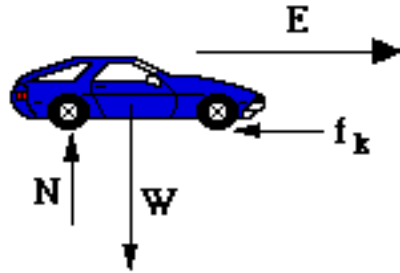


# Teaching Physics Through Problem Solving



$$\Sigma F = ma$$

$$f_k = \mu N$$

$$W = mg$$

**“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**

**Details at <http://groups.physics.umn.edu/phised/>**

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

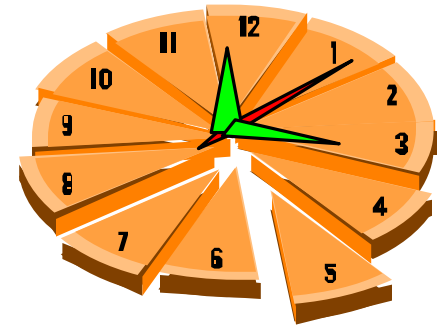
# Task



- Write down what you want from this presentation.
- Form a group of 3.
- Decide on the single most important information you want from this presentation.
- **TIME ALLOTTED**  
10 minutes
- **PROCEDURES**  
*Formulate* a response individually.  
*Discuss* your response with your partners.  
*Listen* to your partners' responses.  
*Create* a new group response through discussion.

# AGENDA

## A Guide for Discussion



- ✓ **Who**  
**are the Students**
- ✓ **What Is It**  
**Course structure**
- ✓ **What**  
**are Problems**  
**is Problem Solving**
- ✓ **How**  
**to Teach It**
- ✓ **Does It Work**  
**Data**

# 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

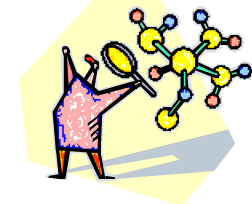
10% senior

# Physics for Biology Majors

## 600 students/term

### Majors

Biological Science	49%
Allied Health	19%
Social Science	7%
Architecture	3%
Engineering	2%
Other	20%
+ Pre-Med	37%



Male	39%
Female	61%

Freshman	7%
Sophomore	38%
Junior	19%
Senior	17%

Had U. Calculus	71%
(Had HS Calculus)	50%
Had HS Physics	71%

Expect A	48%
Work	74%
Work more than 10 hrs/wk	50%

# Calculus Based Physics

## 1200 students/term

### Majors

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



<b>Male</b>	<b>79%</b>
<b>Had Calculus</b>	<b>80%</b>
<b>Had HS Physics</b>	<b>87%</b>

<b>Freshman</b>	<b>64%</b>
<b>Sophomores</b>	<b>22%</b>
<b>Juniors</b>	<b>10%</b>

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

## TASK

Discuss why you assign problems in physics courses.

List the common goals of the problems.

## TIME ALLOTTED

5 minutes

## PROCEDURES

Form a group of 3 people

Choose one person as a recorder

*Formulate* a response individually.

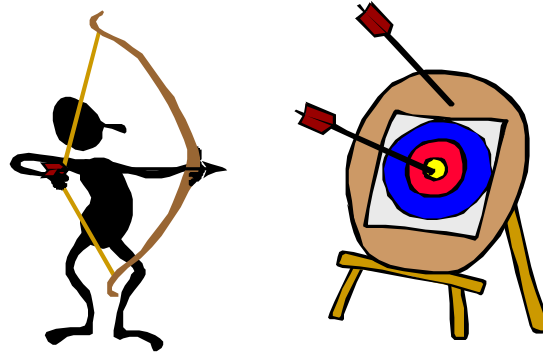
*Discuss* your response with your partners.

*Listen* to your partners' responses.

*Create* a new group response through discussion.



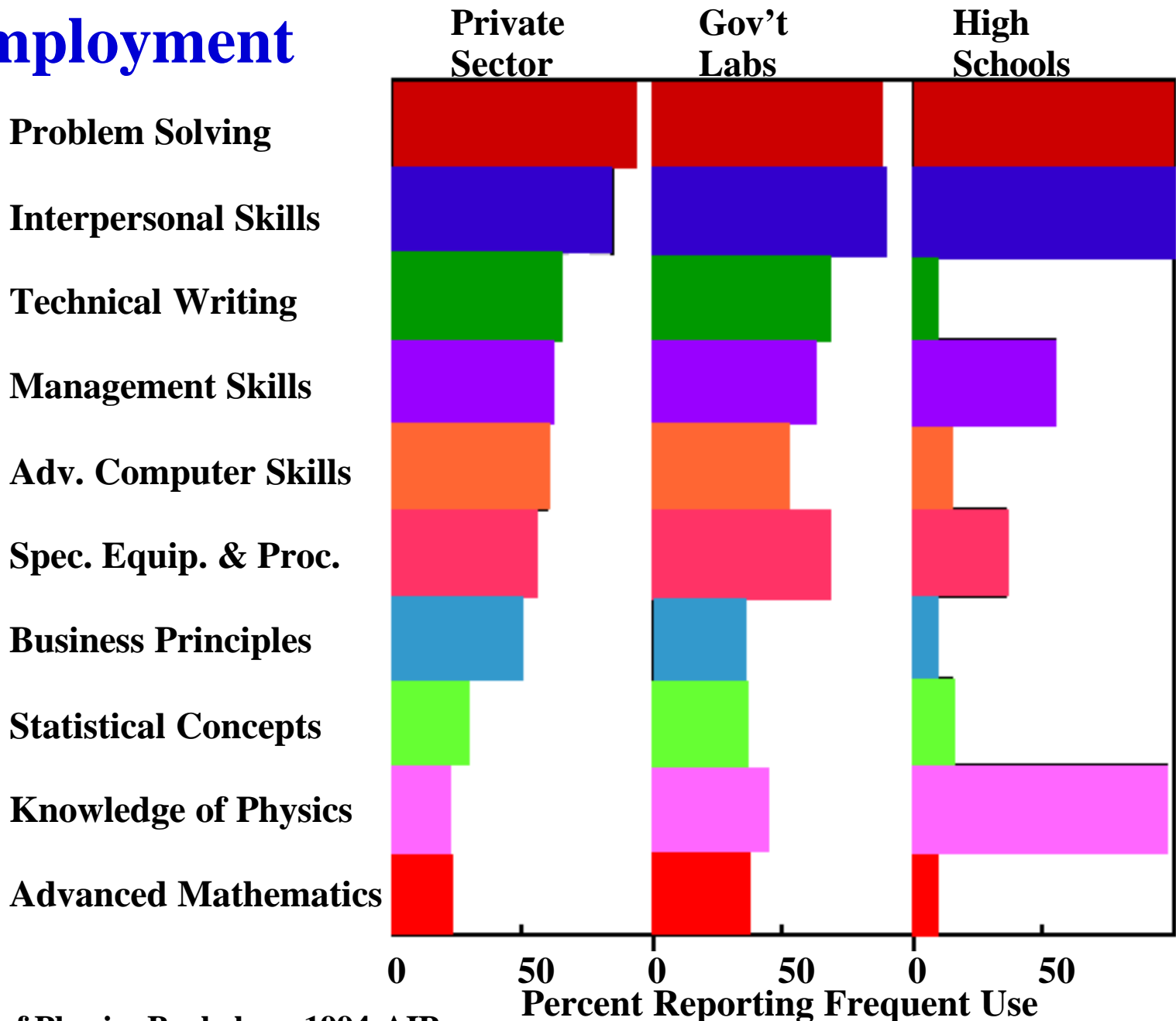
# Should Teaching Problem Solving be an Aim of Introductory Physics?



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



# Employment



Survey of Physics Bachelors, 1994-AIP

# Highest Rated Goals

## Goals: Biology Majors Course 2003

- 4.9 **Basic principles behind all physics**
- 4.4 **General qualitative problem solving skills**
- 4.3 *Use biological examples of physical principles*
- 4.2 *Overcome misconceptions about physical world*
- 4.1 **General quantitative problem solving skills**
- 4.0 *Real world application of mathematical concepts and techniques*

← Modified survey in  
response to CBS  
Curriculum  
Committee

## Goals: Calculus-based Course (88% engineering majors) 1993

- 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) 1987

- 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



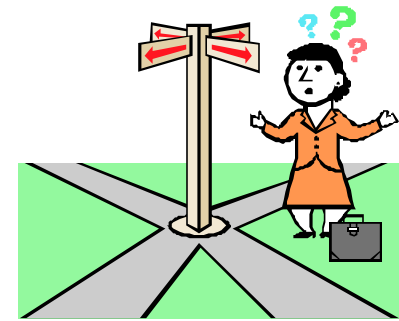
**Exercise vs Problem**



# 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**

# Some Reflective Skills (Metacognition)

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



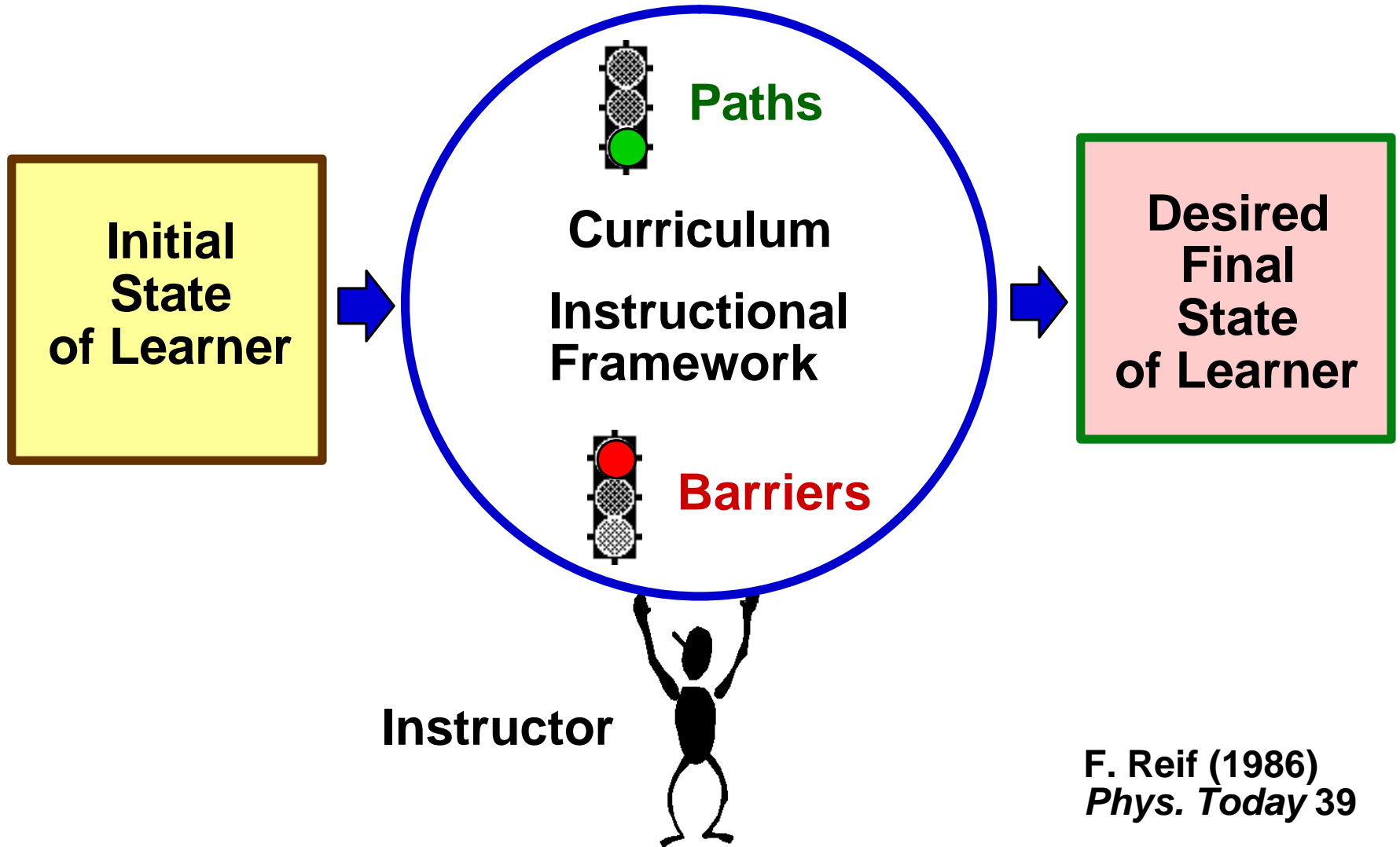
# Some General Tools (Heuristics)

- **Means - Ends Analysis** (identifying goals and subgoals)
- **Working Backwards** (step by step planning from desired result)
- **Successive Approximations** (idealization, approximation, evaluation)
- **External Representations** (pictures, diagrams, mathematics)
- **General Principles of Physics**

# Procedure for Change

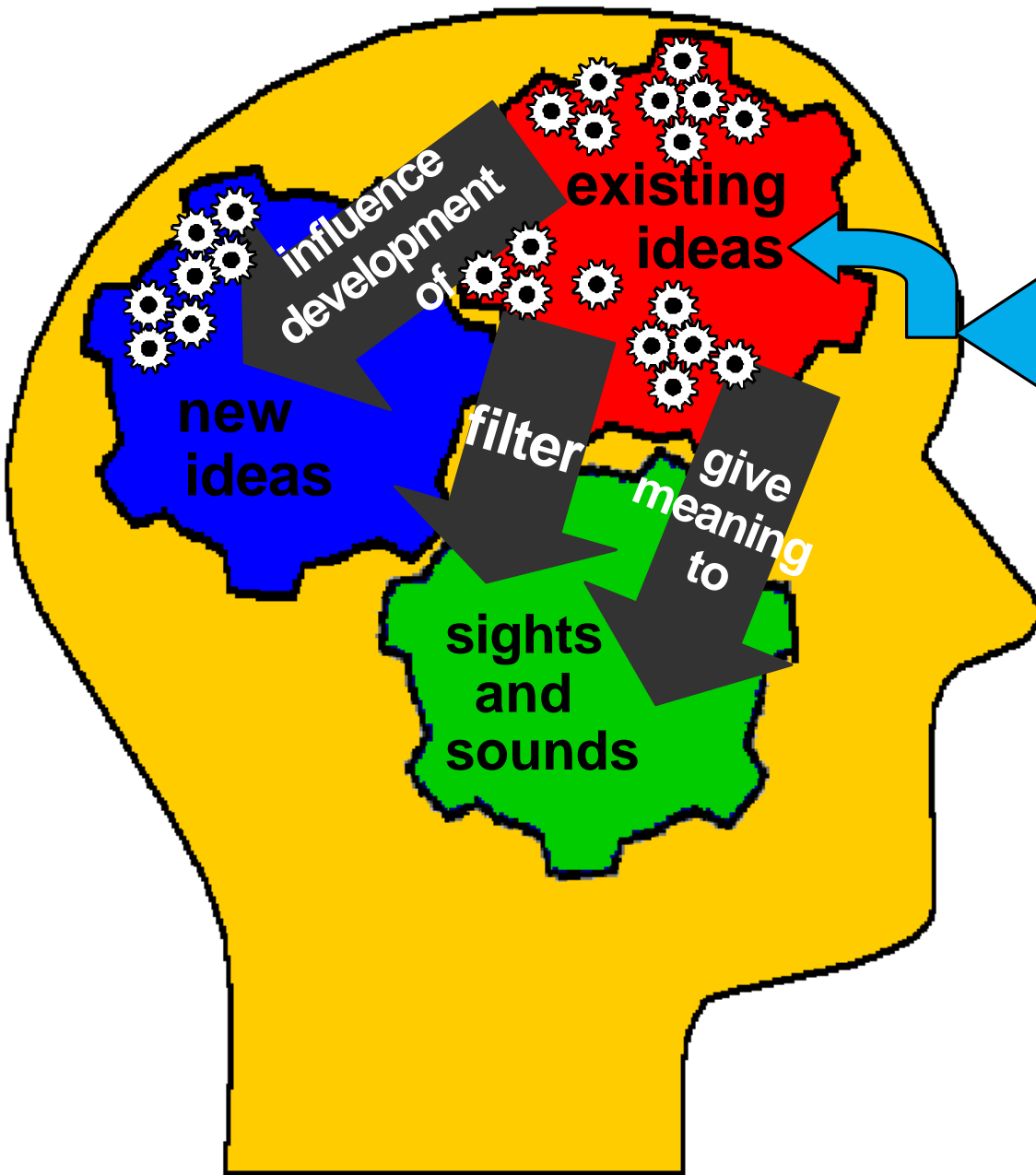
<final | T | initial>

## Transformation Process



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

# Cognitive Apprenticeship Instruction



**INSTRUCTION**

**Learning in the environment of expert practice**



**model**



**coach**



**fade**

Collins, Brown, & Newman (1990)

# Course Structure

## LECTURES

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

## RECITATION SECTION

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

## LABORATORY

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

## TESTS

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



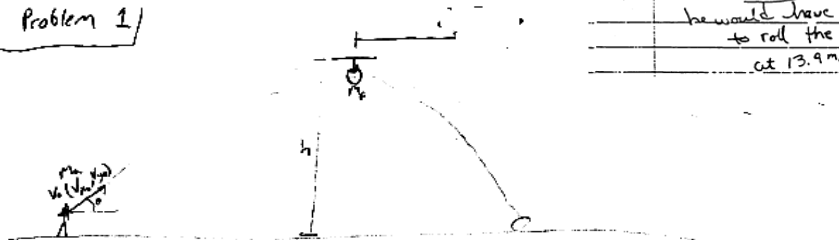
# Student Problem Solutions

Handwritten physics notes on lined paper. At the top, a diagram shows a projectile launched from a height  $h$  with initial velocity  $v_0$  at an angle  $\theta$ . The horizontal distance is  $x$  and the vertical displacement is  $y$ . Equations include:  $x = v_0 t \cos \theta$ ,  $y = v_0 t \sin \theta - \frac{1}{2} g t^2$ ,  $v_x = v_0 \cos \theta$ ,  $v_y = v_0 \sin \theta - g t$ . A calculation shows  $t = 2.10$  s,  $x = 7.4$  m, and  $v_x = 13.9$  m/s. A note says "he would have to roll the rock at 13.9 m/s".

## Initial State



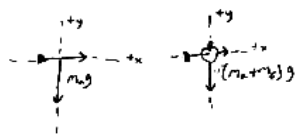
### Problem 1/



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:  $h, m_a, m_f, v_0, \theta$   
 unknown:  $d$

Qualitative relationships:

$$v_{x0} = v_0 \cos \theta \quad p_f = (m_a + m_f) v_{af}$$

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

$$d = v_{xf} t$$

$$p_i = p_f \Rightarrow m_a v_{x0} = (m_a + m_f) v_{af} \Rightarrow v_{af} = \frac{m_a}{m_a + m_f} v_{x0}$$

$$p_i = m_a v_{x0}$$

Target:  $d$

Plan the Solution:

$$d = v_{xf} t$$

$$v_{xf} = \frac{m_a}{m_a + m_f} v_{x0}$$

$$v_{x0} = v_0 \cos \theta$$

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

$$d = \frac{m_a}{m_a + m_f} v_0 \cos \theta \sqrt{\frac{2h}{g}}$$

Check units:

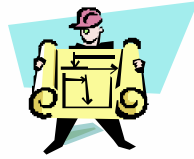
$$m = \frac{m_a}{m_a + m_f} \frac{m}{s} \sqrt{\frac{m}{m/s^2}} \rightarrow \sqrt{m^2} = m$$

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

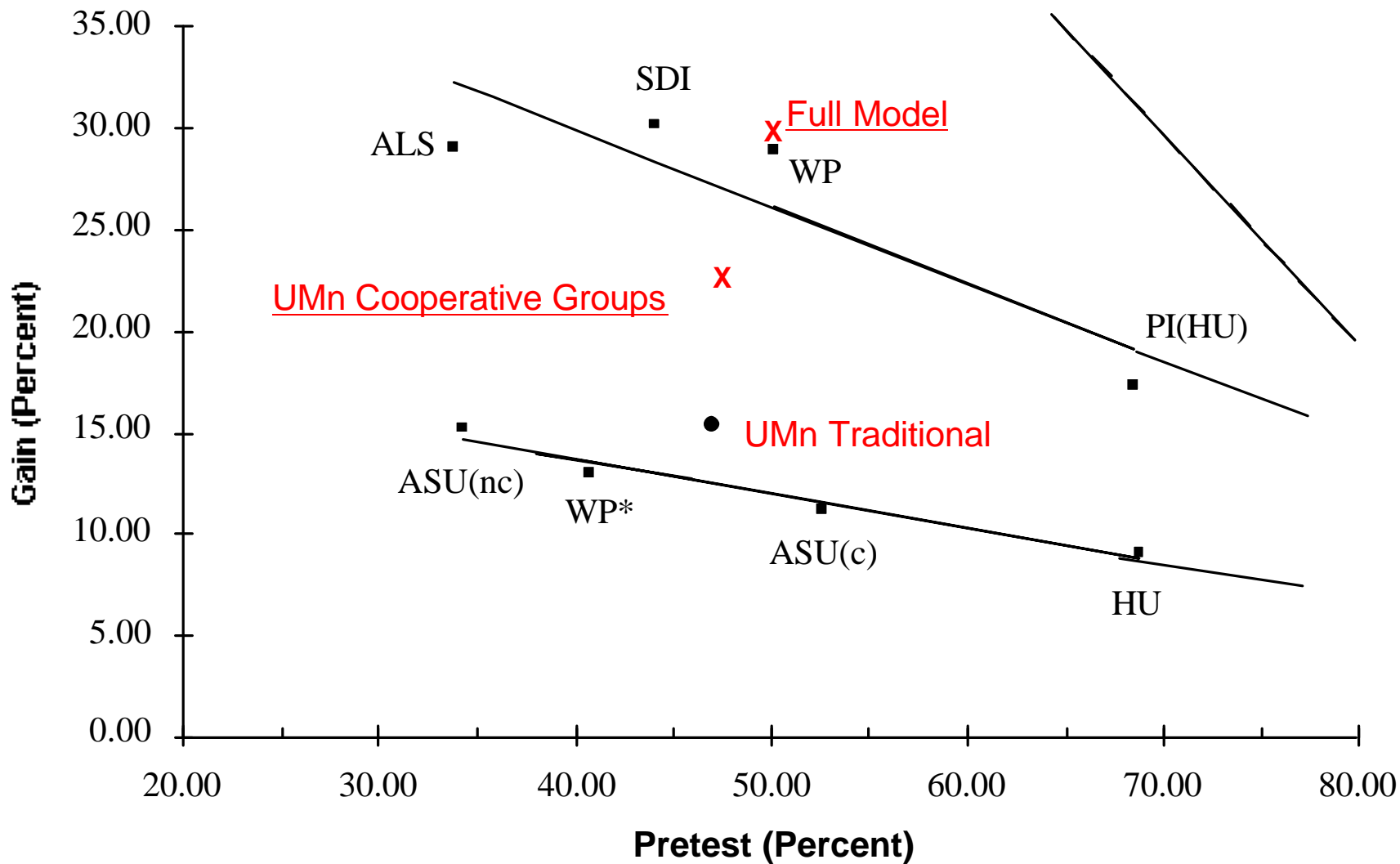
$$m = m \Rightarrow \text{OK}$$

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

## Final State



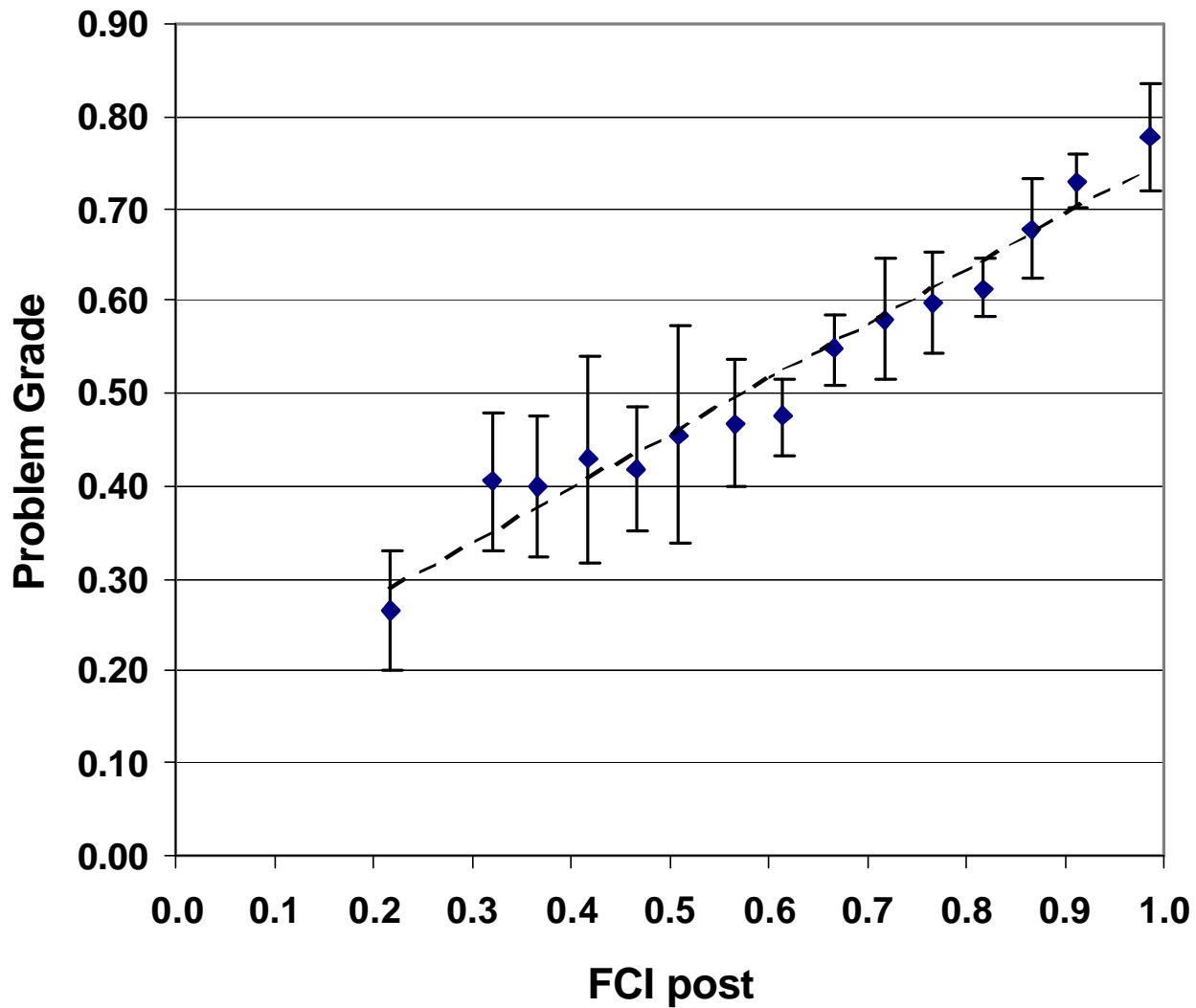
# Gain on FCI



# Final PS vs FCI post

$$y = 0.5935x + 0.1584$$

$$R^2 = 0.9577$$



1301.1 f2001

# Initial State of the Learner

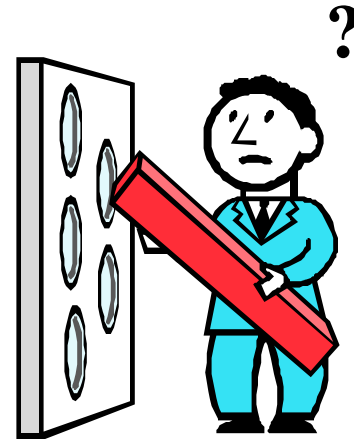
Students have Misconceptions about

**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**

A framed piece of paper with a decorative border containing three physics equations:
$$\Sigma F = ma$$
$$T - f = ma$$
$$a = \frac{T - f}{m}$$

**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

**TIME ALLOTTED - 5 minutes**

***Form a group of 3 people***

***Assign one person to be the recorder.***

***Discuss* your thoughts with your partners.**

***Create* a group response through discussion.**

**PRODUCT**

**A list of individual similarities and differences and a list of your 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  $6.0 \times 10^{-5} \text{ C/m}^3$ . 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  $1.6 \times 10^{-19} \text{ C}$  and  $5.0 \times 10^{-27} \text{ Kg}$ .**

# How Do You Solve This

An infinitely long cylinder of radius  $R$  carries a uniform (volume) charge density  $\rho$ . 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



# 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?

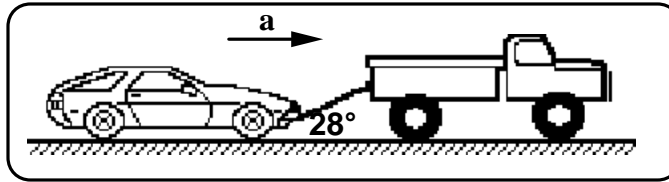
# Competent Problem Solving

## Step

## Bridge

### 1. **Focus** on the Problem

*Translate the words into an image of the situation.*

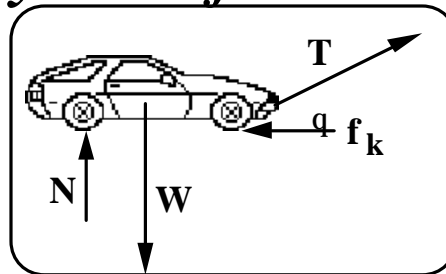


Identify an **approach** to the problem.

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).

$$\sum \vec{F} = m\vec{a}$$

$$f_k = \mu N$$

$$W = mg$$

### 3. **Plan** a Solution

## Step

### 3. Plan a Solution

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

Find  $a$ :

$$[1] \quad \dot{a} F_x = m a_x$$

Find  $\dot{a} F_x$ :

$$[2] \quad \dot{a} F_x = T_x - f_k$$

### 4. Execute the Plan

*Translate the plan into a series of appropriate mathematical actions.*

$$T_x - f_k = m a_x$$

$$T \cos q - m(W - T \sin q) = \frac{W}{g} a_x$$

$$\frac{gT}{W} (\cos q - m \sin q) - mg = a_x$$

### 5. Evaluate the Solution

## Bridge

**Outline the mathematical solution steps.**

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

Solve [2] for  $\dot{a} F_x$  and put into [1].

Solve [1] for  $a_x$ .

**Check units of algebraic solution.**

$$\frac{\hat{e} \frac{m}{\hat{e} s^2} \hat{u} [N]}{[N]} - \hat{e} \frac{m}{\hat{e} s^2} \hat{u} = \hat{e} \frac{m}{\hat{e} s^2} \hat{u} \quad \text{OK}$$

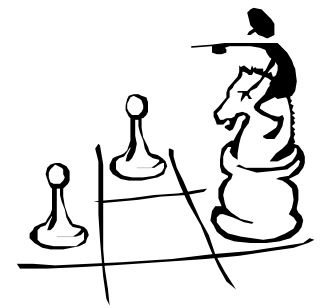
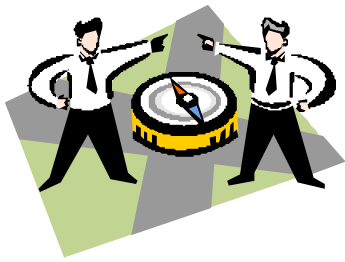
# Appropriate Problems for Practicing Problem Solving

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.

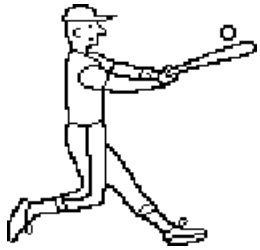




### 3. The task problem must connect to each student's mental processes

- the situation is **real** to the student so other information is connected;
- there is a **reasonable goal** on which to base decision making.

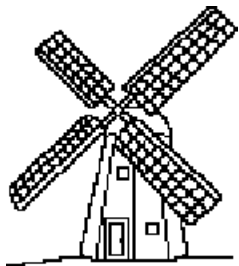
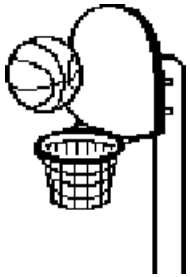




# Context-rich Problems



- 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

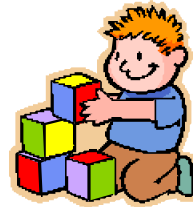
In addition, more difficult context-rich problems can have one or more of the following characteristics:

- 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.)



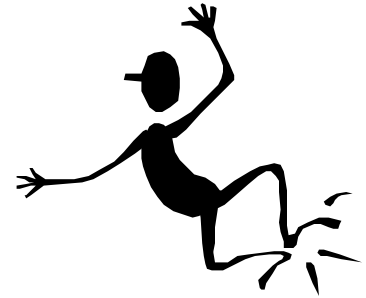
# The Dilemma

**Start with simple problems** to learn expert-like framework.



Success using novice framework.

**Why change?**



**Start with complex problems** so novice framework fails



Difficulty using new framework.

**Why change?**



# Why We Use Cooperative Group Problem Solving

1. Using a problem solving framework seems too long and complex for most students.

**Cooperative-group problem solving allows practice until the framework 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 framework 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

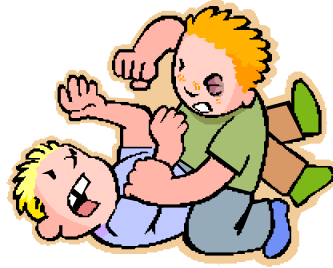
**Their answer or question has been validated by the others.**

# Cooperative Groups



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

# Why Group Problem Solving May Not Work

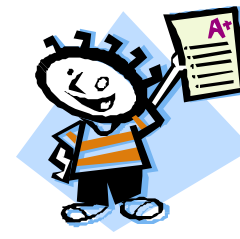


**1. Inappropriate Tasks**

**2. Inappropriate Grading**

**3. Poor structure and management of Groups**

**Curricular Elements Do Not Correspond  
to the Instructor's Beliefs or Values**



# Grading

**EVERYTHING WE WANT STUDENTS TO DO IS GRADED**

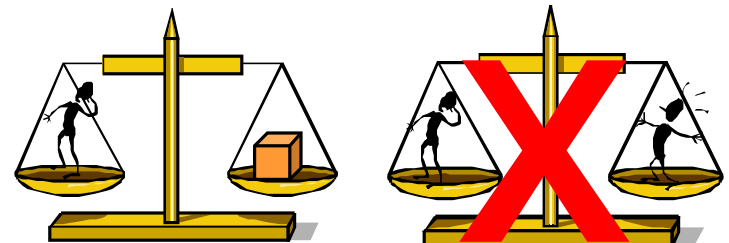
**“If you don’t grade it, they don’t learn it!”**

**We want students to present a logical, organized problem solving procedure using fundamental physics principles.**

- **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

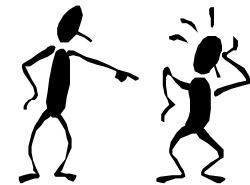
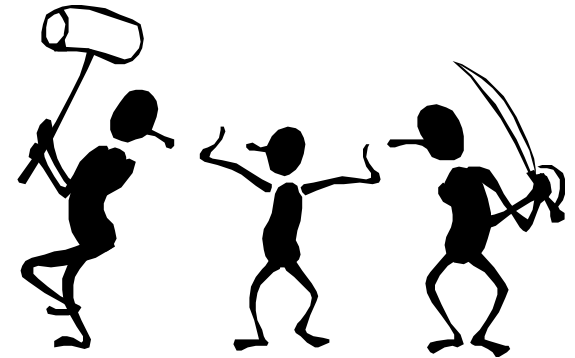




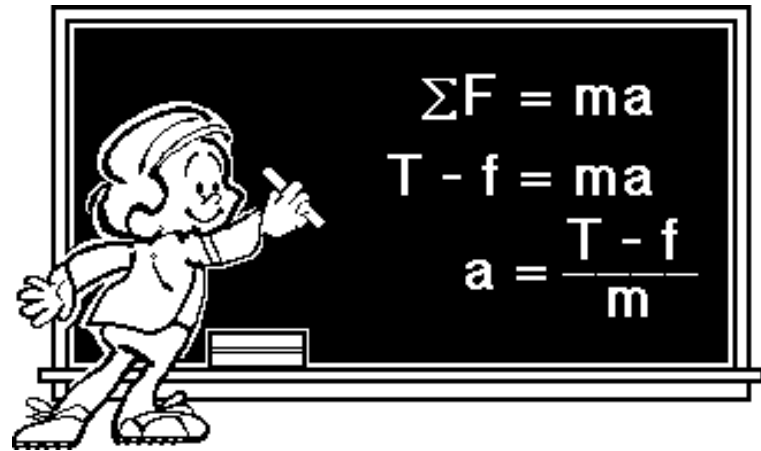
# Structure and Management of Groups

## 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.



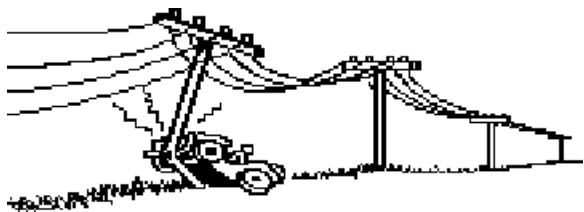


# Appropriate Tasks



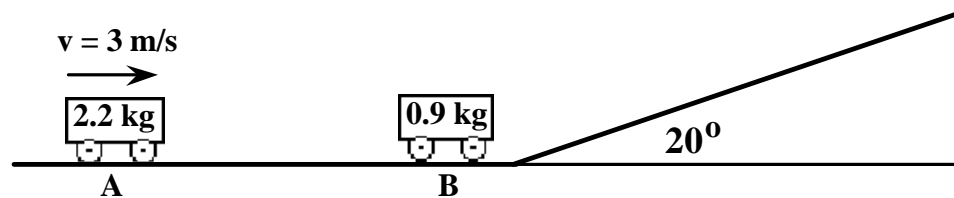
2. The task must be designed so that

- **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**.

# The Course as a System



Use strengths of components acting together

**Lectures** - 3 x 50 min. each week

(150 - 400 students)

**Model construction of knowledge**

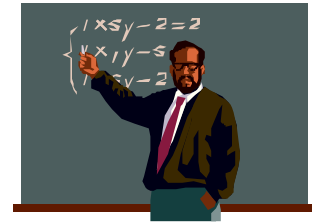
Explicit Storyline

Motivate all concepts

**Model problem solving**

A single explicit framework

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 framework as lecture

Same concepts as lecture



# The End

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for more information:**



**<http://groups.physics.umn.edu/physed/>**