve[1] for a_x.

4. Execute the Plan

Translate the plan into a series of appropriate mathematical actions.

$$T_x - f_k = ma_x$$

$$T\cos\theta - \mu(W - T\sin\theta) = \frac{W}{g}a_x$$

$$\frac{gT}{W}(\cos\theta - \mu\sin\theta) - \mu g = a_x$$

Check units of algebraic solution.

$$\frac{\left[\frac{m}{s^2}\right][N]}{[N]} - \left[\frac{m}{s^2}\right] = \left[\frac{m}{s^2}\right] \quad \text{OK}$$

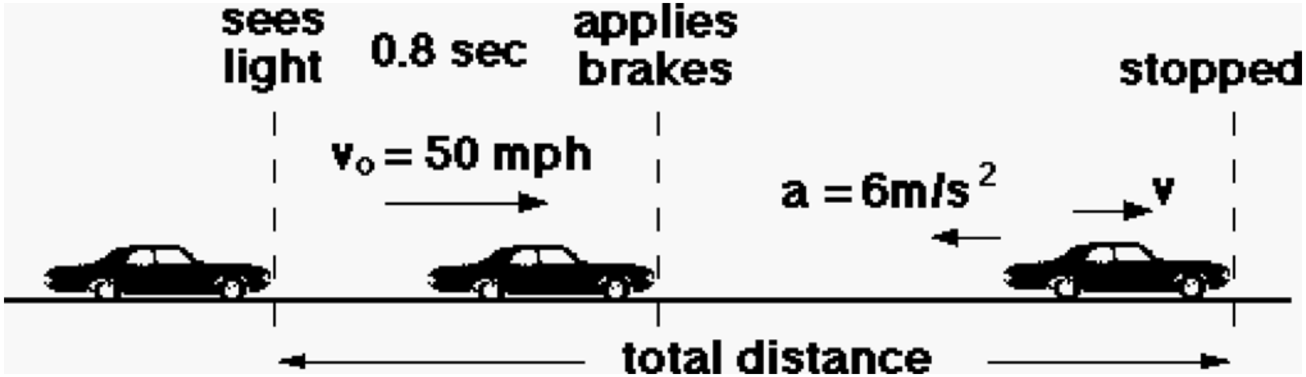
5. Evaluate the Solution

A Problem

You are driving on a freeway following another car when you wonder what your stopping distance would be if that car jammed on its brakes. You are going at 50 mph. When you get home you decide to do the calculation. You measure your reaction time to be 0.8 seconds from the time you see the car's brake lights until you apply your own brakes. Your owner's manual says that your car slows down at a rate of 6 m/s^2 when the brakes are applied.

Focus on the Problem

Picture and Given Information:



Question:

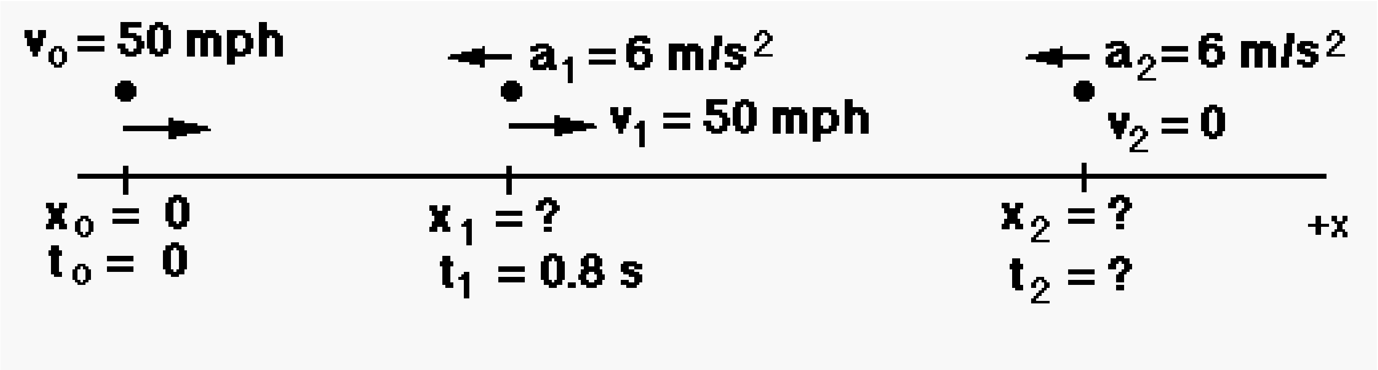
What total distance did the car travel to stop?

Approach:

- The velocity is constant until brakes applied, then the acceleration is constant.
- Use the definition of velocity and acceleration.

Describe the Physics

Diagram and Define Physics Quantities:



Target Quantity(s): Find x_2

Quantitative Relationships:

$$\bar{a} = \frac{\Delta v}{\Delta t} \qquad \bar{v} = \frac{v_i + v_f}{2} \text{ for constant acceleration}$$

$$\bar{v} = \frac{\Delta x}{\Delta t} \qquad v_0 = v_1 = v \text{ (constant velocity)}$$

Plan the Solution

Construct Specific Equations:

Unknowns

Find x_2: x_2

① $\bar{v}_{12} = \dfrac{x_2 - x_1}{t_2 - t_1}$ $\bar{v}_{12}, x_1, t_2$

Find $\bar{v}_{12}$:

② $\bar{v}_{12} = \dfrac{v_2 + v_1}{2} = \dfrac{v}{2}$

Find x_1:

③ $\bar{v}_{01} = v = \dfrac{x_1 - x_0}{t_1 - t_0} = \dfrac{x_1}{t_1}$

Find t_2:

④ $\bar{a}_{12} = a = \dfrac{v_2 - v_1}{t_2 - t_1} = -\dfrac{v}{t_2 - t_1}$

Check for sufficiency:

Four unknowns
$(x_2, \bar{v}_{12}, x_1, t_2)$
Four equations.

Outline math solution:

Solve ④ for t_2,
put into ①.
Solve ③ for x_1,
put into ①.
Solve ② for $\bar{v}_{12}$,
put into ①.
Solve ① for x_2.

Execute the Plan

Follow the Plan:

Solve (4) for t_2

$$a = \frac{-v}{t_2 - t_1}$$

$$at_2 - at_1 = -v$$

$$t_2 = \frac{at_1 - v}{a}$$

$$t_2 = t_1 - \frac{v}{a}$$

Solve (3) for x_1

$$v = \frac{x_1}{t_1}$$

$$x_1 = vt_1$$

Solve (2) for $\bar{v}_2$

$$\bar{v}_2 = \frac{v}{2}$$

Put all into (1)

$$\bar{v}_2 = \frac{x_2 - x_1}{t_2 - t_1}$$

$$\bar{v}_2(t_2 - t_1) = x_2 - x_1$$

$$x_2 = x_1 + \bar{v}_2(t_2 - t_1)$$

$$x_2 = vt_1 + \frac{v}{2}\left(t_1 - \frac{v}{a} - t_1\right)$$

$$x_2 = vt_1 - \frac{v^2}{2a}$$

Calculate Target Variable(s):

$$x_2 = (22.4\,m/s)(0.8\,s) - \frac{(22.4\,m/s)^2}{2(-6\,m/s^2)}$$

$$= 18\ m + 42\ m$$

$$= 60\ m$$

Evaluate the Answer

Is the Answer properly stated?

- **Yes. The total distance traveled by car to stop has been calculated.**

Yes. x_2 is in the units of length

$$x_2 = \left(\frac{m}{s}\right)s + \left[\frac{\left(\frac{m}{s}\right)^2}{\frac{m}{s^2}}\right]$$

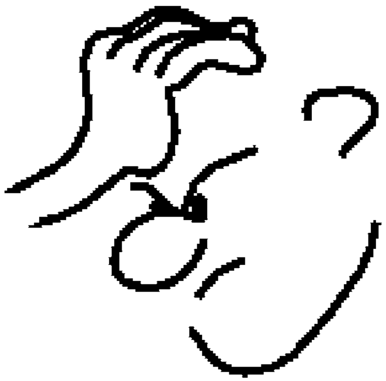
$$= m + m$$

Is the Answer unreasonable?

No. A car length is about 6 m so 10 car lengths is not unreasonable.

Is the answer complete?

Practice Makes Perfect
BUT



Traditional "Problems"

- Can often be solved by manipulating equations
- Little visualization necessary
- Few decisions necessary
- Disconnected from student's reality
- Can often be solved without knowing the subject

What is being practiced?

How Do You Solve This

An infinitely long cylinder of radius R carries a uniform (volume) charge density r. Use Gauss' Law to calculate the field everywhere inside the cylinder.

Compare procedures with the previous problem.

Which motivated you to practice the most elements of expert problem solving?

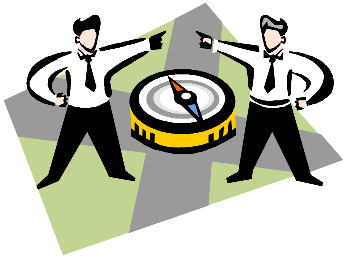
Textbook Problem

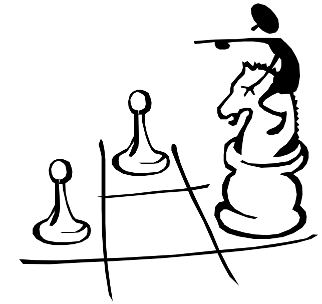
Appropriate Problems for Practicing Problem Solving

The problems must be challenging enough so there is a *real* advantage to using problem solving heuristics.

1. **The problem must be complex enough so the best student in the class is not certain how to solve it.**

   The problem must be simple enough so that the solution, once arrived at, can be understood and appreciated.





2. **The problems must be designed so that**

   - **the major problem solving heuristics are required (e.g. physics understood, a situation requiring an external representation);**

   - **there are several decisions to make in order to do the problem (e.g. several different quantities that could be calculated to answer the question; several ways to approach the problem);**

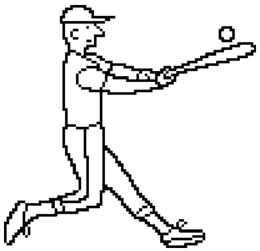
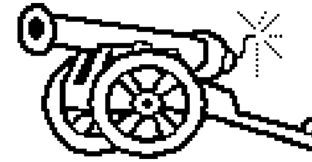
   - **the problem cannot be resolved in a few steps by copying a pattern.**

3. The task problem must connect to each student's mental processes

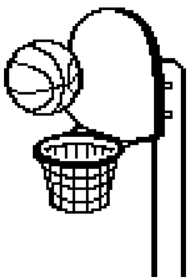
   • the situation is real to the student so other information is connected;

   • there is a reasonable goal on which to base decision making.

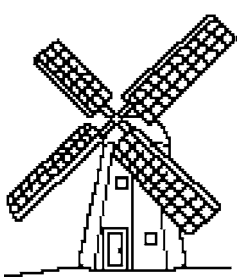
Context-rich Problems

- Each problem is a short story in which the major character is the student. That is, each problem statement uses the personal pronoun "you."




- The problem statement includes a plausible motivation or reason for "you" to calculate something.
- The objects in the problems are real (or can be imagined) -- the idealization process occurs explicitly.



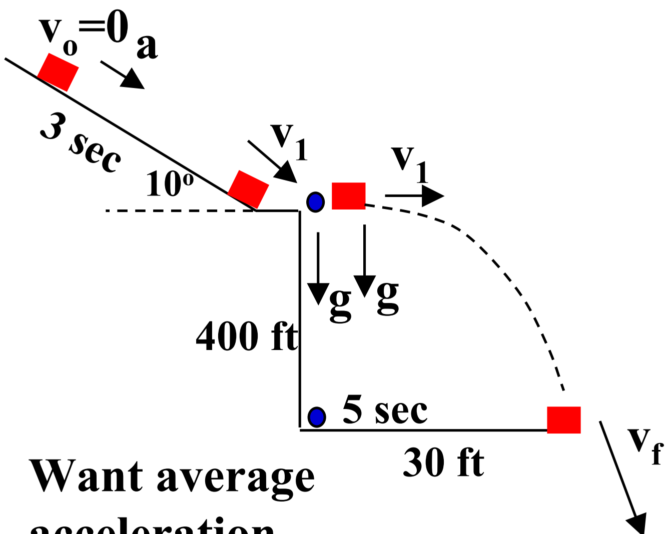

- No pictures or diagrams are given with the problems. Students must visualize the situation by using their own experiences.
- The problem can not be solved in one step by plugging numbers into a formula.

Context-rich Problems

In addition, more difficult context-rich problems can have one or more of the following characteristics:

- The unknown variable is not explicitly specified in the problem statement (e.g., Will this design work?).
- More information may be given in the problem statement than is required to solve the problems, or relevant information may be missing.
- Assumptions may need to be made to solve the problem.
- The problem may require more than one fundamental principle for a solution (e.g., Newton's Laws and the Conservation of Energy).
- The context can be very unfamiliar (i.e., involve the interactions in the nucleus of atoms, quarks, quasars, etc.)

Problem Analysis



Want average acceleration down the hill.

Principles

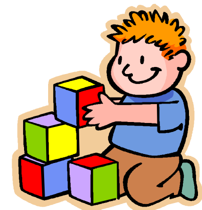
- Average acceleration = (velocity change / time for change)
- Final velocity = initial horizontal velocity of flight
- Vertical & horizontal motion are independent

In flight

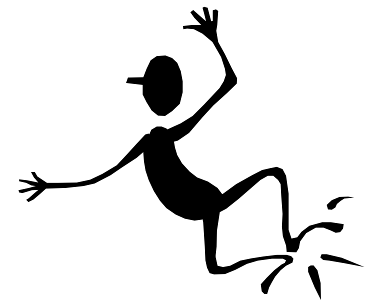
- Horizontal velocity is constant
- Vertical acceleration is constant & same for everything

You have a summer job with an insurance company and are helping to investigate a tragic "accident." At the scene, you see a road running straight down a hill that is at of 10° to the horizontal. At the bottom of the hill, the road widens into a small, level parking lot overlooking a cliff. The cliff has a vertical drop of 400 feet to the horizontal ground below where a car is wrecked 30 feet from the base of the cliff. A witness claims that the car was parked on the hill and began coasting down. He remembers that the car took about 3 seconds to get down the hill. Your boss drops a stone from the edge of the cliff and, from the sound of it hitting the ground below, determines that it takes 5.0 seconds to fall to the bottom. She tells you to calculate the car's average acceleration coming down the hill based on the statement of the witness and the other facts in the case.

The Dilemma



Start with simple problems
to learn expert-like strategy.



Success using novice strategy.

Why change?

Start with complex problems
so novice strategy fails

Difficulty using new strategy.

Why change?

Why We Use Cooperative Group Problem Solving

1. Writing down a problem solving strategy seems too long and complex for most students.

Cooperative-group problem solving allows practice until the strategy becomes more natural.

2. Complex problems that need a strategy are initially difficult.

Groups can solve successfully solve them so students see the advantage of a logical problem-solving strategy early in the course.

Why We Use Cooperative Group Problem Solving

3. The external group interaction forces individuals to observe the planning and monitoring skills needed to solve problems. (Metacognition)

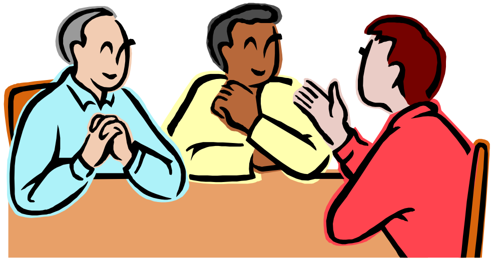
4. Students practice the language of physics -- "talking physics."

5. Students must deal with and resolve their misconceptions.

6. In whole-class discussions, students are less intimidated

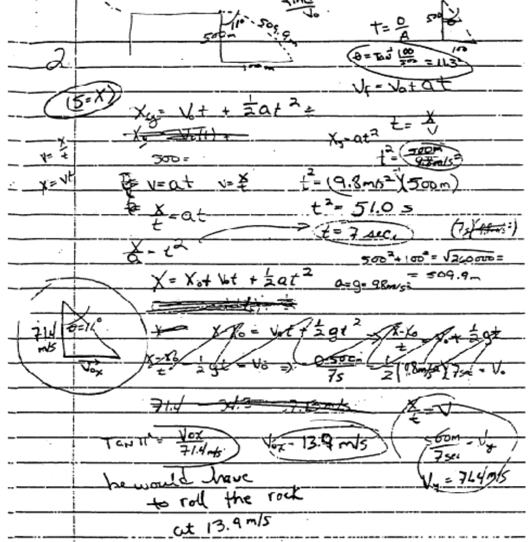
Their answer or question has been validated by the others.

Cooperative Groups



- Positive Interdependence
- Face-to-Face Interaction
- Individual Accountability
- Explicit Collaborative Skills
- Group Functioning Assessment

Student Problem Solutions


d

$(5 = x)$

$x_y = V_o t + \frac{1}{2}at^2$

$t = \frac{D}{A}$

$\theta = \tan^{-1}\frac{100}{500} = 11.3°$

$V_f = V_o t + at$

$V = \frac{x}{t}$

$x = Vt$

$v = at$ $\quad v = \frac{x}{t}$

$x_y = at^2$ $\quad t = \frac{x}{V}$

$t^2 = \frac{500m}{9.8m/s^2}$

$t^2 = (9.8m/s^2)(500m)$

$\frac{x}{t} = at$

$t^2 = 51.0\ s$

$\frac{x}{a} = t^2$

$t = 7\ sec.$

$500^2 + 100^2 = \sqrt{260000} = 509.9m$

$X = X_o + V_o t + \frac{1}{2}at^2$ $\quad a = g = 9.8m/s^2$

$x - x_o = V_o t + \frac{1}{2}gt^2$

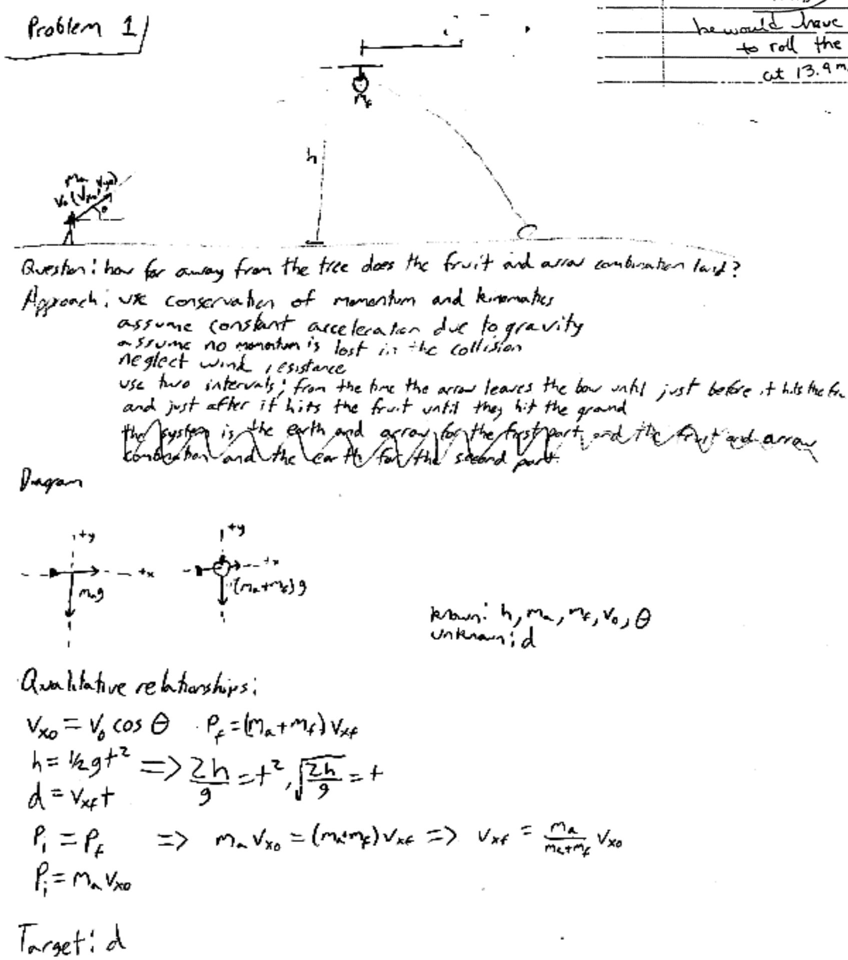
$\frac{500m}{7s}$

$Tan\ 11° = \frac{V_{ox}}{71.4m/s}$ $\quad V_{ox} = 13.9\ m/s$

$\frac{x}{t} = V$ $\quad \frac{500m}{7sec} = V_y$ $\quad V_y = 71.4\ m/s$

he would have to roll the rock at 13.9 m/s

Initial State


Problem 1

Question: how far away from the tree does the fruit and arrow combination land?

Approach: use conservation of momentum and kinematics
assume constant acceleration due to gravity
assume no momentum is lost in the collision
neglect wind resistance
use two intervals; from the time the arrow leaves the bow until just before it hits the fruit and just after it hits the fruit until they hit the ground
~~the system is the earth and arrow for the first part, and the fruit and arrow combination and the earth for the second part~~

Diagram

known: h, m_a, m_f, v_o, θ
unknown: d

Qualitative relationships:

$V_{xo} = V_o \cos\theta$ $\quad P_f = (m_a+m_f)V_{xf}$

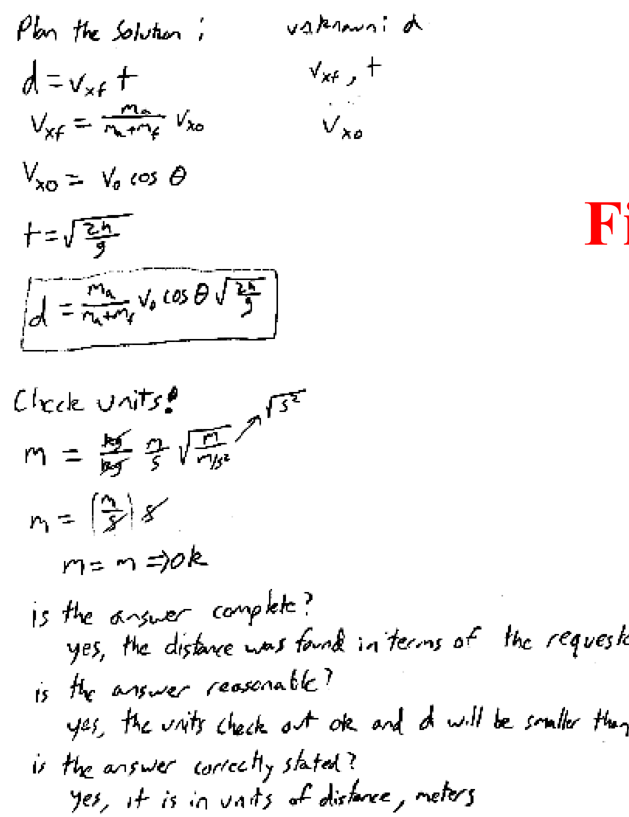
$h = \frac{1}{2}gt^2 \Rightarrow \frac{2h}{g} = t^2, \sqrt{\frac{2h}{g}} = t$

$d = V_{xf}t$

$P_i = P_f \Rightarrow m_a V_{xo} = (m_a+m_f)V_{xf} \Rightarrow V_{xf} = \frac{m_a}{m_a+m_f}V_{xo}$

$P_i = m_a V_{xo}$

Target: d


Plan the Solution:

unknown: d
V_{xf}, t
V_{xo}

$d = V_{xf}t$

$V_{xf} = \frac{m_a}{m_a+m_f}V_{xo}$

$V_{xo} = V_o \cos\theta$

$t = \sqrt{\frac{2h}{g}}$

$d = \frac{m_a}{m_a+m_f}V_o \cos\theta \sqrt{\frac{2h}{g}}$

Check units!

$m = \frac{kg}{kg}\frac{m}{s}\sqrt{\frac{m}{m/s^2}}$ $\quad \sqrt{s^2}$

$m = \left(\frac{m}{s}\right)s$

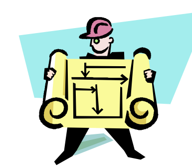
$m = m \Rightarrow ok$

is the answer complete?
yes, the distance was found in terms of the requested values

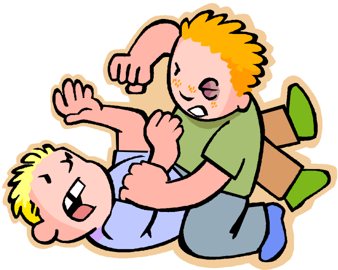
is the answer reasonable?
yes, the units check out ok and d will be smaller than h due to conservation of moment

is the answer correctly stated?
yes, it is in units of distance, meters

Final State

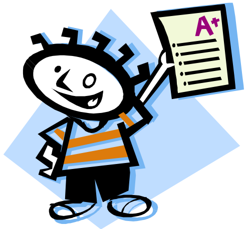


Why Group Problem Solving May Not Work



1. Inappropriate Tasks
2. Inappropriate Grading
3. Poor structure and management of Groups

Grading



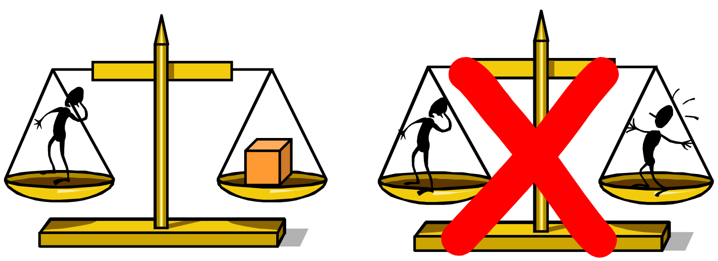
EVERYTHING WE WANT STUDENTS TO DO IS GRADED

"If you don't grade it, they don't learn it!"

- **Always write physics principles and a logical, organized problem solving procedure.**
- **Only basic equations given on test are allowed .**
- **Small, but significant part of grades is for group problem solving.**
- **During lecture, in class questions are occasionally collected and graded.**
- **Prediction solutions for lab problems are graded.**

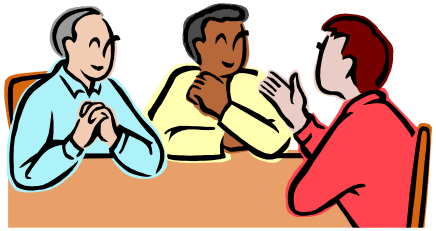
ABSOLUTE SCALE

"If you win, I do NOT lose."

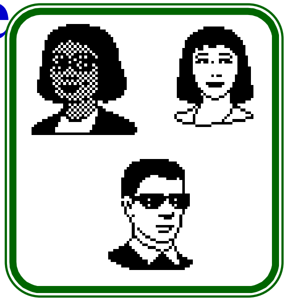


Structure and Management of Groups

1. **What is the "optimal" group size?**
    - three (or occasionally four)



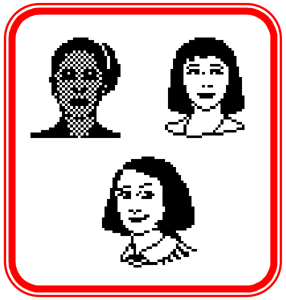
2. **What should be the gender and performance composition of cooperative groups?**



    - two women with one man, or same-gender groups
    - heterogeneous groups:
        - one from top third
        - one from middle third
        - one from bottom third

based on past test performance.

Structure and Management of Groups



3. How often should the groups be changed?

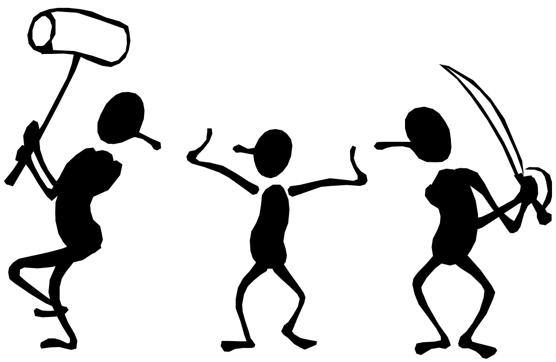
For most groups:

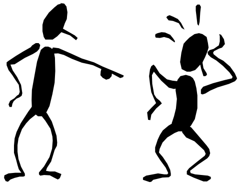
- stay together long enough to be successful
- enough change so students know that success is due to them, not to a "magic" group.
- about four times first semester, twice second semester

Structure and Management of Groups

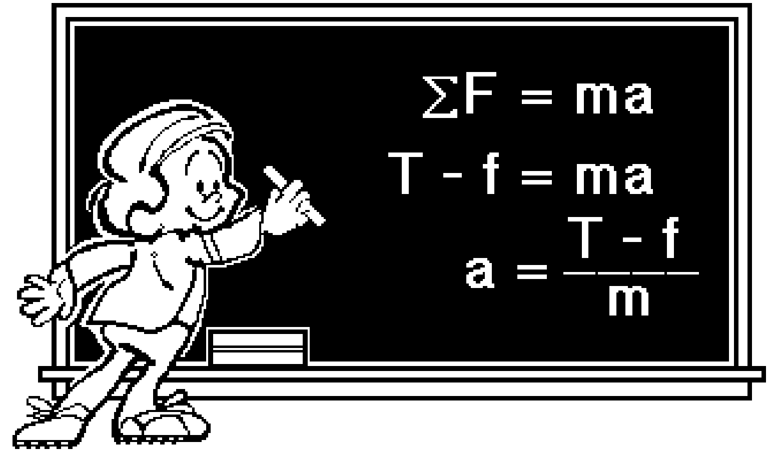
4. How can problems of dominance by one student and conflict avoidance within a group be addressed?

- Group problems are part of each test. One common solution that all members sign.
- Assign and rotate roles:
  - Manager
  - Skeptic
  - Checker/Recorder
  - Summarizer
- Most of grade is based on individual problem solving.
- Students discuss how they worked together and how they could be more effective.





Structure and Management of Groups



5. How can individual accountability be addressed?

- assign and rotate roles, group functioning;
- seat arrangement -- eye-to-eye, knee-to-knee;
- individual students randomly called on to present group results;
- occasionally a group problem counts as a test question --if group member was absent the week before, he or she cannot take group test;
- each student submits an individual lab report. Each member of the group reports on a different problem.

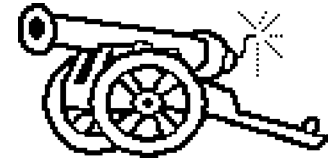
Appropriate Tasks

The problems must be challenging enough so there is a *real* advantage to working in a group.

1. **The problem must be complex enough so the best student in the group is not certain how to solve it.**

   The problem must be simple enough so that the solution, once arrived at, can be understood and appreciated by everyone in the group.

Appropriate Tasks

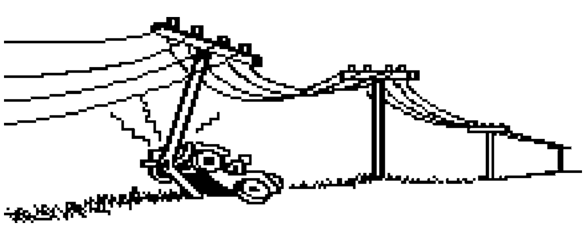


2. The task must be designed so that

   - everyone can contribute at the beginning (e.g., a situation difficult to visualize requires an external representation);

   - there are several decisions to make in order to do the task (e.g., several different quantities that could be calculated to answer the question; several ways to approach the problem); everyone's agreement is necessary.

   - the task relies on applying a strategy not remembering a pattern



From a Textbook

Cart A, which is moving with a constant velocity of 3 m/s, has an inelastic collision with cart B, which is initially at rest as shown in Figure 8.3. After the collision, the carts move together up an inclined plane. Neglecting friction, determine the vertical height *h* of the carts before they reverse direction.

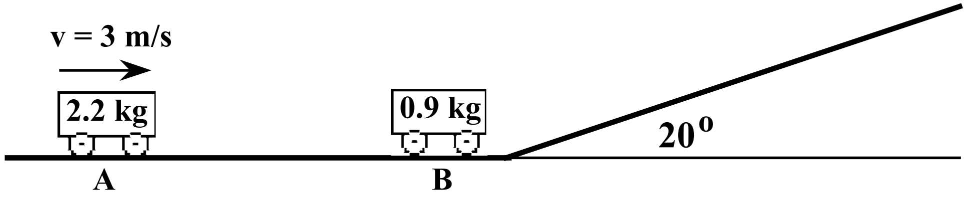


Figure 8.3

Context-rich Problem

You are helping a friend prepare for the next skate board exhibition. The plan for the program is to take a running start and then jump onto a heavy duty 8-lb stationary skateboard. Your friend and the skateboard will glide in a straight line along a short, level section of track, then up a sloped concrete wall. The plan is to reach a height of at least 10 feet above the starting point before turning to come back down the slope. The fastest your friend can run to safely jump on the skateboard is 7 feet/second. Knowing that you have taken physics, your friend wants you to determine if the plan can be carried out. When you ask, you find out that your friend's weight is 130 lbs.

Recitation Sections

Traditional Recitation Sections Do Not Work

- Instructor chooses problems to solve for students
- Students choose problems for instructor to solve
- Instructor gives review of professor's lecture

→ Less efficient lectures

Use Recitation Section for Coaching

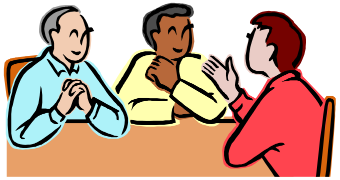
Students work on an appropriate task

- In small groups (peer coaching)
- Intervention by instructor (expert coaching)

Need

- Appropriate task
- Group structure
- Intervention tactics

→ Cooperative Group Problem Solving



Laboratories

Traditional Laboratories Do Not Work

- Disconnected from lecture
- Different goals from lecture
- No modeling requires either

Cookbook
Discovery → Neither effective for learning physics

Use Laboratory for Coaching

Students work on an appropriate task investigating the behavior of the real world.

- In small groups (peer coaching)
- Intervention by instructor (expert coaching)

Need

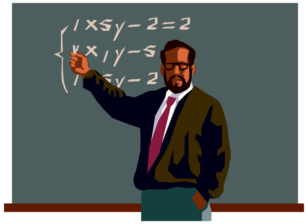
- Appropriate task
- Group structure
- Intervention tactics

→ Cooperative Group Problem Solving

The Course as a System

Use strengths of components acting together

- **Lectures - 3 x 50 min. each week** **(150 - 300 students)**
  - **Model construction of knowledge**
    - **Explicit Storyline**
    - **Motivate all concepts**



  - **Model problem solving**
    - **A single explicit strategy**
    - **Always start from basic principles**

- **Recitation sections - 1 x 50 min. each week**
- **Laboratories - 1 x 110 min. each week** **(15 students)**
  - **Coach problem solving**
    - **Same strategy as lecture**
    - **Same concepts as lecture**

Course Structure

LECTURES

Three hours each week, sometimes with informal cooperative groups. Model constructing knowledge, model problem solving strategy.

RECITATION SECTION

One hour each Thursday -- groups practice using problem-solving strategy to solve context-rich problems. Peer coaching, TA coaching.

LABORATORY

Two hours each week -- *same* groups practice using strategy to solve concrete experimental problems. *Same* TA. Peer coaching, TA coaching.

TESTS

Friday -- problem-solving quiz & conceptual questions (usually multiple choice) every two weeks.

Information Density ("Coverage")

Fall 1997 (Text HRW) – 1st Quarter

Week 1-2	Straight Line Motion
	Chap. 1, 2
Week 3-4	Motion in a Plane
	Chap. 3 (not 3.7), 4 not (4.8, 4.9, 4.10)
Week 4-6	Forces
	Chaps. 5, 6(not 6.3), 7.6(1st part)
Week 7-10	Conservation of Energy & Momentum
	Chaps. 7 not (7.8, 7.9), 8 not (8.5, 8.8), 9.4, 9.6, 9.8, 10

Fall 2001 (Text Tipler) – Part of Semester

Week 1-2	Straight Line Motion
	Chap. 1, 2 (not pg. 26)
Week 2-3	Motion in a Plane
	Chap. 3
Week 4-6	Forces
	Chaps. 4, 5
Week 7-8	Conservation of Energy
	Chaps. 6, 7 not (7.3, 7.4)
Week 9-10	Conservation of Momentum
	Chaps. 8 not (8.7, 8.8)

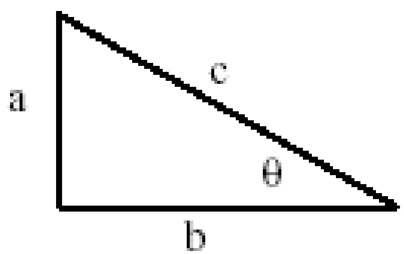
SCHEDULE Physics 1301

Week 1-2 Describing Straight Line Motion Chap. 1, 2 (not pg. 26)
Laboratory I Laboratory Manual
Problem-Solving Techniques Competent Problem Solver Chap. 1, 2
Week 2-3 Motion in a Plane Chap. 3
Problem-Solving Techniques Competent Problem Solver Chap. 3
Laboratory II Laboratory Manual
Week 4-6 Forces Chaps. 4, 5
Problem-Solving Techniques Competent Problem Solver Chap. 4
Laboratory II, III Laboratory Manual
Week 7-8 Conservation of Energy Chaps. 6, 7 not (7.3, 7.4)
Problem-Solving Techniques Competent Problem Solver Chap. 5
Laboratory IV Laboratory Manual
Week 9-10 Conservation of Momentum Chaps. 8 not (8.7, 8.8)
Laboratory V Laboratory Manual
Week 11-12 Rigid Body Motion Chaps. 9, 10.1
Laboratory VI Laboratory Manual
Week 12 Applications - Statics Chap. 12 not (12.7, 12.8)
Laboratory VI, VII Laboratory Manual
Week 13 Conservation of Angular Momentum Chap. 10 not (10.5)
Laboratory VII Laboratory Manual
Week 14-15 Oscillations Chap. 14
Laboratory VIII Laboratory Manual

Physics 1301W.300 Final Examination Fall 2002

This is a closed book, closed notes exam. The **ONLY** formulas that may be used are those given below. Define all symbols and justify all mathematical expressions used. State all assumptions used to solve a problem. Credit is given only for a logical and complete solution that is clearly communicated. Partial credit will be given for a well communicated problem solving strategy based on correct physics. MAKE SURE YOUR NAME, ID #, SECTION #, and TA's NAME ARE ON EACH PAGE! Each problem is worth 25 points: In the context of a unified solution, a useful picture, defining the question, and giving your approach is worth 6 points; a complete physics diagram defining the relevant quantities, identifying the target quantity, and specifying the relevant equations is worth 6 points; planning the solution by constructing the mathematics leading to an algebraic answer is worth 7 points; calculating a correct answer is worth 4 points; and evaluating the validity of the answer is worth 2 points. Each of the 33 multiple choice questions is 1 point.

Useful Mathematical Relationships:



For a right triangle: $\sin\theta = \frac{a}{c}$, $\cos\theta = \frac{b}{c}$, $\tan\theta = \frac{a}{b}$,

$$a^2 + b^2 = c^2, \quad \sin^2\theta + \cos^2\theta = 1$$

Small angles: $\sin\theta \approx \theta$, $\cos\theta \approx 1 - \frac{\theta^2}{2}$

For a circle: $C = 2\pi R$, $A = \pi R^2$

For a sphere: $A = 4\pi R^2$, $V = \frac{4}{3}\pi R^3$

If $Ax^2 + Bx + C = 0$, then $x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$

$$\frac{d}{dz}\left(z^n\right) = nz^{n-1} , \quad \frac{d}{dz}(\cos z) = -\sin z , \quad \frac{d}{dz}(\sin z) = \cos z , \quad \frac{df(z)}{dt} = \frac{df(z)}{dz}\frac{dz}{dt}, \quad \int\left(\frac{dw}{dz}\right)dz = w ,$$

$$\frac{d}{dz}\int w\,dz = w , \quad \int z^n dz = \frac{z^{n+1}}{n+1} \; (n \neq -1)$$

Fundamental Concepts and Principles:

$v_{x\,av} = \frac{\Delta x}{\Delta t}$	$s_{av} = \frac{dist}{\Delta t}$	$a_{x\,av} = \frac{\Delta v_x}{\Delta t}$	$\theta = \frac{\Delta C}{r}$	$\omega_{av} = \frac{\Delta\theta}{\Delta t}$	$\alpha_{av} = \frac{\Delta\omega}{\Delta t}$
$v_x = \frac{dx}{dt}$	$s = \frac{dr}{dt}$	$a_x = \frac{dv_x}{dt}$	$\omega = \frac{d\theta}{dt} = \frac{v_t}{r}$	$\alpha = \frac{d\omega}{dt} = \frac{a_t}{r}$	$\sum \vec{F} = m\vec{a}$
$\tau = rF_t$	$\sum \vec{\tau} = I\vec{\alpha}$	$W = \int_{path} \vec{F} \bullet d\vec{\ell}$	$KE = \frac{1}{2}mv^2$	$E_f - E_i = \Delta E_{transfer}$	$\vec{p} = m\vec{v}$
$\vec{p}_f - \vec{p}_i = \Delta\vec{p}_{transfer}$	$\vec{p}_{transfer} = \int \vec{F}dt$	$\vec{r}_{com} = \frac{\sum m_i \vec{r}_i}{\sum m_i} = \frac{\int \vec{r}dm}{\int dm}$		$I = \sum m_i r_i^2 = \int r^2 dm$	$\vec{L} = I\vec{\omega}$
$\vec{L}_f - \vec{L}_i = \Delta\vec{L}_{transfer}$	$\vec{L} = \vec{r} \times \vec{p}$	$\vec{L}_{transfer} = \int \vec{\tau}dt$		$f = \frac{1}{T}$	

Under Certain Conditions:

$x_f = \frac{1}{2}a(\Delta t)^2 + v_{ox}\Delta t + x_o$	$F = \mu_k F_N$	$F \le \mu_s F_N$	$F = k\Delta x$	$KE = \frac{1}{2}I\omega^2$	$PE = mgy$	$PE = \frac{1}{2}kx^2$
$\theta_f = \frac{1}{2}\alpha(\Delta t)^2 + \omega_o\Delta t + \theta_o$	$a = \frac{v^2}{r}$	$I = I_{cm} + Md^2$	$v_{cm} = r\omega$	$x = A\cos(2\pi ft + \delta)$		

Useful constants: 1 mile = 5280 ft, $g = 9.8\ m/s^2 = 32\ ft/s^2$

1. You are watching a James Bond movie on TV when an exciting chase scene begins. Driving his specially modified Aston Martin, Bond is trying to outrun a woman driving a Mustang on a twisting mountain road. As he drives around the curve, he shoots a jet of oil on the road causing the coefficient of friction to become very small. He makes it around the curve but she skids off the road into a canyon below. During the commercial, your mind drifts and you wonder whether or not the chase was realistic so you decide to calculate fast he can go and still make the curve and how slow she would have to go to also make it. As a first step, you calculate each speed in terms of the radius of the curve, the angle that the curve is banked, and the coefficient of static friction between the tires and the road.

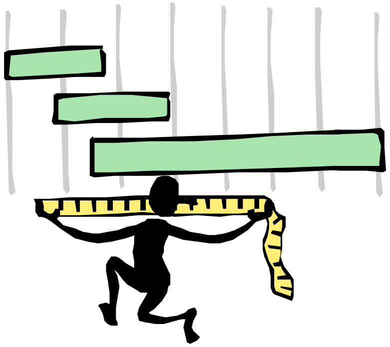
2. You have just moved into a new apartment and find yourself faced with the problem of sliding your refrigerator into the space provided in the kitchen. From the moving company you see that your refrigerator weighs 200 lb. The refrigerator is 67 inches tall, 33 inches wide and 33 inches deep and the center of mass of the refrigerator is at its center. If the coefficient of static friction between your kitchen floor and the bottom of your refrigerator is 0.75, what is the maximum distance above the floor that you can safely push on the refrigerator to get it started but not tip?

3. Your have been hired as a technical advisor for the police to help in the scientific investigation of crimes. A shooting happened in an apartment but the people in a neighboring apartment claim that they did not hear a shot. You have been assigned to use the physical evidence to determine if they are telling the truth. You know that if the bullet travels faster than the speed of sound, 330 m/s, most of the noise comes from the sonic boom that no silencer can eliminate. You search the crime scene in the apartment and find that a bullet went through a cookbook and then entered the wall. From the dust patterns on a table, the book was sitting on the edge of the table when the bullet ripped through its center knocking it to the floor. From the entrance and exit hole in the book, the bullet was going horizontally as it passed through it. When you find the bullet hole in the wall, you measure that the bullet dropped by 5.0 mm since passing through the book. You dig the bullet out of the wall and measure its mass as 2.4 grams. You also measure the height of the table above the floor, 1.5 m, the distance of the book on the floor from the table, 0.30 m, the distance from the wall to the table, 5.0 m, and the mass of the book, 1.1 kg. The police want you to tell them the speed of the bullet so that they can tell whether the neighbors are telling the truth.

4. You are helping a friend whose hobby is building artistic clocks. Your friend wants the clock timing regulated by a ring that swings from a point on its rim. The goal is to make the period of the swing 2.0 seconds. Your friend wants you to determine the mass and radius of the ring that will make it work.

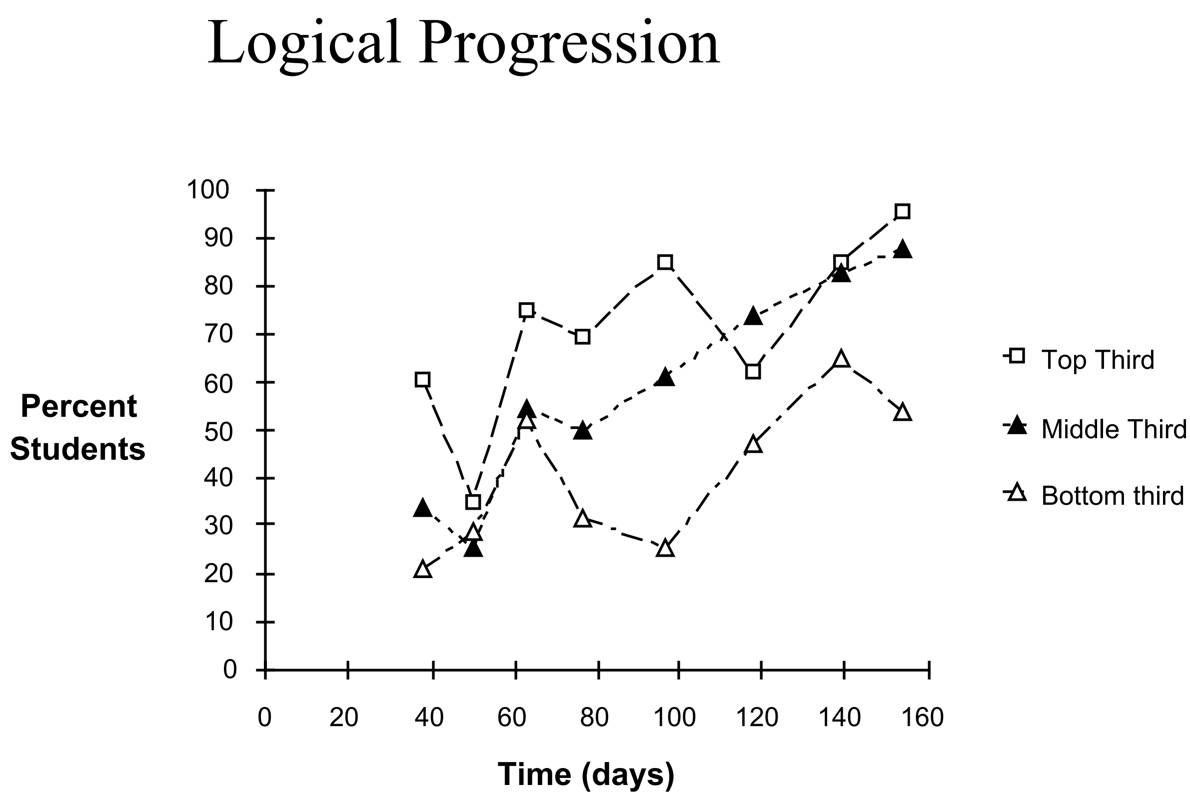
5. You have been asked to design the apparatus for a spectacular opening for an ice show. A small skater glides down a ramp and then along a short level track of ice. The skater bends to be as small as possible when grabbing the bottom end of a large vertical rod that is free to turn vertically about an axis through its center. The plan is for the skater to hold onto the rod while it swings the skater to its top. You have been asked to give the minimum height of the ramp in terms of the mass of the skater, the mass of the rod, and the length of the rod so that the skater can make it to the top. Doing a quick integral tells you that the moment of inertia of the rod about its center is 1/3 of what its moment of inertia would be if all of its mass were concentrated at one of its ends.

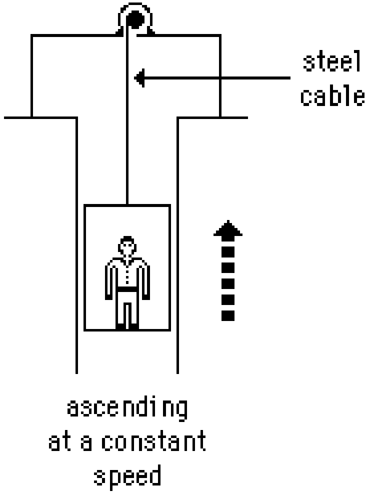
Data



- Analysis of student exams
- Observation of student interactions
- Measures of conceptual understanding
  - FCI (Force Concept Inventory)
  - Other inventories
  - Open ended questions
  - Interviews
- Measures of hierarchical structure of physics
- Measures of student satisfaction
- Ease of implementation

Improvement in Problem Solving





FCI Question 17

An elevator is being lifted up an elevator shaft at a constant speed by a steel cable, as shown in the figure. All frictional effects are negligible. In this situation, forces on the elevator are such that:

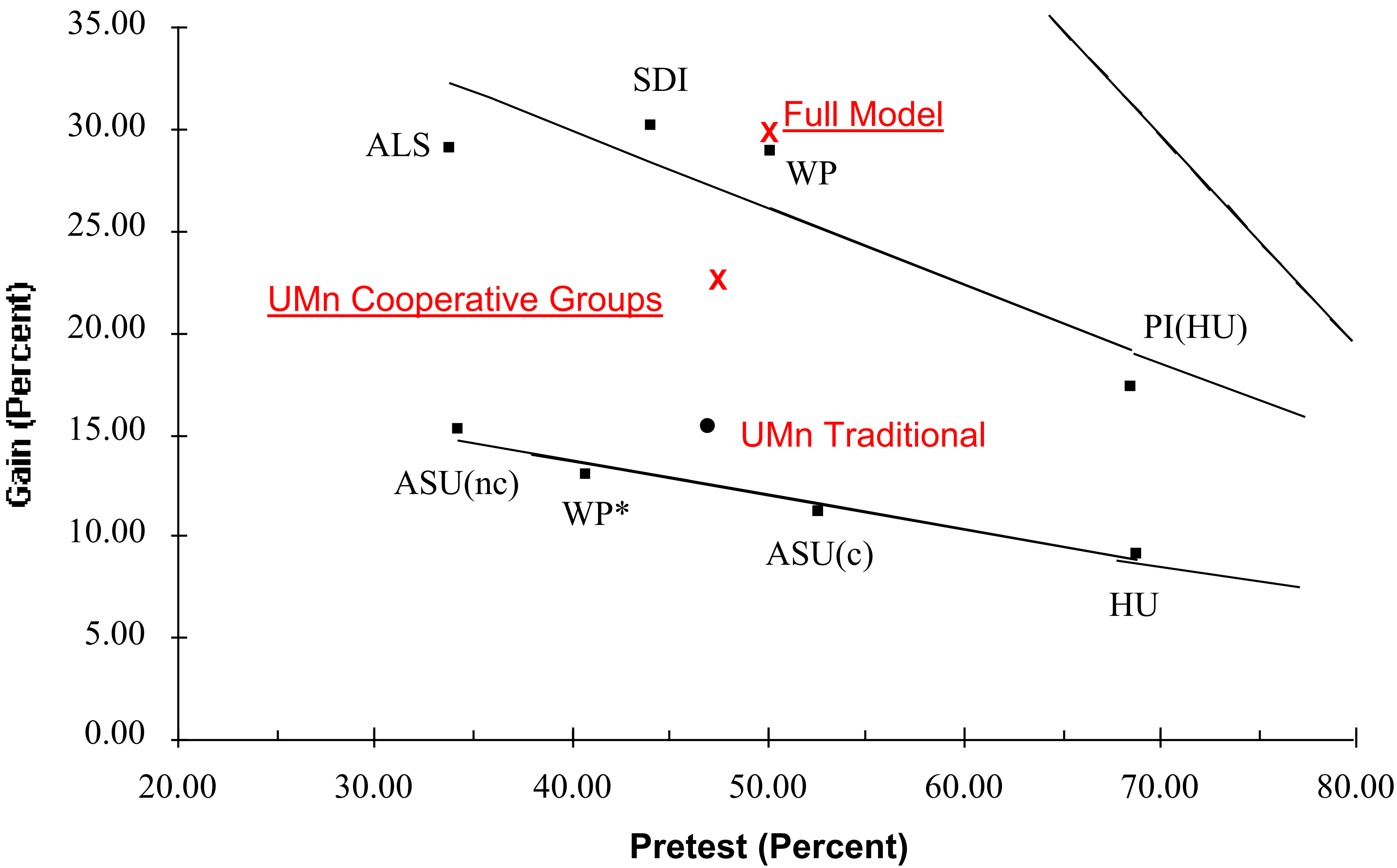
	Pre	Post
(A) the upward force by the cable is greater than the downward force of gravity.	64	36
(B) the upward force by the cable is equal to the downward force of gravity.	18	60
(C) the upward force by the cable is smaller than the down ward force of gravity.	2	0
(D) the upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air.	11	2
(E) None of the above. (The elevator goes up because the cable is shortened, not because an upward force is exerted on the elevator by the cable).	5	1

FCI Question 4

A large truck collides head-on with a small compact car.
<u>During the collision</u>**,**

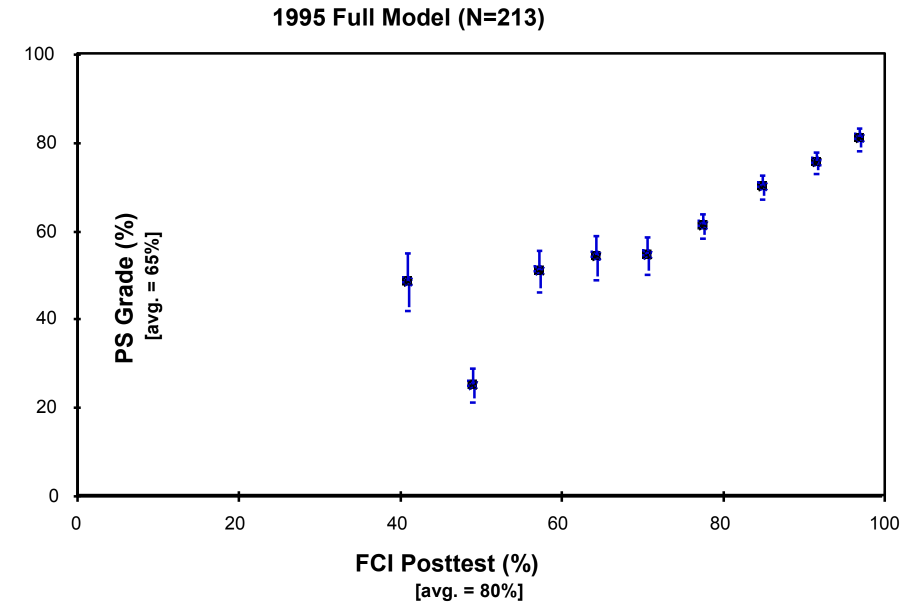
	Pre	Post
(A) the truck exerts a greater amount of force on the car than the car exerts on the truck	79	46
(B) the car exerts a greater amount of force on the truck than the truck exerts on the car.	2	1
(C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.	0	0
(D) the truck exerts a force on the car, but the car doesn't exert a force on the truck.	0	0
(E) the truck exerts the same amount of force on the car as the car exerts on the truck.	19	53

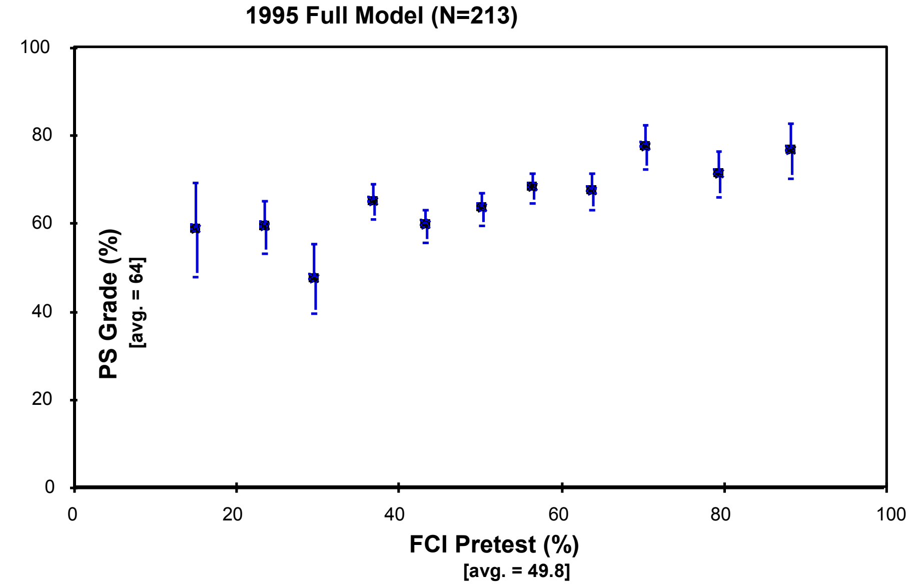
Gain on FCI

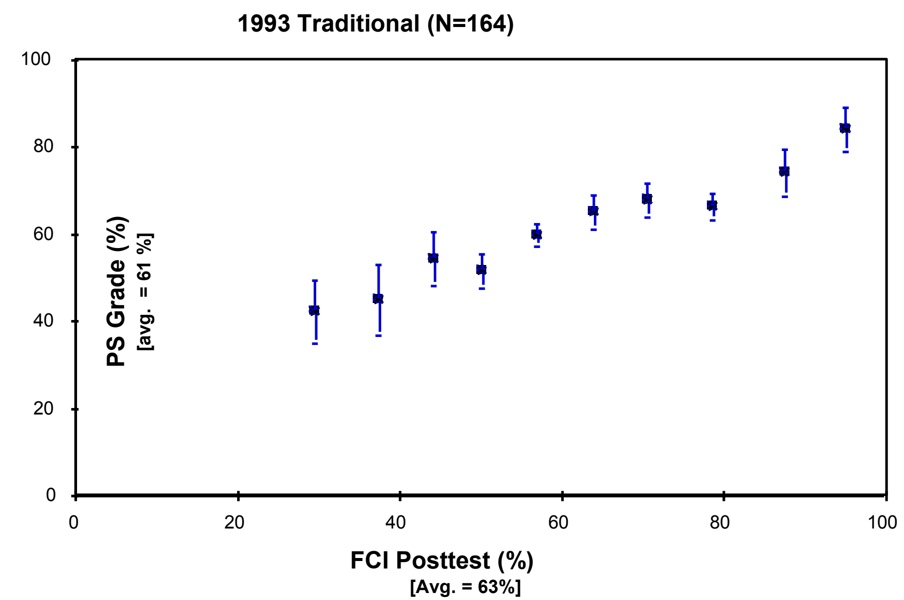


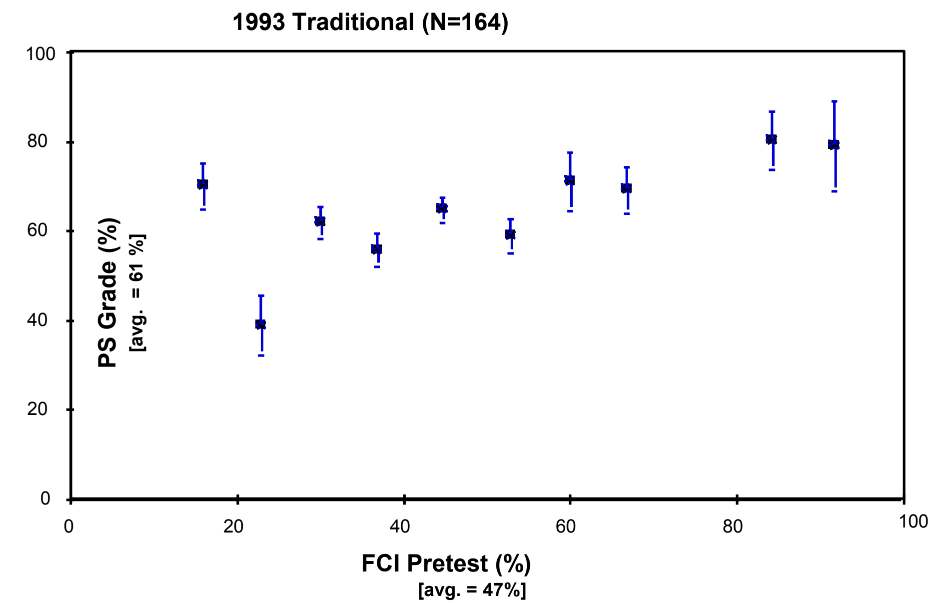
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Gain (Percent)
SDI
Full Model
ALS
WP
UMn Cooperative Groups
PI(HU)
UMn Traditional
ASU(nc)
WP*
ASU(c)
HU
20.00
30.00
40.00
50.00
60.00
70.00
80.00
Pretest (Percent)

FCI and Problem Solving

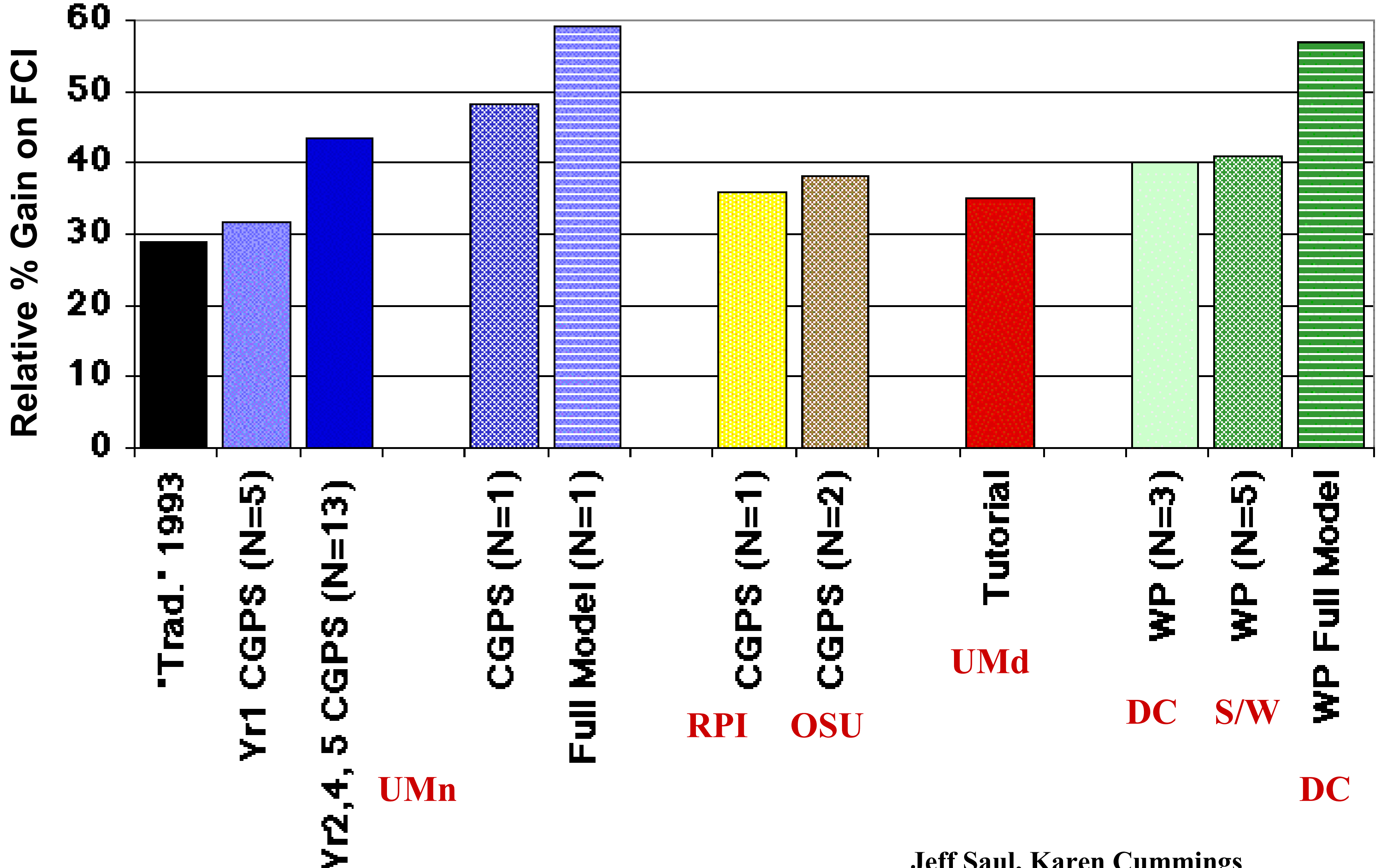






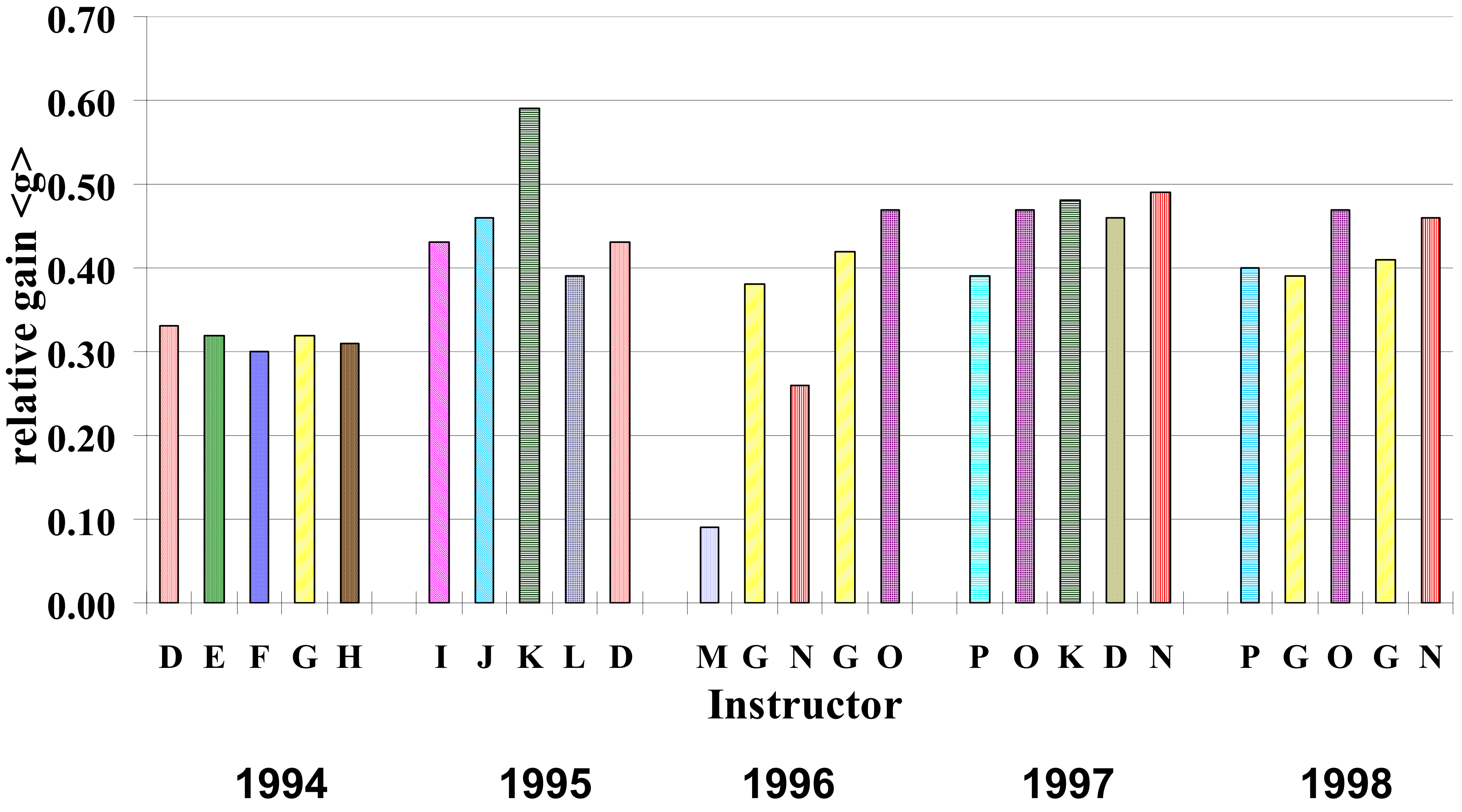


Comparisons of Full and Partial Models

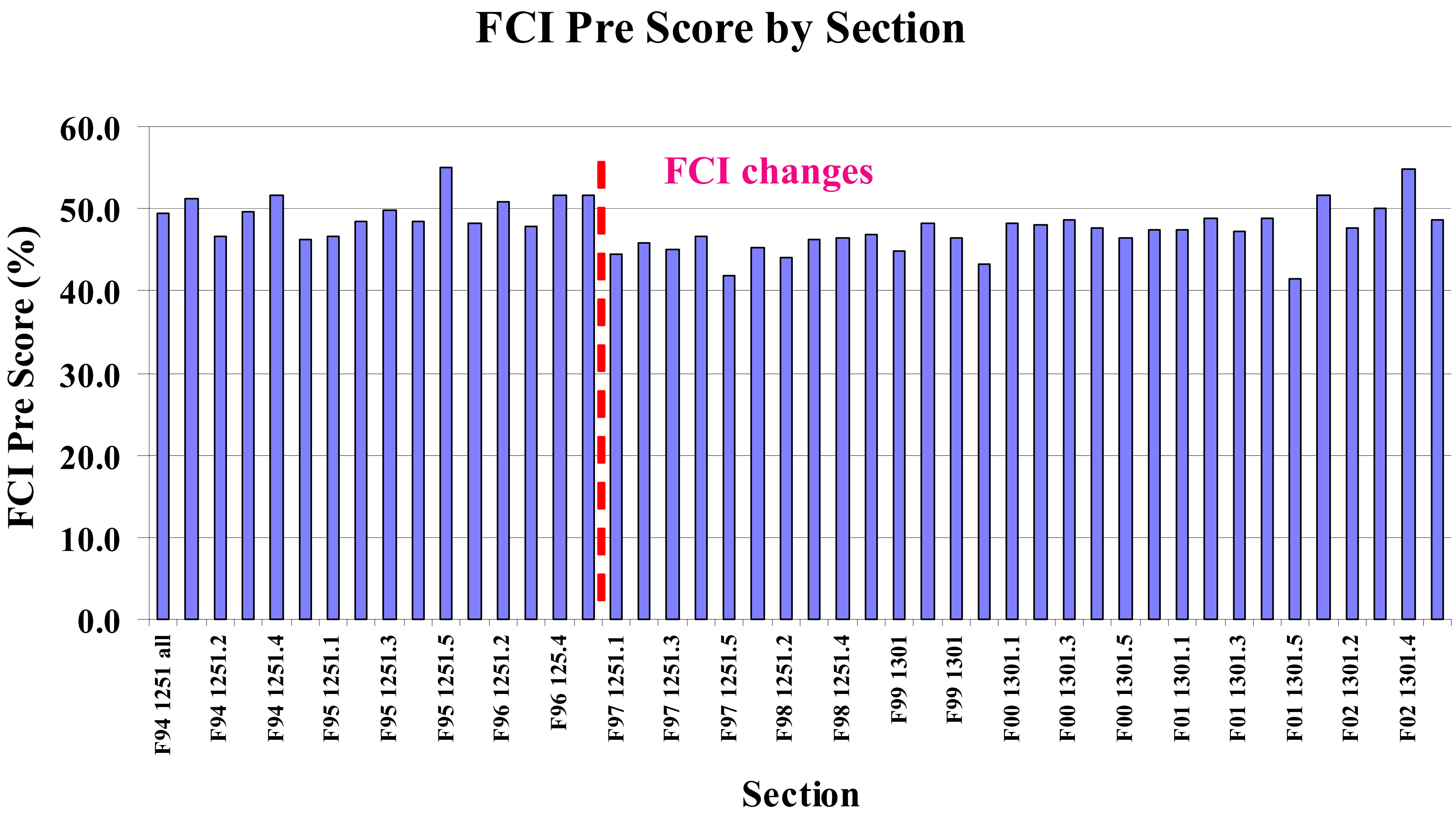


Jeff Saul, Karen Cummings

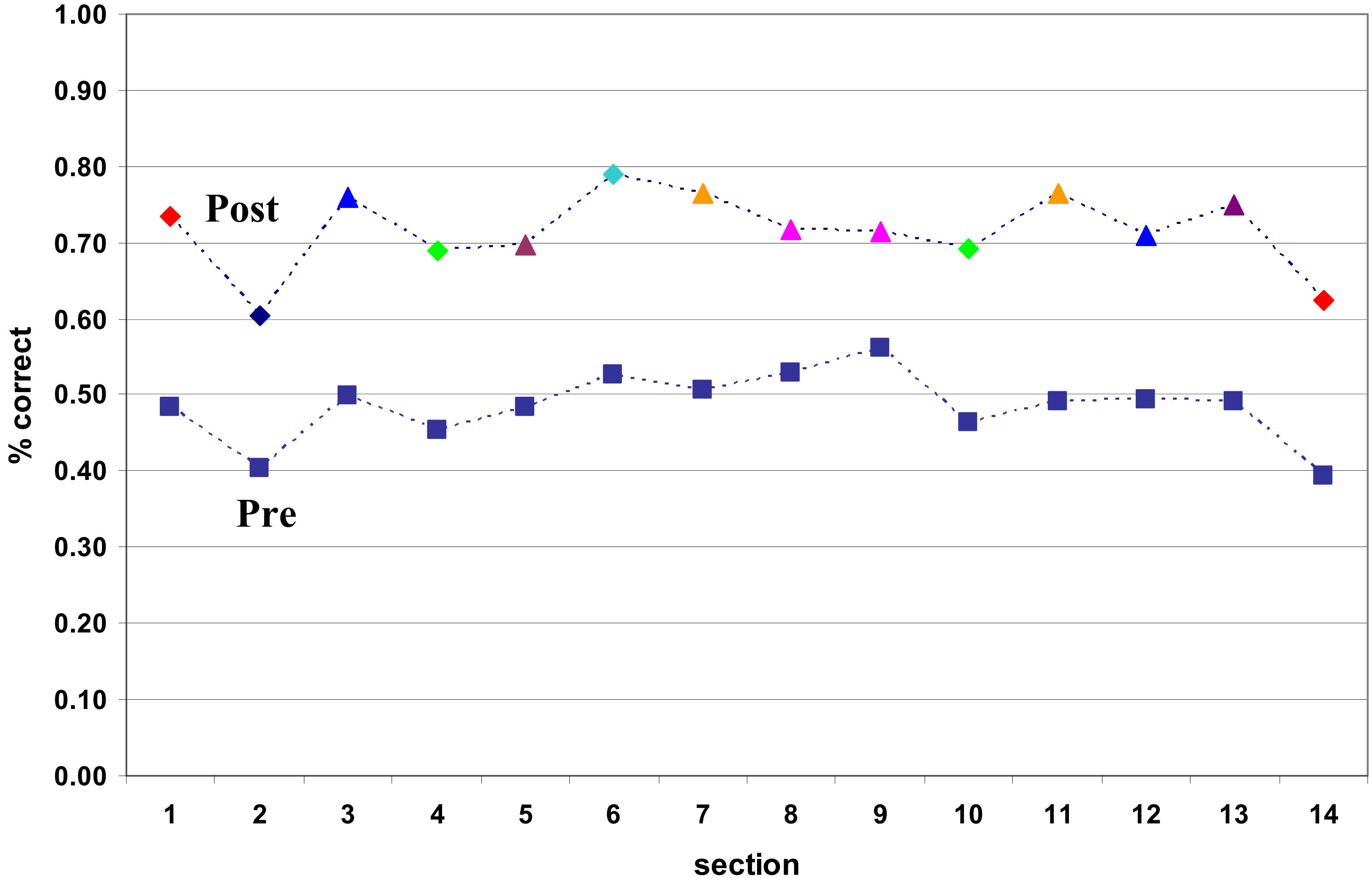
How Stable is Faculty Implementation of CGPS?



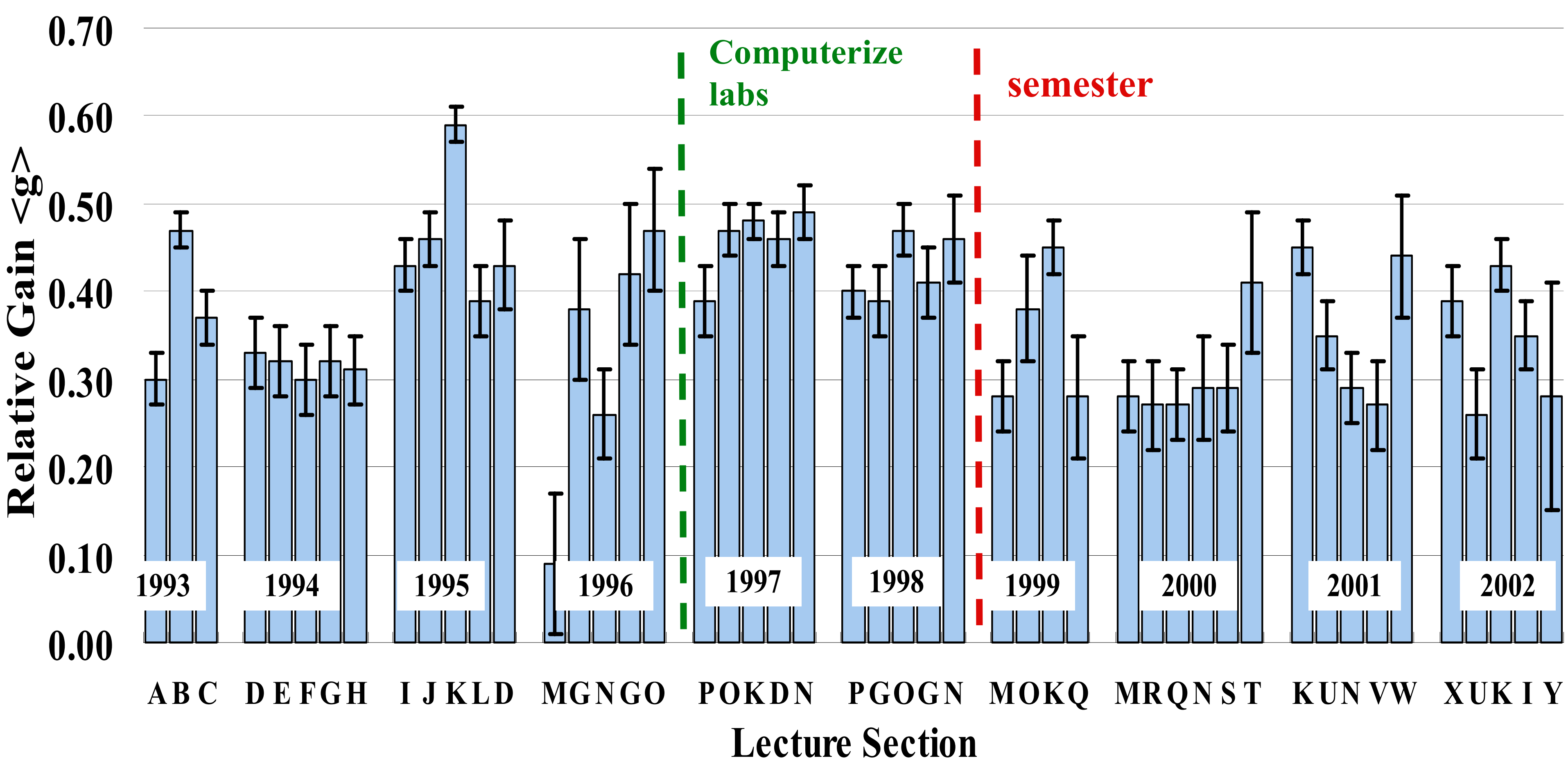
Incoming Students – A Decade



FCI by discussion/lab section

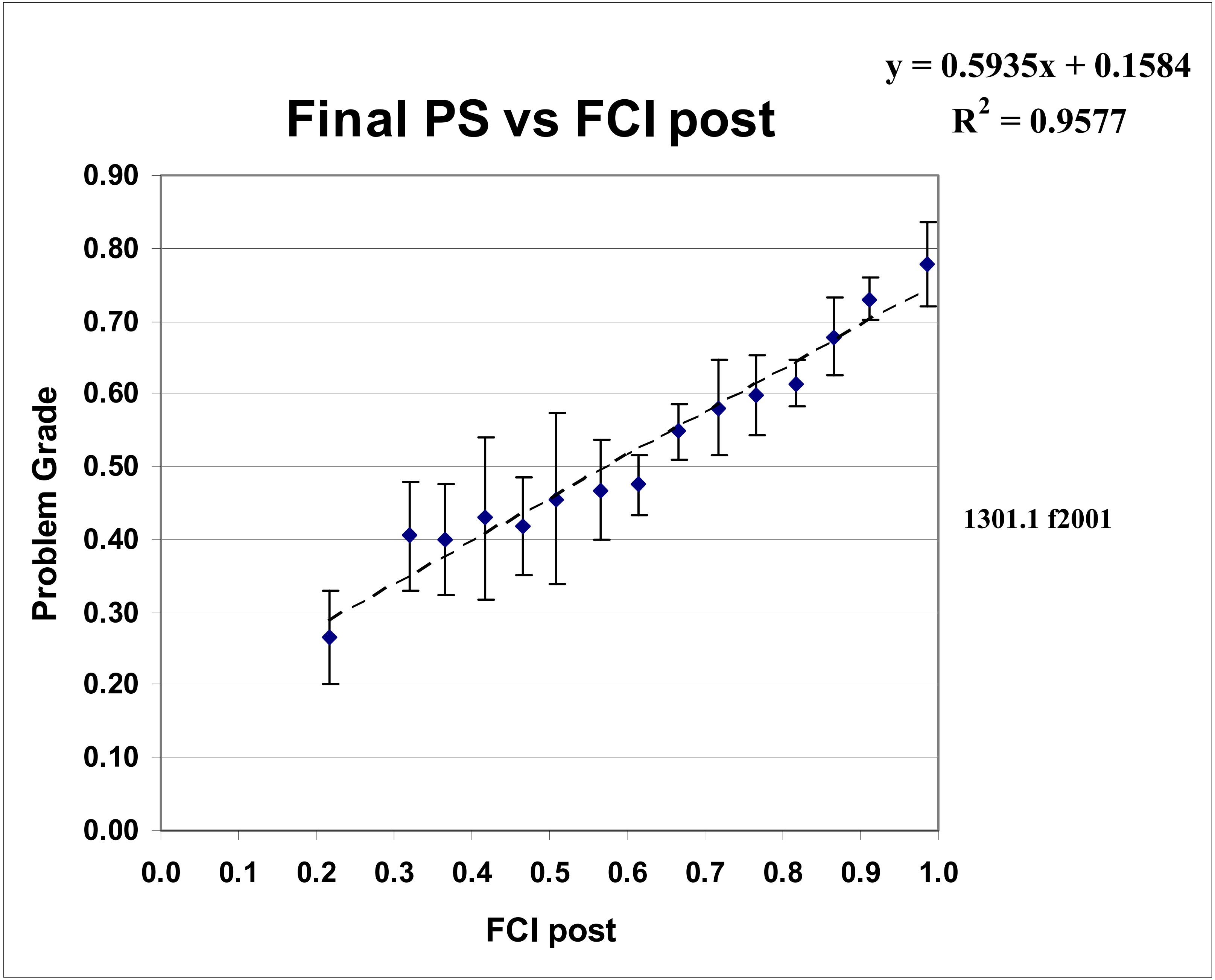


FCI Gains
University of Minnesota, 1993-2002
Introductory Calculus-Based Physics (Fall Sections)



each letter represents a different instructor

I - Standard Error of the Mean



y = 0.5935x + 0.1584
R^2 = 0.9577
Final PS vs FCI post
Problem Grade
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
FCI post
1301.1 f2001

Problem Solving Procedure

	SA	A	N	D	SD
11. The problem-solving procedure taught in class makes sense.	41 *23*	46 *65*	7 *7*	4 *2*	2 *2*
12. The instructor provided adequate examples of how to use the problem solving procedure.	53 *31*	40 *58*	3 *4*	3 *6*	1 *1*
13. Using the suggested problem solving procedure has helped me to solve problems more effectively.	37 *22*	31 *44*	15 *13*	7 *14*	9 *7*
14. The solution sheet format was a useful guide for problem solving	25 21	39 *55*	25 *10*	10 *10*	1 *4*
15. Problems can be solved more effectively in a group than individually.	17 *16*	49 *46*	18 *14*	14 *18*	1 *6*
16. Taking tests as a group helped me to understand the course material.	4 *9*	62 *48*	21 *21*	10 *18*	2 *4*

1991 class (n = 99) 1992 class (n = 135)

Lecture and Recitation

	SA	A	N	D	SD
1. The instructor covered too little material in the course.	4	13	20	45	18
	2	*5*	*24*	*52*	*17*
2. The mixture of presenting new material and solving problems was about right.	17	63	9	10	
	12	*67*	*10*	*11*	*1*
3. Pausing in lecture to allow students to discuss the concepts with others was a good idea.	26	47	21	4	2
	24	*40*	*26*	*9*	*2*
4. The recitations sessions were well coordinated with the lecture.	7	75	11	5	2
	8	*62*	*11*	*12*	*7*
5. The discussion with my group helped me to understand the course material.	13	53	13	17	4
	8	*47*	*9*	*28*	*8*
6. My group worked well together to to complete problem solving activities.	14	59	18	7	2
	4	*53*	*17*	*21*	*5*

* 1991 class (n = 99) 1992 class (n = 135)

Student Opinion of Context Rich Problems in the Laboratory

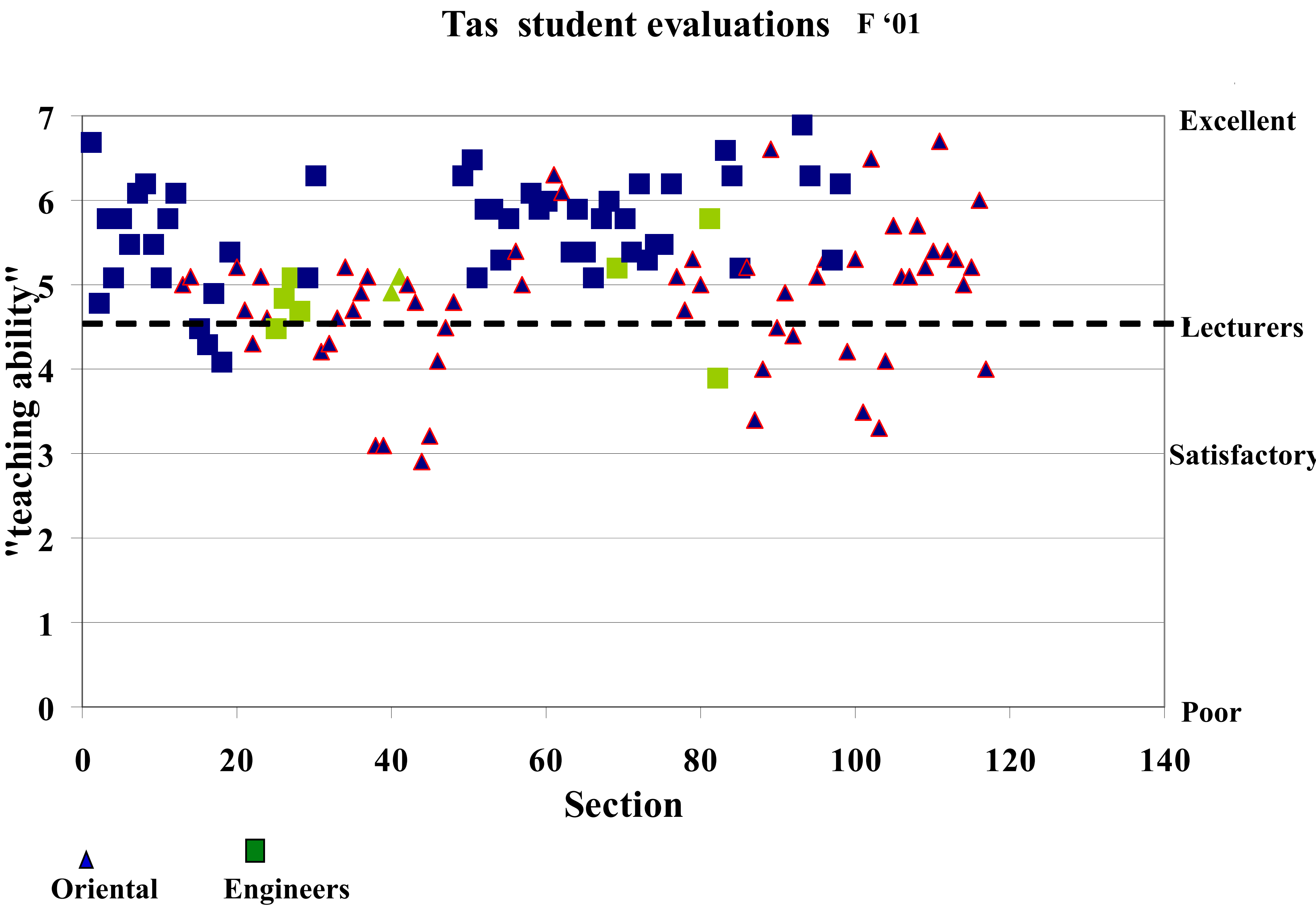
1. Do you think the lab activities were too easy, too hard, or just about the right level of difficulty?

too easy	just about right	too hard
9%	86%	5%

2. The written instructions in the lab manual were designed to guide your group in making decisions, without explaining how to conduct the lab. Do you think the written instructions provided too much guidance, too little guidance, or just about the right amount of guidance?

too little	just about right	too much
33%	60%	3%

N=100 (random)



Tas student evaluations F '01
"teaching ability"
7
6
5
4
3
2
1
0
Excellent
Lecturers
Satisfactory
Poor
0
20
40
60
80
100
120
140
Section
Oriental
Engineers

How Does the Acceleration Compare Up and Down the Ramp?

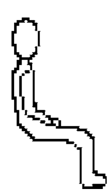
Type of Response	CGPS Algebra-based (n = 112) pre (%)	CGPS Algebra-based (n = 112) post (%)	Traditional Calculus-based (n = 100) pre (%)	Traditional Calculus-based (n = 100) post (%)
1. Includes accepted idea	6	79	19	40
2. Includes alternative conception				
a. confuse v and a, but believe motion up and down is the same	58	16	57	51
b. confuse v and a, but believe motion up and down is different	35	2	17	6
3. Uncodeable	1	3	7	3

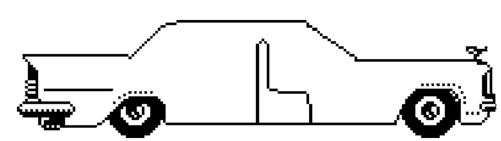
Two Open-Response Questions

You are a passenger in a car which is traveling on a straight road while it's increasing speed from 30 mph to 55 mph. You wonder what forces cause you and the car to accelerate. When you pull over to eat, you decide to figure it out.

(a) On the picture below, draw and label arrows (vectors) representing all the forces acting on the passenger(or car) while it is accelerating. . . Beside the Picture, describe in words each force shown.

(b) Which force(s) cause the passenger (or car) to accelerate? Explain your reasoning.

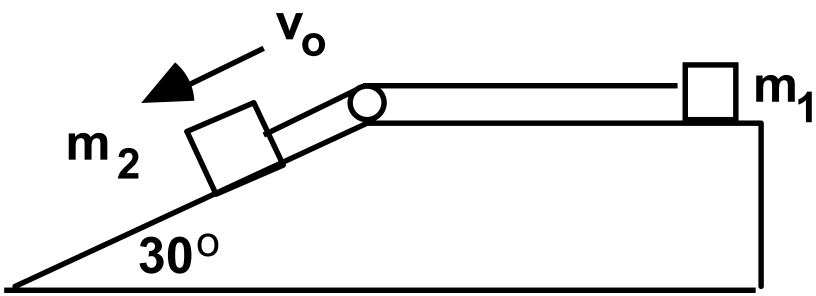




What is the Nature of the Forces on the Passenger?

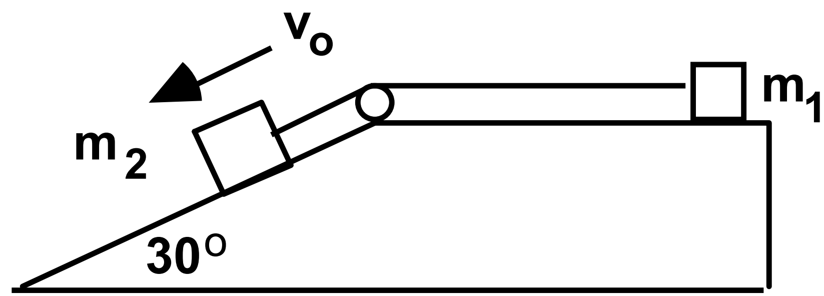
Type of Response	FCI post 68%		FCI 72%	FCI 82%
	Baseline (n = 100)		Coop Group (n=85)	Full Model (n=71)
	pre (%)	post (%)	post (%)	post (%)
1. Only Newtonian forces	12	41	59	76
2. Newtonian forces, but some are 3rd Law pair on wrong object	24	24	8	4
3. Include non-Newtonian forces (e.g., acceleration of car, engine, inertia, etc.)	62	35	32	20
4. Uncodeable	8	1	0	0

Atwood Solutions
1993 (N = 174)



Type of Solution	%
1. Correct or minor errors	29
2. Careless; many omissions; no sense of order	9
3. Incorrect Physics Approaches	52
4. Mathematics Problems	
a. Can't solve simultaneous equations	6
b. Trigonometry or algebra errors	3

Incorrect Physics Approaches: Atwood Machine



	%
a. $F_{unknown} = \sum F_{known}$ $T = F_{net} = f_1 + f_2 - m_2 g \sin\theta$	22
b. $\sum F = 0$ $\sum F = T - f_1 - f_2 = 0$	13
c. $F_{unknown} = ma$ $F = T = ma = m_2 g \sin\theta$	6
d. Incomplete, can't tell	11

The End

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