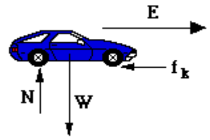
Teaching Introductory Physics Through Problem Solving

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



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

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

Pat Heller, Leon Hsu, Vince Kuo – University of Minnesota
Charles Henderson– Western Michigan University
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Laura McCullough – University of Wisconsin, Stout
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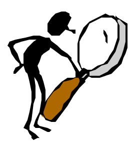
Jennifer Blue – Miami University, Ohio
Mark Hollabaugh -Normandale Community College
Ron Keith – Emporia State University

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

Supported in part by NSF, FIPSE and the University of Minnesota 1



Research Based Curriculum and Assessment

Details and discussion in the workshop

Goals

- Why Solve Problems?
- What are Problems?
- Experts and Novices

Students

- Skills & Misconceptions

Teaching Problem Solving?

- Instructional Framework
- Supporting Problem Solving

Instructors

- Beliefs & Values

How Well Does It Work

- Data

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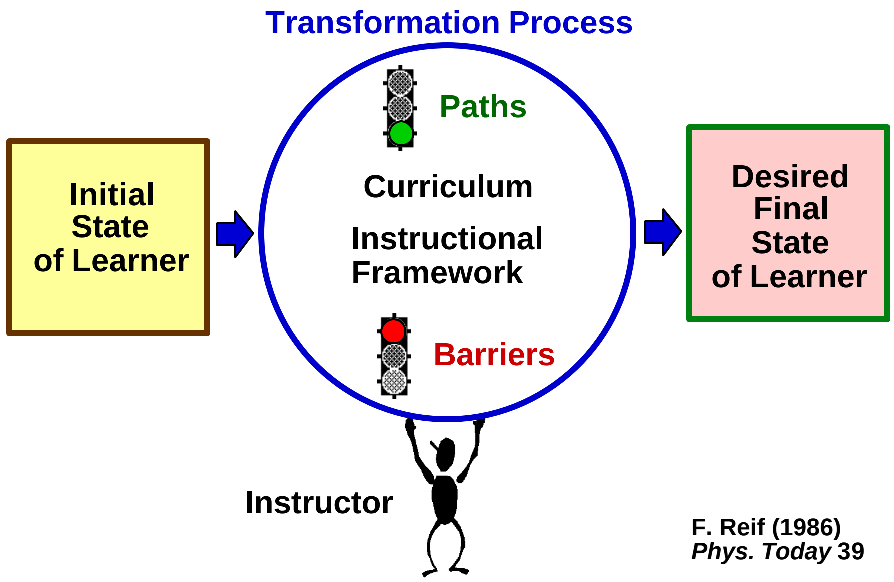
Research Based Curriculum



F. Reif (1986)
Phys. Today 39

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Why Teach Students to Solve Problems?

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

What is IT?

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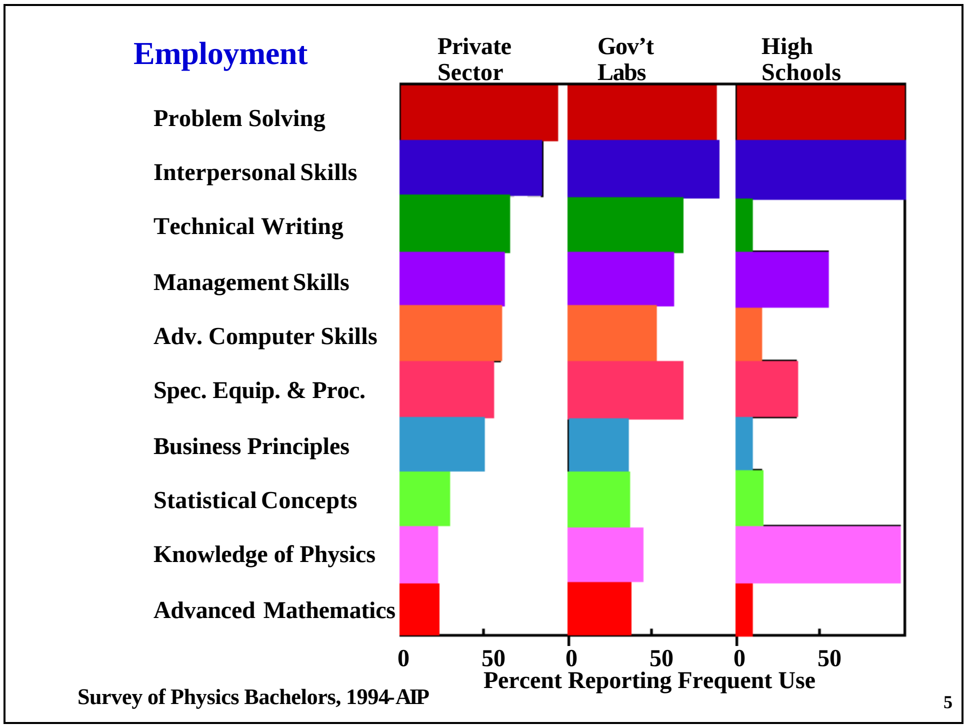

What Do Departments Want?

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

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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

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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

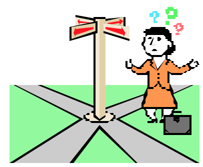
8

Teaching Students to Solve Problems

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

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Problem Solving Requires

Metacognative Skills

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

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Initial State of the Learner

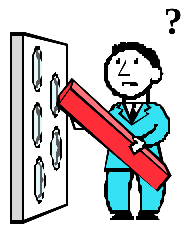
Students have Misconceptions about

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”.

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Students’ Misconceptions About Problem Solving

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

Memorize formulas

Memorize solution patterns

Bring in "crib" sheets

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

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

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Practice Makes Perfect
BUT

Traditional "Problems"

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

What is being practiced?

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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.

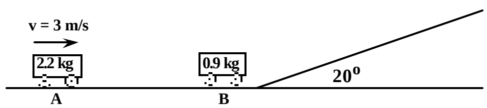

Figure 8.3

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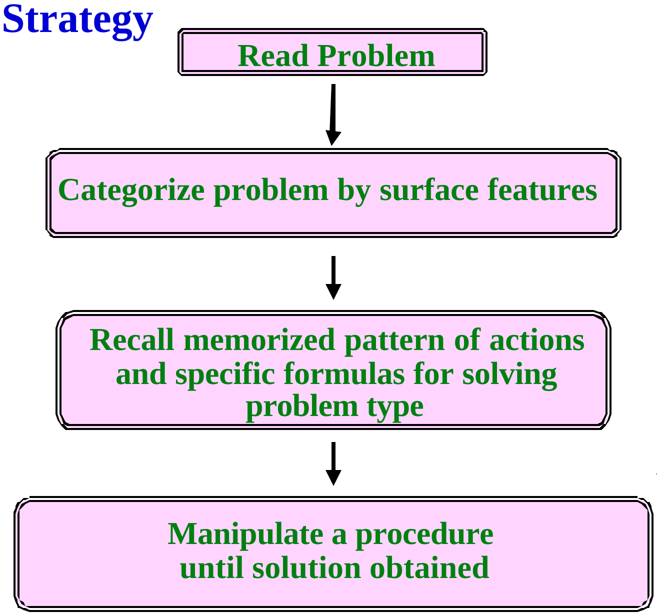
Novice Strategy



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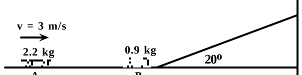

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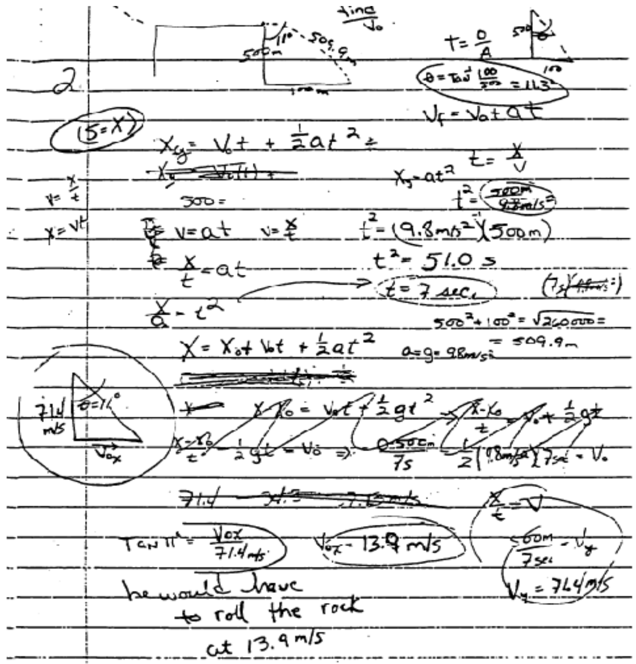
Typical Student Test



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Appropriate Problems for 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.

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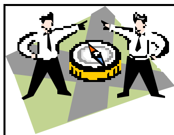
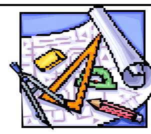
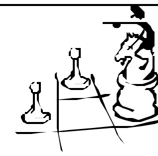




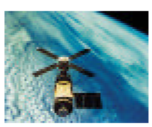
2. **The problems must be designed so that**

   • 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.

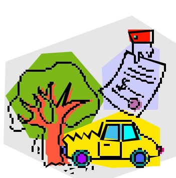
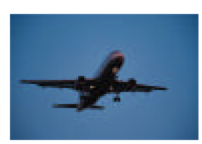





3. **The task problem must connect to each student's mental processes**

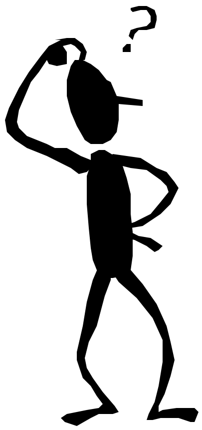
   • the situation is real to the student so other information is connected;

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

This Does Not Reinforce 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

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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.

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Expert Strategy

Acquire Problem

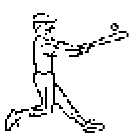
Understand problem (visualization).
Decide tentatively what principles to try.

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?

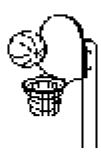
Execute the plan
Check consistency

Check/Evaluate answer

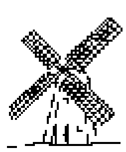


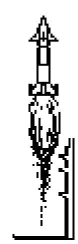
Context-rich Problems

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



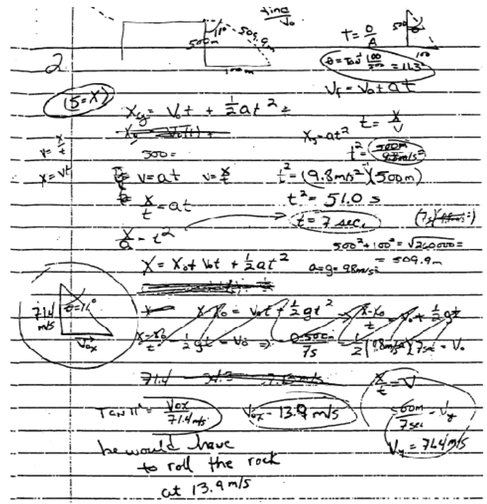
- **The problem statement includes a plausible motivation or reason for "you" to calculate something.**
- **The objects in the problems are real (or can be imagined) -- the idealization process occurs explicitly.**





- **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.**

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



Students need instructional support to solve problems

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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?

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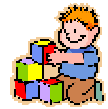
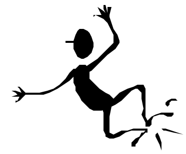
The Dilemma



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?

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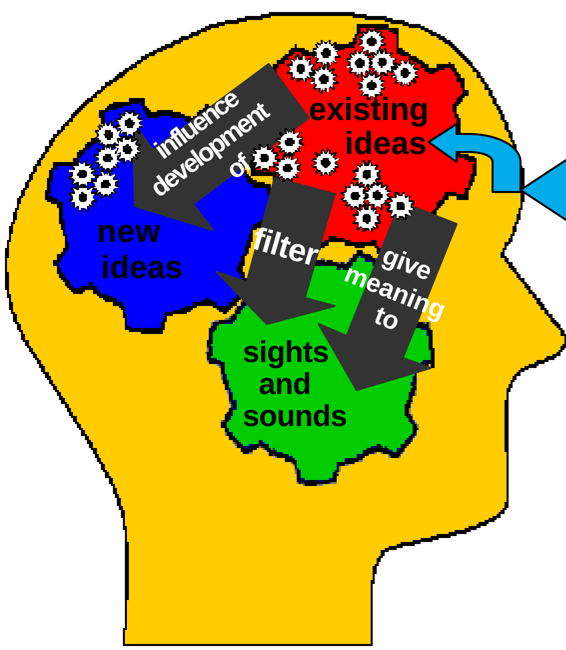
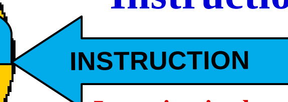
Cognitive Apprenticeship Instruction





Learning in the environment of expert practice

model

coach

fade

Collins, Brown, & Newman (1990)

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Cooperative Group Problem Solving

Emphasis: Fundamental Physics Principles & Problem Solving

Problem Design and Problem-solving Framework
based on expert-novice research

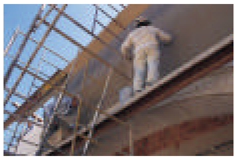
Coaching based on collaborative learning research

Constraints: Lecture, Recitation and Laboratory

- Lectures: MODEL concept construction in problem context and competent problem solving
- Recitation and Laboratory: COACH problem solving

Scaffolding

- Context-rich problems that require physics decisions
- Explicit problem-solving framework
- Structured cooperative groups



- Remove scaffolding: FADE support

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Cooperative Groups

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

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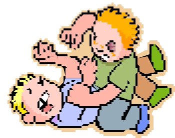
Why Group Problem Solving May Not Work



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

Today's Workshop

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

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Interview to Probe Instructor Beliefs &Values about Teaching Problem Solving in Introductory Physics

1½ - 2 hour interview based on instructional "artifacts":

☑ **3 Instructor solutions:** varied in the details of their explanation, physics approach, and presentation structure

☑ **5 Student solutions:** based on student final examination solutions to represent features of student practice

☑ **4 Problem types:** represent a range of the types of problems used in introductory physics courses

All artifacts were based on a single problem that instructors were asked to solve before the interview.

Details in Charles Henderson's thesis on our web site

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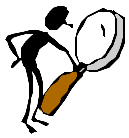
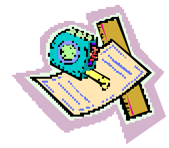
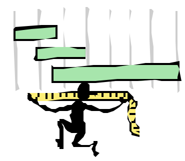


Data



- 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
  - Surveys
  - Dropout rate



- Ease of implementation
- Survey goals of faculty consumers
- Interviews to determine instructor instructional framework

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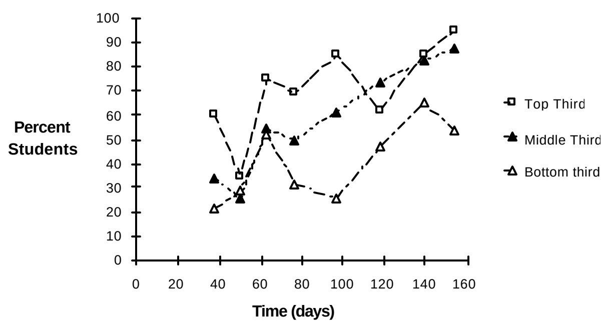
Improvement in Problem Solving

Logical Progression



General Approach - does the student understand the physics

Specific Application of the Physics - starting from the physics they used, how did the student apply this knowledge?

Logical Progression - is the solution logically presented?

Appropriate Mathematics - is the math correct and useful?

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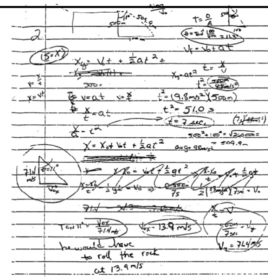
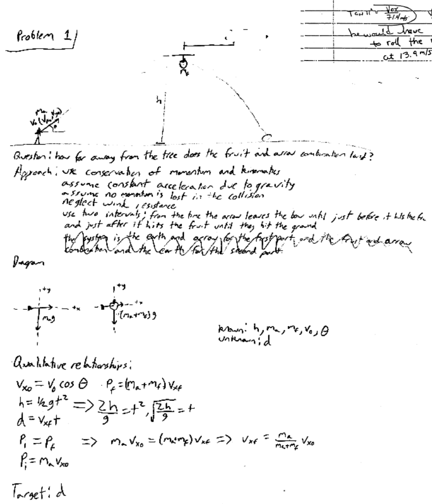
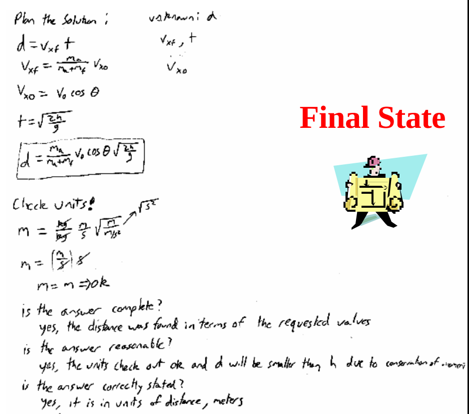
Student Problem Solutions



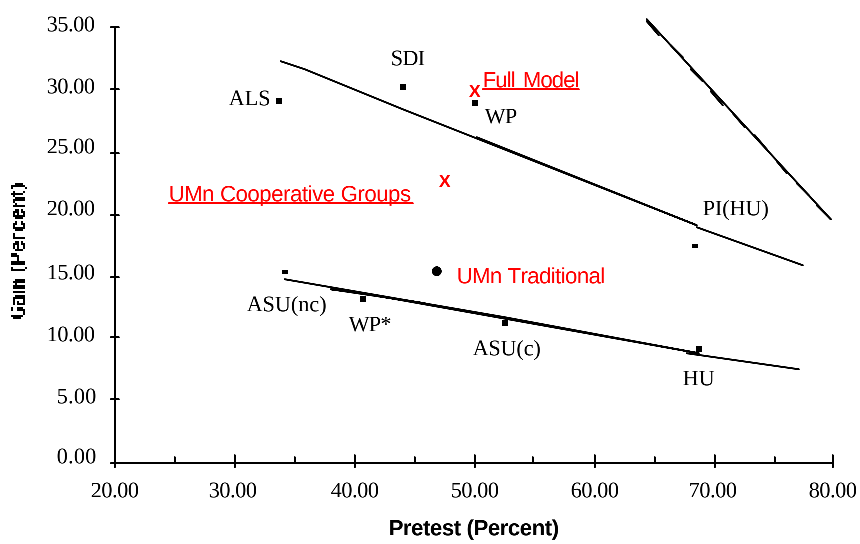
Initial State





Final State

Gain on Force Concept Inventory



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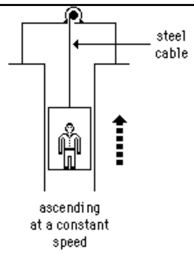

FCI Question

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:

(A) the upward force by the cable is greater than the downward force of gravity.

(B) the upward force by the cable is equal to the downward force of gravity.

(C) the upward force by the cable is smaller than the down ward force of gravity.

(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.

(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).

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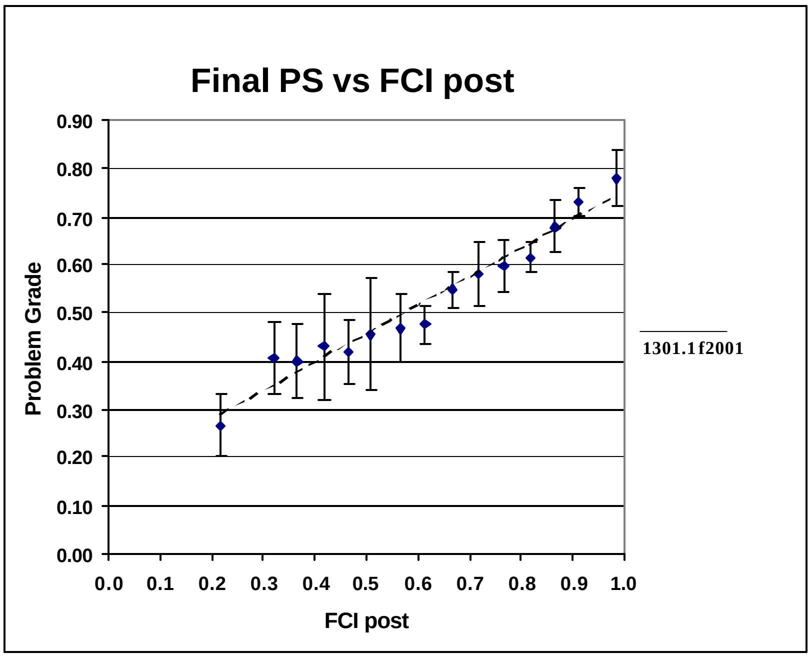

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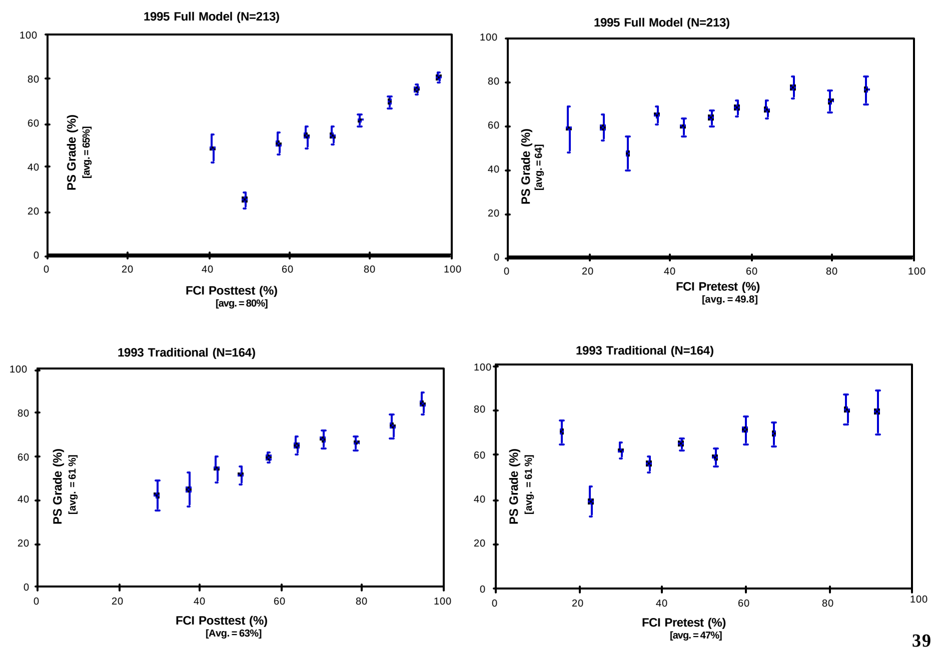
FCI and Problem Solving



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Student opinion

(algebra based)

	SA (agree)	A	N	D	SD (disagree)
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)

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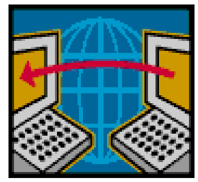
The End

Please visit our website for more information:



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

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