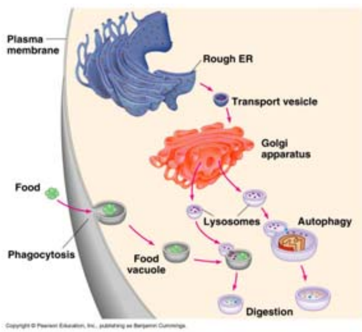
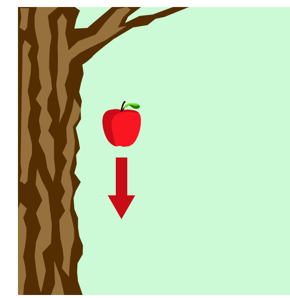
Designing an Introductory Physics Course As a Learning Environment



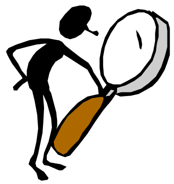


Ken Heller
School of Physics and Astronomy
University of Minnesota

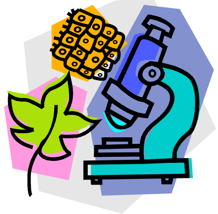
15 year continuing project to improve undergraduate education with contributions by many faculty and graduate students of U of M Physics Department
In collaboration with U of M Physics Education Group - P. Heller, et al.

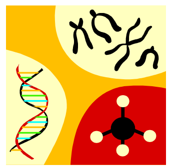
Details at http://groups.physics.umn.edu/physed

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



Physics for Biology Majors





Decide on Content
Decide on Pedagogy
Fit into Constraints
Reflect on Goals
Assess for Content

↓

Decide on Goals
Design for Constraints
Choose Content
Choose Pedagogy
Assess for Goals

Setting Goals

- Whose and how to ask?
- Do they make sense in a physics course?
- At what level can you accomplish them?

Constraints

- Student Skills & Preconceptions
- Instructors' Skills & Preconceptions
- Class size, rooms, funds, time, support

Content

- What is necessary?

Pedagogy

- Theoretical Background
- Instructional Framework
- Tools

Assess How Well It Works

- Data & Quality Assurance

What Is The State of Introductory Physics Course for Biology Majors?

5 lectures/week
50 minutes
300 - 400 students

Connected lab
2 hours/week
16 students

No recitation sections

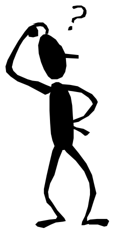
More topics than 3 semester calculus based course in 2 semesters

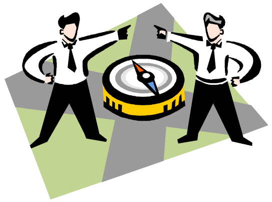
Step 2 ($) add discussion sections
• Coach Problem Solving
Integrate content & lab
Change content focus

Step 1 (no cost) reduce pace to reasonable rate
• Reduce frustration
Problem Solving Lab

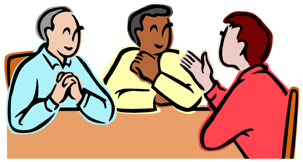
Determine Goals

- **Questionnaire for Faculty Clients (assistance from F. Lawrenz)**
  - Open ended responses
  - Rating scale for goals
  - Forced choices for content
  - Forced choice for lab and discussion section structure

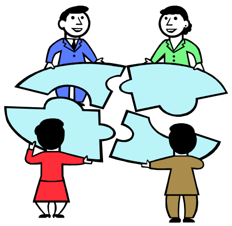




- **Physics Faculty review of Questionnaire results**
  - Reasonable
  - Coherent Physics Course
  - Possible



- **Use Existing Resources**
  - Structure: Lectures, Laboratories, Discussion Sections
  - People: Faculty, Graduate TAs, Undergraduate TAs



Biology Faculty Free Responses - Goals

1. In your opinion, what is the primary reason your department requires students to take this physics course?

Underlying Principles

- To get basics for understanding parts of chemistry, Biochemistry, physiology, other biological disciplines such as cell biology.
- To gain necessary background knowledge about heat, motion, light, & other physical processes to be well-educated scientists.
- The concepts and techniques of Biochemistry rely on understanding physics.
- Physics is basis of the physical interactions which define much of what occurs in biochemistry.
- A number of biological phenomena can't be understood without a feel for the physical principles underlying them.
- So that they will know the principle physical laws that underlie chemistry and biology.

Analysis by V. Kuo

Application

• To be able to apply physical principles to Biochemistry questions.

• To learn the laws of physics that constrain what organisms do. Also to be able to apply physics in lab settings.

Problem solving/math

• To understand the basic laws of physics; to be able to apply physical principles to other problems; to overcome fear of math, quantitative approach to science.

• General understanding of how 1st & 2nd order linear differential equations explain behavior of various physical systems (mechanics, thermodynamics, electricity).

• Living things rely on a number of physical principles. Concepts we cover in lecture & techniques/equipment used in the laboratory require an understanding of physics. Physics is fundamental to many biological processes, & develop skills in problem-solving & modeling.

• Provide basic concepts in physics as applied to biological functions; learn how to think quantitatively about these applied physics concepts.

Biology Faculty Ratings – Goals (19 given)

Many different goals could be addressed through this course. Would you please rate each of the following possible goals in relation to its importance for your students on a scale of 1 to 5?

1 = unimportant 2 = slightly important 3 = somewhat important 4 = important 5 = very important

	1	2	3	4	5	*	Ave
Know the basic principles behind all physics (e.g. forces, conservation of energy, ...)	0	0	0	17	83	35	4.8
Know the range of applicability of the principles of physics (e.g. conservation of energy applied to fluid flow, heat transfer, …)	0	0	9	61	26	9	4.0
Be familiar with a wide range of physics topics (e.g. specific heat, AC circuits, rotational motion, geometrical optics, fluids, relativity, …)	4	9	48	17	22	13	3.4
Solve problems using general quantitative problem solving skills within the context of physics	4	4	9	43	39	22	4.1
Solve problems using general qualitative logical reasoning within the context of physics	0	4	13	35	48	9	4.3
Formulate and carry out experiments	0	9	43	26	13	0	3.3

Analyze data from physical measurements	4	0	26	39	30	0	3.9
Use modern measurement tools for physical measurements (e.g. spectrophotometers, computer data acquisition, timing techniques,...)	0	4	35	30	26	4	3.7
Use computers to solve problems within the context of physics	9	9	35	30	9	0	3.1
Overcome misconceptions about the behavior of the physical world	0	4	24	26	43	17	4.0
Understand and appreciate 'modern physics' (e.g. nuclear decay, quantum optics, cosmology, quantum mechanics, elementary particles,...)	0	26	52	22	0	0	3.0
Provide biological examples of physical principles within the context of physics	0	9	13	13	65	35	4.3
Understand and appreciate the historical development and intellectual organization of physics	9	30	43	17	0	0	2.7
Express, verbally and in writing, logical, qualitative thought in the context of physics	4	4	39	43	9	0	3.5

Express, verbally and in writing, logical, qualitative thought in the context of physics	**5**	**0**	**35**	**45**	**10**	**0**	**3.4**
Provide real world applications of mathematical concepts and techniques within the context of physics	**0**	**5**	**20**	**45**	**30**	**0**	**4.0**
Use with confidence the physics topics covered	**5**	**0**	**40**	**50**	**5**	**0**	**3.5**
Apply the physics topics covered to new situations not explicitly taught by the course	**5**	**5**	**20**	**45**	**25**	**5**	**3.6**
Prepare students for the MCAT	**20**	**25**	**40**	**5**	**5**	**0**	**2.4**
Other goal. Please specify here. ***See attached note!***	**0**	**0**	**0**	**0**	**10**	**0**	**5.0**

Other Goals:

1. **Would prefer bio students take physics as early in their careers as possible, but this is often difficult to arrange.**
2. **Provide examples of physics within a biological context. (5)**
3. **Conceptual thinking. Seeing a big picture rather then only memorizing facts. Concept mapping is a useful tool for organizing the details around a main concept or theme. (5)**

Highest Rated

Goals: Biology Majors Course 2003

- **4.9** Basic principles behind all physics (*1)
- **4.4** General qualitative problem solving skills
- **4.3** *Use biological examples of physical principles (*2)*
- **4.2** *Overcome misconceptions about physical world* (*4)
- **4.1** General quantitative problem solving skills (*3)
- **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*

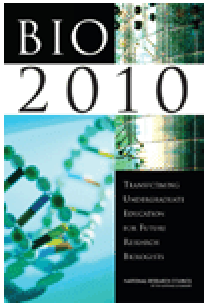
Goals: Algebra-based Course (24 different majors) 1987

- **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

Lowest Rated

	1	2	3	4	5	*	Ave
Prepare students for the MCAT	20	25	40	5	5	0	2.4
Understand and appreciate the historical development and intellectual organization of physics	10	25	50	15	0	0	2.7
Understand and appreciate 'modern physics' (e.g. nuclear decay, quantum optics, cosmology, quantum mechanics, elementary particles,...)	0	30	45	25	0	0	3.0
Use computers to solve problems within the context of physics	10	10	35	30	10	0	3.1
Formulate and carry out experiments	10	10	40	25	15	0	3.3

Goals Chosen



- **Fundamental Principles**
  - Limit formula use to practice using basics
  - Depth rather than coverage
- **Mathematical Problem Solving**
  - Qualitative reasoning important
  - Systematic problem solving framework
- **Biological Context**
  - Complex problems
- **Discussion Sections**
  - Coaching Groups Working on Complex Problems
- **Laboratories**
  - Solutions to Well Defined Problems

Use Context Rich Problems

Course Structure Constraints

LECTURES	**Three hours each week taught by professor**
RECITATION SECTION	**One hour each week taught by TA**
LABORATORY	**Two hours each week taught by TA.**
TESTS	**Given in lecture period. Three hour final exam.**

1 hr = 50 min

Laboratory Structure

The laboratory associated with this course is typically taught by graduate teaching assistants and could be structured in several ways. Please place an 'X' by that structure most appropriate for your students.

45% **A lab with well defined directions explaining how to use a simple apparatus to verify a physical principle.**

35% **A lab with a well defined question or problem illustrating a physical principle and minimal guidance about how to use the simple apparatus.**

35% **A lab where the students are given a general concept from which they must formulate an experimental question, then design and conduct an experiment from a choice of apparatus.**

20% **Other. Please describe.**

Discussion Section Structure

The discussion sections associated with this course are typically taught by graduate teaching assistants and could be structured in several ways. Please place an 'X' by that structure most appropriate for your students.

10 % **Students ask the instructor to solve specific homework problems on the board.**

30 % **Instructor asks students to solve specific homework problems on the board.**

15 % **Instructor asks students to solve unfamiliar textbook problems, then gives the solution on the board.**

20 % **Instructor asks students to solve "real world" problems individually and write their solution on the board.**

70 % **Students work in small groups to solve "real world" problems with coaching from the instructor.**

10 % **Students work in small groups to solve conceptual questions with coaching from the instructor.**

15 % **Other. Please describe.**

Student Constraints

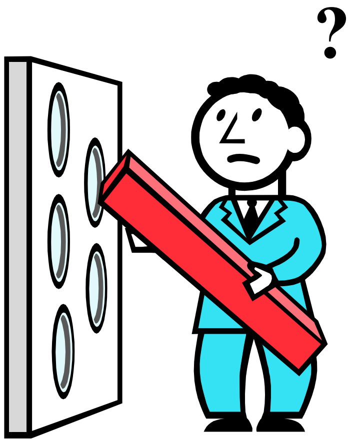
Students have Misconceptions about

The Field of Physics

Learning Physics

Nature

Problem-solving



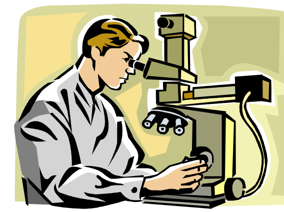
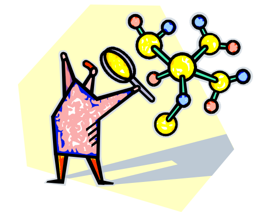
All combine to make it difficult for students to solve problems.

Not the same as “getting a problem right”.

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%

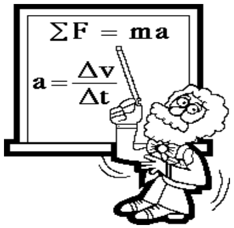
%T	%*		
90	15	Potential energy and conservation of energy	✓
85	15	Kinetic energy and work	✓
85	20	Entropy and the second law of thermodynamics	✓
85	15	Electric charge and force	✓
85	13	Electric potential	✓
80	0	Linear motion	✓
80	0	Forces and Newton's Laws	✓
75	15	Units, dimensions and vectors	✓
75	5	Temperature and ideal gas	✓
75	0	Electric field	✓
75	5	Molecules and gases (e.g. probability distributions of velocity, equipartition)	
75	9	Mirrors and lenses	✓
70	0	Momentum and collisions	✓
70	9	Nuclear physics and radioactive decay	✓
65	0	Two dimensional motion	✓
65	0	Gravitation	✓
65	4	Currents in materials (e.g. resistance, insulator, semiconductors)	✓
65	15	Heat flow and the first law of thermodynamics	✓
65	0	Magnetic forces and fields	✓
60	4	Geometrical optics (e.g. reflection and refraction)	✓
60	0	Diffraction	✓
55	0	Oscillatory motion	✓
55	4	Currents and DC circuits	✓

23 Chapters

21 Chapters

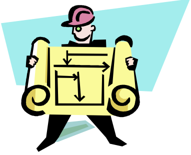
%T	%*	
50	0	Rotations and torque
45	5	Applications of Newton's laws ✓
45	0	Angular momentum
45	0	Gauss' law
45	4	Currents and magnetic fields (e.g. Ampere's law, Biot-Savart law) ✓
45	0	Interference ✓
40	5	Fluid mechanics
40	5	Properties of solids (e.g. stress, strain, thermal expansion)
40	0	Capacitors and dielectrics ✓
40	4	Maxwell's equations and electromagnetic waves
40	0	Relativity
35	4	Faraday's law ✓
35	0	Superposition and interference of waves
30	0	Mechanical waves
30	0	Statics
30	0	Magnetism and matter (e.g. ferromagnetism, diamagnetism)
30	9	AC circuits
30	0	Atomic physics ✓
20	0	Quantum physics
15	0	Magnetic Inductance ✓
15	0	Particle physics
0	0	Other. Please specify.

Curriculum first semester



- **Conservation and systems**
  - Scale (macroscopic and microscopic)
  - Transfer & Interaction
  - Cycles
  - Balance and accounting
    - Growth
    - Population increase
- **Energy of systems**
  - Kinetic Energy
  - Stored Energy
    - Potential energy
    - Internal energy
    - Chemical energy
- **Energy transfer**
  - Material
  - Heat
  - Force (macroscopic & microscopic)
  - Direction and vectors
- **Other Conservation**
  - Momentum
- **Mechanisms of Interactions**
  - Forces and change
    - Directions and vectors
  - Kinematics and rates of change
    - Velocity and acceleration
    - Directions and vectors
  - Oscillations

Topics – First Semester Plan



Week	Topic	Chapter
1-2	Conservation, Systems, & Cyclic Processes - Electric Circuits	21, 20
2-3	Energy & Energy Transfer	6
4-5	Energy & Thermal Processes	16, 17
6-7	Cyclic Processes & Entropy	18
8-9	Conservation of Energy & Momentum	7, 8

Week	Topic	Chapter
10-11	Interaction Mechanisms -Forces	4
11-12	Applications - Forces	5, 11, 19
13-14	Predicting Motion	2, 3
14-15	Oscillations	12

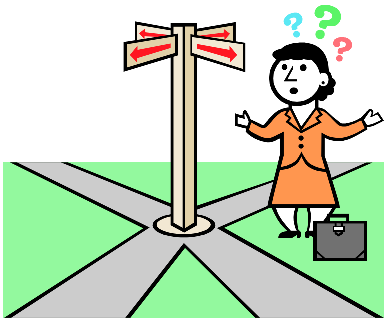
Textbook: Serway & Jewitt
Principles of Physics – 3rd Edition

Problem Solving is a Useful for Learning Physics

Solving Problems Requires Conceptual Knowledge:

A Framework for Decisions about Physics

- Visualize situation
- Determine goal
- Choose applicable principles
- Choose relevant information
- Construct a plan
- Arrive at an answer
- Evaluate the solution



Larkin, J. H. & Reif, F. (1979)
Heller, J. & Reif, F. (1984)

Students must be taught problem solving *explicitly*

The difficulty -- major misconceptions, poor reflective skills, weak general tools

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**

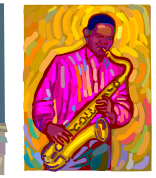
Problem-solving Framework

Used by experts in all fields

(i.e. Polya 1957)

Chi, M., Glaser, R., & Rees, E. (1982)





STEP 1 — **Recognize the Problem**

What's going on?

STEP 2 — **Describe the problem in terms of the field**

What does this have to do with ...... ?

STEP 3 — **Plan a solution**

How do I get out of this?

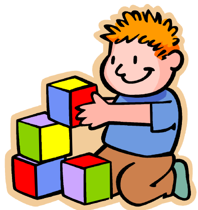
STEP 4 — **Execute the plan**

Let's get an answer

STEP 5 — **Evaluate the solution**

Can this be true?

The Dilemma



Start with simple problems
to learn expert-like strategy.
Success using novice strategy.

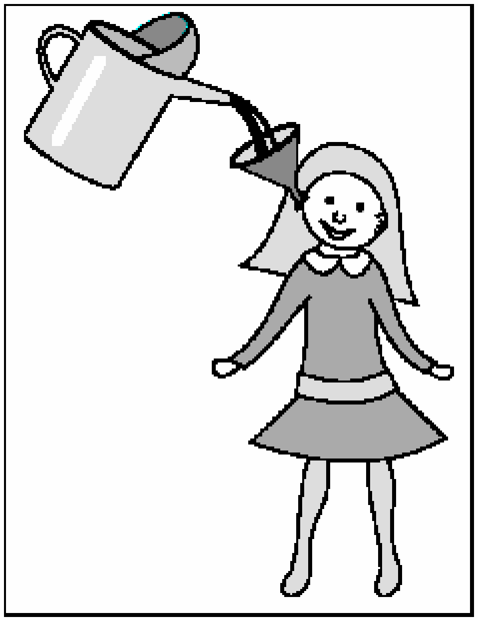
Why change?

Start with complex problems
so novice strategy fails
Difficulty using new strategy.

Why change?

The "Clear Explanation" Misconception

Commonly held by Faculty, TAs, Students, & Administrators



Instructor Pours knowledge into students.

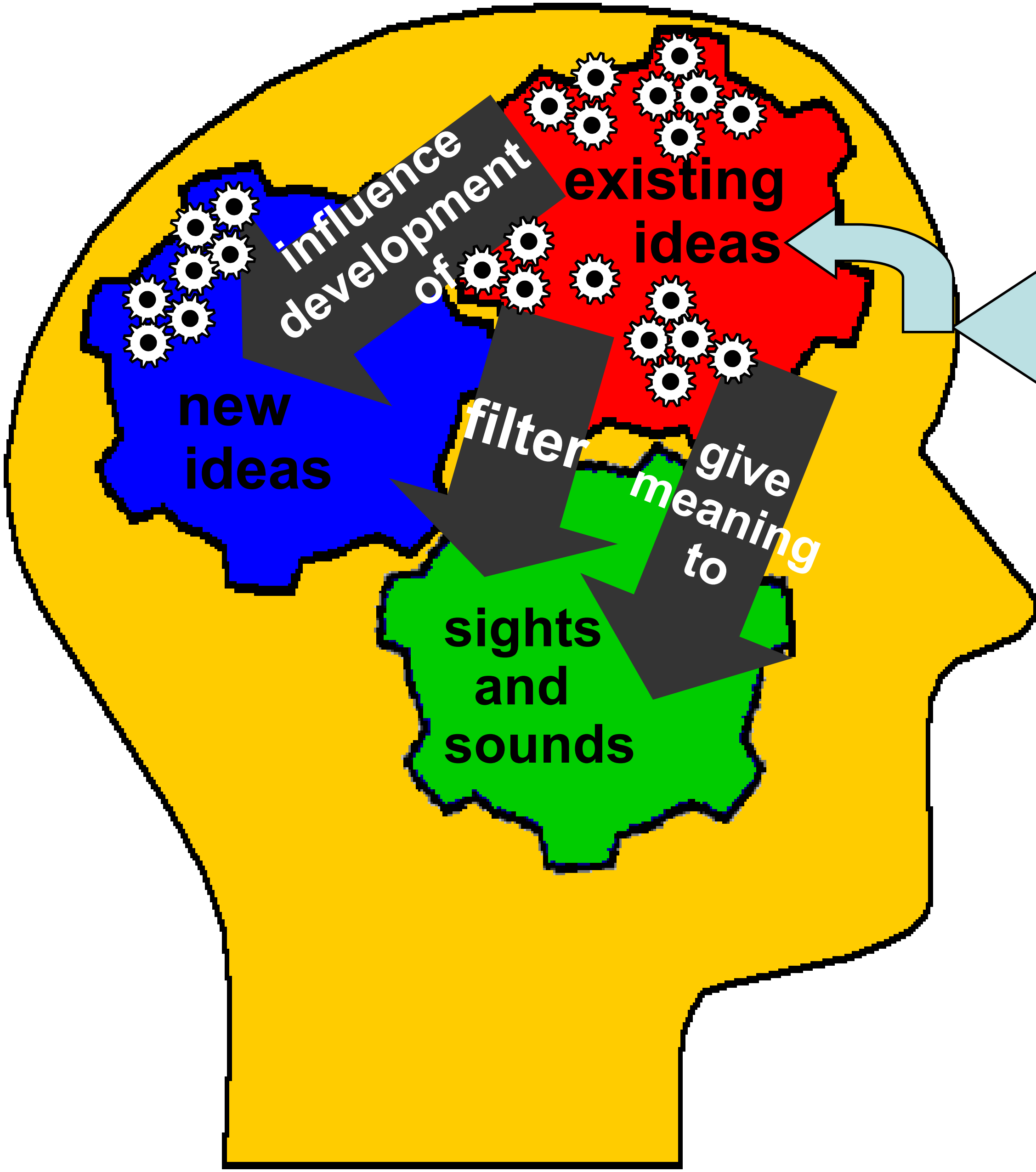
Little knowledge is retained.

Impedance mismatch between student and instructor.

Learning is more complicated

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

Cognitive Apprenticeship Instruction



Learning in the environment of expert practice

model

coach

fade

Collins, Brown, & Newman (1989)

The Course as a System

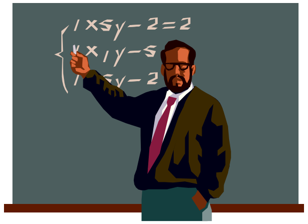
Use strengths of components acting together

Lectures - 3 x 50 min. each week **(200 - 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 **(16 students)**

Coach problem solving

Same framework as lecture

Same concepts as lecture

Heller, P., Foster, T. & Heller, K. (1997)

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 (model), Recitation (coach), and Laboratory (coach)

Scaffolding Heller, P. & Hollabaugh, M. 1992

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

Johnson & Johnson, 1984

- Remove scaffolding: FADE support

Final Exam Physics 1301 (Sci & Eng) f 2002

1. You are watching a James Bond movie on TV when an exciting chase scene begins. Driving his specially modified Aston Martin, Bond is trying to outrun a woman driving a Mustang on a twisting mountain road. As he drives around the curve, he shoots a jet of oil on the road causing the coefficient of friction to become very small. He makes it around the curve but she skids off the road into a canyon below. During the commercial, your mind drifts and you wonder whether or not the chase was realistic so you decide to calculate fast he can go and still make the curve and how slow she would have to go to also make it. As a first step, you calculate each speed in terms of the radius of the curve, the angle that the curve is banked, and the coefficient of static friction between the tires and the road.

2. You have just moved into a new apartment and find yourself faced with the problem of sliding your refrigerator into the space provided in the kitchen. From the moving company you see that your refrigerator weighs 200 lb. The refrigerator is 67 inches tall, 33 inches wide and 33 inches deep and the center of mass of the refrigerator is at its center. If the coefficient of static friction between your kitchen floor and the bottom of your refrigerator is 0.75, what is the maximum distance above the floor that you can safely push on the refrigerator to get it started but not tip?

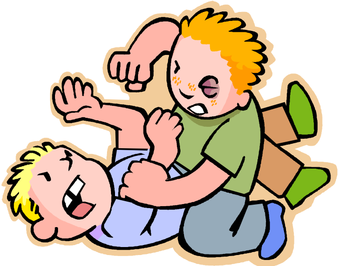
Final Exam
Physics 1301
(Sci & Eng)
f 2002

3. Your have been hired as a technical advisor for the police to help in the scientific investigation of crimes. A shooting happened in an apartment but the people in a neighboring apartment claim that they did not hear a shot. You have been assigned to use the physical evidence to determine if they are telling the truth. You know that if the bullet travels faster than the speed of sound, 330 m/s, most of the noise comes from the sonic boom that no silencer can eliminate. You search the crime scene in the apartment and find that a bullet went through a cookbook and then entered the wall. From the dust patterns on a table, the book was sitting on the edge of the table when the bullet ripped through its center knocking it to the floor. From the entrance and exit hole in the book, the bullet was going horizontally as it passed through it. When you find the bullet hole in the wall, you measure that the bullet dropped by 5.0 mm since passing through the book. You dig the bullet out of the wall and measure its mass as 2.4 grams. You also measure the height of the table above the floor, 1.5 m, the distance of the book on the floor from the table, 0.30 m, the distance from the wall to the table, 5.0 m, and the mass of the book, 1.1 kg. The police want you to tell them the speed of the bullet so that they can tell whether the neighbors are telling the truth.

4. You are helping a friend whose hobby is building artistic clocks. Your friend wants the clock timing regulated by a ring that swings from a point on its rim. The goal is to make the period of the swing 2.0 seconds. Your friend wants you to determine the mass and radius of the ring that will make it work.

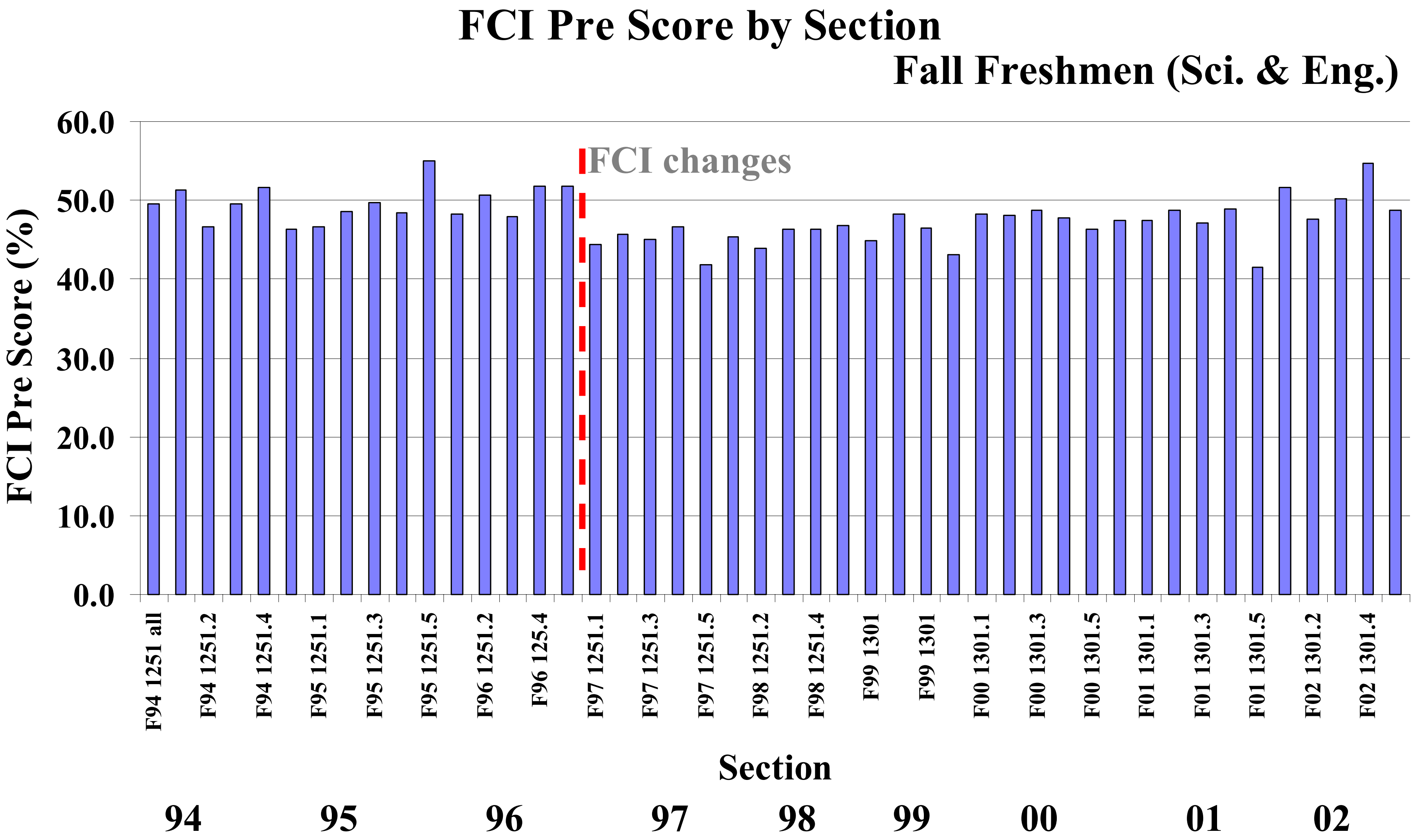
5. You have been asked to design the apparatus for a spectacular opening for an ice show. A small skater glides down a ramp and then along a short level track of ice. The skater bends to be as small as possible when grabbing the bottom end of a large vertical rod that is free to turn vertically about an axis through its center. The plan is for the skater to hold onto the rod while it swings the skater to its top. You have been asked to give the minimum height of the ramp in terms of the mass of the skater, the mass of the rod, and the length of the rod so that the skater can make it to the top. Doing a quick integral tells you that the moment of inertia of the rod about its center is 1/3 of what its moment of inertia would be if all of its mass were concentrated at one of its ends.

Why Group Problem Solving May Not Work



1. Inappropriate Tasks
2. Inappropriate Grading
3. Poor structure and management of Groups
4. Curricular Elements Do Not Correspond to the Instructor's Beliefs or Values

Quality Assurance



Halloun, I. A. & Hestenes, D. (1985)
Hestenes, D., Wells, M. & Swackhamer, G. (1992)

Typical FCI Results

Physics 1201 – Physics for Biology Majors (stage 1)

Input = 39% **Output = 53%** **G = .23**

Stage I (L. Hsu) – Reduce Content Density, Problem Solving Framework, Problem Solving Laboratories, Computerize Reading Quiz, Index Card Lecture Response System, Traditional Order, No Discussion Sections

Next Stage – Add Discussion Sections for Coaching (cooperative groups), Reorder Content, Match Labs to Content, Electric Response System in Lecture

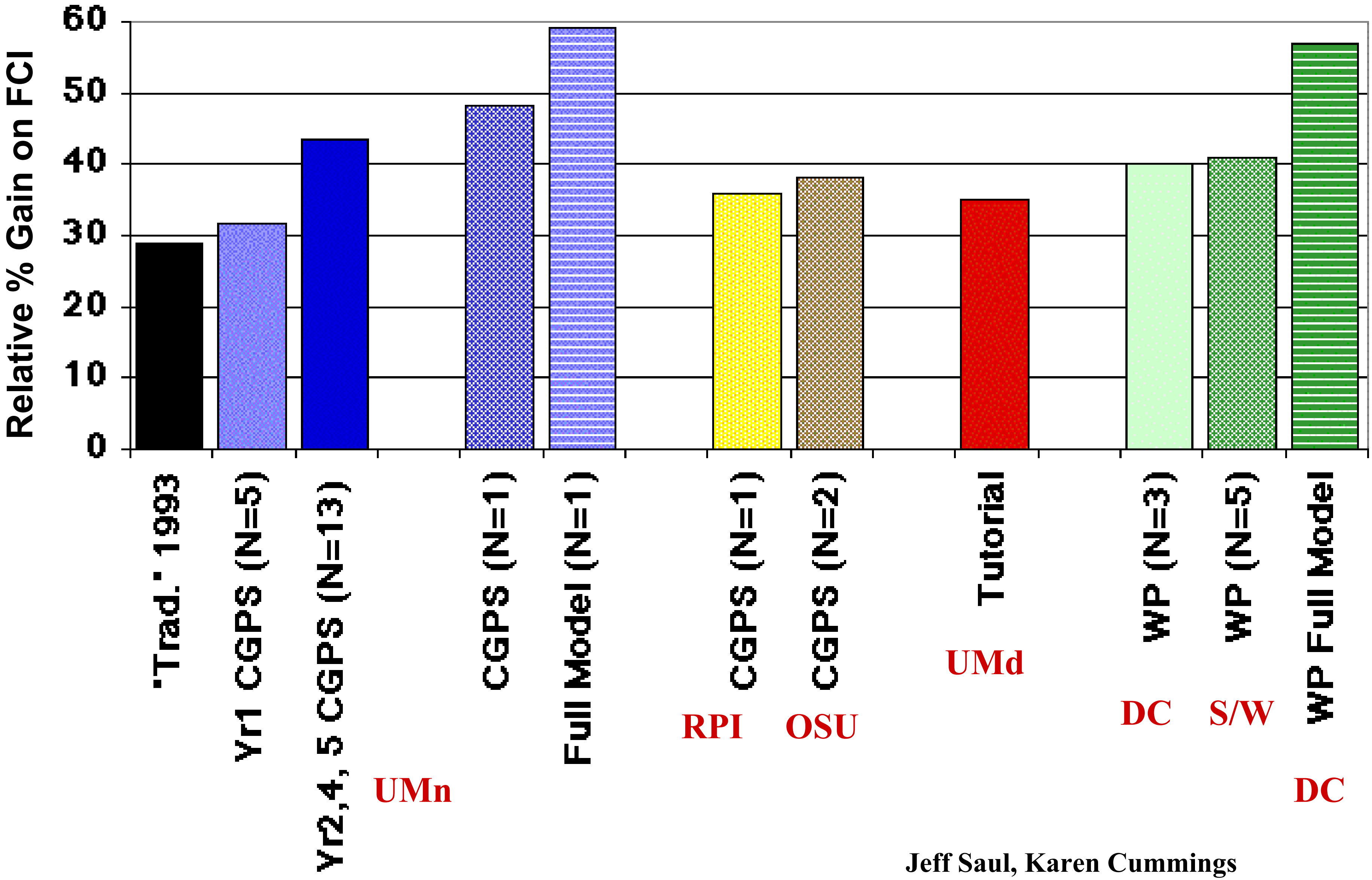
Physics 1301 – Physics for Science & Engineering (mature CGPS)

Input = 46% **Output = 70%** **G = .44**

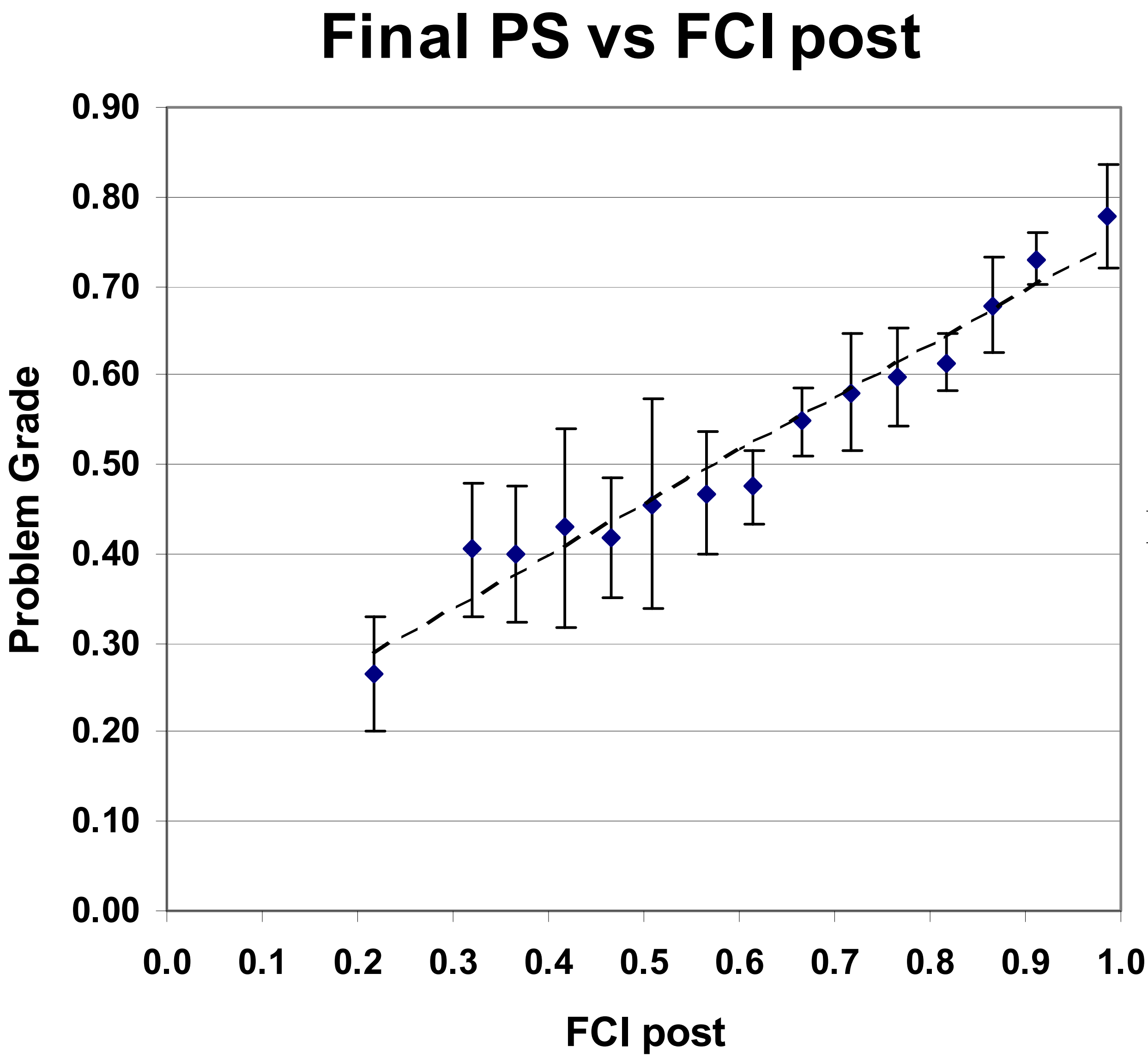
Physics 1001 – Energy & Environment ("traditional" conceptual)

Input = 34% **Output = 35%** **G = .015**

Comparisons of Full and Partial Models



Jeff Saul, Karen Cummings



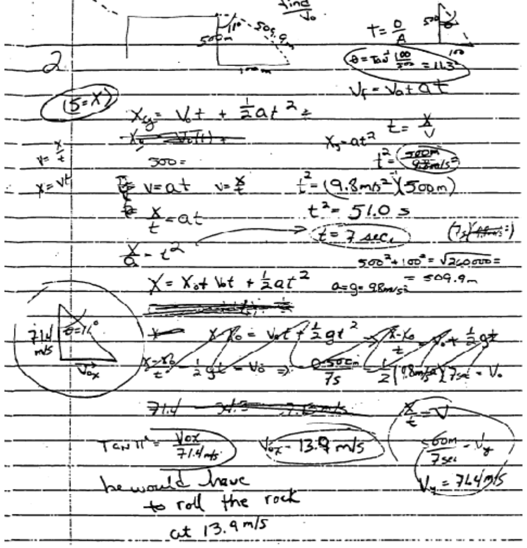
Physics 1301

FCI is a good Quality Assurance Tool

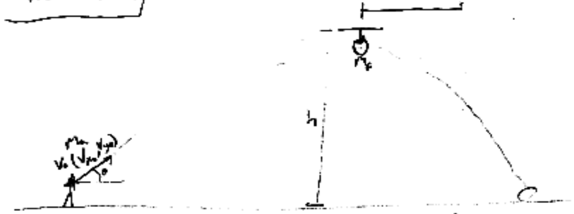
Heller, P., Huffman, D (1995)

Student Problem Solutions

Physics 1301



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:

$v_{xo} = v_0 \cos\theta \quad P_f = (m_a + m_f) v_{xf}$

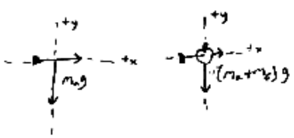
$h = \frac{1}{2} g t^2 \Rightarrow \frac{2h}{g} = t^2, \sqrt{\frac{2h}{g}} = t$

$d = v_{xf} t$

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

$P_i = m_a v_{xo}$

Target: d



Plan the Solution; unknown: d

$d = v_{xf} t$ — v_{xf}, t

$v_{xf} = \frac{m_a}{m_a + m_f} v_{xo}$ — 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!

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

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

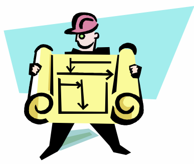
$m = m \Rightarrow ok$

is the answer complete?
yes, the distance was found in terms of the requested values

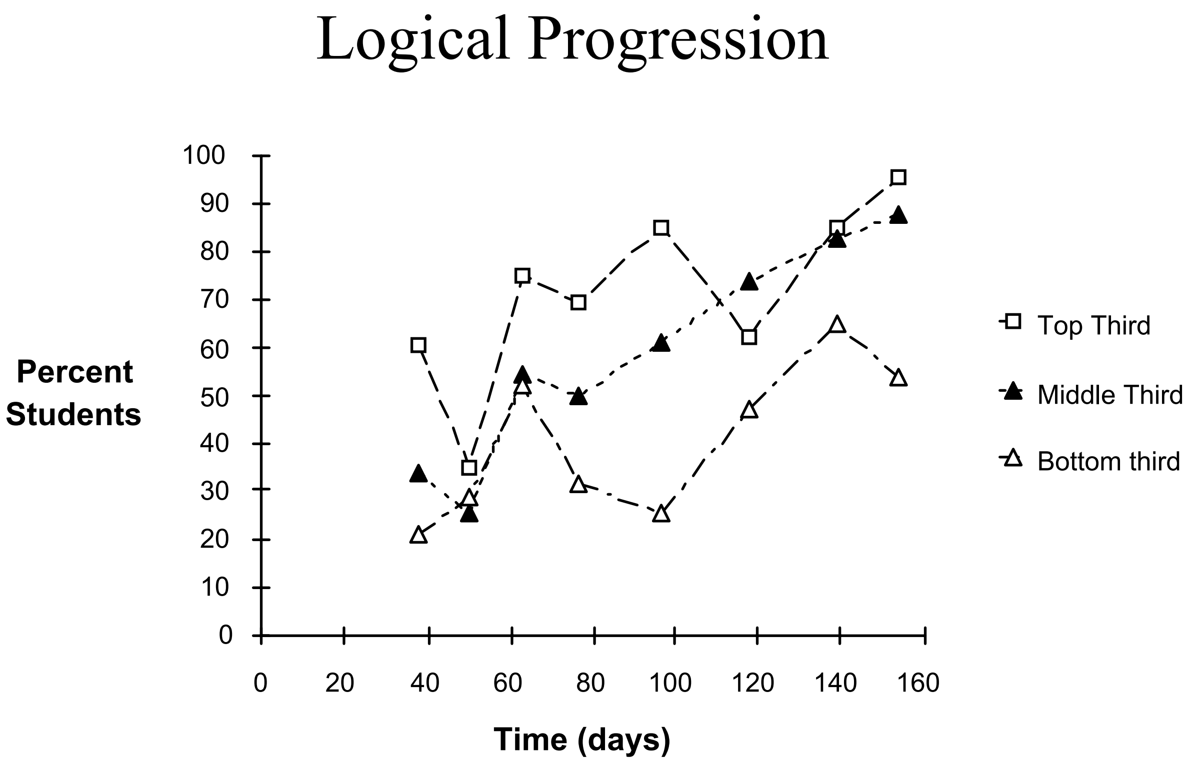
is the answer reasonable?
yes, the units check out ok and d will be smaller than h due to conservation of moment

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

Final State



Improvement in Problem Solving



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?

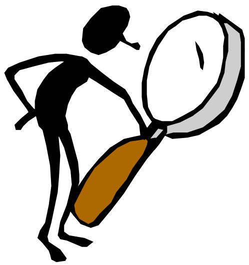
Logical Progression - is the solution logically presented?

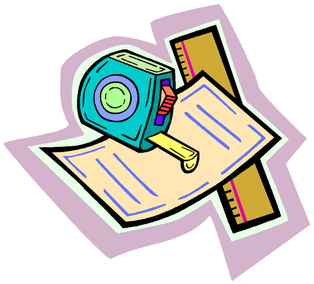
Appropriate Mathematics - is the math correct and useful?

Course Structure

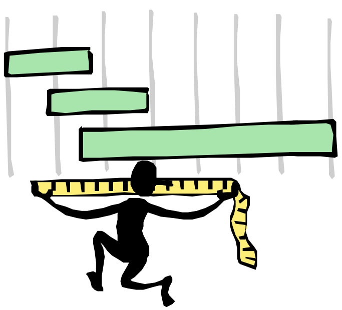
LECTURES	**Three hours each week, sometimes with informal cooperative groups. Model constructing knowledge, model problem solving framework.**
RECITATION SECTION	**One hour each Thursday – cooperative groups practice using problem-solving framework to solve context-rich problems. Peer coaching, TA coaching.**
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.**

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

The End

Please visit our website for more information:

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