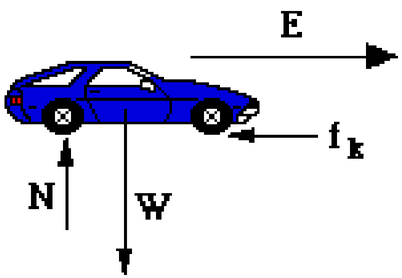
Teaching Physics Through Problem Solving

Making the Traditional Approach Effective



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

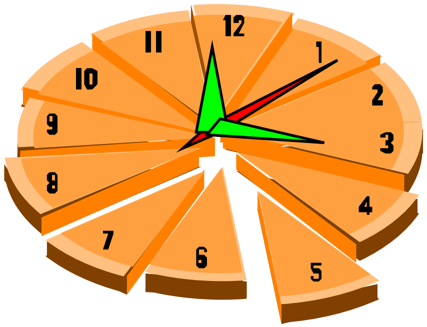
"I understand the concepts, I just can't solve the problems."

Ken Heller
School of Physics and Astronomy
University of Minnesota

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 - P. Heller and graduate students

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

AGENDA
A Guide for Discussion



- ✓ **Problem Goals**
  - **Why Solve Problems?**
  - **What are Problems?**
- ✓ **What's the Problem?**
  - **Modeling a Strategy**
  - **Supporting Real Problem Solving**
- ✓ **Designing Problems**
  - **What is Context-Rich?**
  - **Why?**
- ✓ **How Does It Work**
  - **Data**

Where We Started
The Introductory Physics Course

4 lectures/week
50 minutes
200 students

Disconnected lab
2 hours/week
16 students

No recitation sections

Not a popular course to teach or take!

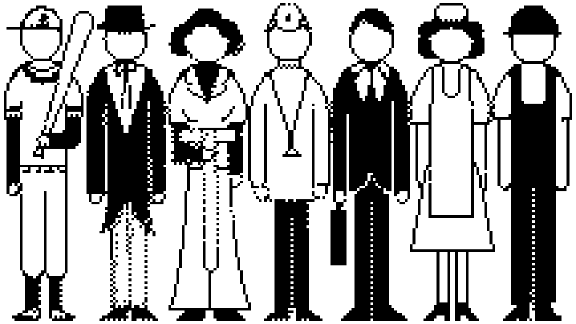
Algebra Based Physics Students
300 students/term

Interest

Architecture	45%
Paramedical	26%

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

Agriculture / ecology 9%

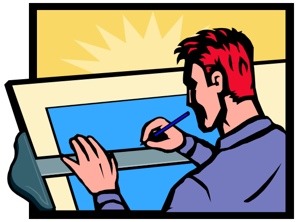
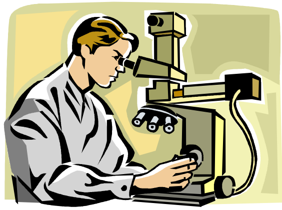


equal female / male

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%

TASK

Discuss why you assign
problems in physics courses.

List the common goals
of the problems.

TIME ALLOTTED

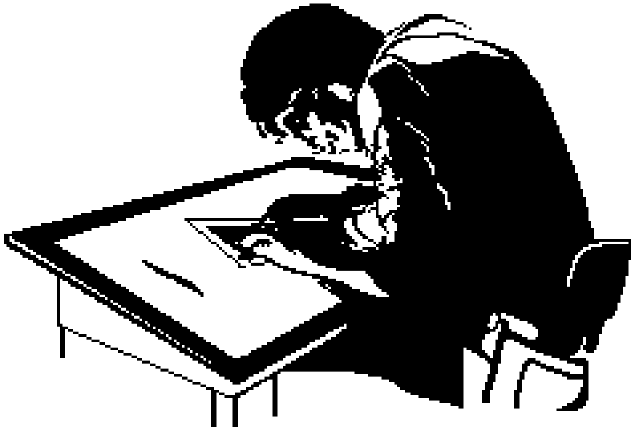
5 minutes

PROCEDURES

Formulate a response individually.
Discuss your response with your partners.
Listen to your partners' responses.
Create a new group response through discussion.

Why Teach Students to Solve Problems?

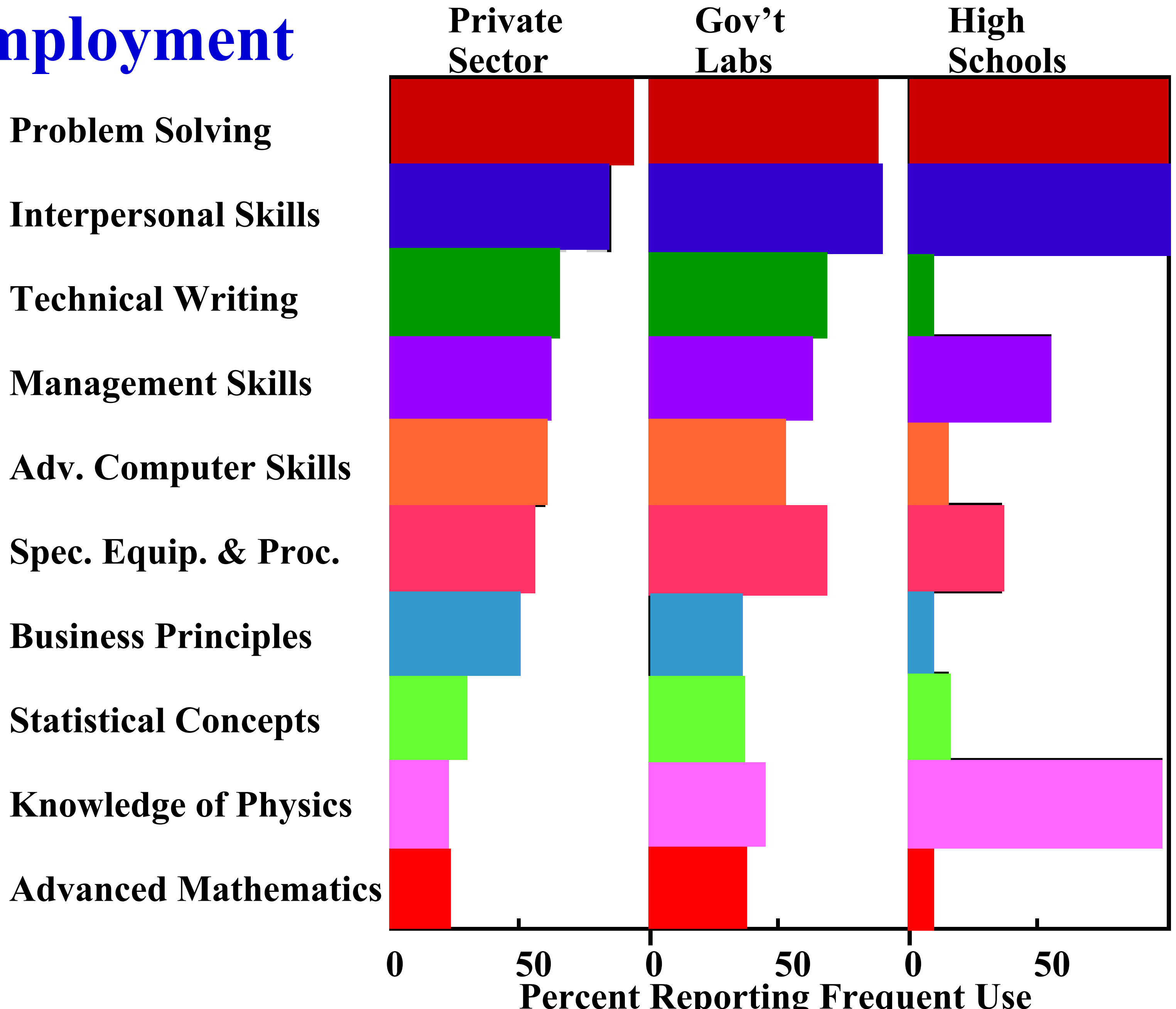
- Society Wants It
- Industry Wants It
- Other Departments Want It
- Our Department Wants It



Do they really want the same thing?

Should we help?

Employment



Survey of Physics Batchelors, 1994-AIP

What Do Departments Want?

Goals: Calculus-based Course (88% 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

What Is Problem Solving?

"Process of Moving Toward a Goal When Path is Uncertain"

- If you know how to do it, its not a problem.

Problems are solved using tools

General-Purpose Heuristics

Not algorithms

"Problem Solving Involves Error and Uncertainty"

A problem for your student is not a problem for you

Exercise vs Problem

M. Martinez, Phi Beta Kappa, April, 1998

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

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 taught *explicitly*

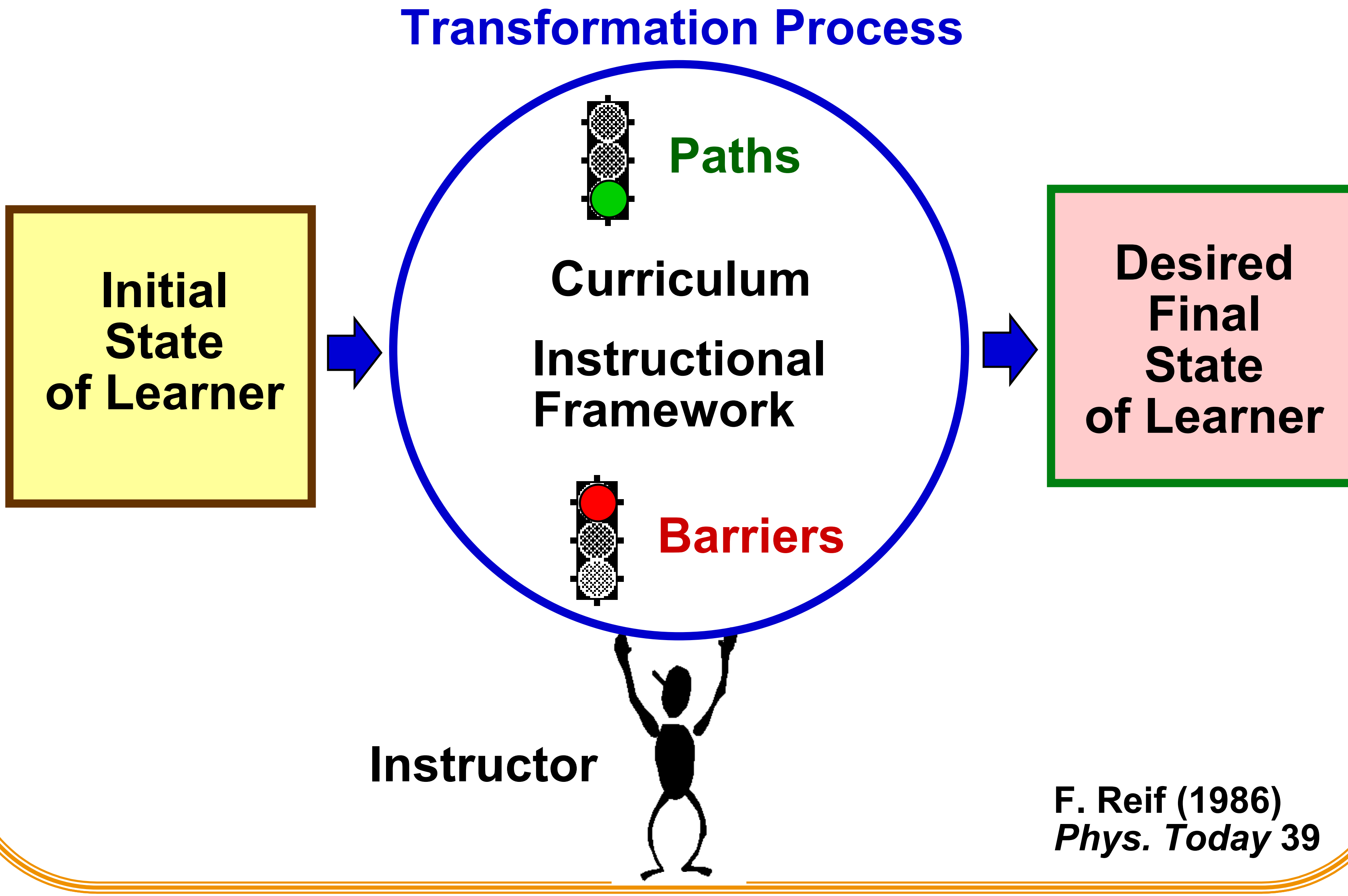
The difficulty -- major misconceptions, lack of metacognitive skills, no heuristics

Problem Solving Needs

Metacognative Skills

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

Procedure for Change



F. Reif (1986)
Phys. Today 39

Initial State of the Learner

Students have Misconceptions about

The Field of Physics

Learning Physics

Nature

Problem-solving Strategy

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

Not the same as “getting a problem right”.

Misconceptions About Learning Physics

Professor explains what is required for that topic

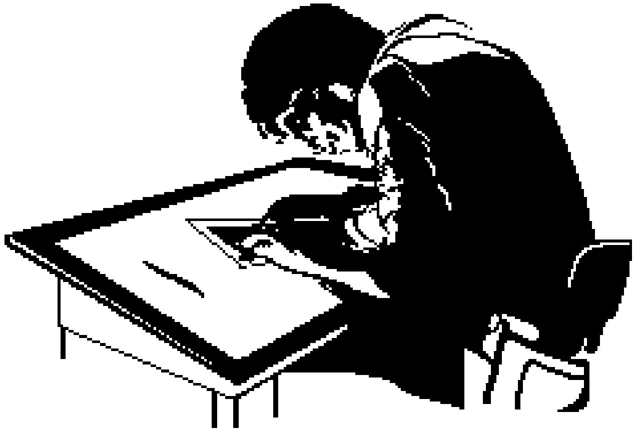
Clear explanations which follow the textbook.

"I understand the material,
I just can't do the problems"

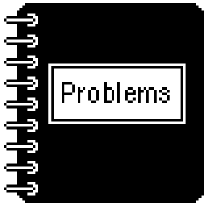
The test is exactly what the professor clearly explained.

Test problems follow
exactly worked examples.

"I can do the homework
but your test problems
are too different."



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

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

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?

- ✓ Look at the next problem
- ✓ Discuss how you would go about solving this problem

TIME ALLOTTED - 5 minutes

Discuss **your thoughts with your partners.**

Create **a group response through discussion.**

PRODUCT

A full group discussion of similarities and differences and recommend elements of problem solving

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.

Expert
"Real "Problem

Acquire Problem

↓ *derived cues*

Understand problem (visualization).
Decide tentatively what principles to try.

↓

Redescribe problem in terms of the field:
qualitative inferences, diagrams, and consideration of constraints
Categorize by possible approach

↓

Plan: Start with an expression of principles, work *backwards* from unknown.
Check -- enough information?

↓

Execute the plan
Check consistency

↓

Check/Evaluate answer

Now 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.

What is the difference in how you solved the two problems?

Chap 24, prob. 24, Fishbane, Gasiorowicz, Thornton

Expert -- "Exercise"

Read Problem

↓ ***derived cues***

Categorize problem by principle(s) needed to solve problem

↓

Draw abbreviated diagram of situation

↓

Start with expression of principles and work *forwards* to solution

Novice

Read Problem

↓ *literal cues*

Categorize problem by surface features

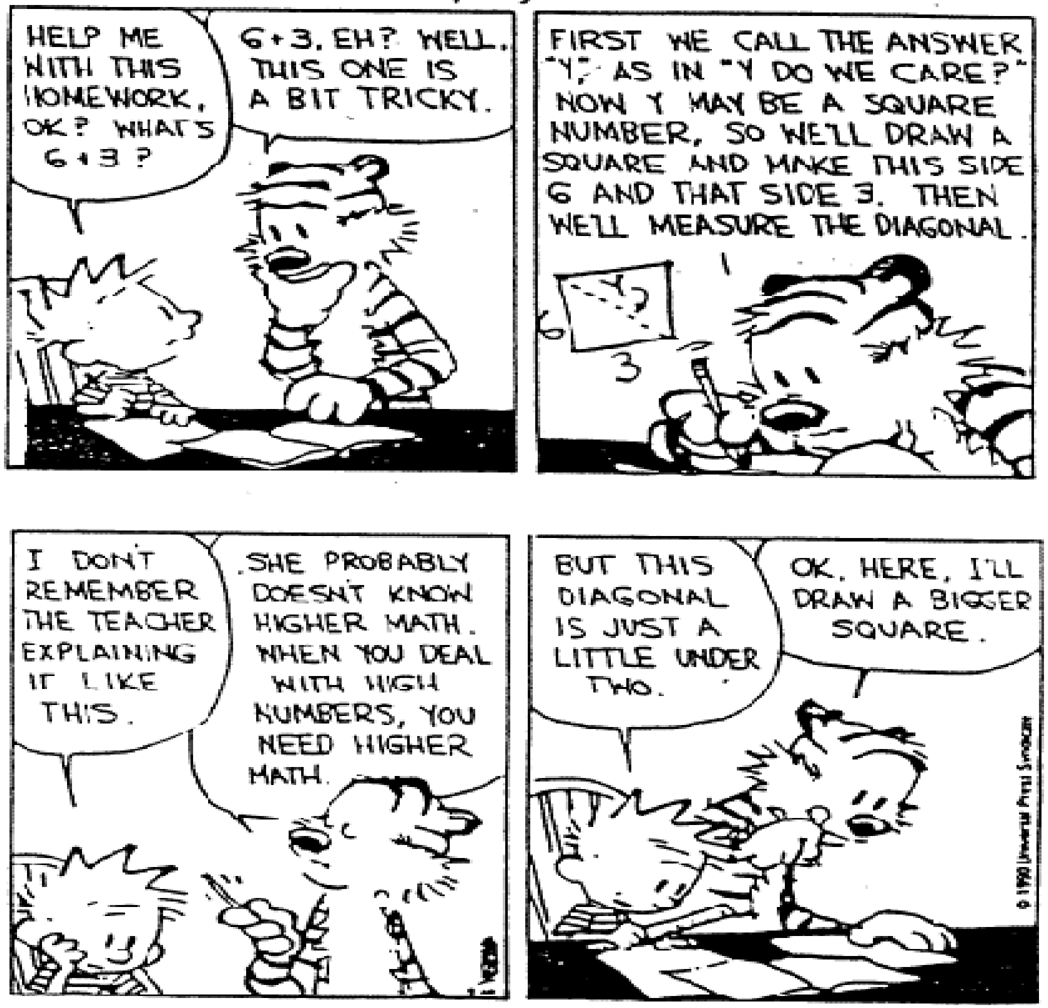
↓

Recall memorized pattern of actions and specific formulas for solving problem type

↓

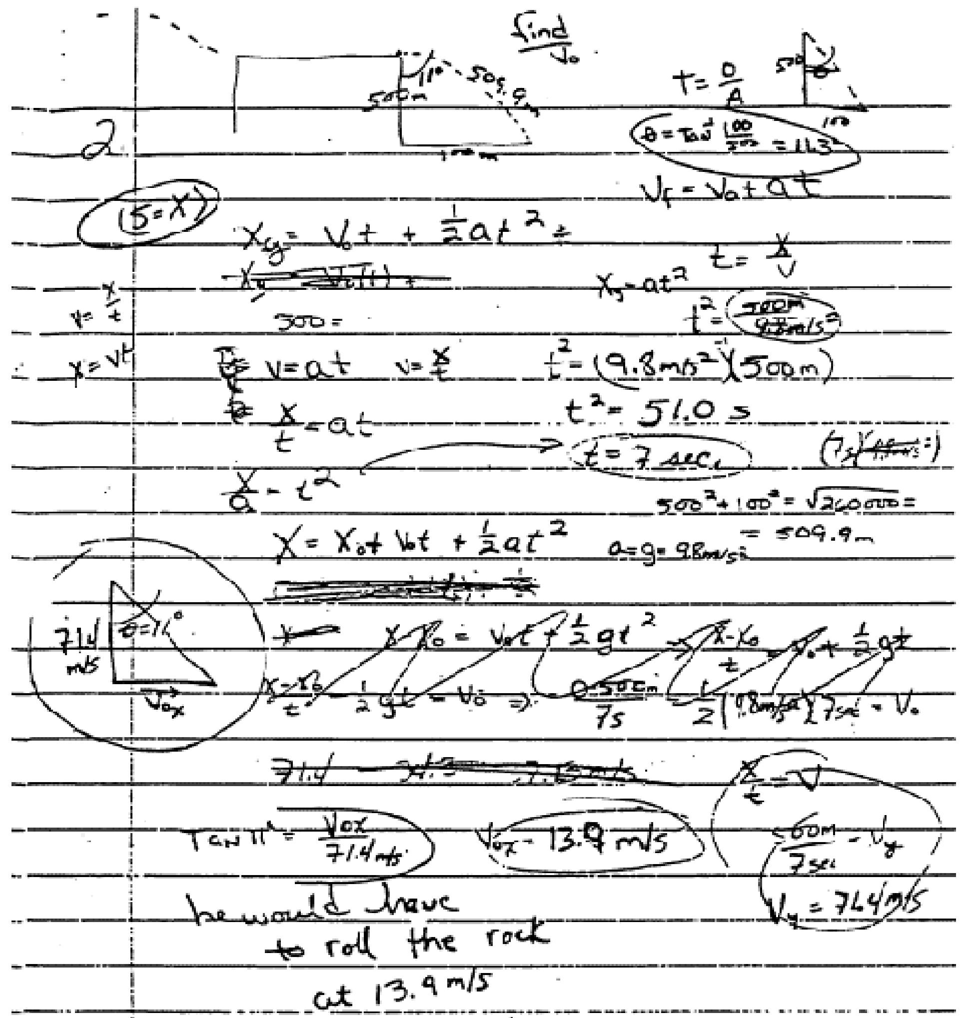
Manipulate a procedure until solution obtained

Calvin and Hobbes / By,Bill Watterson



"Novice" Solution to Cowboy Bob Problem

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.



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?

The Monotillation of Traxoline

(attributed to Judy Lanier)

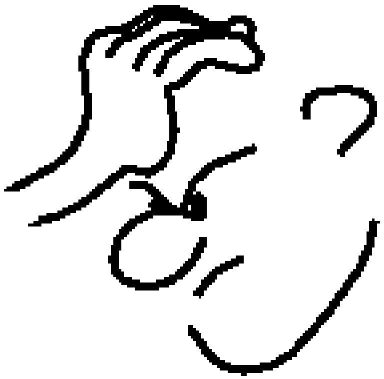
It is very important that you learn about traxoline. Traxoline is a new form of zionter. It is montilled in Ceristanna. The Ceristannians gristerlate large amounts of fevon and then brachter it to quasel traxoline. Traxoline may well be one of our most lukized snezlaus in the future because of our zionter lescelidge.

Answer the following questions.

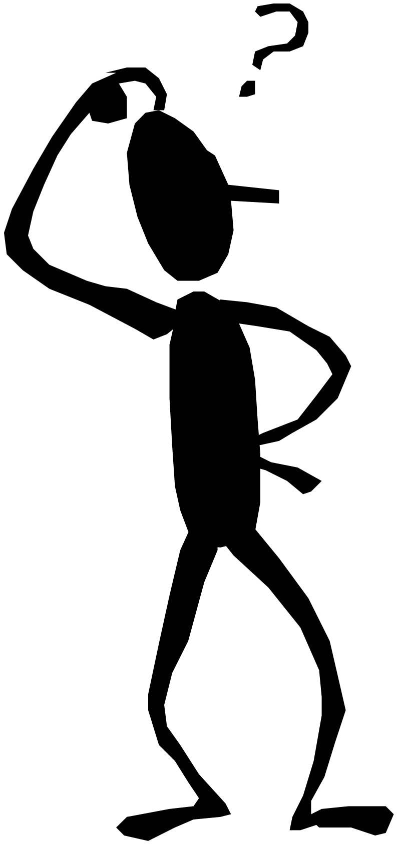
1. **What is traxoline?**
2. **Where is traxoline montilled?**
3. **How is traxoline quasselled?**
4. **Why is it important to know about traxoline?**

The Problem with Traditional Problems

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



Do You Practice Problem Solving?



A block starts from rest and accelerates for 3.0 seconds. It then goes 30 ft. in 5.0 seconds at a constant velocity.

a. What was the final velocity of the block?

b. What was the acceleration of the block?

Textbook Problem

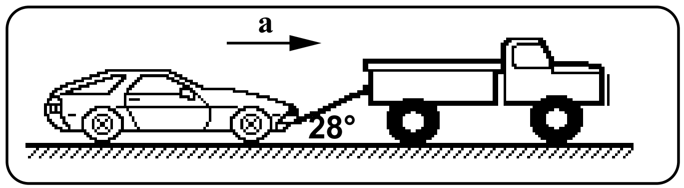
Do You Practice Problem Solving?

You have a summer job with an insurance company and are helping with the investigating accidents. At one scene, a road runs straight down a hill with a slope of 10° to the horizontal. At the bottom of the hill, the road is horizontal for a short distance becoming a 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 its base. A witness claims that the car was parked on the hill and began coasting down the road taking about 3 seconds to get down the hill. Your boss drops a stone from the edge of the cliff and determines that it takes 5.0 seconds to fall to the bottom. You are told 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.

Step	Bridge

1. Focus on the Problem

Translate the words into an image of the situation.

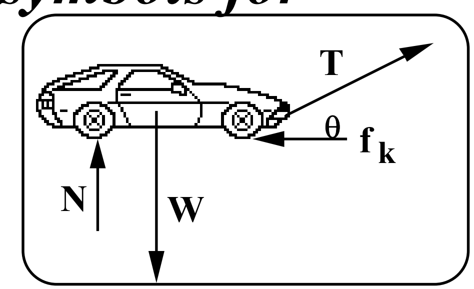


Identify an approach to the problem.

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.

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

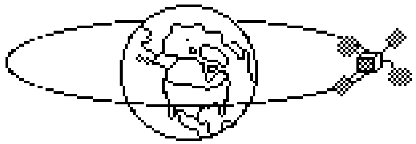
5. Evaluate the Solution

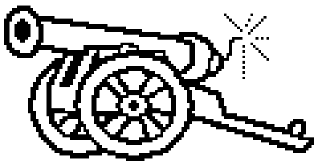
Appropriate Tasks

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.

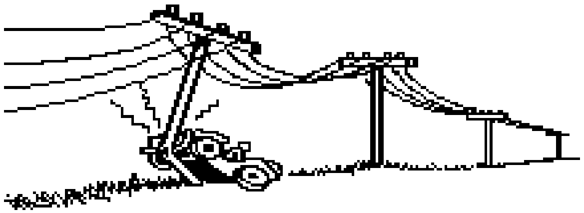




Appropriate Tasks

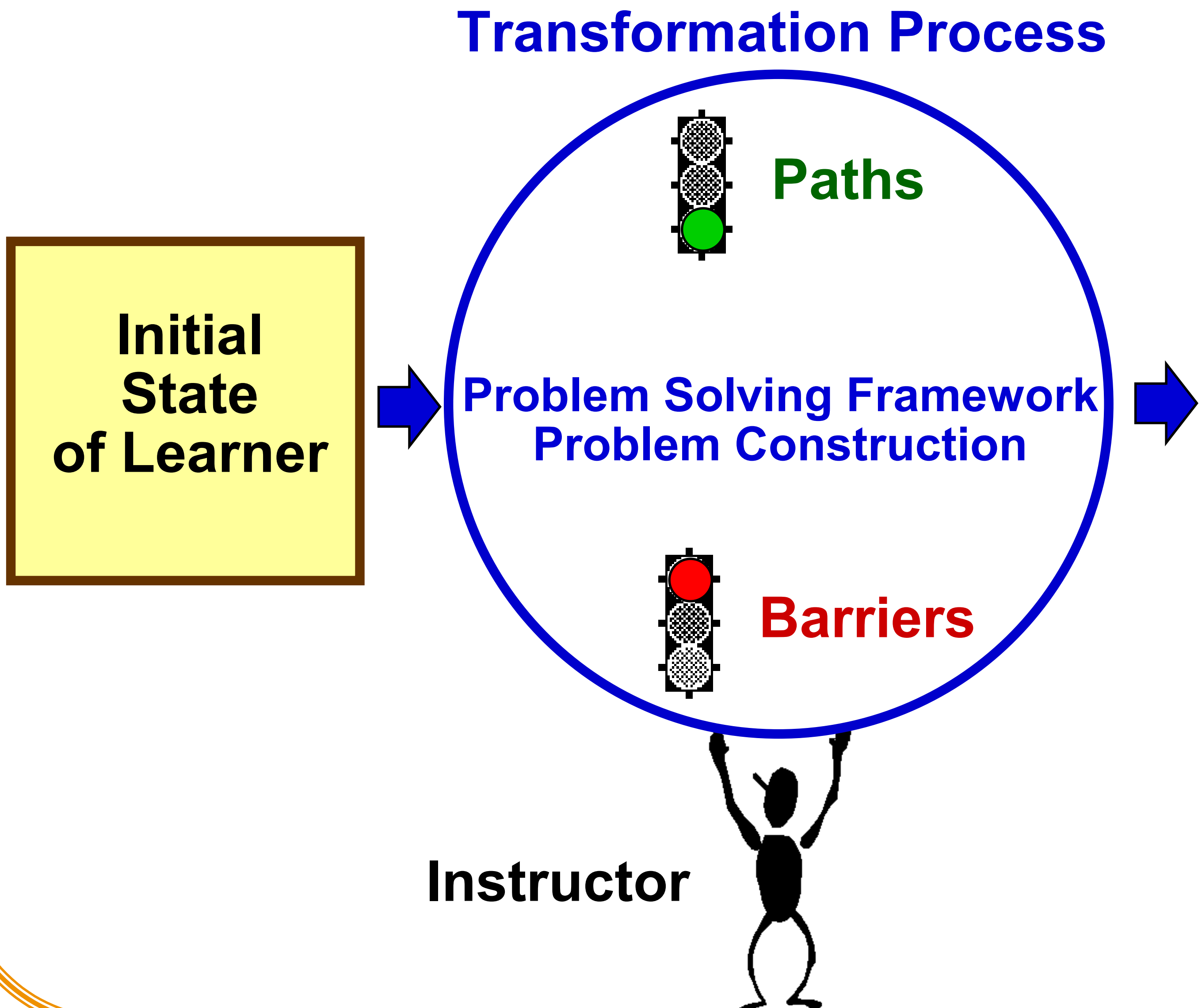
2. The task must be designed so that

- 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 task (e.g. several different quantities that could be calculated to answer the question; several ways to approach the problem);
- the task cannot be resolved in a few steps by copying a pattern.



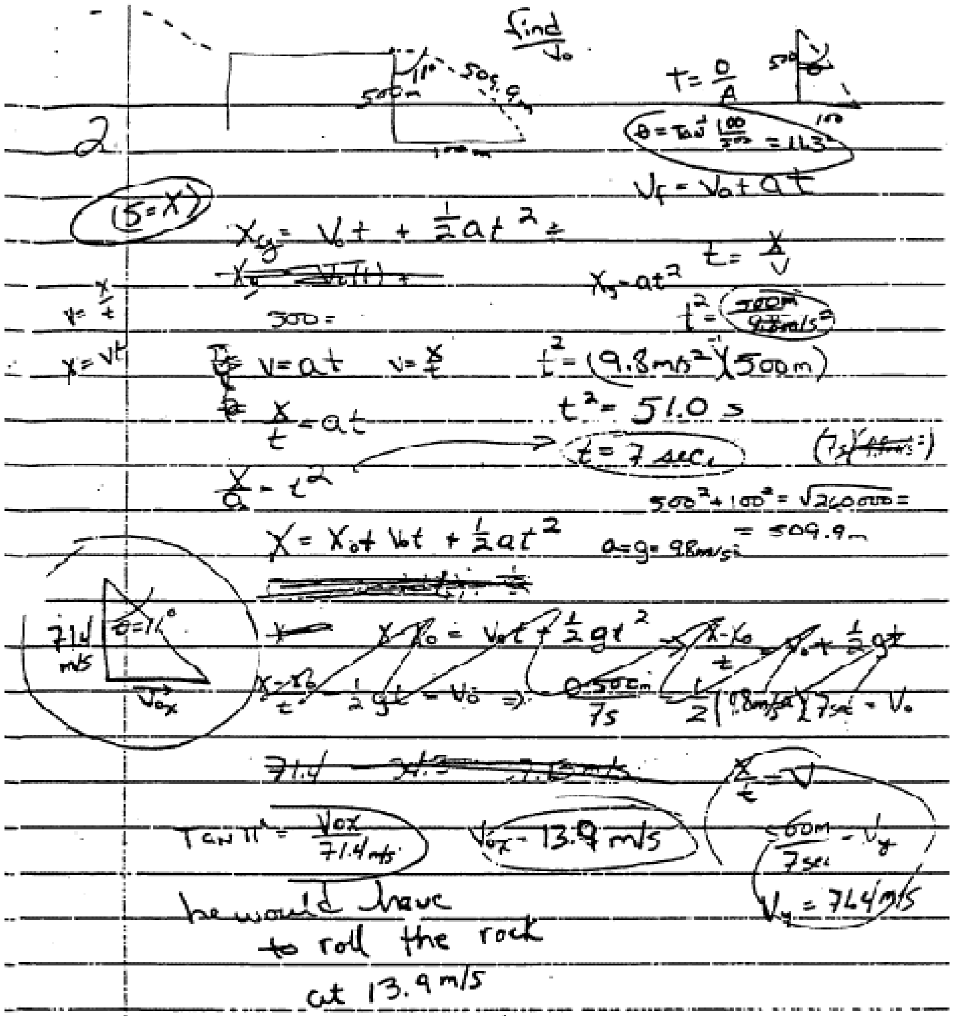
Procedure for Change

<final | T | initial>



F. Reif (1986)
Phys. Today 39

"Novice" Solution to Cowboy Bob Problem



Students need more support than a problem solving framework to solve problems

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

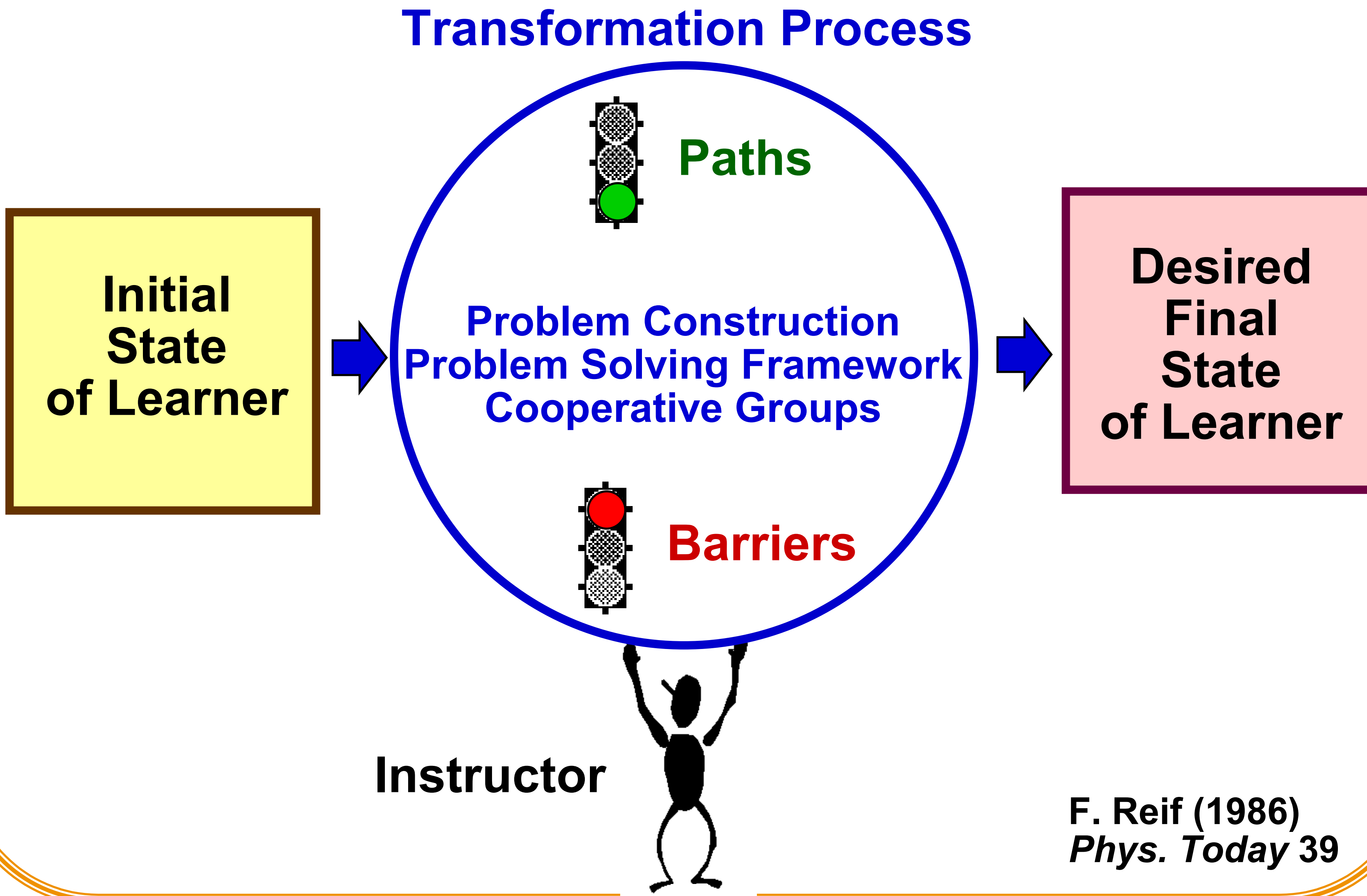
Their answer or question has been validated by the others.

Cooperative Groups

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

Procedure for Change

<final | T | initial>



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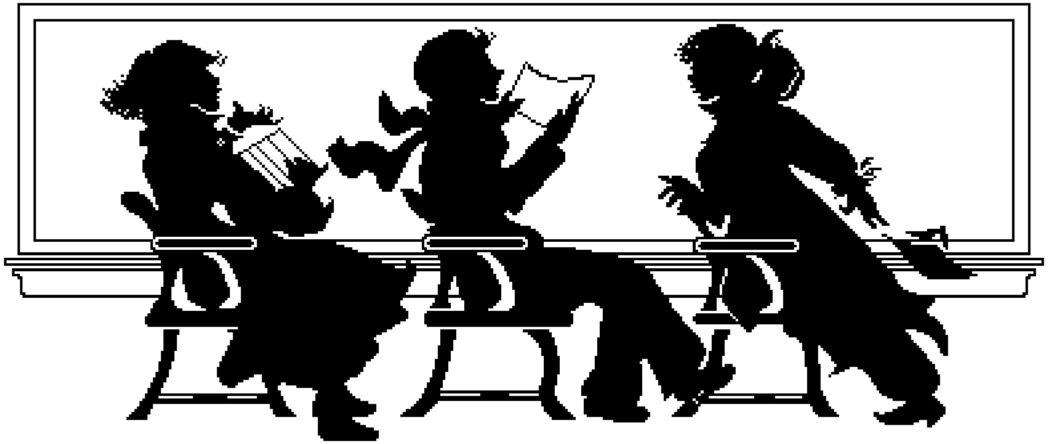
Why Cooperative Group Problem Solving May Not Work

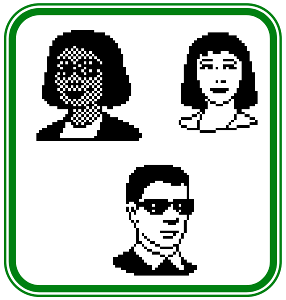


1. Poor structure and management of Groups
2. Inappropriate Tasks
3. Inappropriate Grading

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 form bottom third based on past test performance.

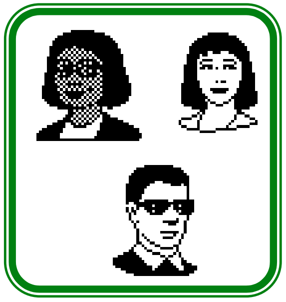


Structure and Management of Groups

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.

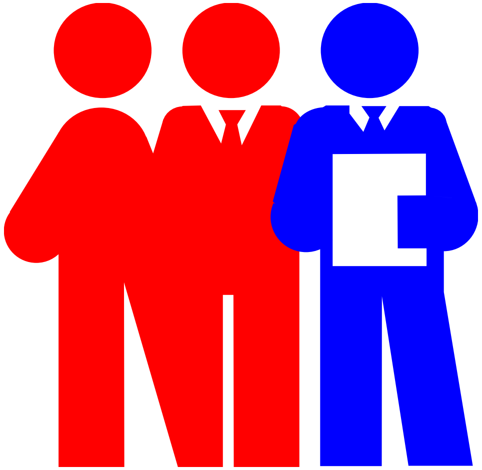


- about four times first semester, twice second semester

Structure and Management of Groups

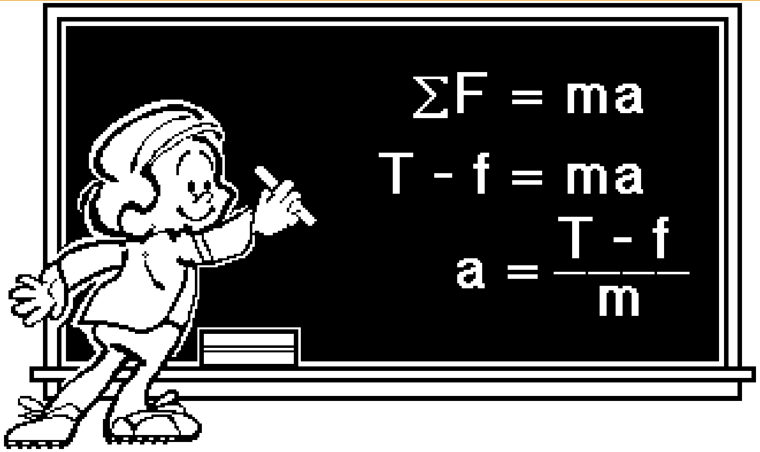
4. How can problems of dominance by one student and conflict avoidance within a group be addressed?

- one problem solution turned in that all members sign
- assign and rotate roles:
  - Manager
  - Skeptic
  - Checker/Recorder
  - Summarizer



- give students time to discuss how well they worked together and what they could do to work together better next time.

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.

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 on 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."

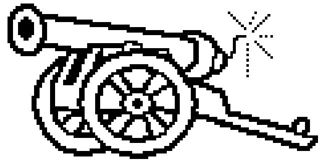
Appropriate Tasks

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

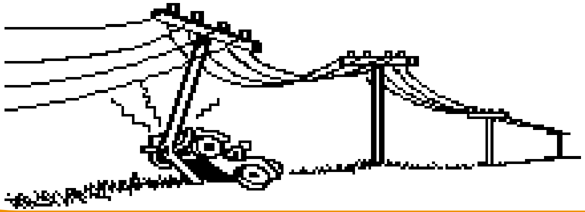


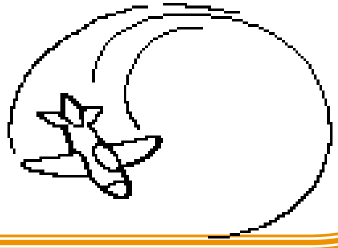
2. **The task must be designed so that**

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

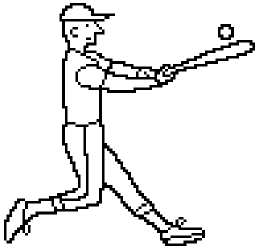
   • **there are several decisions to make in order to do the task (e.g., several different quantities that could be calculated to answer the question; several ways to approach the problem); everyone's agreement is necessary.**

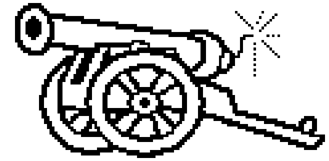
   • **the task relies on applying a strategy not remembering a pattern**



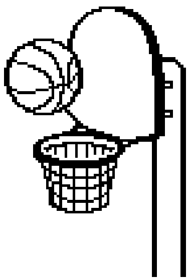


Context-rich Problems

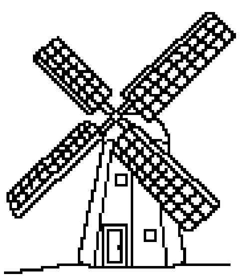


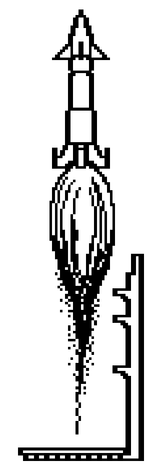


- Each problem is a short story in which the major character is the student. That is, each problem statement uses the personal pronoun "you."



- 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.)

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.

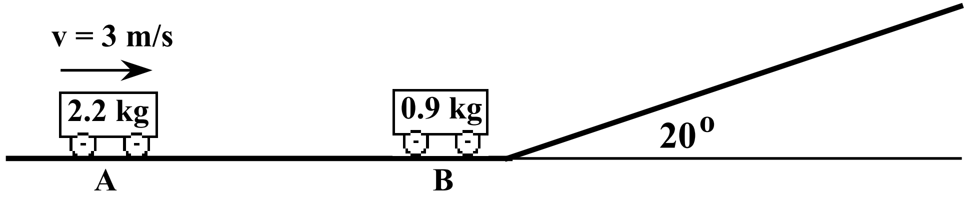


Figure 8.3

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.

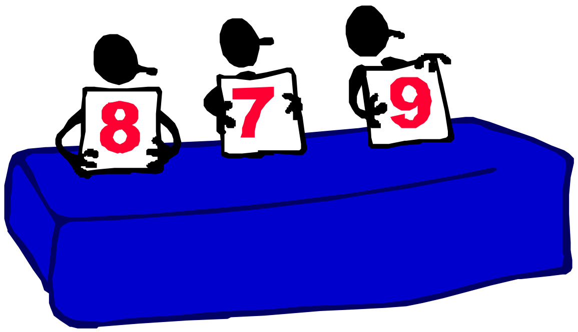
- In small groups (peer coaching)
- Intervention by instructor (expert coaching)

Need

- Appropriate task
- Group structure
- Intervention tactics

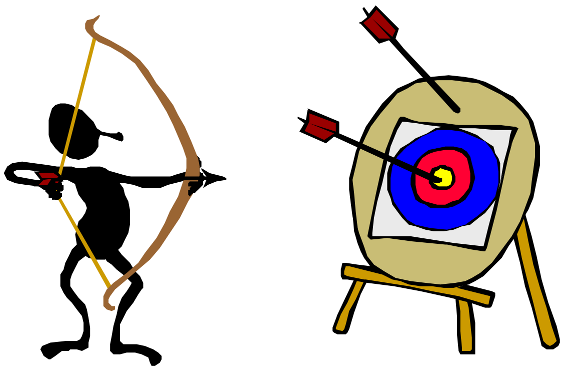
→ Cooperative Group Problem Solving

“Laws” of Instruction

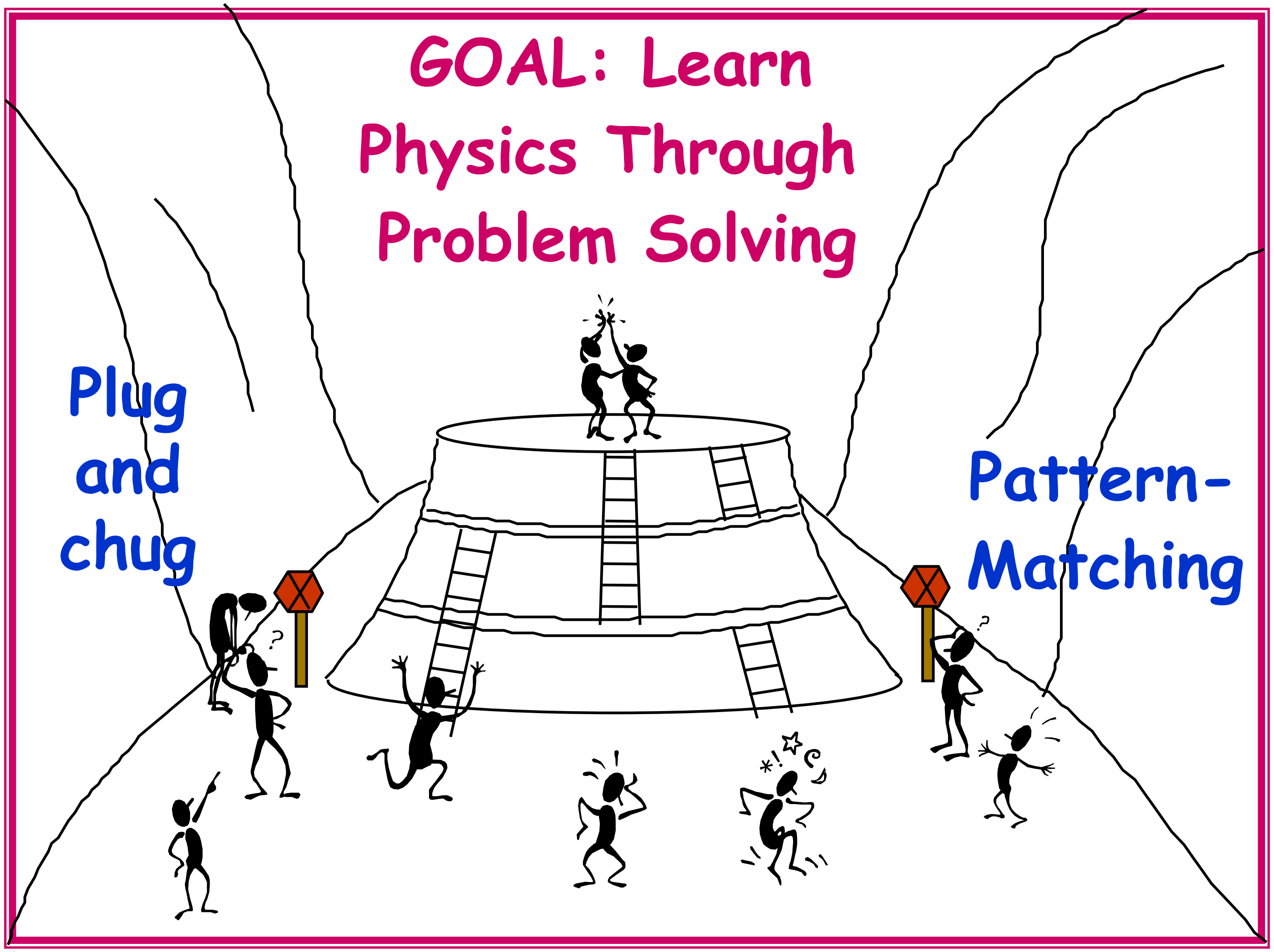


Zeroth Law: If you don't grade for it, students won't do it.

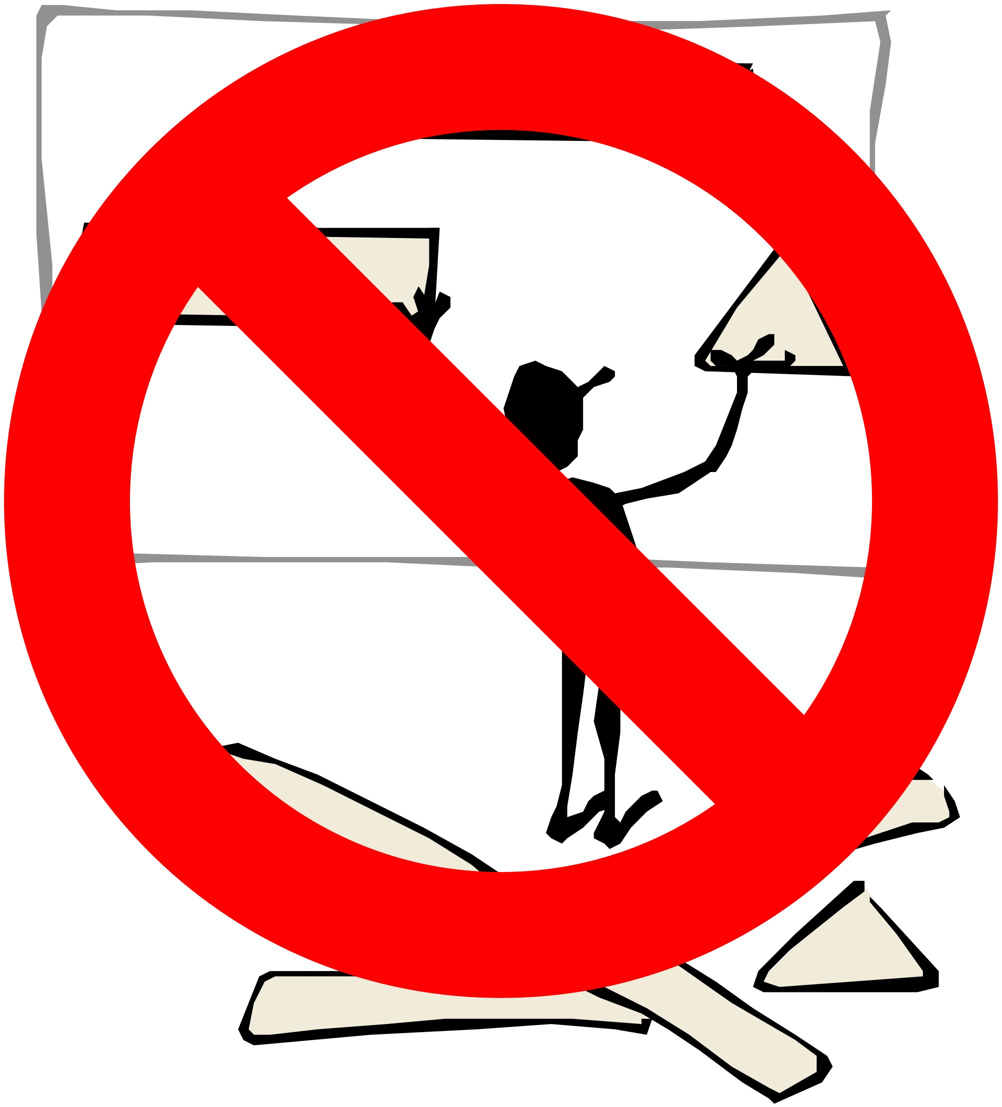
1st Law: Doing something once is not enough.



2nd Law: **Make it easier for students to do what you want them to do and difficult to do what you don't want (paths and barriers).**

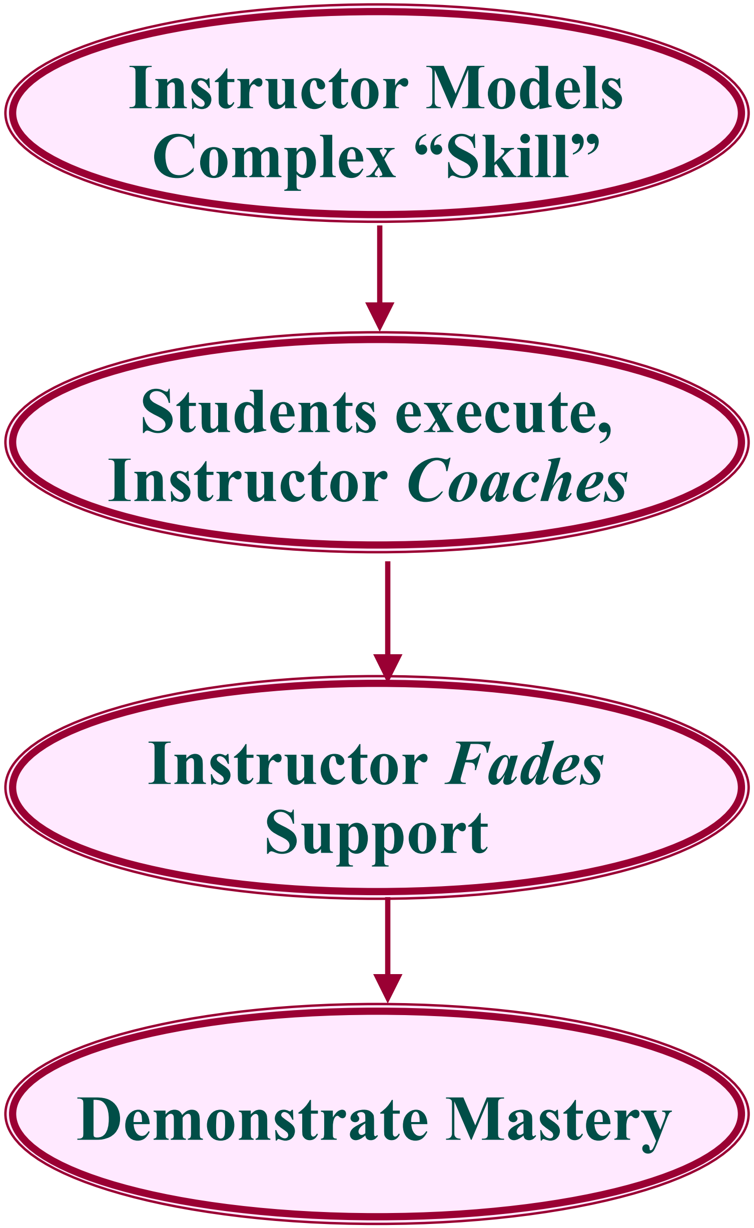


3rd Law: Don't change course in midstream!



Cognitive Apprenticeship Paradigm

Collins, Brown, & Newman (1990)



Knowledge Use & Acquisition

- Student personal theories are interlinked by experience
- Desired behavior explicitly demonstrated in context
- Students practice desired behavior in context with coaching
- Personal theories changed as necessary

Cooperative Group Problem Solving

Physics in a Culture of Expert Practice
Solving "Real" Problems

Emphasis: Problem Solving

Problem design based on expert-novice research
Explicit problem-solving strategy

Modify Lecture Style, Recitation and Laboratory

- Lectures: MODEL concept construction in problem context, and expert problem solving
- Recitation and Laboratory: COACH expert-like problem solving in structured cooperative groups
  - Context-rich problems that require physics decisions
  - Explicit problem-solving framework
- Remove scaffolding: FADE support for individual expert-like problem solving

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.

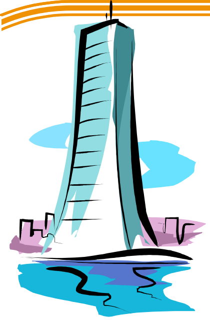
LABORATORY

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.

Building Problem Solving



STUDENTS

Modeling
Lecture

- Topics
- Procedures
- Demos
- Discussion
- Questions
- Exams

Grading

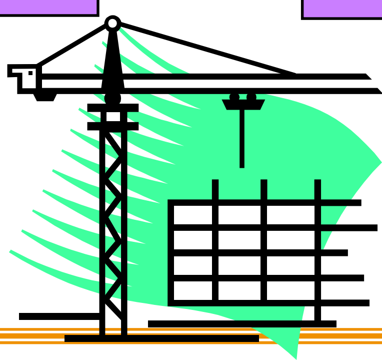
Coaching
Discussion
Labs

Problem Solving Framework
Cooperative Groups
Context Rich Problems

Office Hours

Fading
Outside

- Reading
- Homework
- Predictions
- Lab Reports
- Studying
- Quizzes

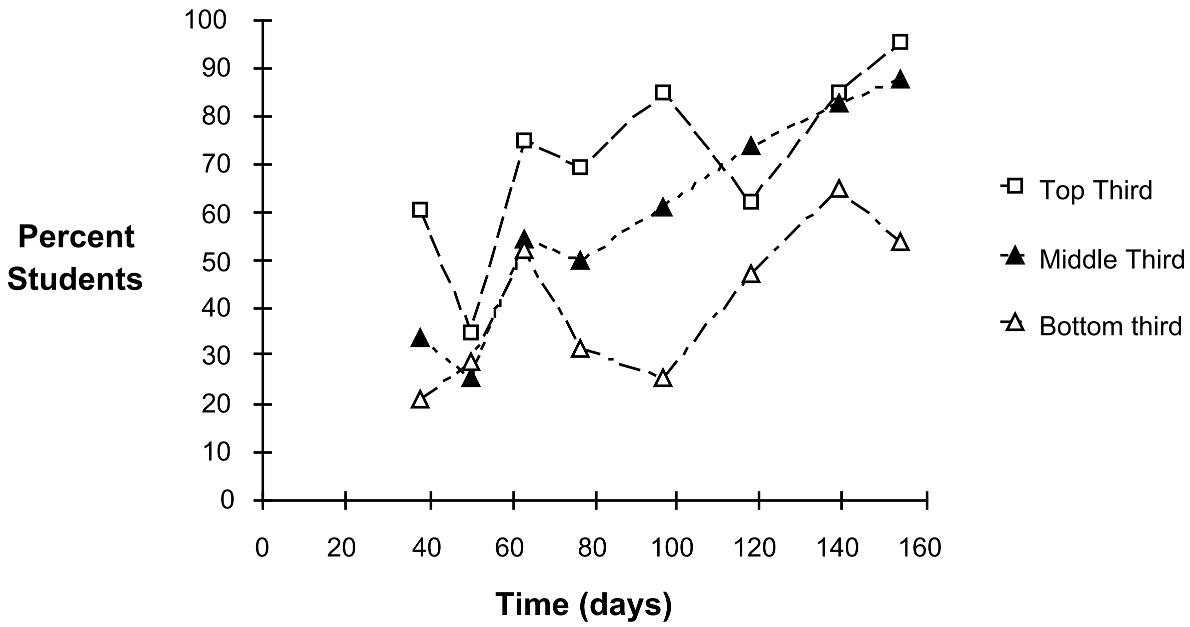


Data

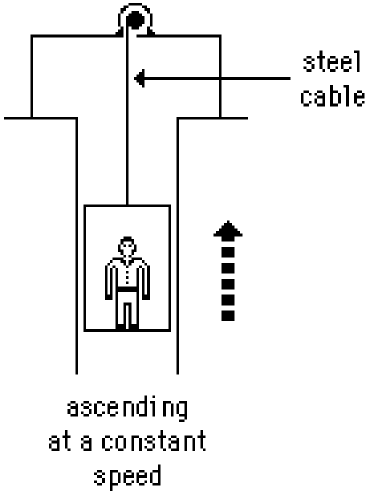
- Analysis of student exams
- Observation of student interactions
- Measures of conceptual understanding
  - FCI (Force Concept Inventory)
  - Other inventories
  - Open ended questions
  - Interviews
- Measures of hierarchical structure of physics
- Measures of student satisfaction
- Ease of implementation

Improvement in Problem Solving

Logical Progression



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:

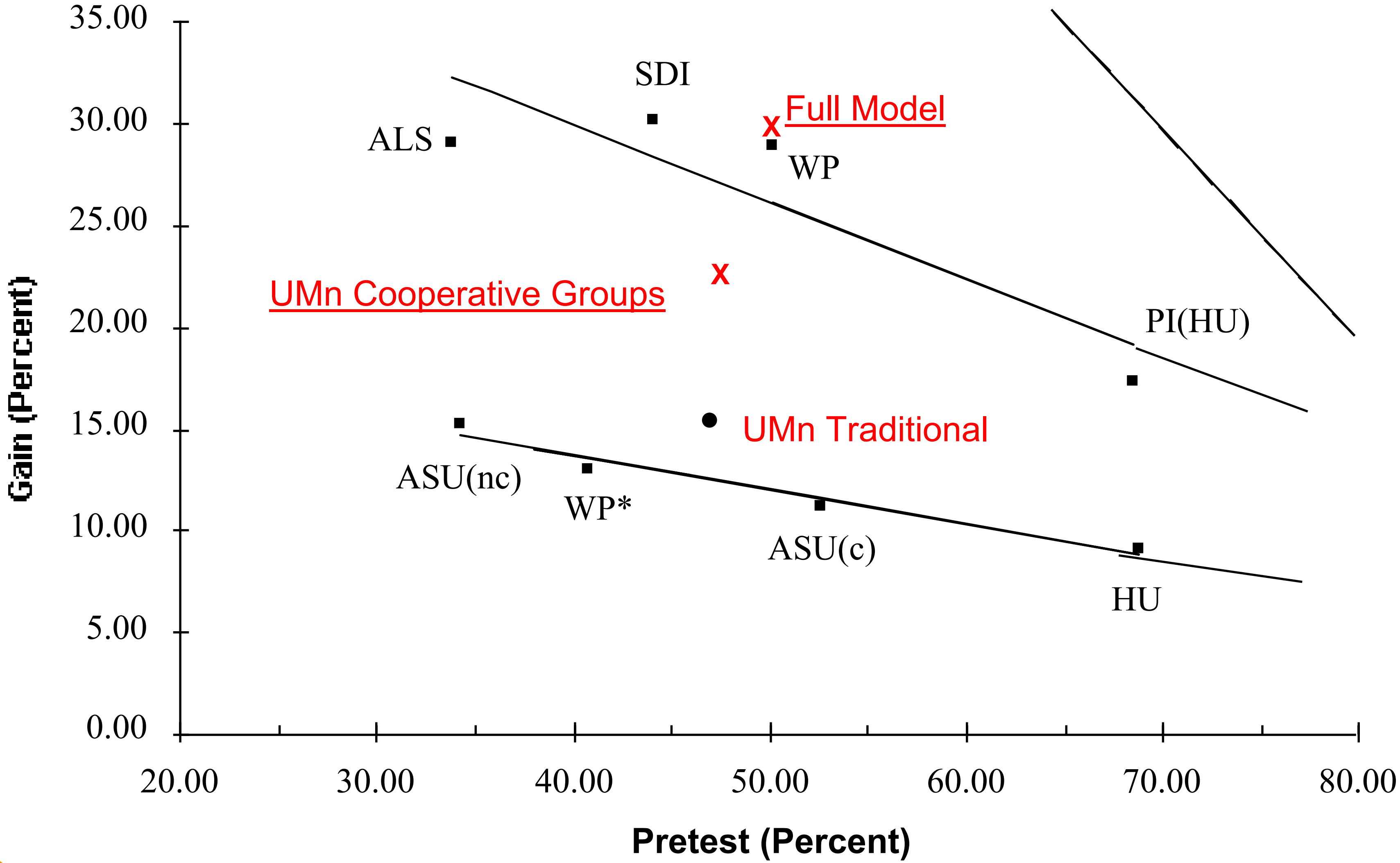
	Pre	Post
(A) the upward force by the cable is greater than the downward force of gravity.	64	36
(B) the upward force by the cable is equal to the downward force of gravity.	18	60
(C) the upward force by the cable is smaller than the down ward force of gravity.	2	0
(D) the upward force by the cable is 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.
During the collision,

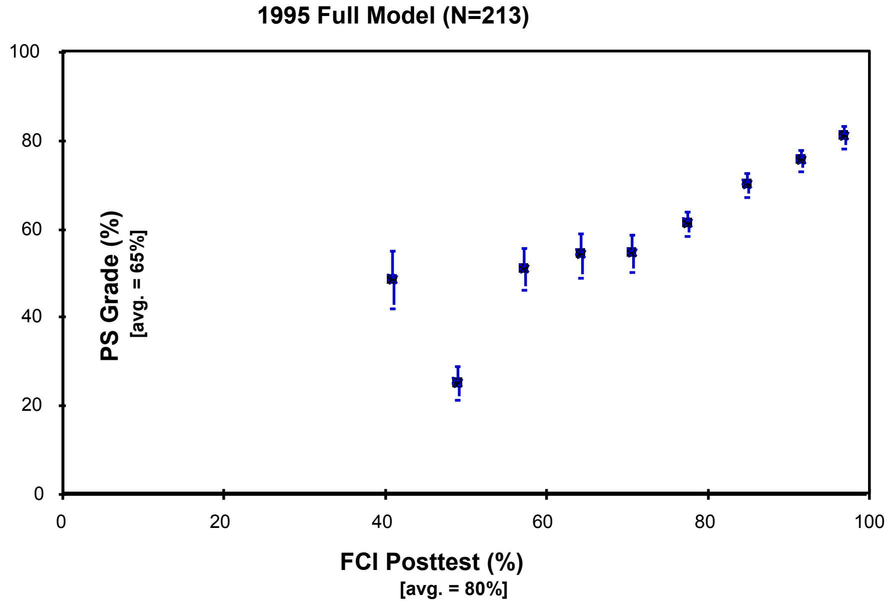
	Pre	Post
(A) the truck exerts a greater amount of force on the car than the car exerts on the truck	79	46
(B) the car exerts a greater amount of force on the truck than the truck exerts on the car.	2	1
(C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of 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

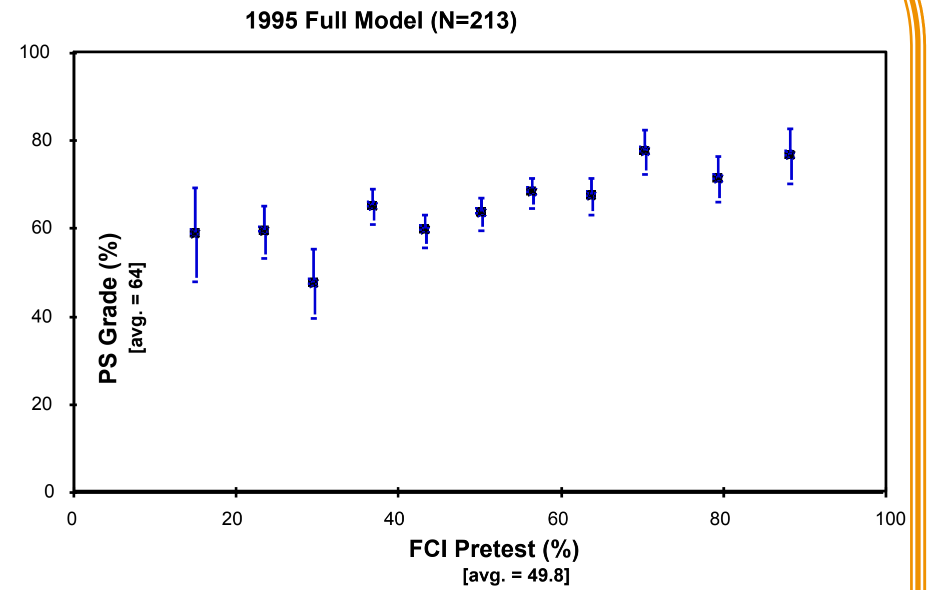
Gain on FCI

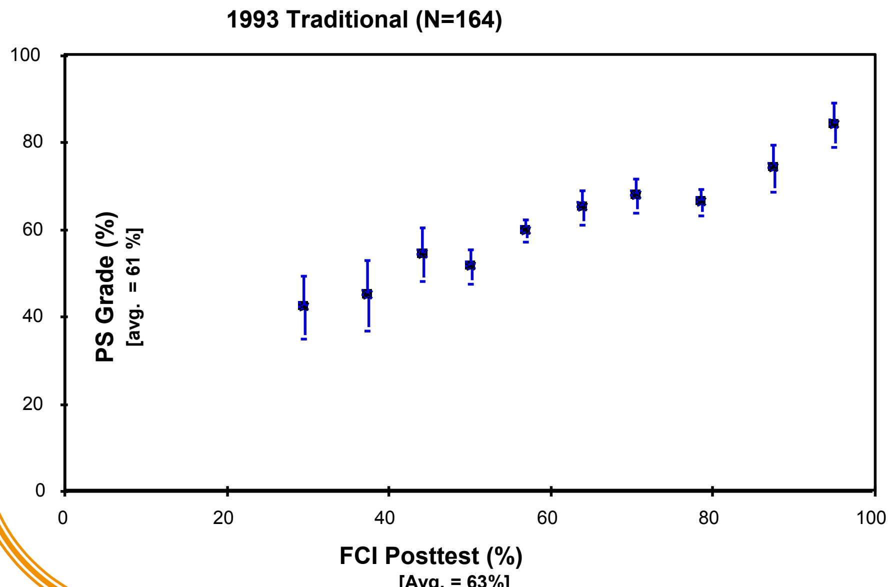


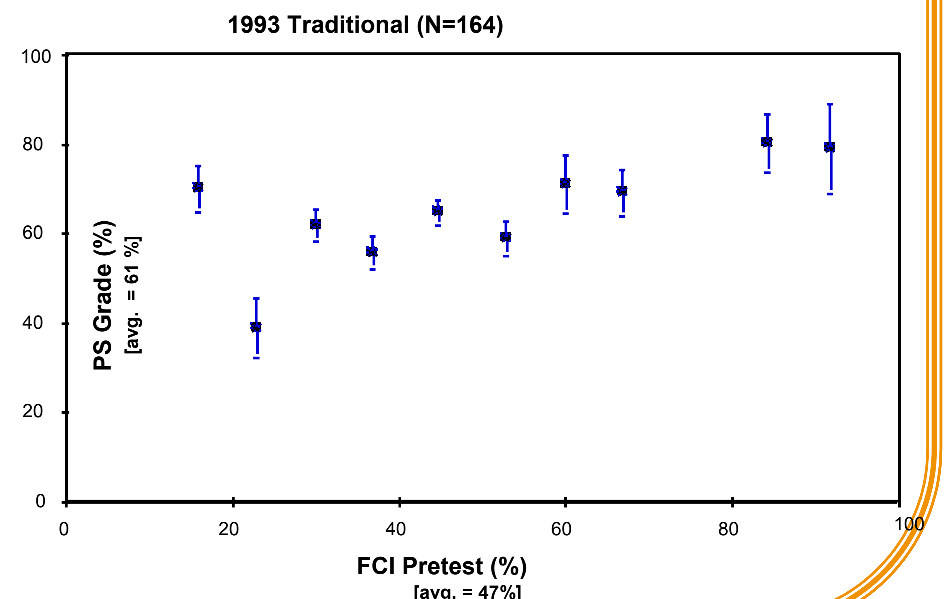
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Gain (Percent)
20.00
30.00
40.00
50.00
60.00
70.00
80.00
Pretest (Percent)
SDI
ALS
Full Model
WP
UMn Cooperative Groups
PI(HU)
UMn Traditional
ASU(nc)
WP*
ASU(c)
HU

FCI and Problem Solving

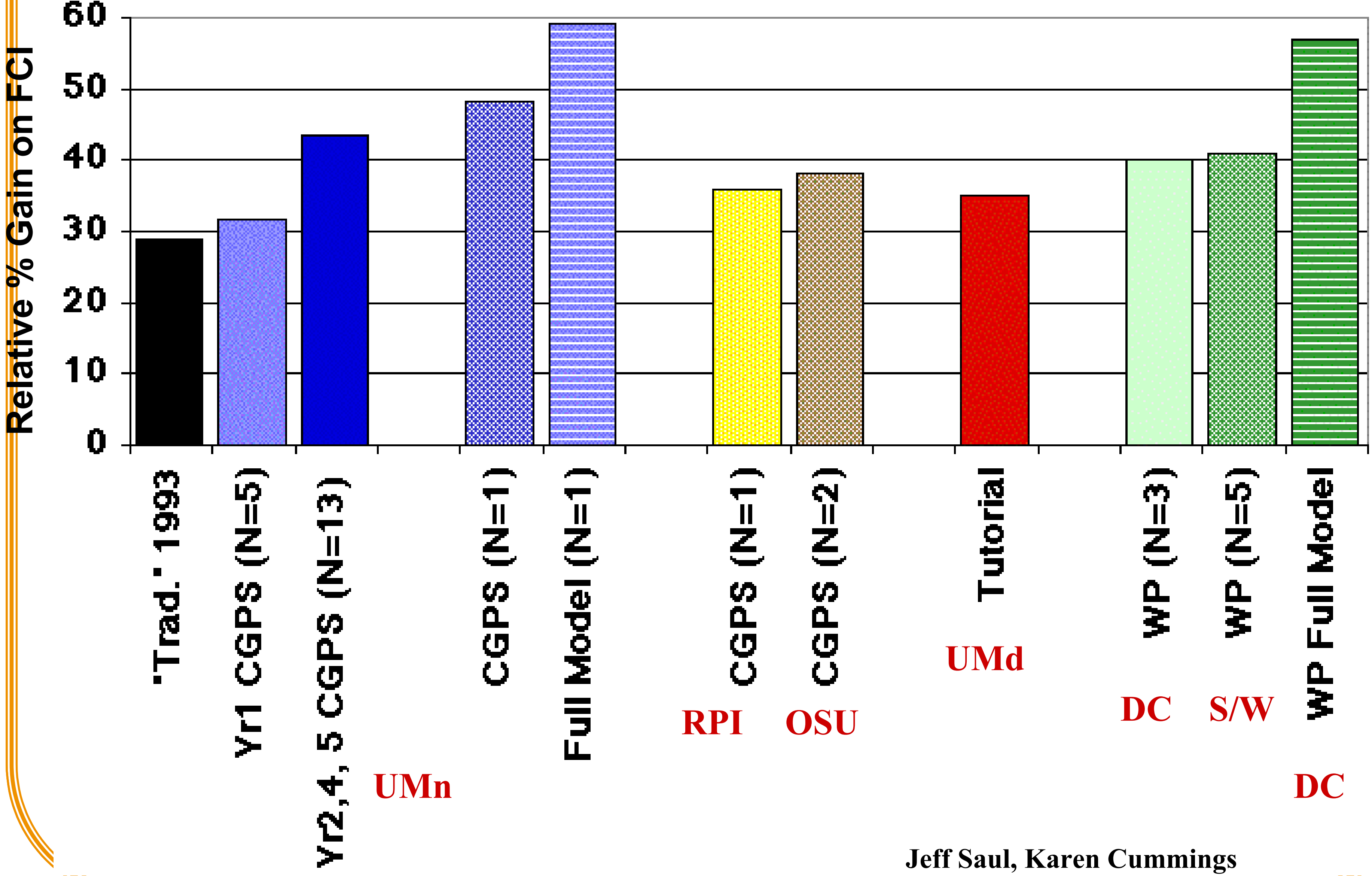






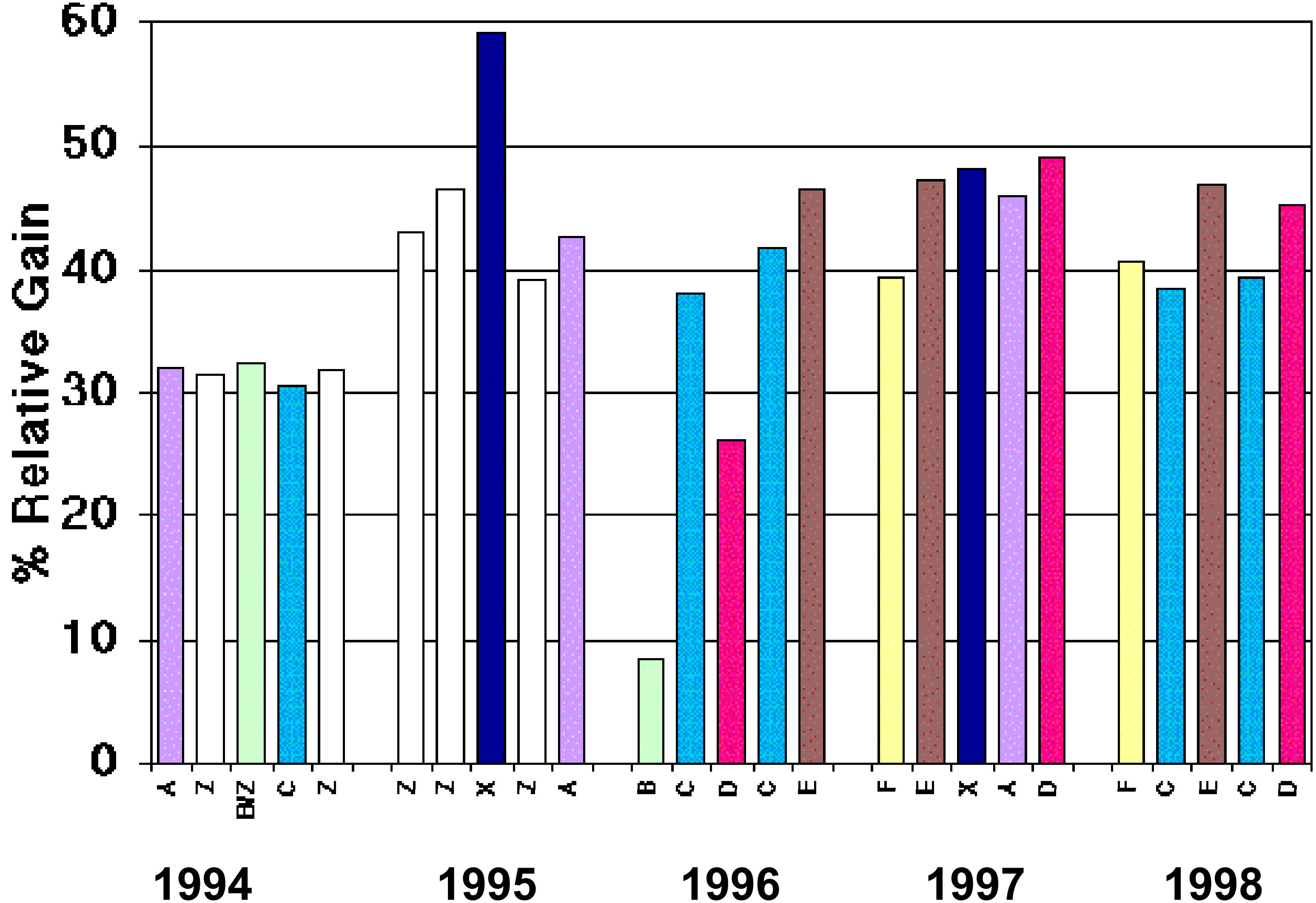


Comparisons of Full and Partial Models



Jeff Saul, Karen Cummings

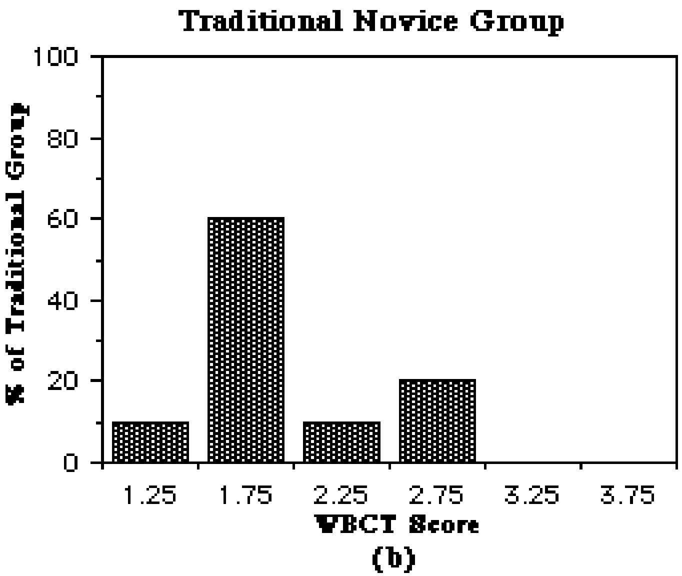
How Stable is Faculty Implementation of CGPS?



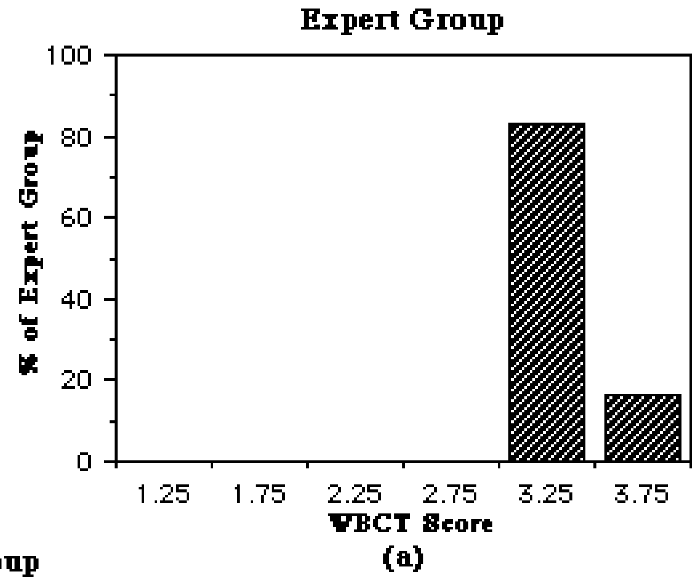
University of Minnesota Faculty

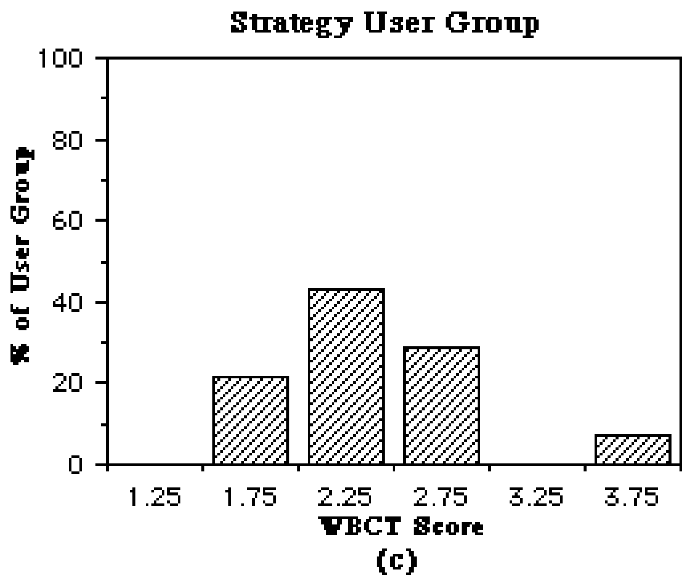
Hierarchical

Surface features



Physics principles





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)

How to Change a Textbook "Problem"

1. Choose a textbook exercise or problem.
2. If the problem does not have one, determine a context (real objects with real motions or interactions) for the problem. Use an unfamiliar context for a very difficult group problem.
3. Decide on a motivation -- Why would "you" want to calculate something in this context?
4. Determine if you need to change the target quantity to
   - (a) make the problem more than a one-step exercise, or
   - (b) make the target quantity fit your motivation.
5. Write the problem like a short story.
6. If you want to create a more difficult individual or group problem,
   - (a) determine extra information that someone in the situation would be likely to have, or leave out common-knowledge information (e.g, the boiling temperature of water).
   - (b) write the story so the target quantity is not explicitly stated, or
   - (c) think of different information that could be given, so two approaches would be needed to solve the problem instead of one approach.

How Does the Acceleration Compare Up and Down the Ramp?

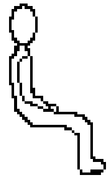
Type of Response	CGPS Algebra-based (n = 112) pre (%)	CGPS Algebra-based (n = 112) post (%)	Traditional Calculus-based (n = 100) pre (%)	Traditional Calculus-based (n = 100) post (%)
1. Includes accepted idea	6	79	19	40
2. Includes alternative conception				
a. confuse v and a, but believe motion up 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

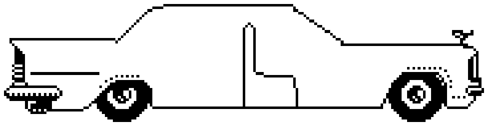
Two Open-Response Questions

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.

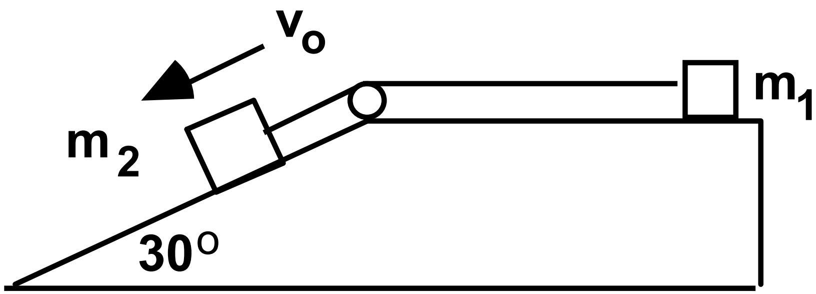




What is the Nature of the Forces on the Passenger?

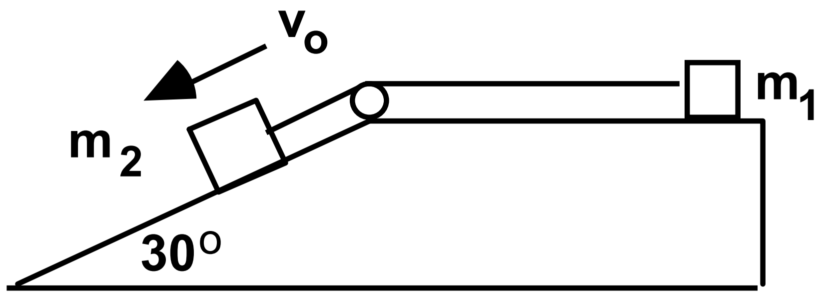
Type of Response	Baseline (n = 100) pre (%)	Baseline (n = 100) post (%)	Coop Group (n=85) post (%)	Full Model (n=71) post (%)
	FCI post 68%		FCI 72%	FCI 82%
1. Only Newtonian forces	12	41	59	76
2. Newtonian forces, but some are 3rd Law pair on wrong object	24	24	8	4
3. Include non-Newtonian forces (e.g.,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

Please visit our website for more information:

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

Build A Context-Rich Problem

- Choose Basic Physics Principle(s)
- Decide on Difficulty Level
- Address a Misconception?
- Involve a Special Technique?
- Choose a Context
- Decide on a Motivation
- Choose Target and Input Quantities
- Decide on Decisions to be Made
- Check Solution (more than 1-step, no subtle insights)
- Check Evaluation Possibilities

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%

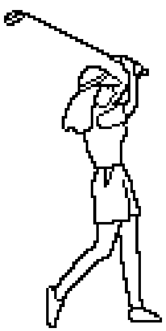
2. The written instructions in the lab manual were designed to guide your group in making decisions, without explaining how to conduct the lab. Do you think the written instructions provided too much guidance, too little guidance, or just about the right amount of guidance?

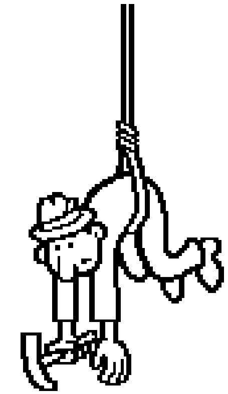
too little	just about right	too much
33%	60%	3%

N=100 (random)

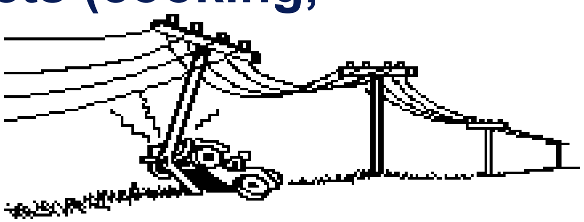
Some Common Contexts

- physical work (pushing, pulling, lifting objects vertically, horizontally, or up ramps)
- suspending objects, falling objects





- sports situations (falling, jumping, running, throwing, etc. while diving, bowling, playing golf, tennis, football, baseball, etc.)
- situations involving the motion of bicycles, cars, boats, trucks, planes, etc.
- astronomical situations (motion of satellites, planets)
- heating and cooling of objects (cooking, freezing, burning, etc.)



Some Motivations

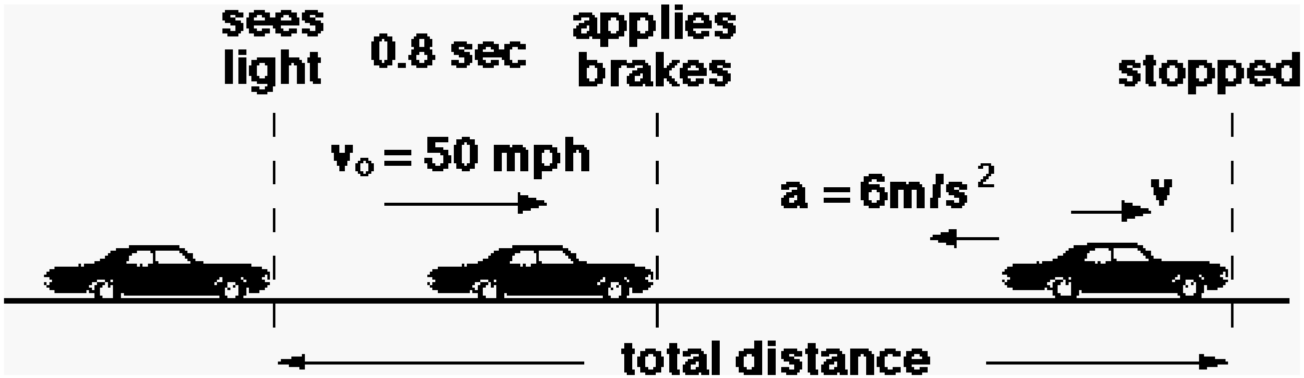
1. You are . . . . (everyday situation) and need to figure out . . . .
2. You are watching . . . . (an everyday situation) and wonder . . . .
3. You are on vacation and observe/notice . . . . and wonder . . . .
4. You are watching TV or reading an article about . . . . and wonder . . .
5. Because of your knowledge of physics, your friend asks you to help him/her . . . .
6. You are writing a science-fiction or adventure story for your English class about . . . . and need to figure out . . . .
7. Because of your interest in the environment and your knowledge of physics, you are a member of a Citizen's Committee (or Concern Group) investigating . . . .
8. You have a summer job with a company that . . . . Because of your knowledge of physics, your boss asks you to . . . .
9. You have been hired by a College research group that is investigating . . . . Your job is to determine . . . .
10. You have been hired as a technical advisor for a TV (or movie) production to make sure the science is correct. In the script . . . ., but is this correct?
11. When really desperate, use motivation of an artist friend designing a kinetic sculpture!

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:

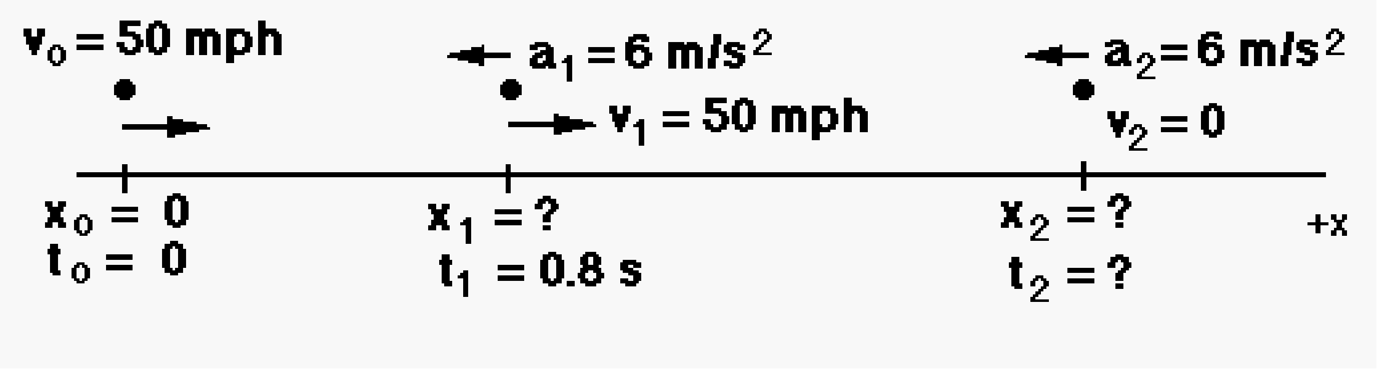
What total distance did the car travel to stop?

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?

Design of a Problem

Difficulty	Symptom	Design feature
Visualizing a physical situation	Physically impossible results. No pictures or diagrams drawn	No pictures given. Situation not trivial.
Connection to reality	"Fragile" knowledge. Difficulty applying to slightly different situations.	Reasonable motivation. Realistic situation described. Avoid "physics' words.
Gender or cultural bias	Lack of interest or intellectual involvement. Difficulty visualizing.	Actors are "you" & unnamed acquaintances
"Idealizing" a situation	Difficulty applying to slightly different situations.	A realistic situation reduces in a straightforward way to a simple one after visualization.

Difficulty	Symptom	Design feature
Integrating correct conceptual knowledge	Misconceptions remain	Realistic situation described. Misconception will prevent correct solution.
Applying knowledge	Difficulty applying to slightly different situations.	Realistic situation described. Decisions necessary for applicable concept or technique.
Solving "wrong" problem. Pattern matching.	Oversimplification or misreading of problem.	Realistic situation which must be interpreted in terms of physics.
Mathematical rigor.	Math "magic".	Problem can be solved in a straightforward way using basic concepts.
Logical analysis.	Random equations.	Problem requires more than one mathematical/logical step.

Constructing Problems

Paths | **Barriers**

Visualization and Pictorial Representation

Paths:
- Real Things Interacting
- Personal Viewpoint
- Reason for Interaction

Barriers:
- No Pictures
- Objects have Complex Relationships

General Principles of Physics

Paths:
- Real Things Interacting
- Reason for Interaction

Barriers:
- Must Determine Relevant Information
- Minimize "Physics" Clues

Constructing Problems

Paths | **Barriers**

Planning and Mathematical Representation

- Straightforward Solution using Means-Ends Analysis
- No One-Step Solutions

Evaluation

- Real Things Interacting
- Reason for Interaction
- Answer Not Obvious

Problem-solving Laboratories

Real Problems

Always context-rich problems

Embody alternative conceptions

Use problem solving strategy

Work in Cooperative Groups

Laboratory Exercise Structure

- the problem
- the equipment
- prediction
- methods questions
- exploration
- measurement
- analysis and conclusion

Problem Solving Labs

A "Lab" lasts 2 - 3 weeks, and consists of several related problems in a topic area.

Each problem takes 1 - 2 hours to complete in a lab session..

There are more problems than the typical group can complete in the time allotted

- teaching team choose a preferred order and minimum number of problems to match the emphasis of the lectures;
  - instructor can select additional problems to meet the needs of individual groups.

Theory is given only in the text to emphasize that the lab is an integral part of the course.

The Problem

You are the technical advisor for the next Bruce Willis action adventure movie, Die Even Harder. The script calls for a spectacular stunt. Bruce Willis is dangling over a cliff from a long rope that is tied to the Bad Guy, who is on the ice-covered ledge of the cliff. The Bad Guy's elastic parachute line is tangled in a tree located several feet from the edge of the cliff. Bruce and the Bad Guy are in simple harmonic motion. At the top of his motion, Bruce tries to grab the cliff edge while the Bad Guy tries to cut the rope with his knife.

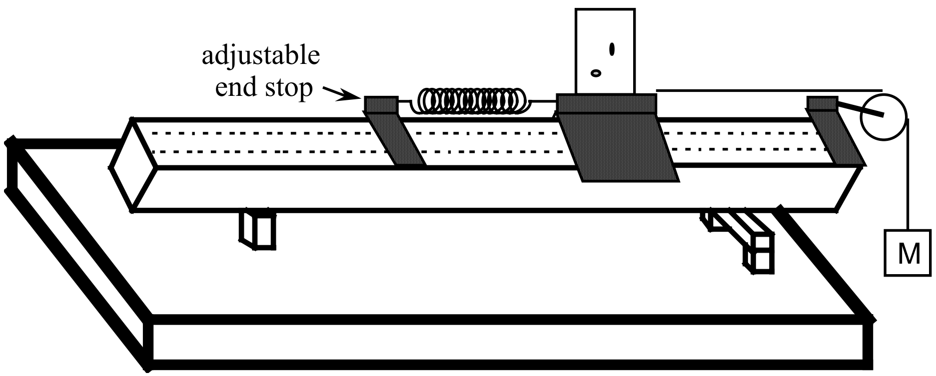
It is expensive to have Bruce hanging from the rope while the crew gets close-ups of the Bad Guy. However, the stunt double weighs more than Bruce. The director wants you to tell her:

Will the motion of the actors change if the heavier stunt man is used instead of Bruce Willis?.

You decide to solve this problem by modeling the situation with the equipment described below.

Equipment

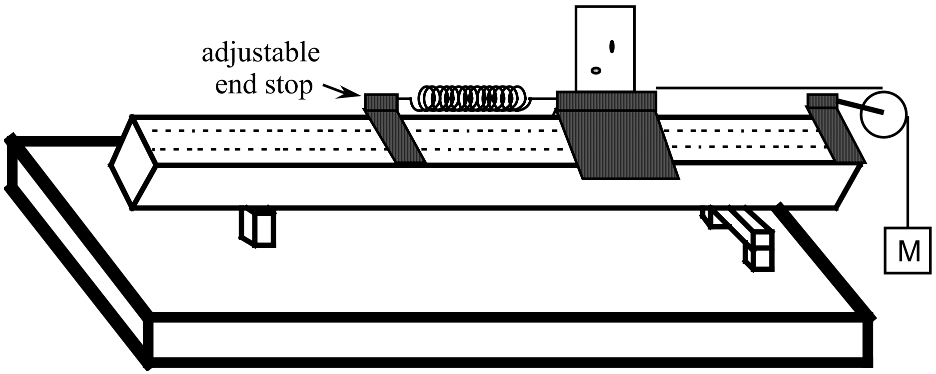
You have an air track with an adjustable end stop, a pulley which attaches to the end of the air track, a spring, a glider, some string, a mass hanger and masses, and a stopwatch.



The air track represents the ice-covered ledge of the cliff, the adjustable end-stop represents the tree, the spring represents the elastic cord, the glider represents the Bad Guy, the string represents the rope, and the hanging mass represents Bruce Willis or his stunt double in this problem.

Prediction

Predict **quantitatively** **how the frequency of oscillation of the system depends on the mass hanging over the table.**



Use your equation to sketch a graph of the oscillation frequency versus hanging mass.

Will the frequency increase, decrease or stay the same as the hanging mass increases?

Methods Questions

To complete your prediction, it is useful to apply a problem-solving strategy such as the one outlined on page 35 of your text:

1. **Make two sketches of the situation (similar to the diagram in the Equipment section), one when the glider and hanging mass are at their equilibrium position, and one at some other time while the system is oscillating. On your sketches, show the direction of the acceleration of the glider and hanging mass. Identify and label the known (measurable) and unknown quantities.**
2. **Draw force diagrams of the oscillating glider and hanging mass. Label the forces.**

Exploration

Find the best place for the adjustable end stop on the air track. DO NOT STRETCH THE SPRING PAST 40 CM OR YOU WILL DAMAGE IT, but stretch it enough so the glider and hanging mass oscillate smoothly.

Determine the best glider mass. Remember to attach the masses onto the glider in pairs to keep the glider balanced. Determine the best range of hanging masses to use.

Practice releasing the glider and hanging mass smoothly and consistently. How long does it take for the oscillations to stop? How can you affect this time? When should you take the period measurement? Over how many cycles?

Measurement

If necessary, determine the spring constant of your spring. From your results of Problem #1, select the best method for measuring spring constants. Justify your choice. What is the uncertainty in your measurement?

For each different hanging mass, measure the period of oscillation of the glider and hanging mass. How many times should you measure each period to be sure that it is reliable? What is the uncertainty of each measurement?

Analyze your data as you go along, so you can determine the size and number of different hanging masses you need to use. Collect enough data to convince yourself and others of your conclusion about how the oscillation frequency depends on the hanging mass.

Analysis

For each hanging mass, calculate the oscillation frequency (with uncertainty) from your measured period.

Graph the frequency versus the hanging mass. On the same graph, show your predicted relationship.

What are the limitations on the accuracy of your measurements and analysis? Over what range of values does the measured graph match the predicted graph best? Do the two curves start to diverge from one another. If so, where? What does this tell you about the system?

Conclusion

Does the oscillation frequency increase, decrease or stay the same as the hanging mass increases? State your result in the most general terms supported by your analysis.

What will you tell the director? Do you think the motion of the actors in the stunt will change if the heavier stunt man is used instead of Bruce Willis? How much heavier than Bruce would the stunt man have to be to produce a noticeable difference in the oscillation frequency of the actors? Explain your reasoning in terms the director would understand so you can collect your paycheck.