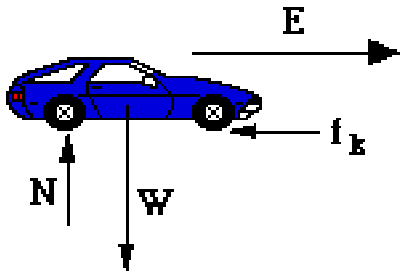
Teaching Physics Through Problem Solving



$$\sum F = ma$$

$$f_k = \mu N$$

$$W = mg$$

"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

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

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

Task

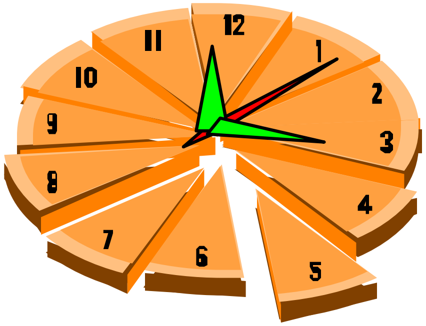
- Write down what you want from this presentation.

- 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

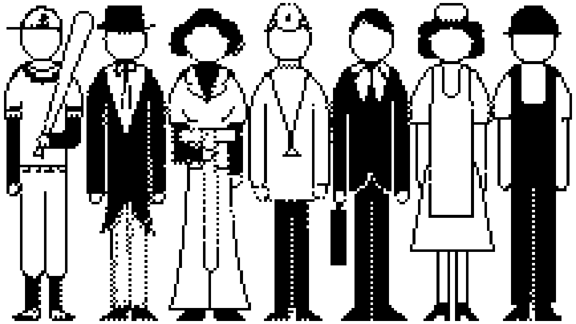


- ✓ **Who**
  - **are the Students**
- ✓ **What Is It**
  - **Course structure**
- ✓ **What**
  - **are Problems**
  - **is Problem Solving**
- ✓ **How**
  - **to Teach It**
- ✓ **Does It Work**
  - **Data**

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

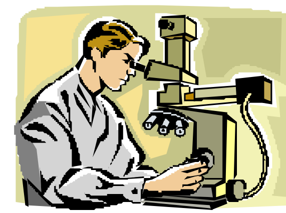
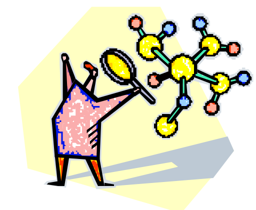
30% junior

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%

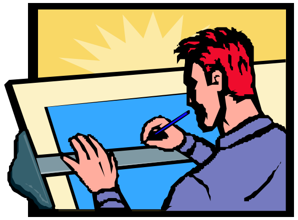
Freshman	7%
Sophomore	38%
Junior	19%
Senior	17%

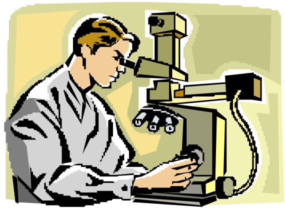
Male	39%
Female	61%

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	
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

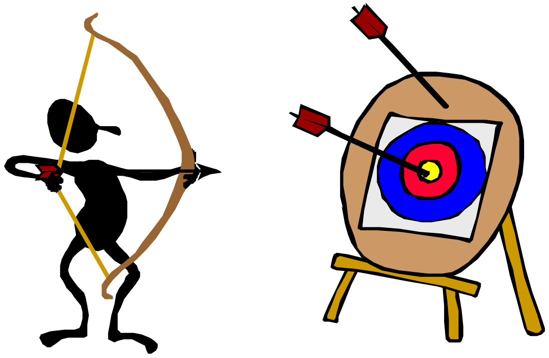
5 minutes

PROCEDURES

Form a group of 3 people
Choose one person as a recorder

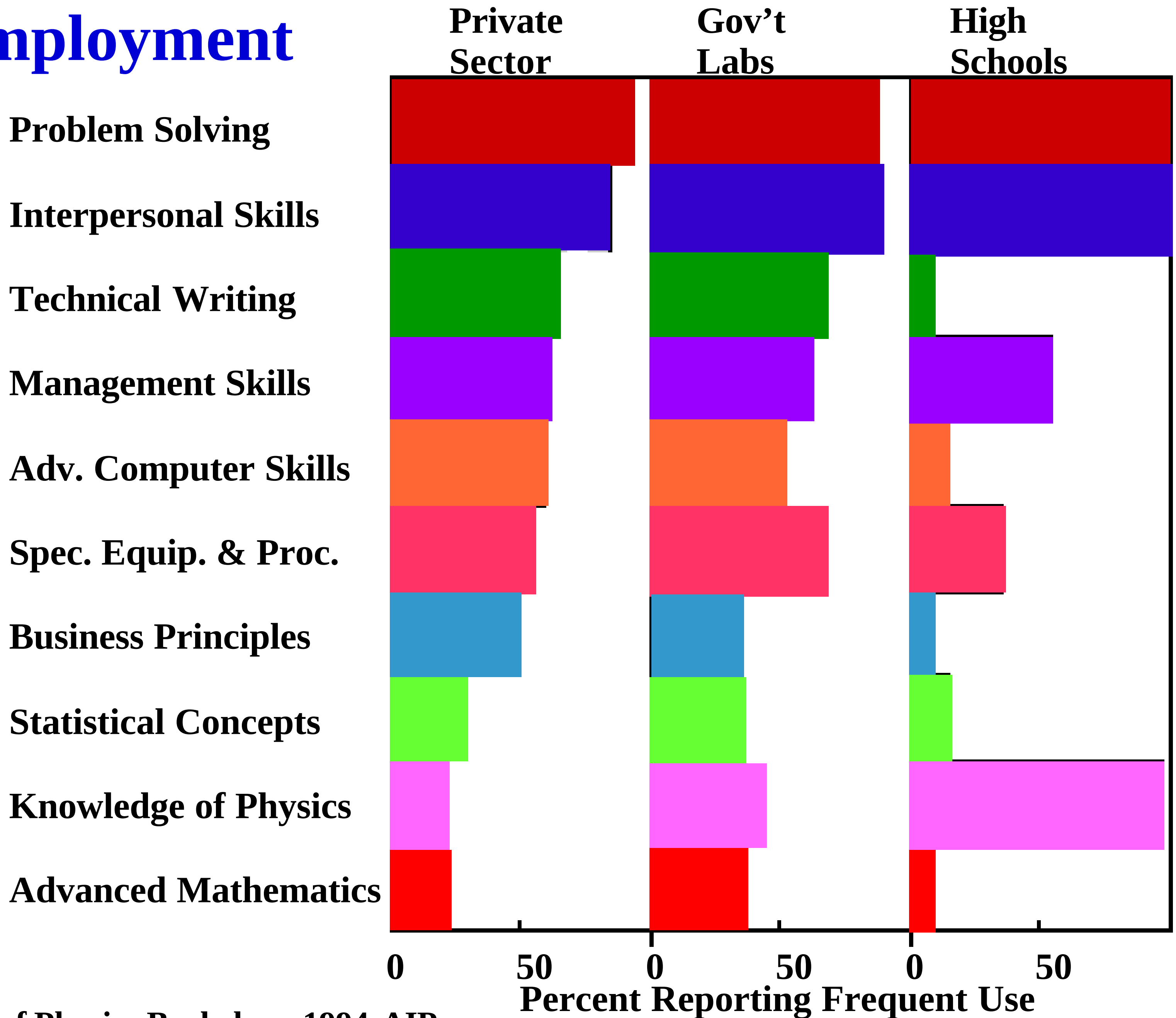
Formulate **a response individually.**
Discuss **your response with your partners.**
Listen **to your partners' responses.**
Create **a new group response through discussion.**

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

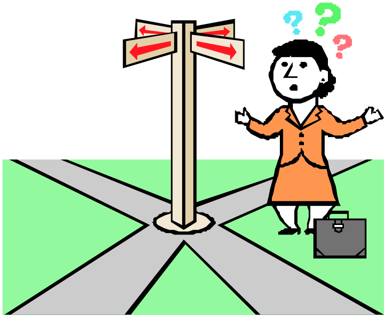
Exercise vs Problem

M. Martinez, Phi Delta Kappan, April, 1998

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)

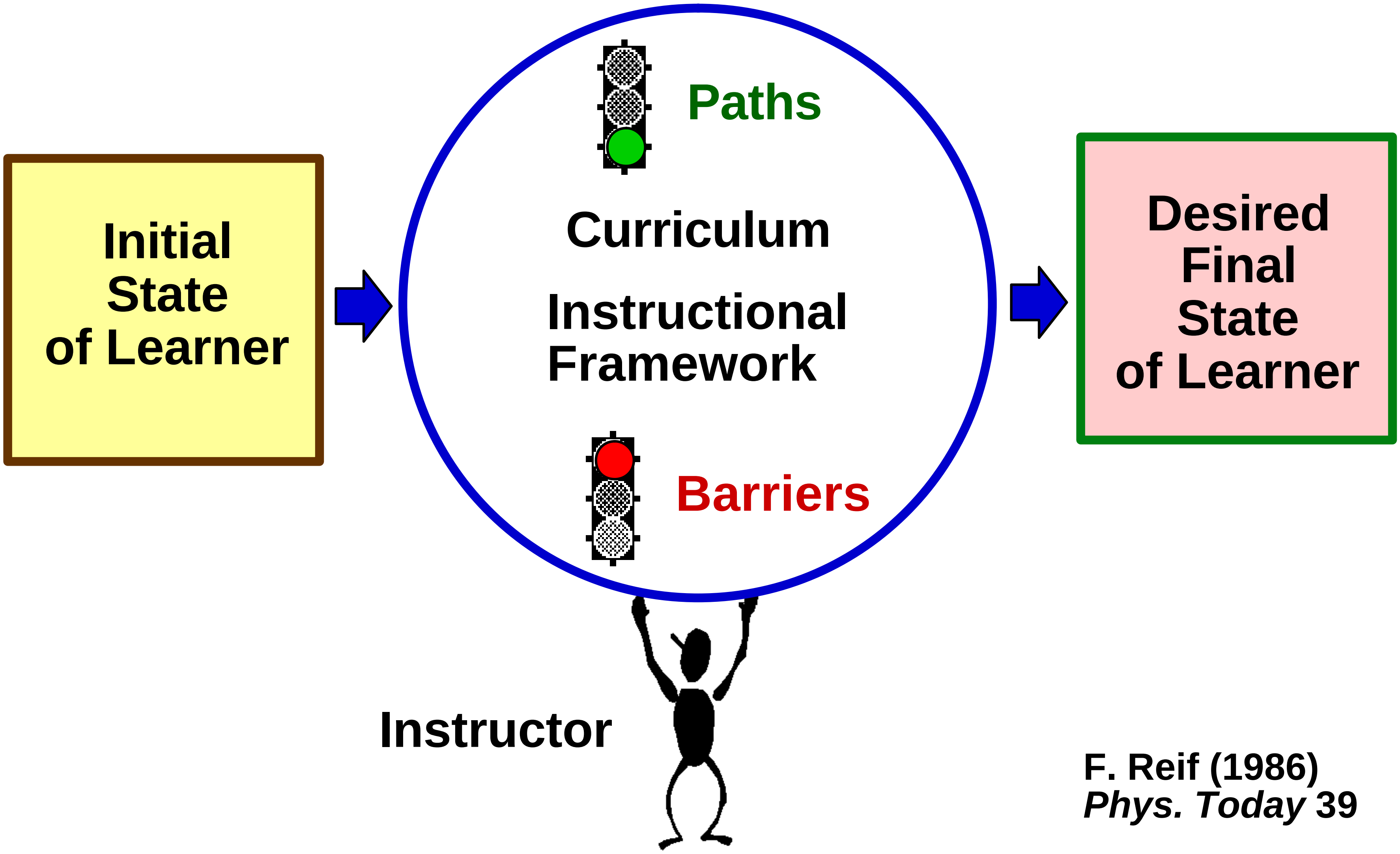
- **Means - Ends Analysis (identifying goals and subgoals)**
- **Working Backwards (step by step planning from desired result)**
- **Successive Approximations (idealization, approximation, evaluation)**
- **External Representations (pictures, diagrams, mathematics)**
- **General Principles of Physics**

M. Martinez, Phi Delta Kappan, April, 1998

Procedure for Change

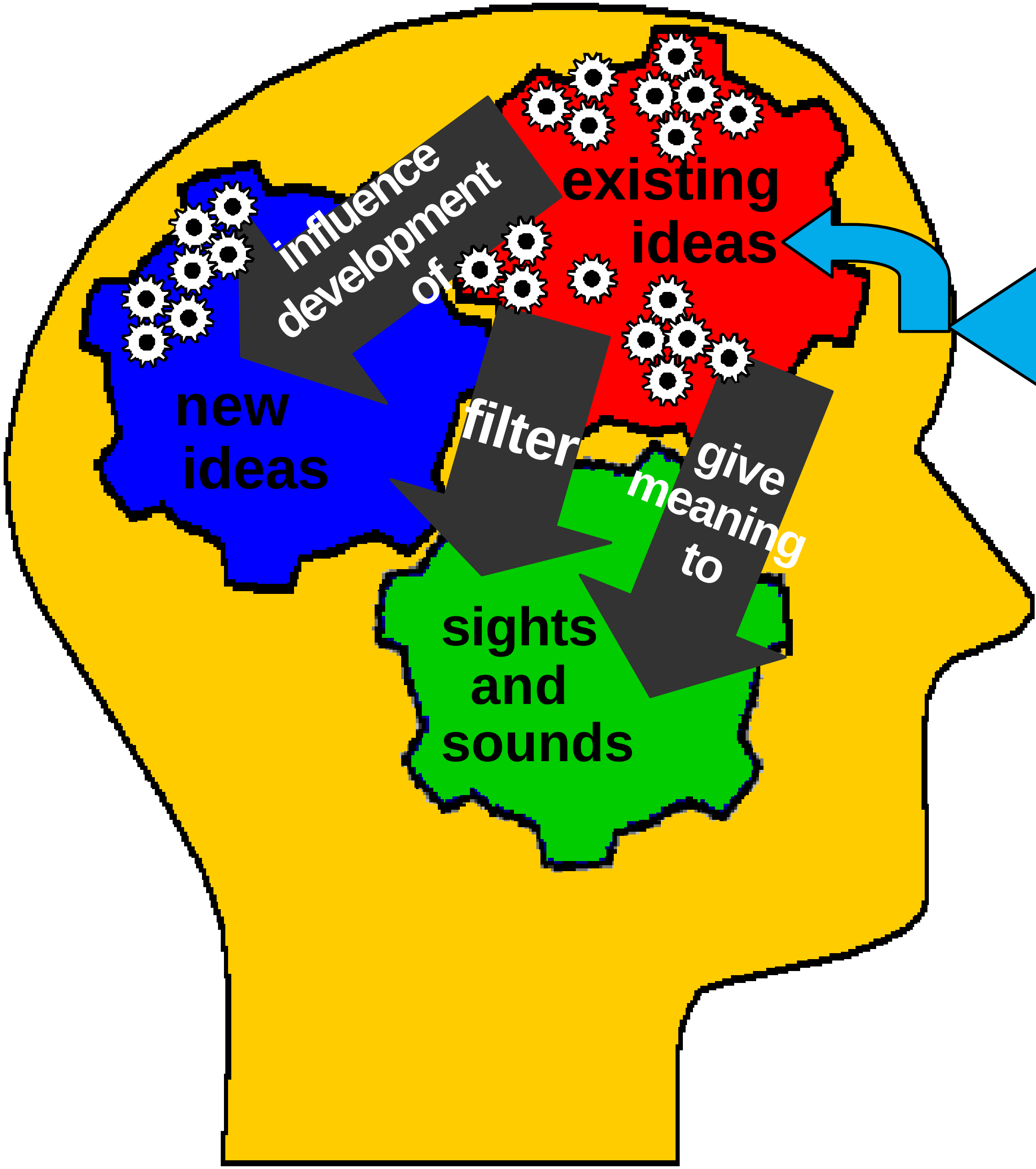
<final | T | initial>

Transformation Process



F. Reif (1986)
Phys. Today 39

Cognitive Apprenticeship Instruction



Learning in the environment of expert practice

model

coach

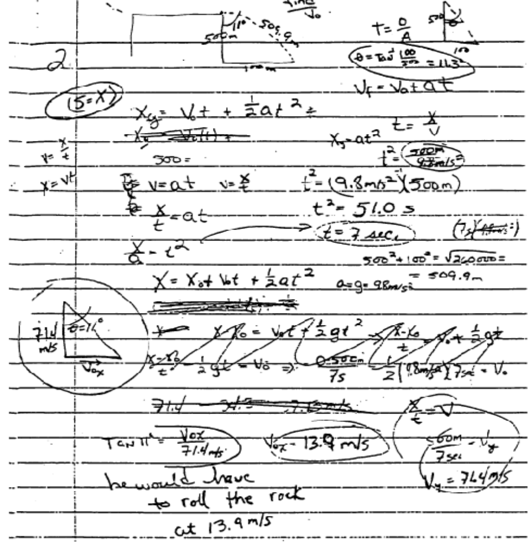
fade

Collins, Brown, & Newman (1990)

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



2

$x_y = V_i t + \frac{1}{2} a t^2$

$V_f = V_0 + at$

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

$X_y = at^2$

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

$t^2 = 51.0\,s$

$t = 7\,sec.$

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

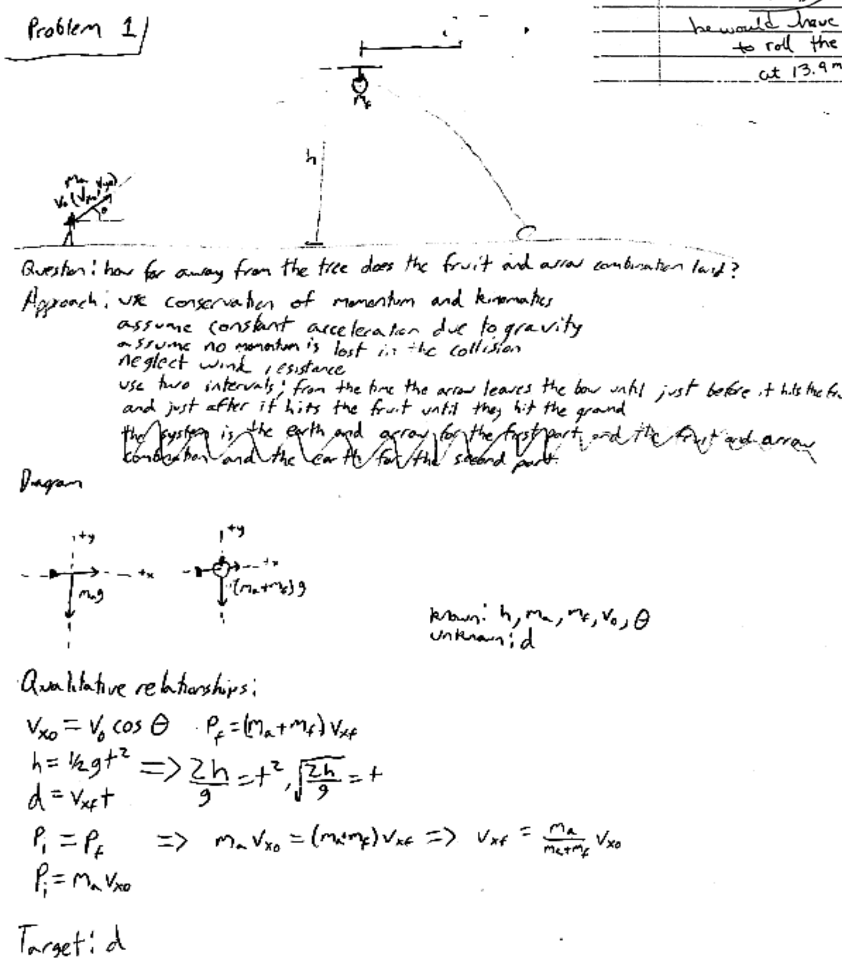
$X = X_0 + V_0 t + \frac{1}{2} a t^2$ $a = g = 9.8\,m/s^2$

$\tan 11° = \frac{V_{ox}}{71.4\,m/s}$ $V_{ox} = 13.9\,m/s$

$\frac{500\,m}{7\,sec} = V_y$ $V_y = 71.4\,m/s$

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

Diagram

known: h, m_a, m_f, v_0, θ

unknown: d

Qualitative relationships:

$V_{xo} = V_0 \cos\theta$ $P_f = (m_a + m_f) V_{xf}$

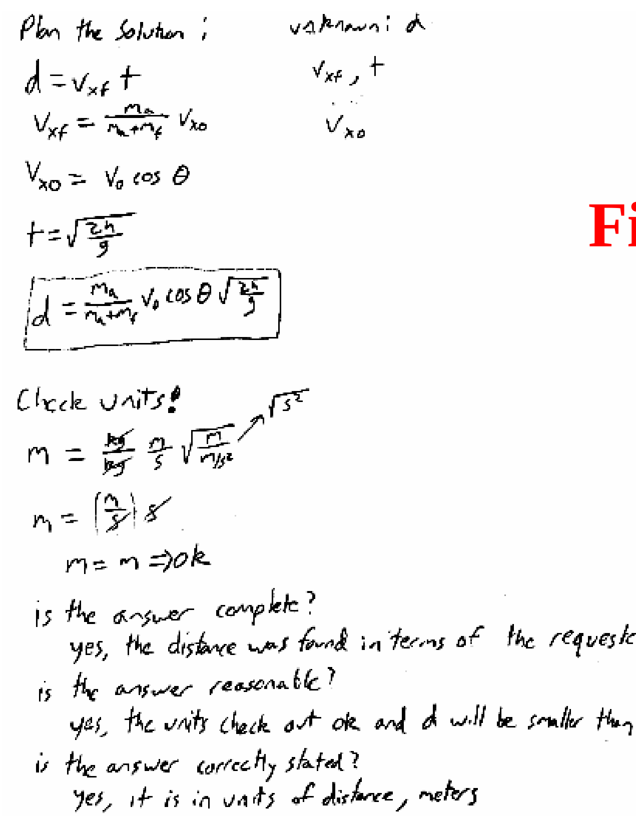
$h = \frac{1}{2} g t^2 \Rightarrow \frac{2h}{g} = t^2, \sqrt{\frac{2h}{g}} = t$

$d = V_{xf} t$

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

$P_i = m_a V_{xo}$

Target: d



Plan the Solution:

unknown: d

V_{xf}, t

V_{xo}

$d = V_{xf} t$

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

$V_{xo} = V_0 \cos\theta$

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

$d = \frac{m_a}{m_a + m_f} V_0 \cos\theta \sqrt{\frac{2h}{g}}$

Check units!

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

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

$m = m \Rightarrow ok$

is the answer complete?

yes, the distance was found in terms of the requested values

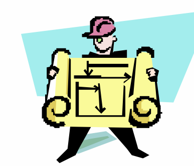
is the answer reasonable?

yes, the units check out ok and d will be smaller than h due to conservation of momentum

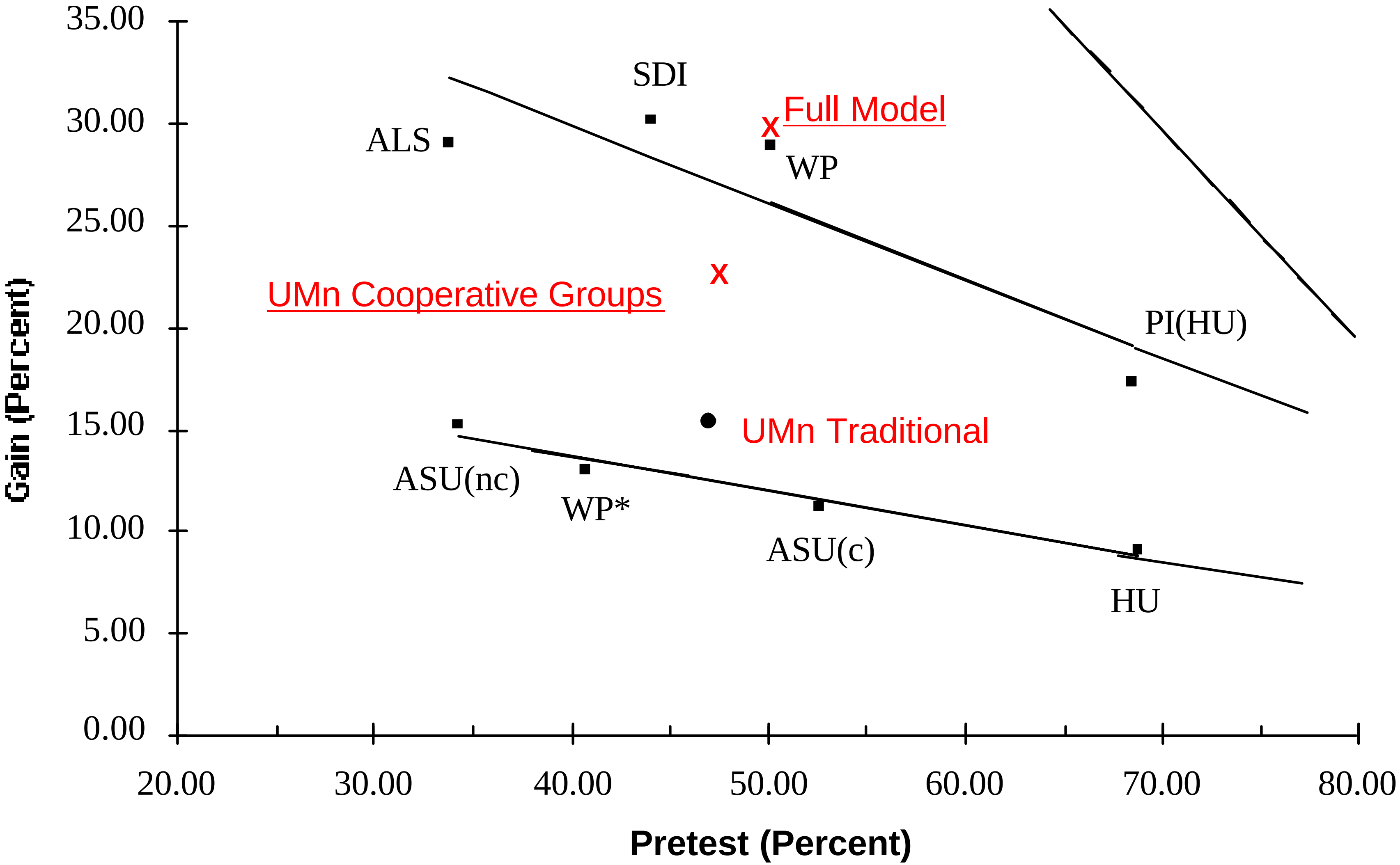
is the answer correctly stated?

yes, it is in units of distance, meters

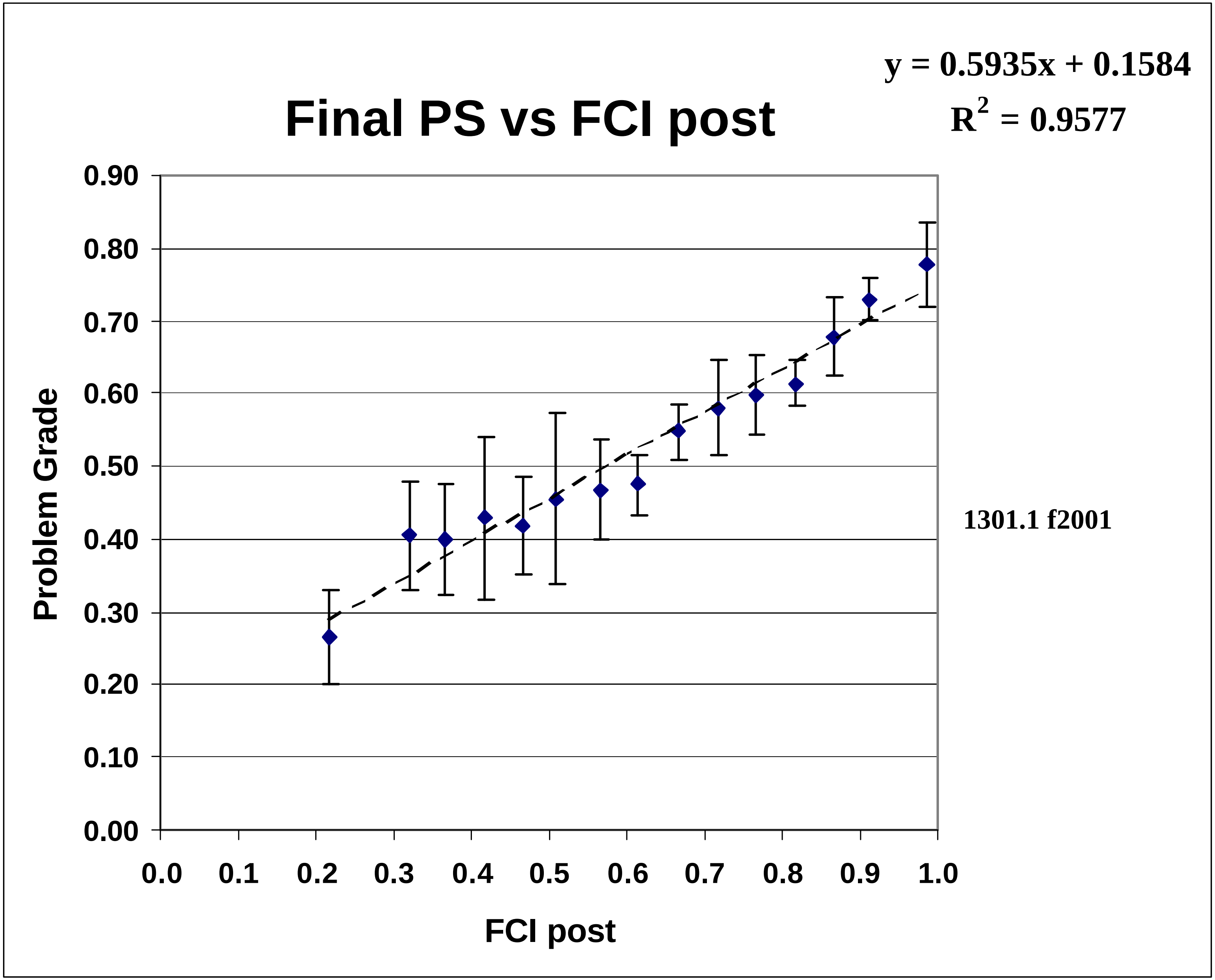
Final State



Gain on FCI



35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Gain (Percent)
SDI
ALS
Full Model
X
WP
X
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)


Final PS vs FCI post
y = 0.5935x + 0.1584
R^2 = 0.9577
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

Initial State of the Learner

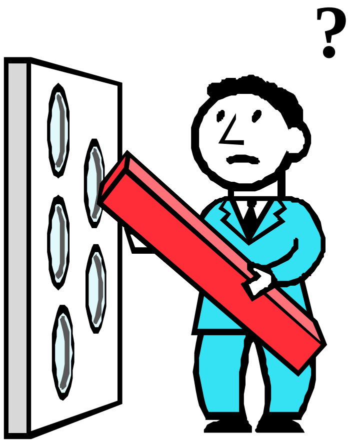
Students have Misconceptions about

The Field of Physics

Learning Physics

Nature

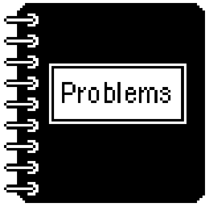
Problem-solving



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

$$\sum F = ma$$

$$T - f = ma$$

$$a = \frac{T - f}{m}$$

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?

- ✓ 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 6.0×10^{-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.

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.

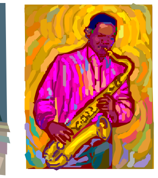
Which motivated you to practice the most elements of expert problem solving?

Textbook Problem

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

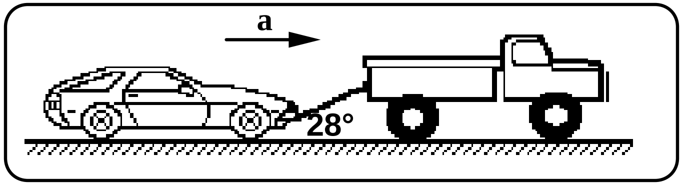
Can this be true?

Competent Problem Solving

Step	Bridge

1. **Focus** on the Problem

Translate the words into an image of the situation.

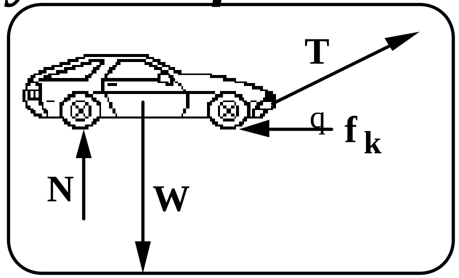


Identify an approach to the problem.

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).

$$\sum F = ma$$

$$f_k = \mu N$$

$$W = mg$$

3. **Plan** a Solution

Step **Bridge**

3. Plan a Solution

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

Find a:

$[1] \quad \sum F_x = m a_x$

Find $\sum F_x$:

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

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.

$$T_x - f_k = m a_x$$

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

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

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

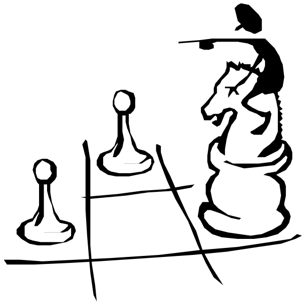
Appropriate Problems for Practicing Problem Solving

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.





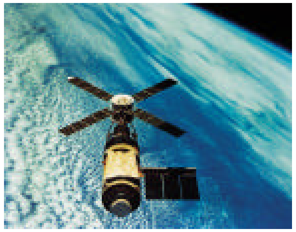
2. The problems must be designed so that

   • 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.

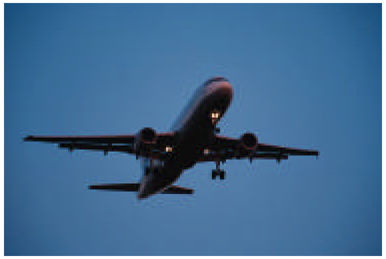




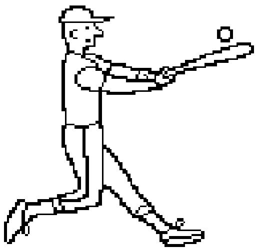
3. The task problem must connect to each student's mental processes

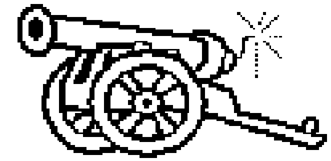
• the situation is real to the student so other information is connected;

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

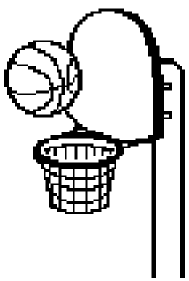


Context-rich Problems

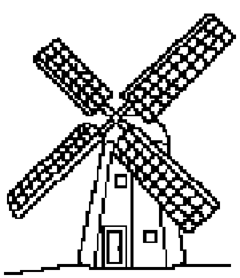


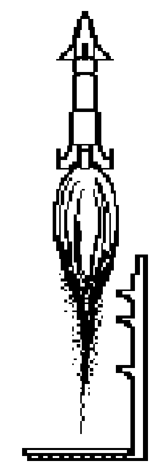


- **Each problem is a short story in which the major character is the student. That is, each problem statement uses the personal pronoun "you."**



- **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.**





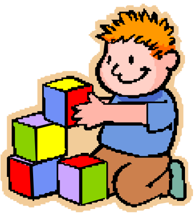
- **No pictures or diagrams are given with the problems. Students must visualize the situation by using their own experiences.**
- **The problem can not be solved in one step by plugging numbers into a formula.**

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)

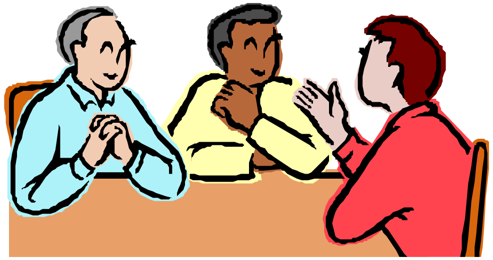
4. Students practice the language of physics -- "talking physics."

5. Students must deal with and resolve their misconceptions.

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

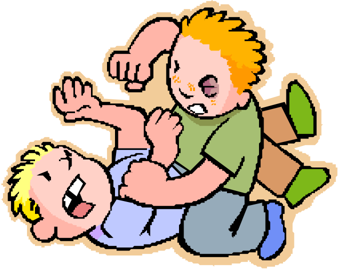
Their answer or question has been validated by the others.

Cooperative Groups



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

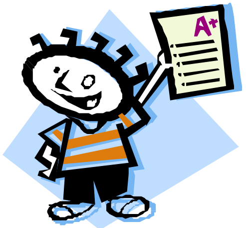
Why Group Problem Solving May Not Work



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

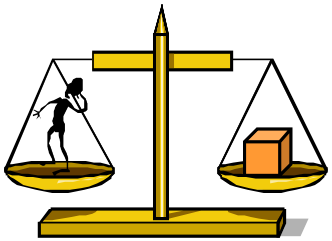
"If you don't grade it, they don't learn it!"

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

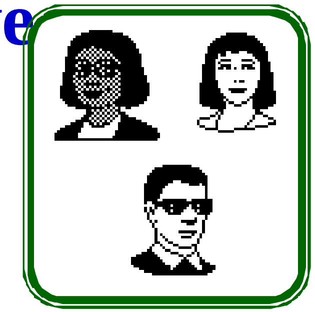
"If you win, I do NOT lose."



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 form bottom third

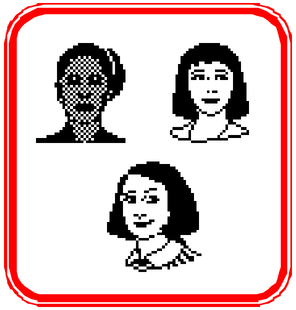
     based on past test performance.

Structure and Management of Groups

3. **How often should the groups be changed?**

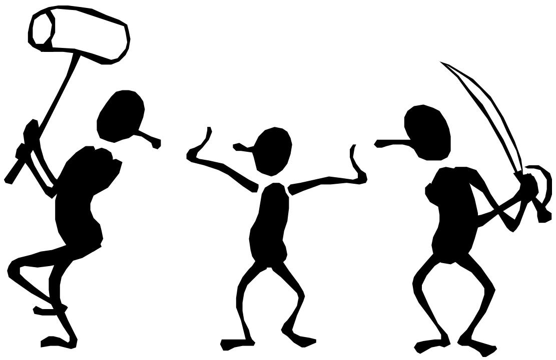
For most groups:

- **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**

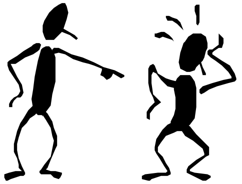


Structure and Management of Groups

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

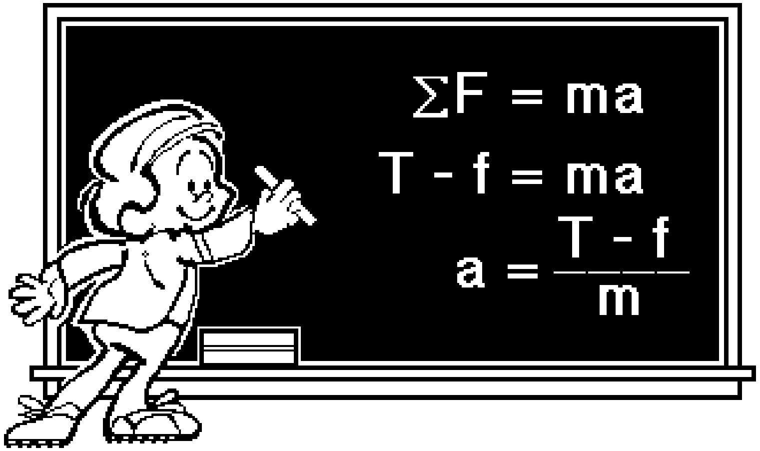


- Group problems are part of each test. One common solution that all members sign.
- Assign and rotate roles:
  - Manager
  - Skeptic
  - Checker/Recorder
  - Summarizer



- 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?

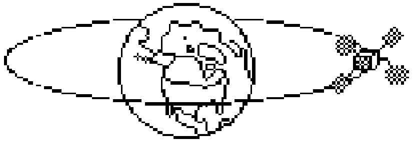
- assign and rotate roles, group functioning;
- seat arrangement -- eye-to-eye, knee-to-knee;
- individual students randomly called on to present group results;
- occasionally a group problem counts as a test question --if group member was absent the week before, he or she cannot take group test;
- each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

Appropriate Tasks

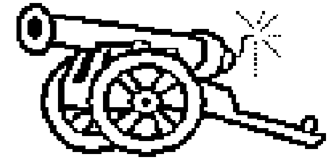
The problems must be challenging enough so there is a *real* advantage to working in a group.

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

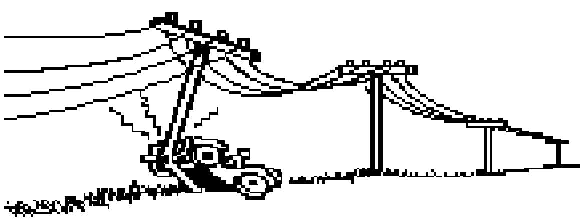


2. **The task must be designed so that**

• 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.

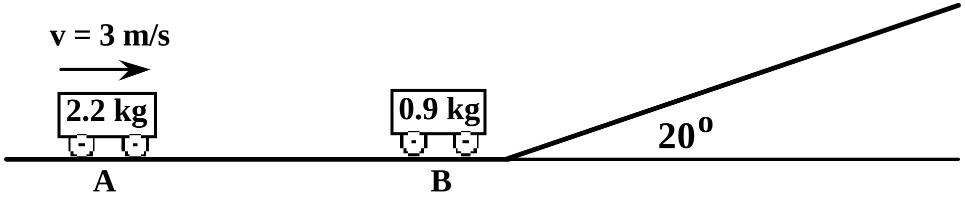


Figure 8.3

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

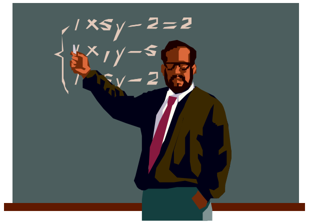
Use strengths of components acting together

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

Please visit our website for more information:

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