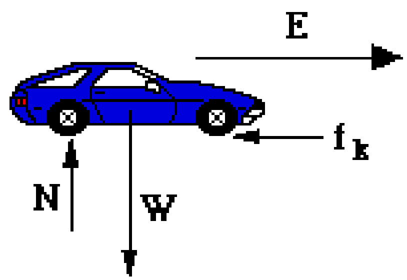
How to Help Your Students Develop Expertise in Problem Solving – While Learning Physics



$$\sum F = ma$$

$$f_k = \mu N$$

$$W = mg$$

"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, grad students, post docs

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**
  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.**

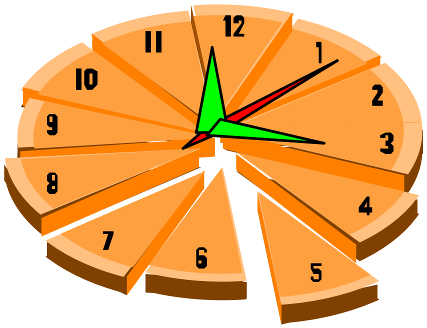
From the Groups – Session 1

What is a problem solving skill?
Instructive examples of what problems students have with problems
How do you differentiate between problem solving with critical thinking and plug and chug
How does one teach problem solving in a concept based course
How do I make my students understand the problem
What is the most efficient route in problem solving
Instructional strategy. For modeling problem solving
If you have explained a problem where do you go from there
How do you reconcile understanding the concept but not solving the problem with solving the problem and not understanding the concept.

From the Groups – Session 1

How much classroom time and what techniques
Get students to use numerical problem solving which emphasizing concepts
Diverse student backgrounds wrt math background
Problem solving in groups
Teach order of magnitude estimates
Do the algebra first
How to convince students to practice
Can you do it?
Help students identify the main point of the problem
Get students to struggle and say what they are confused about
How to make students independent, check answers are reasonable
Tell students how to solve complex multistep problems
How to get students to step back, analyze (read) the problem and develop a strategy to solve it.

Cooperative Problem Solving
A Guide for Discussion

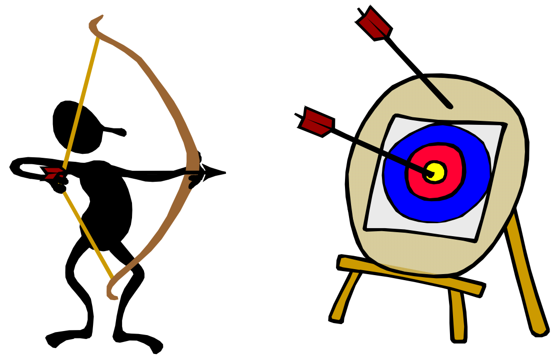


1. **Why is problem solving important?**
2. **What are problems?**
3. **How to teach problem solving?**
   1. **Course structure**
   2. **Student difficulties**
   3. **Useful problems**
   4. **Logical framework**
   5. **Cooperative groups**
4. **Does It Work**

   Concepts

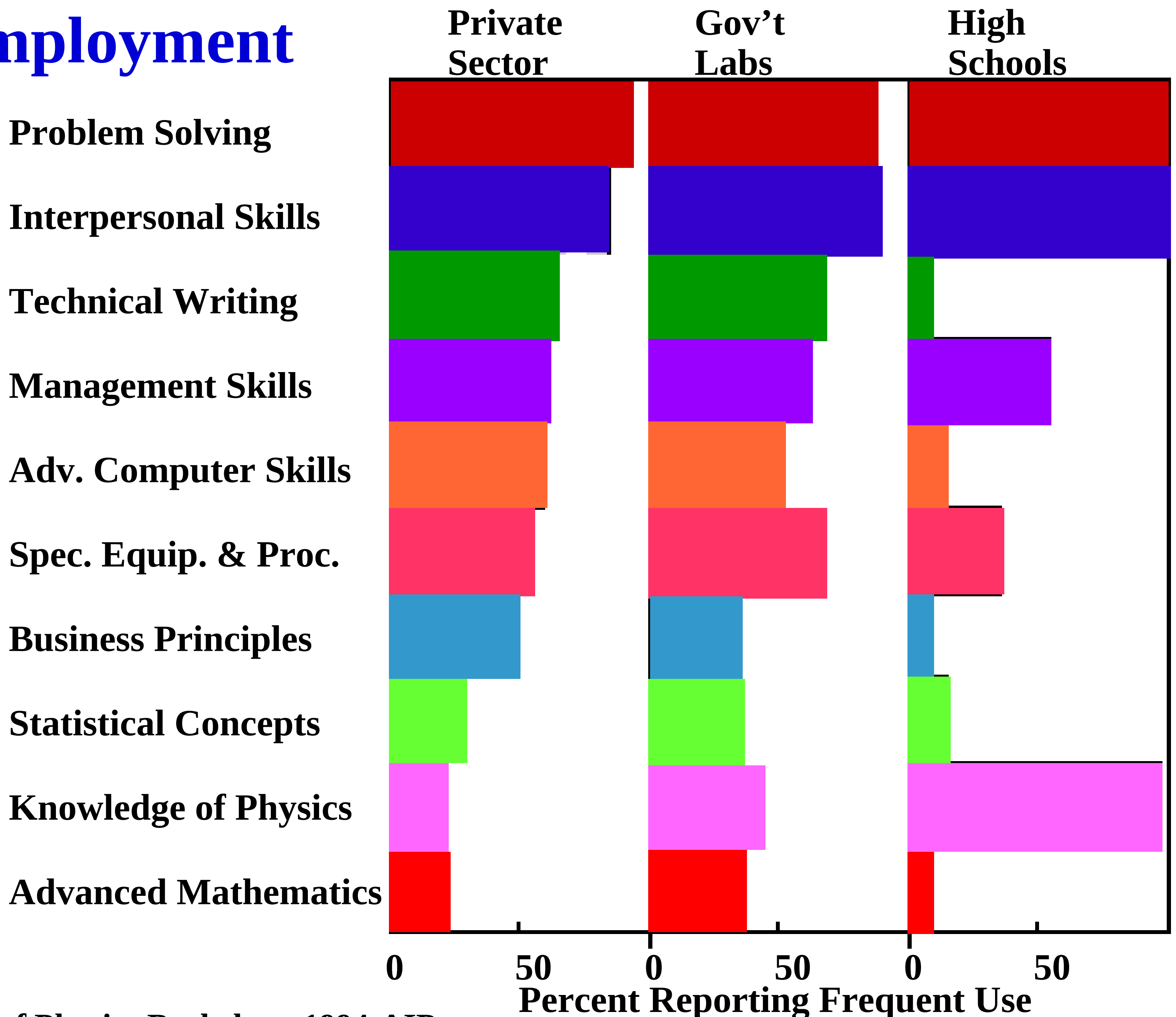
   Problem solving

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*** ←

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 general purpose tools

Heuristics

Not specific 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

Metacognition – Reflecting on Your Own Thought Process

- **Managing time and direction**
- **Determining next step**
- **Monitoring understanding**
- **Asking skeptical questions**

Some General Tools (Heuristics)

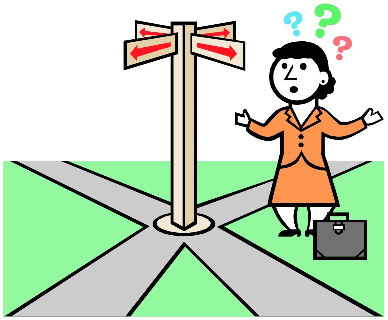
- **Means - Ends Analysis (identifying goals and subgoals)**
- **Working Backwards (step by step planning from desired result)**
- **Successive Approximations (idealization, approximation, evaluation)**
- **External Representations (pictures, diagrams, mathematics)**
- **General Principles of Physics**

M. Martinez, Phi Delta Kappan, April, 1998

Solving Problems Requires Conceptual Knowledge:

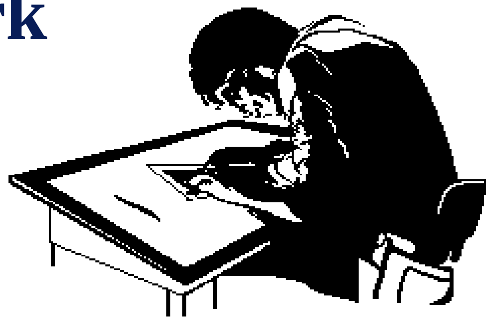
Making Decisions within an organized Framework

- **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*

Student Difficulties Solving Problems



- Lack of an Organizational Framework
- Physics Misknowledge
  - Incomplete (lack of a concept)
  - Misunderstanding (weak misknowledge)
  - Misconceptions (strong misknowledge)
- No Understanding of Range of Applicability – Mathematics & Physics
  - Always True
  - True under a broad range of well-defined circumstances
  - True in very special cases
  - True in this situation

The "Clear Explanation" Misconception

Commonly held by Faculty, TAs, Students, & Administrators

Instructor pours knowledge into students.

Little knowledge is retained.

Student's Fault

Impedance mismatch between student and instructor.

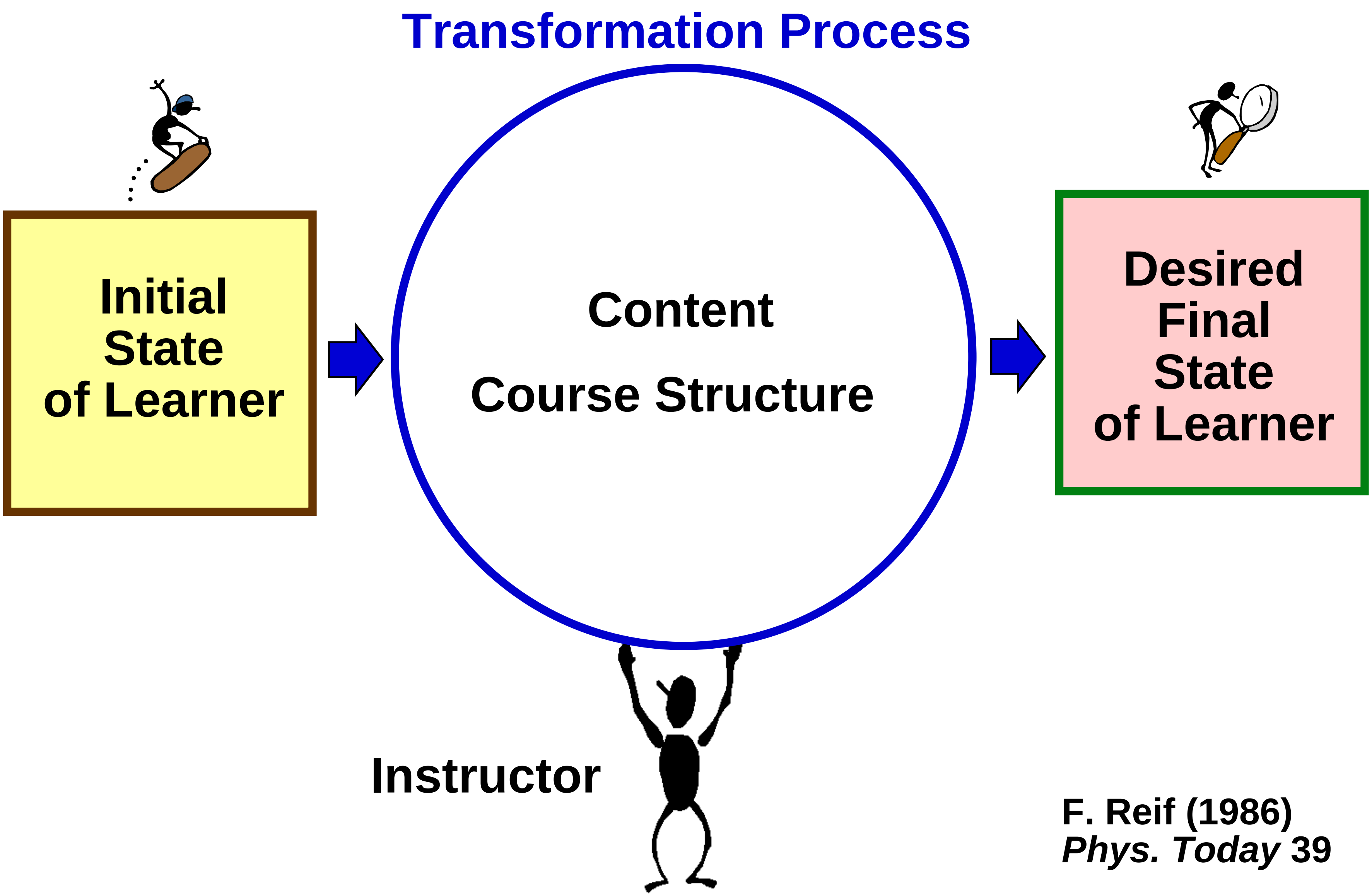
Instructor's Fault

Learning is more complicated

Leonard et. al. (1999). Concept-Based Problem Solving.

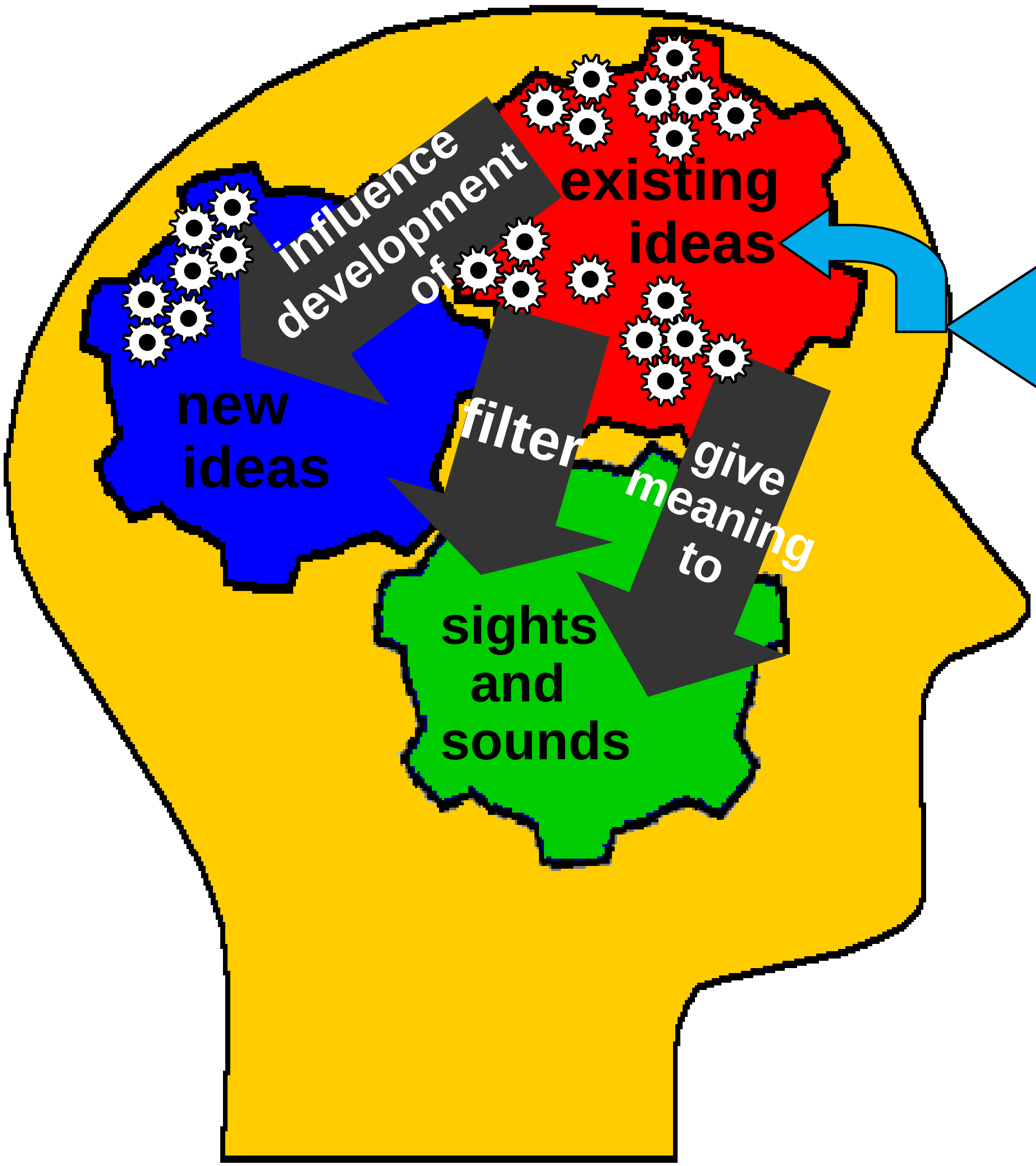
The Teaching Process – A Physicist View

<final | T | initial>



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

Cognitive Apprenticeship Instruction



Learning in the environment of expert practice

model

coach

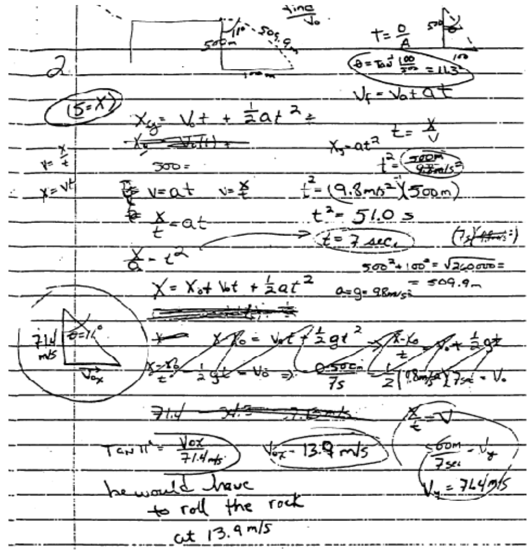
fade

Collins, Brown, & Newman (1990)

Our 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 three weeks.**

Student Problem Solutions


$V_f = V_0 + at$

$X_y = V_t + \frac{1}{2}at^2$

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

$t^2 = 51.0 s$

$t = 7 sec.$

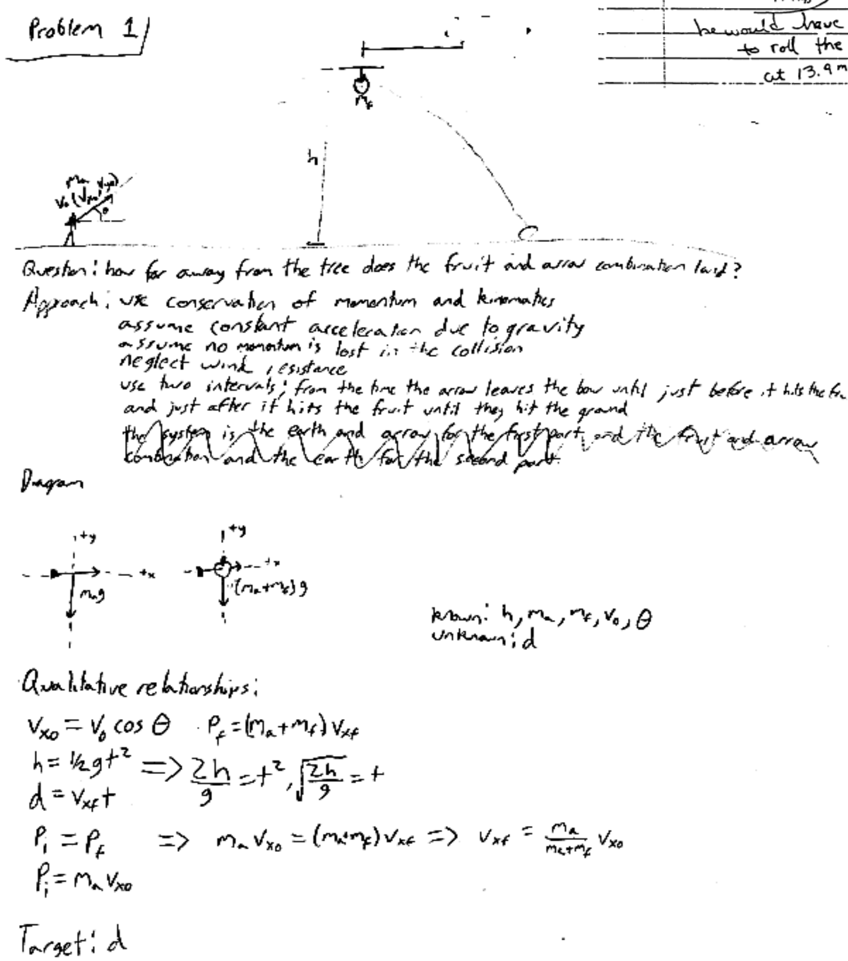
$X = X_0 + V_0 t + \frac{1}{2}at^2$

$V_{0x} = 13.9 m/s$

$V_y = 71.4 m/s$

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 fr[uit] 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:

$V_{x0} = V_0 \cos\theta \quad P_f = (m_a + m_f)V_{xf}$

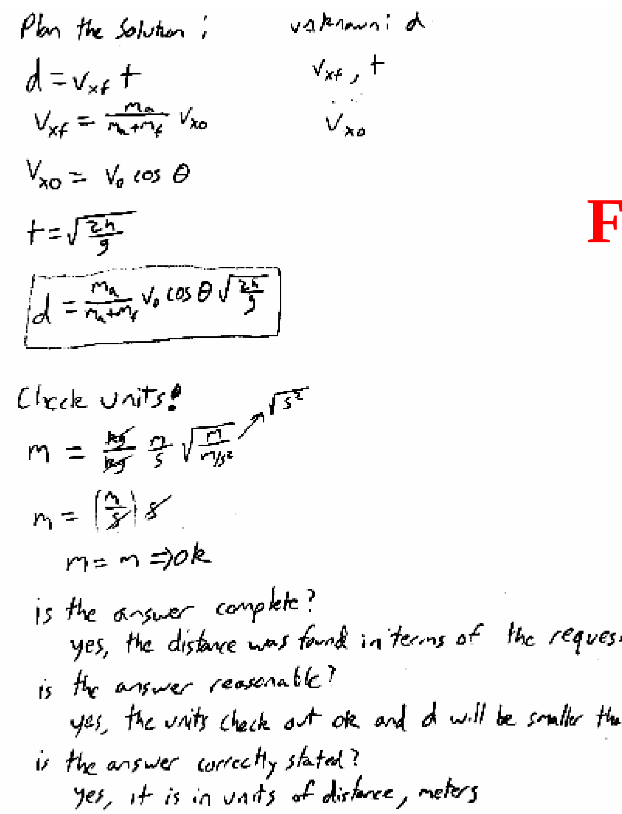
$h = \frac{1}{2}gt^2 \Rightarrow \frac{2h}{g} = t^2, \sqrt{\frac{2h}{g}} = t$

$d = V_{xf}t$

$P_i = P_f \Rightarrow m_a V_{x0} = (m_a + m_f)V_{xf} \Rightarrow V_{xf} = \frac{m_a}{m_a + m_f}V_{x0}$

$P_i = m_a V_{x0}$

Target: d


Plan the Solution:

unknown: d

$d = V_{xf}t$ — V_{xf}, t

$V_{xf} = \frac{m_a}{m_a + m_f}V_{x0}$ — 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!

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

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

$m = m \Rightarrow ok$

is the answer complete?

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

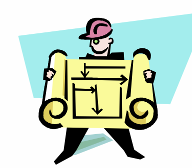
is the answer reasonable?

yes, the units check out ok and d will be smaller than h due to conservation of moment[um]

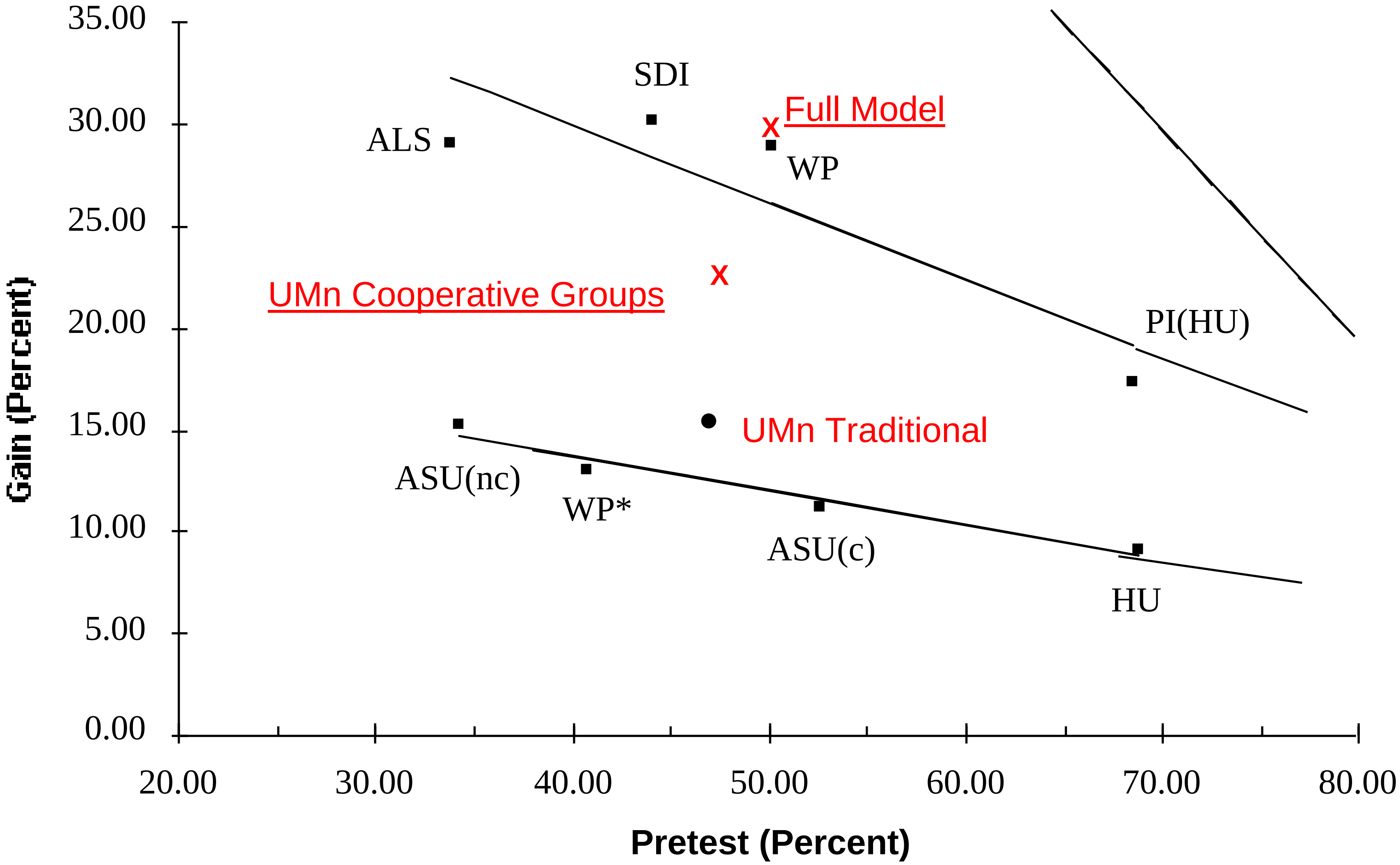
is the answer correctly stated?

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)
20.00
30.00
40.00
50.00
60.00
70.00
80.00
Pretest (Percent)
SDI
ALS
Full Model
X
WP
X
UMn Cooperative Groups
PI(HU)
UMn Traditional
ASU(nc)
WP*
ASU(c)
HU

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?**

A Complex Process

The procedure is quite simple. First you arrange them into different groups. Of course, one group may be sufficient depending on how much there is to do. You may have to go somewhere else due to lack of facilities.

Next you actually accomplish your goal. But a mistake can be costly. It is important not to overdo things. It is usually better to do too few things than too many. This is especially important when issues of compatibility arise. At first, the whole procedure might seem complicated since timing can be crucial. In the immediate future it is unlikely that the need for this process will diminish.

After the procedure is completed, one forms different groups again. Then things can be put into their appropriate places. Every so often the whole cycle will then need to be repeated. However, that is a part of life.

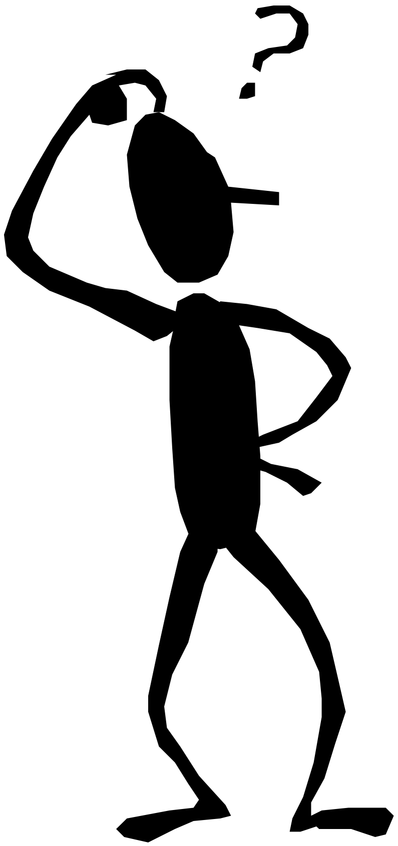
Answer the following questions.

1. **What is the process being discussed?**
2. **What facilities are needed?**
3. **What are some compatibility issues?**
4. **Why is it important to form groups?**

Laundry

Textbook Problem

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?**

Beginning Context-Rich Problem

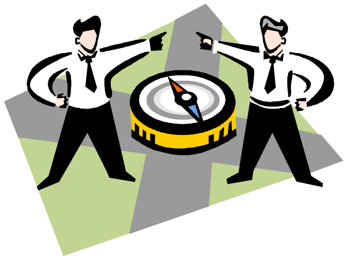
You have a summer job with an insurance company and are helping to investigate a tragic "accident." At the scene, you see a road running straight down a hill that is at 10° to the horizontal. At the bottom of the hill, the road widens into a small, level parking lot overlooking a cliff. The cliff has a vertical drop of 400 feet to the horizontal ground below where a car is wrecked 30 feet from the base of the cliff. A witness claims that the car was parked on the hill and began coasting down the road, taking about 3 seconds to get down the hill. Your boss drops a stone from the edge of the cliff and, from the sound of it hitting the ground below, determines that it takes 5.0 seconds to fall to the bottom. 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. Obviously, your boss suspects foul play.

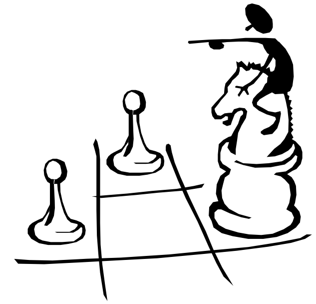
Appropriate Problems for Practicing Problem Solving

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.**

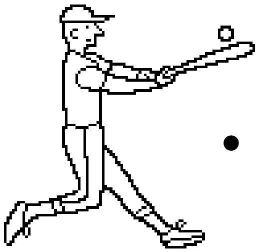


3. The task problem must connect to each student’s mental processes

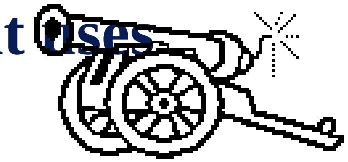
   • the situation is real to the student so other information is connected;

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

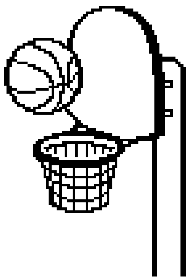
Context-rich Problems



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

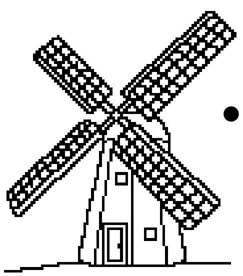


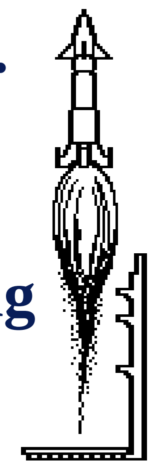
- Some decisions are necessary to proceed.



- 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) – students must practice idealization.
- No pictures or diagrams are given with the problems. Students must visualize the situation by using their own experiences.





- The problem can not be solved in one step by plugging numbers into a formula.

Context-rich Problems

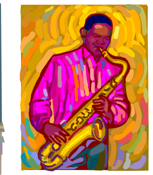
In addition, more difficult context-rich problems can have one or more of the following characteristics:

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

Problem-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

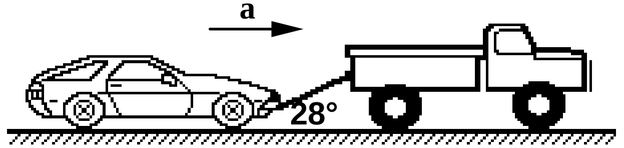
Can this be true?

Competent Problem Solving

Step | **Bridge**

1. **Focus** on the Problem

Translate the words into an image of the situation.

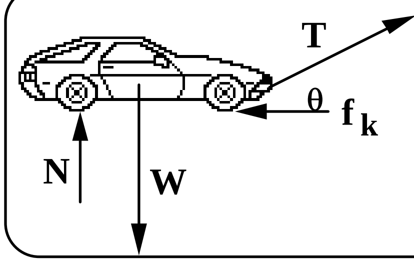


Identify an approach to the problem.

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] $\sum F_x = ma_x$

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.

$$T_x - f_k = ma_x$$

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

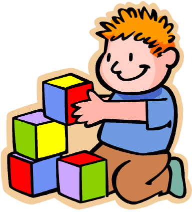
$$\frac{gT}{W}(\cos\theta - \mu\sin\theta) - \mu g = a_x$$

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

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 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 Use Cooperative Group Problem Solving

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

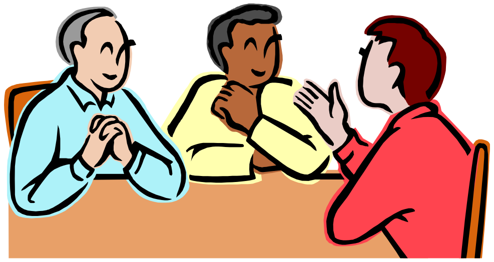
4. Students practice the language of physics -- "talking physics."

5. Students must deal with and resolve their misconceptions.

6. Coaching by instructors is more effective

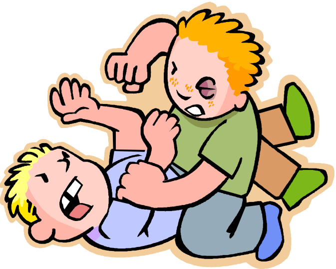
   External clues of group difficulties
   Group processing of instructor input

Cooperative Groups



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

Why Group Problem Solving May Not Work

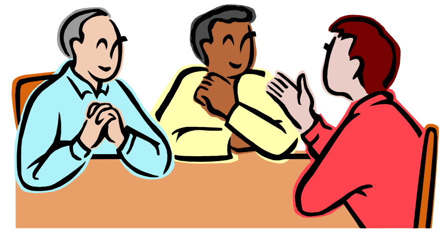


1. Inappropriate Tasks
2. Inappropriate Grading
3. Poor structure and management of Groups

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

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?**

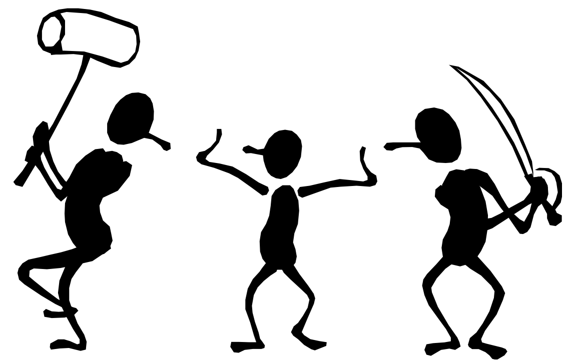
For most groups:

- **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**

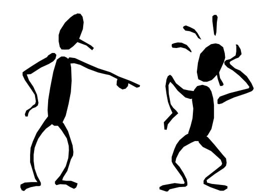
Structure and Management of Groups

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

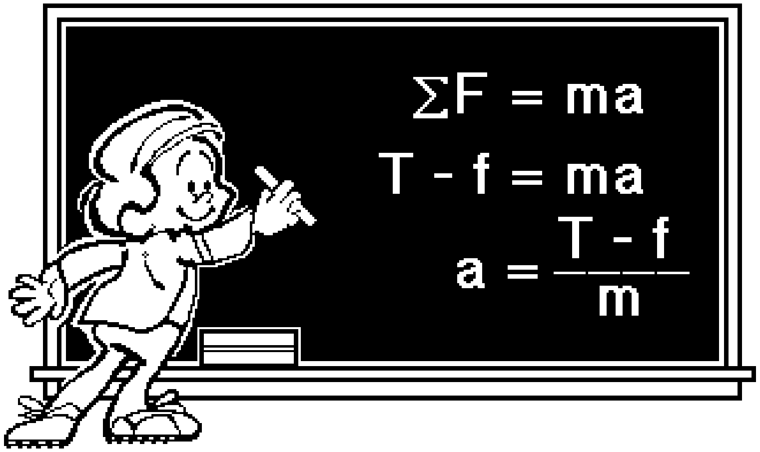


- Most of grade is based on individual problem solving.



- 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.

The End

Please visit our website for more information:

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