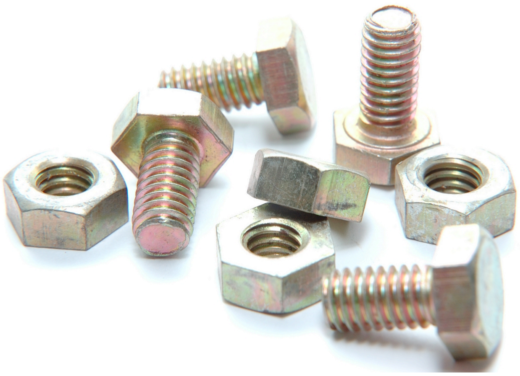
Helping Your Students Develop Expertise in Problem Solving – While Learning Physics



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

Ken Heller

School of Physics and Astronomy
University of Minnesota

30 year continuing project to improve undergraduate education by:
Many faculty and graduate students of U of M Physics Department
In collaboration with U of M Physics Education Group

For more details google: "per minn" or "per umn" or "per minnesota"

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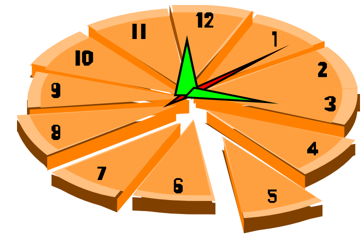
Improving Student Problem Solving - Specific Examples & A Guide for Discussion



- Example Course System Built Around Problem Solving
- Critical Components in Teaching Problem Solving
  1. Appropriate tasks – Problem structure
  2. Appropriate grading – Reward problem solving
  3. Support for students – Pace, coaching, lectures, labs, test structure, unifying message
- Essential Elements for Learning <final | T | initial>
  1. Modeling – Explicitly demonstrating what you want students to do
  2. Coaching – Letting students do it their way with instant feedback
  3. Fading – Students working alone with decreasing support
  4. Repetition - Students always start from fundamentals
  5. Transfer – Students expect to solve unfamiliar problems

Breakout sessions: the details important to you

How? What happens if? I tried X and it worked or didn't work. Backing from theory & experiment? Results? Computer Coach research?

Introductory Physics – example of an instructional system

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LECTURES

3 hours each week (~200 students)
sometimes with informal groups, peer coaching. Demonstrate constructing knowledge & using a problem solving framework.

DISCUSSION SECTION

1 hour each Thursday (~18 students)
groups practice using problem-solving framework to solve context-rich problems. Peer coaching, TA coaching.

LABORATORY

2 hours each week (~18 students)
same groups practice solving concrete laboratory problems. *Same* TA. Peer coaching, TA coaching.

TESTS

Problem-solving (written) & conceptual questions (multiple choice) every ~3 weeks.

In groups Thursday & individual Friday

Scaffolding – computer reading tests, clickers, JITT, limit formula usage, sample quizzes, problem solving framework, context rich problems, computer coaches

Fast paced but not killing

Course organization follows textbook

Physics for Engineers and Physical Science Students (1301)

Week	Topic	Chapter
1	Intro/ 1D Motion	1, 2, 3
2	Momentum	3,4
3	Energy/ Relative 1D Motion (Quiz #1)	5, 6
4	Interactions/ Potential Energy	6, 7
5	Forces and 1D motion	8
6	Forces (Quiz #2)	8, 9
7	Work/Energy	9
8	Motion in 2D	10
9	Friction/Work (Quiz #3)	10, 11
10	Rotation/Angular Momentum	11
11	Torque/Static Equilibrium	12
12	Rotational Dynamics	12
13	Rotational Dynamics/Oscillations (Quiz #4)	12,15
14	Oscillations/Gravity	15, 13
15	Gravity and Review	13
16	Final Exam	

Textbook: Mazur, Principles & Practice of Physics (Chapters 1 – 15, not 14)

Physics for Biology and Pre-Med Students – Calculus based (1201)

Course organization doesn't follows textbook

Week	Topic
1- 3	**Forces and Equilibrium/Problem Solving** (Vectors, All forces including friction, spring, buoyancy) Chapter: 1.1, 3.1-.5, .12, 13.1, 4.10
4	**Torque and Equilibrium** Chapter: 4.1, .2, .4 – .9
5 - 8	**Force, Energy Transfer, and Conservation of Energy** (Energy in all systems including fluid flow) Chapter: 1.1 –1.3, 6.1- .6, .9, .11, 13.2 - .8
9–10	**Energy, Systems & Cycles** (including fluid circularity system, thermodynamics) Chapter: 14.4, 12.3 - .7, 10.1- .6, 11.1 - .2, .7
11 –12	**Entropy & Free Energy** (entropy as probability) Notes, Chapter: 11.3
13 –14	**Using Force to Predict Motion, Newton's 2nd Law and Acceleration** (including gravitational force and projectile motion, motion through a fluid, circular motion, oscillatory motion) Chapter: 1, 2, 3.6 - .8, .12, 5.1, 5.2, 9, 14.5
15	**Review**
16	**Final Exam**

Biomechanics

Energy use & energy cycles

Entropy driven processes

Complex motion

Chapter order

1
3
13
4
1
6
13
14
12
10
11
1
2
3
5
9
14

Textbook: Sternheim & Kane, General Physics (Chapters 1 – 14, not 7, 8)

Survey of Faculty Who Require Physics? (5 pt scale)

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

(5 pt scale)

- 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

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

Inventory of Your Student's Problem Solving

Student Problem Solving

Undesirable behavior

1) -
2) -
3) -
4) -
5) -
6) -
7) -
8) -
9) -
10) -

Desirable behavior

1) -
2) -
3) -
4) -
5) -
6) -
7) -
8) -
9) -
10) -

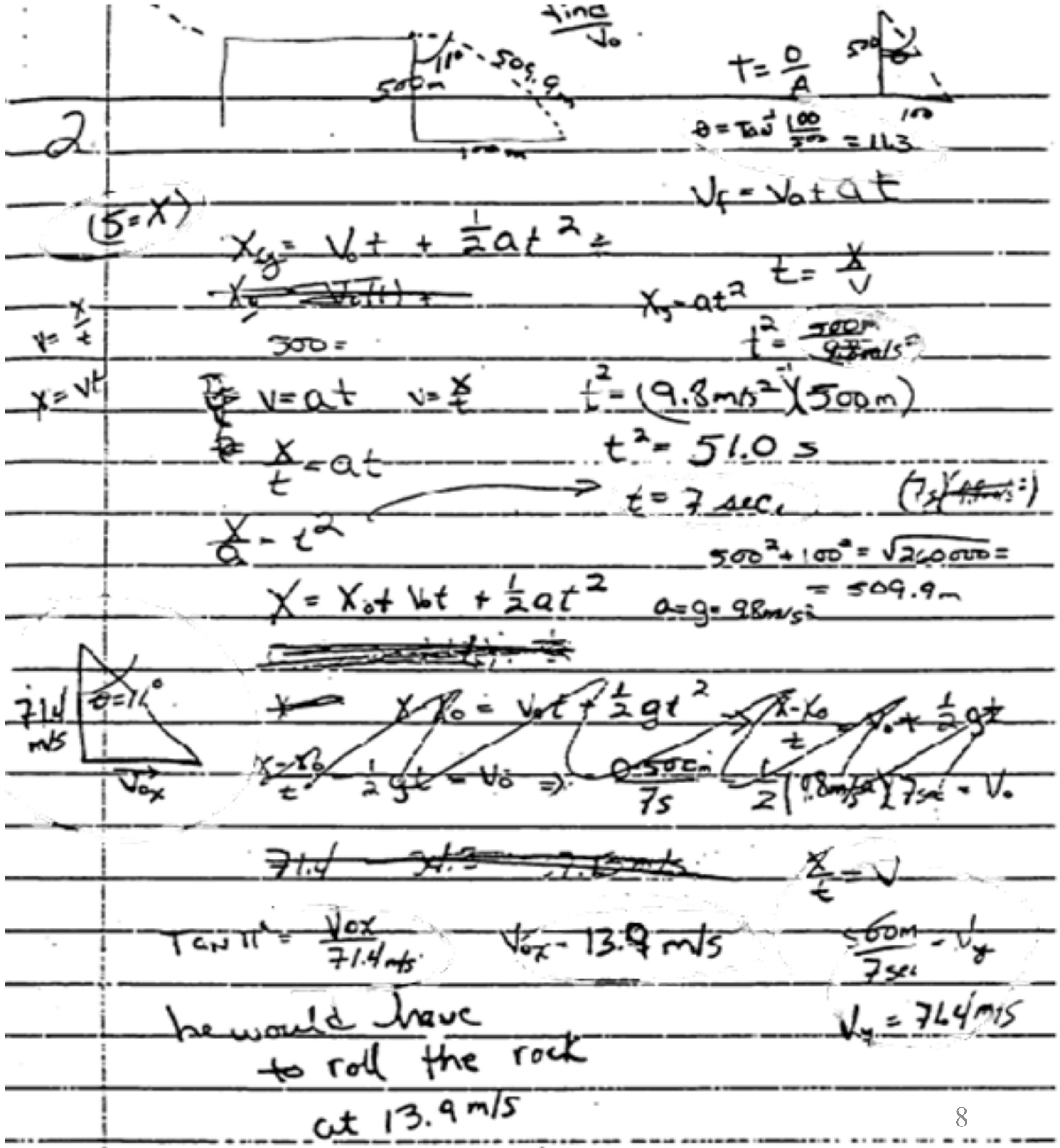
Prioritize !

Encourage desired behavior.
Discourage undesirable behavior.

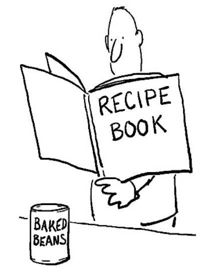
Grading must align with your priorities.

Undesirable problem solving behavior

Cowboy Bob is camped on the top of Table Rock. Table Rock has a flat horizontal top, vertical sides, and is 500 meters high. A band of outlaws is at the base of Table Rock 100 meters from the side wall. Cowboy Bob decides to roll a large boulder over the edge and onto the outlaws. Determine how fast Bob will have to roll the boulder to reach the outlaws.



Solving Physics Problems

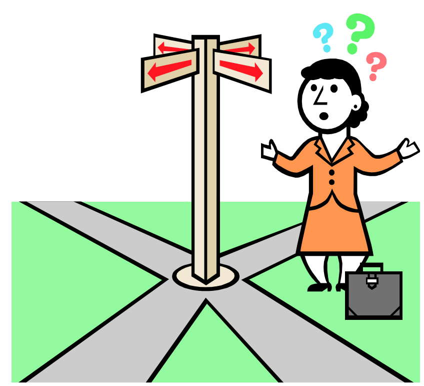


Undesirable outlook (Novice): Solving a problem requires a following a recipe that connects the situation to the goal. Every type of situation has its own recipe. Uses formulas.

Desirable outlook (Expert): Solving a problem requires constructing a set of decisions that connects the situation to the goal using a few basic principles. All situations are approached the same way. Uses equations.

Desirable Behavior – making decisions by:

- Visualizing a situation
- Specifying goals
- Making assumptions
- Constructing representations
- Identifying useful ideas
- Learning new ideas
- Connecting ideas using techniques such as diagrams, logic, mathematics
- Evaluating the process and its results

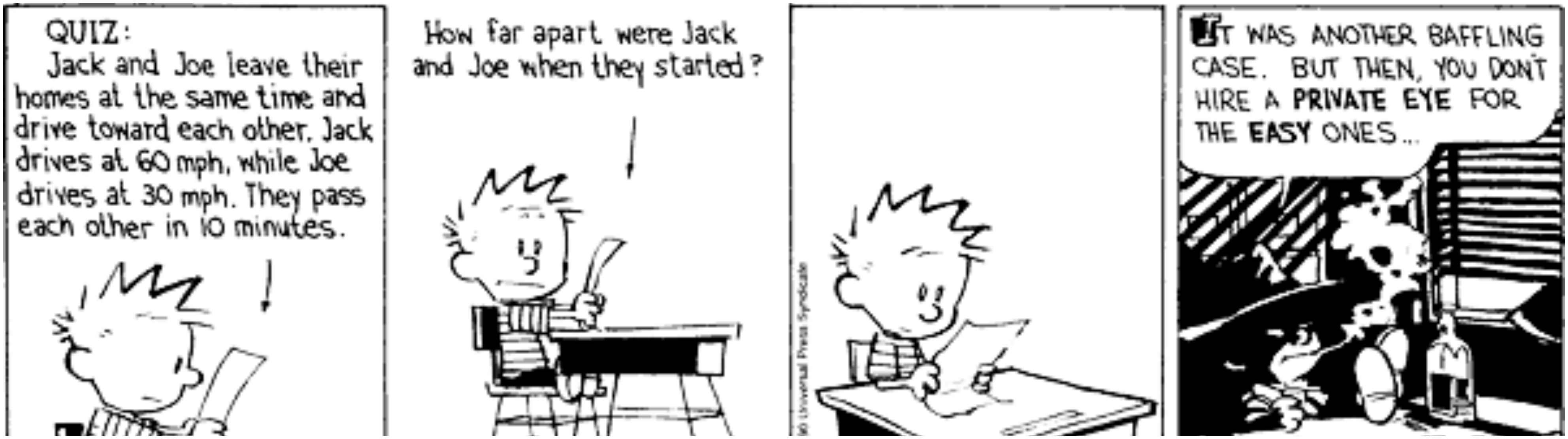


Problem solving requires metacognition (active control of your thought processes)

- Planning
- Monitoring
- Evaluating

Appropriate Grading

We want students to do this:



Cannot base grade primarily on the right answer

Making mistakes is a hallmark of problem solving -

Martinez, Phi Delta Kappan, April, 1998

Unfortunately institutions often do this

We want students to help each other. But grading on a curve penalizes this.

Student Grading Guidance on Each Test

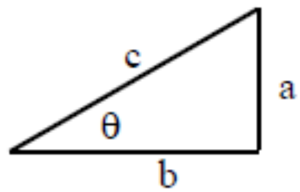
This is a closed book, closed notes quiz. Calculators are permitted. The ONLY formulas that may be used are those given below. Define all symbols and justify all mathematical expressions used. Make sure to state all of the assumptions used to solve a problem. Credit will be given only for a logical and complete solution that is clearly communicated with correct units. Partial credit will be given for a well communicated problem solving strategy based on correct physics. Each problem is worth 25 points: In the context of a unified solution, partial credit will be awarded as follows:

- **a useful picture, defining the question, and giving your approach is worth 6 points;**
- **a complete physics diagram defining the relevant quantities, identifying the target quantity, and specifying the relevant equations with reasons is worth 6 points;**
- **planning the solution by constructing the mathematics leading to an algebraic answer and checking the units of that answer is worth 7 points;**
- **calculating a numerical value with correct units is worth 3 points; and**
- **evaluating the validity of the answer is worth 3 points.**

Equation sheet at end of first semester: Calculus Based Physics for Biology Majors

Control Equations: Only these are allowed

Useful Mathematical Relationships:



For a right triangle: $\sin\theta = \frac{a}{c}$, $\cos\theta = \frac{b}{c}$, $\tan\theta = \frac{a}{b}$,

$a^2 + b^2 = c^2$, $\sin^2\theta + \cos^2\theta = 1$

For a circle: $C = 2\pi R$, $A = \pi R^2$

If $Ax^2 + Bx + C = 0$, then $x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$

$\frac{d(z^n)}{dz} = nz^{n-1}$, $\frac{d(\cos z)}{dz} = -\sin z$, $\frac{d(\sin z)}{dz} = \cos z$, $\frac{d(e^{az})}{dz} = ae^{az}$, $\frac{df(z)}{dt} = \frac{df(z)}{dz}\frac{dz}{dt}$, $\frac{d(\ln z)}{dz} = \frac{1}{z}$,

$\int\left(\frac{df}{dz}\right)dz = f$

Fundamental Concepts, Principles, and Definitions:

$\sum \vec{F} = m\vec{a}$	$\rho = \frac{m}{V}$	$\tau = rF_\perp$	$\vec{\tau} = \vec{r} \times \vec{F}$	$a_x = \frac{dv_x}{dt}$	$v_x = \frac{dx}{dt}$
$\sigma = \frac{F}{A}$	$\epsilon = \frac{\Delta\ell}{\ell}$	$KE = \frac{1}{2}mv^2$	$\frac{dE_{transfer}}{dx} = F_x$	$E_f - E_i = E_{input} - E_{output}$	
$X_f - X_i = X_{input} - X_{output}$	$\frac{d\mathcal{U}}{dx} = -F_x$	$P = \frac{F}{A}$	$\varepsilon = \frac{\text{Energy desired}}{\text{Energy input}}$		
$\mathcal{P} = \frac{dE}{dt}$	$S = k\ln\Omega$	$\mathcal{F} = \mathcal{U} - TS$			

Under Certain Conditions:

$\sum F_x = 0$	$F = mg$	$F = -kx$	$F = \mu_k n$	$F \le \mu_s n$	$\sum \tau = 0$	$F = -bv$
$\frac{dU}{dT} = cm$	$\frac{dU}{dT} = cn$	$Q = Av$	$\Delta P = QR$	$\mathcal{P} = Q\Delta P$	$PV = NRT$	$PV = nkT$
$W = -T\,\Delta S$						

33 equations

Grading Is A 2 Step Process (students know the criteria)

A : 25 -21 B: 20-17 C: 16-13 D : 12-10 F : 9-0

Qualitative grading – Fast Sorting

A: Good working knowledge of the physics, mathematics, and logic; some minor mistakes, no major mistakes

B: Adequate working knowledge of the physics, math, and logic; only one major physics error, some minor mistakes

C: Shows familiarity with the physics, math, and logic; reasonable interpretation of the problem related to physics, attempts to construct a logical problem solution; a few major physics errors; minor mistakes

D: Shows evidence of having attended class or read the text; does not interpret the problem in a complete manner and relate it to physics, cannot construct a logical problem solution; many major physics errors and missing concepts; minor mistakes

F: Could have been written by student who has never taken physics or read the textbook.

Point allocation

- a useful picture, defining the question, and giving your approach - 6 points;
- a complete physics diagram defining the relevant quantities, identifying the target quantity, and specifying the relevant equations with reasons - 6 points;
- planning the solution by constructing the mathematics leading to an algebraic answer and checking the units of that answer - 7 points;
- calculating a numerical value with correct units - 3 points;
- evaluating the validity of the answer - 3 points

The two should agree

Building an Appropriate Task

If you want students to learn to solve problems, they need to practice solving problems and be evaluated on their problem solutions.

Why is this is not a good test question?

Why is this is not a good practice question?

A block of mass m = 2.5 kg starts from rest and slides down a frictionless ramp that makes an angle of θ= 25° with respect to the horizontal floor. The block slides a distance *d* down the ramp to reach the bottom. At the bottom of the ramp, the speed of the block is measured to be *v* = 12 m/s.

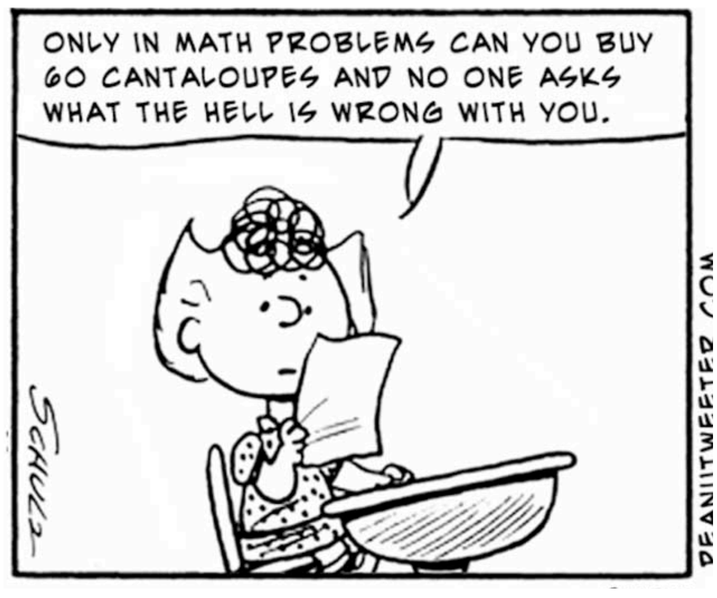
(a) Draw a diagram, labeling θ and d.

(b) What is the acceleration of the block, in terms of g?

(c) What is the distance *d*, in meters?

- Robs students of practice making decisions
- Does not reinforce motivation – reason to solve problems
- Students do not practice linking to their existing information

All tasks need a reasonable motivation



Original

A block of mass m = 2.5 kg starts from rest and slides down a frictionless ramp that makes an angle of θ= 25° with respect to the horizontal floor. The block slides a distance *d* down the ramp to reach the bottom. At the bottom of the ramp, the speed of the block is measured to be *v* = 12 m/s.

(a) Draw a diagram, labeling θ and d.

(b) What is the acceleration of the block, in terms of g?

(c) What is the distance *d*, in meters?

Better

A 2.5 kg block starts from the top and slides down a slippery ramp reaching 12 m/s at the bottom. How long is the ramp? The ramp is at 25° to the horizontal floor .

Practice making decisions

- **Logic of solution.**
- **Name of quantities**
- **Assumption for friction**

Even Better

You are working with a design team to build a system to transport boxes from one part of a warehouse to another. In the design, boxes are placed at the top of the ramp sliding down to their destination. A box slides easily because the ramp is covered with rollers. Your job is to calculate the maximum length of the ramp if the heaviest box is 25 kg and the ramp is at 5.0° to the horizontal. To be safe, no box should go faster than 3.0 m/s when it reaches the end of the ramp.

Requires student decisions.
Practice making assumptions.
Connects to student reality.
Has a motivation (why should I care?).
Can be evaluated because the numbers make sense

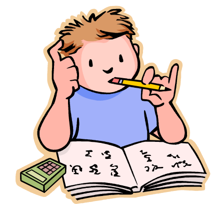
Context Rich Problem

Standard Student Problem-solving Framework

STEP 1

What Kind of Problem is This?

Does it match something I have done before?



STEP 2

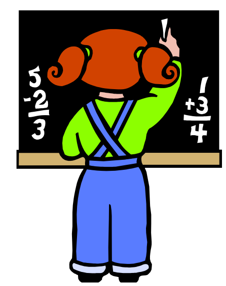
What Equation Is Needed?

One should match this situation

STEP 3

Do Some Math

Plug in numbers



STEP 4

Do Some More Math

Manipulate equations to get the an answer.

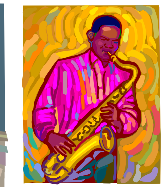
STEP 5

Is It Done?

Stop when I get an answer.

Problem Solving Framework
Used by experts in all fields





G. Polya, 1945

STEP 1 **Recognize the Problem**

What's going on and what do I want?

Not a linear sequence. Requires continuous reflection and iteration.

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 what I want?

STEP 4 **Execute the plan**

Let's get the answer.

STEP 5 **Evaluate the solution**

Can this be true?

"I was a student in first year physics you taught 20 years ago. Since those days I have made a good living as an RF integrated circuit design engineer. I am writing to let you know not a week goes by without a slew of technical problems to be solved, and the first thing that comes to mind is the "define the problem" which I recently reminded myself that it was you who instilled this ever so important step in problem solving. I would like to thank you because your influence has helped me excel and become a better engineer."

email received June, 2012

Problem Solving Decision Framework Details

Instructor needs to continually show how to use this framework in class

STEP 1

Focus the Problem

Draw a useful picture of the situation
Specify useful quantities: identify what you know & don't know
State the question in terms of something you can calculate.

STEP 2

Describe the physics

Require conceptual knowledge

State general principles that might be useful to approach this problem
Give any constraints imposed by the situation
State any approximations that might be useful
Draw any diagrams that might be useful
Translate the general principles into equations specific to the situation

STEP 3

Plan a solution

Requires an organized method

Identify your target quantity
Construct a mathematical chain linking your target to known quantities
Check to see if you have sufficient information.

STEP 4

Execute the plan

← The only math

Follow your plan to calculate an answer
Check your units. If they don't check, find the mistake.

Solving a problem requires many decisions and takes time.

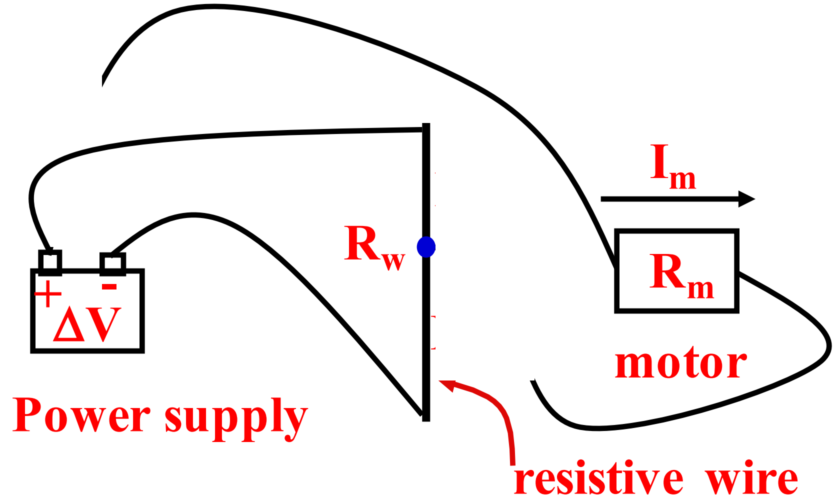
STEP 5

Evaluate the solution

Did you answer the question?
Justify that your answer is not unreasonable? If it is, find the mistake.

Modeling solving a problem

You are on a team designing a rotary motor microtome. The speed of the motor is controlled by the current through it. To make a control, you connect a resistive wire in series with the voltage source. One terminal of the motor is then connected to one terminal of the source. The other terminal of the motor is connected to a point on the resistive wire that can be adjusted. This connection divides the resistive wire into two resistors whose ratio can be changed by moving the point of contact on the resistive wire. To determine the precision of this arrangement, you decide to determine how the resistance ratio changes the current through the motor as a function of the properties of the voltage source, the motor, and the resistive wire.



Know

Properties of battery: ΔV

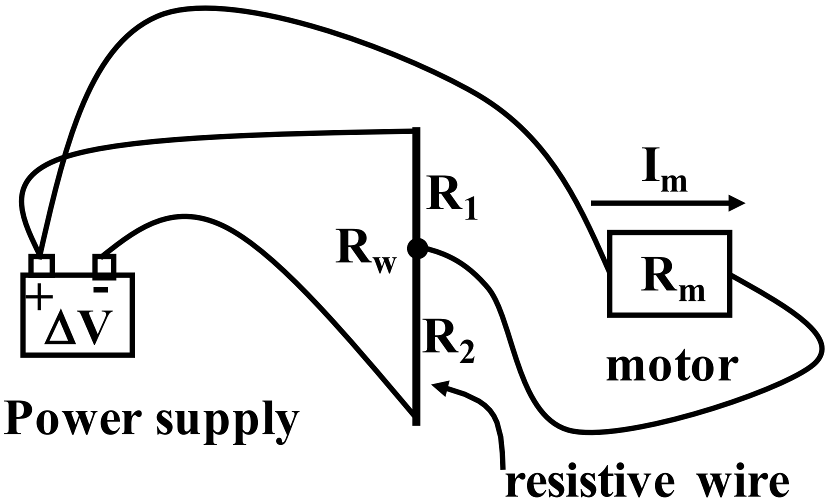
Properties of motor: R_m

Resistance of resistive wire: R_w

Ratio of R_1 to R_2

Question:

What is the current through the motor as a function of the ratio of R_1 to R_2, the resistance of the motor, the voltage difference of the battery, and the total resistance of the resistive wire?



Know
Properties of battery: ΔV
Properties of motor: R_m
Resistance of resistive wire: R_w
Ratio of R_1 to R_2

Question:
What is the current through the motor as a function of the ratio of R_1 to R_2, the resistance of the motor, the voltage difference of the battery, and the total resistance of the resistive wire?

Approach:

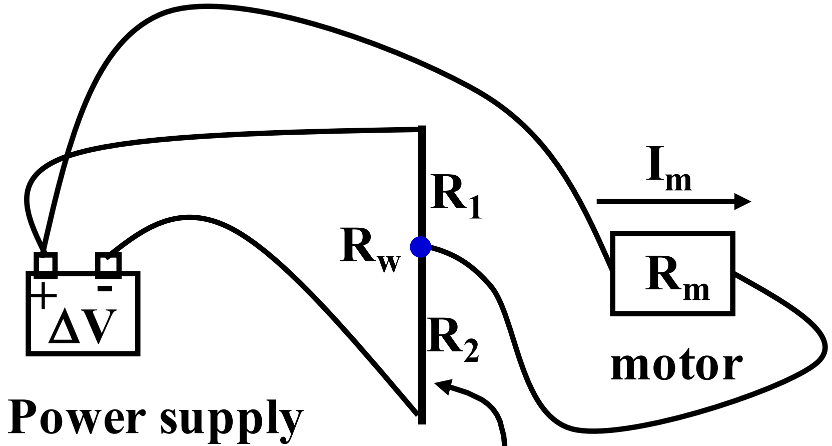
Use conservation of charge.

- **The current through into an object equals the current out of an object.**
- **The current into a junction equals the sum of the current out of that junction.**

Use conservation of energy.

- **Follow a single electron around the circuit.**
- **System: an electron**
- **Initial time: electron leaves battery**
- **Final time: electron enters battery.**
- **Energy input: none**
- **Energy output: from motor, resistive wire**

Assume:
The motor and the resistive wire are ohmic. The voltage drop across them is proportional to the current through them.



resistive wire

Approach:

Use conservation of charge.

- The current through into an object equals the current out of an object.
- The current into a junction equals the sum of the current out of that junction.

Use conservation of energy.

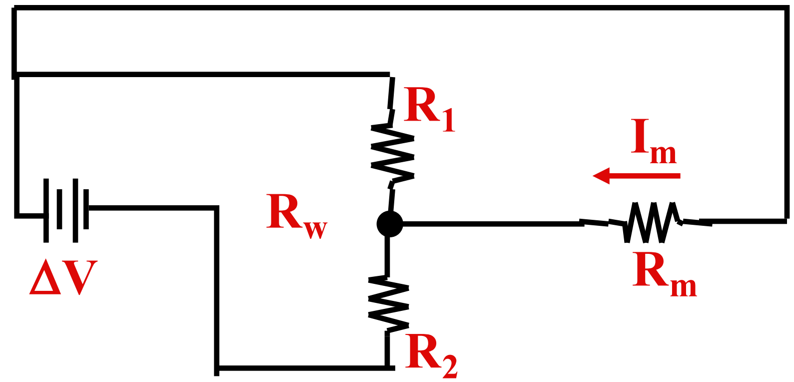
- Follow a single electron around the circuit.
- System: an electron
- Initial time: electron leaves battery
- Final time: electron enters battery.
- Energy input: none
- Energy output: from motor, resistive wire

Assume:

The motor and the resistive wire are ohmic. The voltage drop across them is proportional to the current through them.

Diagram

Can simplify the diagram



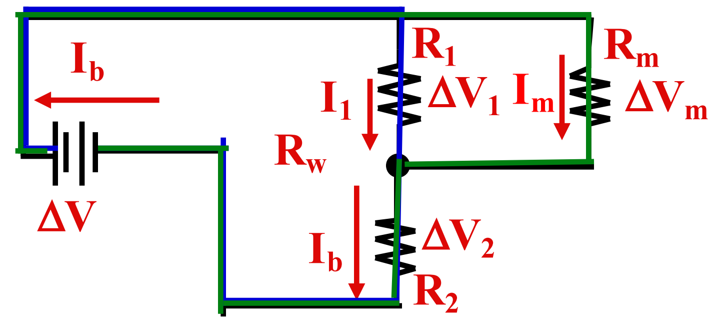
Know:

ΔV

R_m

$r = R_1/R_2$

R_w



Add other important quantities

Target: I_m

Quantitative information:

Conservation of charge: $I_b = I_1 + I_m$

Conservation of energy:

$\Delta V = \Delta V_1 + \Delta V_2$ Blue path

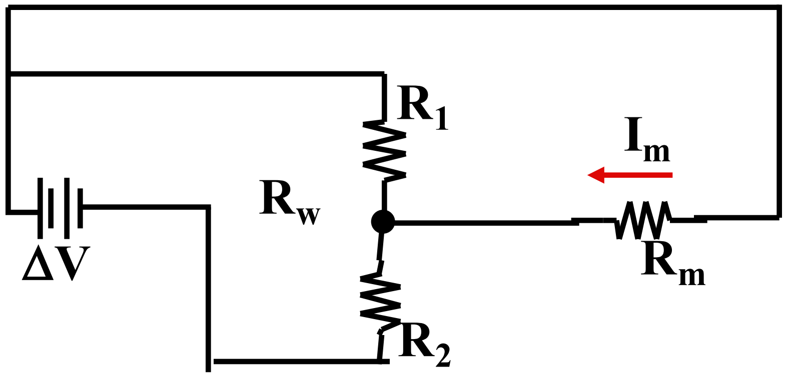
$\Delta V = \Delta V_m + \Delta V_2$ Green path

$\Delta V_1 = I_1 R_1$ $\Delta V_2 = I_b R_2$

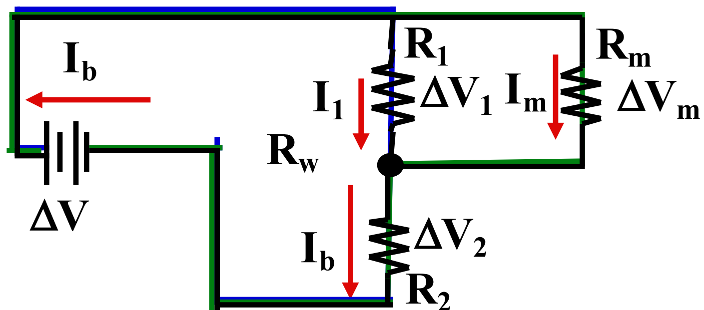
$\Delta V_m = I_m R_m$

$R_w = R_1 + R_2$ $r = R_1/R_2$

Diagram



Know:
ΔV
R_m
$r = R_1/R_2$
R_w



Add other important quantities

Target: I_m

Quantitative information:

Conservation of charge: $I_b = I_1 + I_m$ √

Conservation of energy:

$\Delta V = \Delta V_1 + \Delta V_2$ Blue path

$\Delta V = \Delta V_m + \Delta V_2$ Green path

$\Delta V_1 = I_1 R_1$ √ $\Delta V_2 = I_b R_2$ √

$\Delta V_m = I_m R_m$

$R_w = R_1 + R_2$ √ $r = R_1/R_2$

Plan		unknowns
Find I_m		I_m
$I_b = I_1 + I_m$	[1]	I_b, I_1
Find I_1		
$\Delta V_1 = I_1 R_1$	[2]	ΔV_1, R_1
Find R_1		
$R_w = R_1 + R_2$	[3]	R_2
Find R_2		
$\Delta V_2 = I_b R_2$	[4]	ΔV_2
Find I_b		

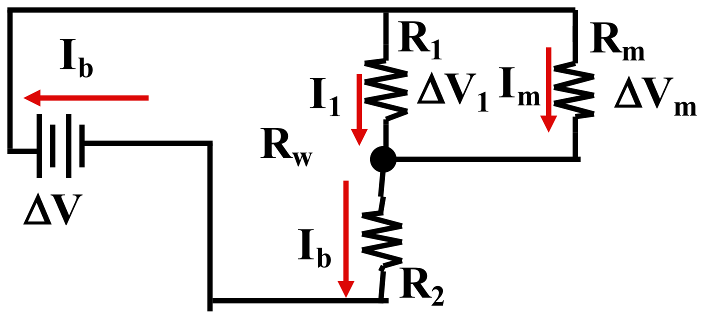
No equation?????
Dead end!!

Other choices possible?

Save equation [4] for I_b and find another equation for R_2

Try using $r = R_1/R_2$

Diagram



Know:

ΔV $\quad r = R_1/R_2$

R_m $\quad R_w$

Target: I_m

Quantitative relationships:

Conservation of charge: $I_b = I_1 + I_m$ √

Conservation of energy:

$\Delta V = \Delta V_1 + \Delta V_2$ √

$\Delta V = \Delta V_m + \Delta V_2$ √

$\Delta V_1 = I_1 R_1$ √ $\quad \Delta V_2 = I_b R_2$ √

$\Delta V_m = I_m R_m$ √

$R_w = R_1 + R_2$ √ $\quad r = R_1/R_2$ √

Plan

Plan		unknowns
Find I_m		I_m
$I_b = I_1 + I_m$	[1]	I_b, I_1
Find I_1		
$\Delta V_1 = I_1 R_1$	[2]	ΔV_1, R_1
Find R_1		
$R_w = R_1 + R_2$	[3]	R_2
Find R_2		
$r = R_1/R_2$	[4]	
Find ΔV_1		
$\Delta V = \Delta V_1 + \Delta V_2$	[5]	ΔV_2
Find ΔV_2		
$\Delta V = \Delta V_m + \Delta V_2$	[6]	ΔV_m
Find ΔV_m		
$\Delta V_m = I_m R_m$	[7]	
Find I_b		
$\Delta V_2 = I_b R_2$	[8]	

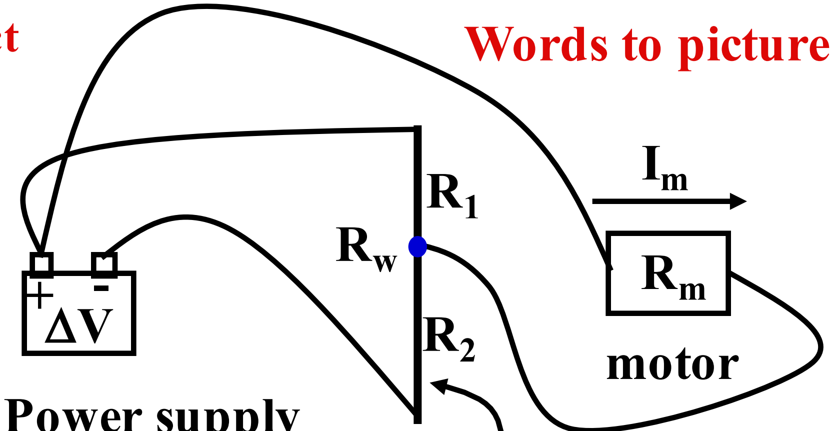
8 unknowns, 8 equations OK to solve

Recap

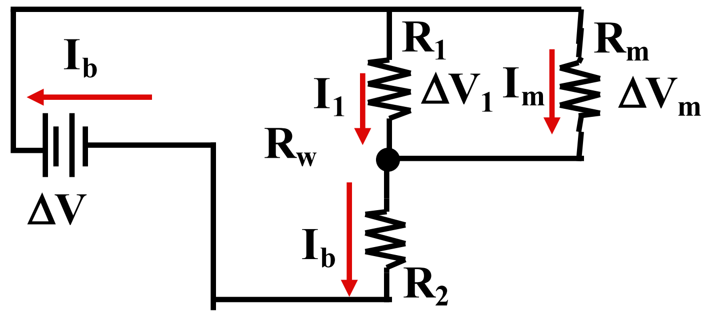
You are on a team designing a rotary motor microtome. The speed of the motor is controlled by the current through it. To make a control, you connect a resistive wire in series with the voltage source. One terminal of the motor is then connected to one terminal of the source. The other terminal of the motor is connected to a point on the resistive wire that can be adjusted. This connection divides the resistive wire into two resistors whose ratio can be changed by moving the point of contact on the resistive wire. To determine the precision of this arrangement, you decide to determine how the resistance ratio changes the current through the motor as a function of the properties of the voltage source, the motor, and the resistive wire.

Moving contact resistive wire called a potentiometer or pot.

Words to picture



Picture to diagram



Target & knowns

Target: I_m

Know:

ΔV $\quad r = R_1/R_2$

R_m $\quad R_w$

Physics

Ohm's law

$$\Delta V_m = I_m R_m$$

$$\Delta V_1 = I_1 R_1$$

$$\Delta V_2 = I_b R_2$$

Conservation of charge

$$I_b = I_1 + I_m$$

Conservation of energy

$$\Delta V = \Delta V_1 + \Delta V_2$$

$$\Delta V = \Delta V_m + \Delta V_2$$

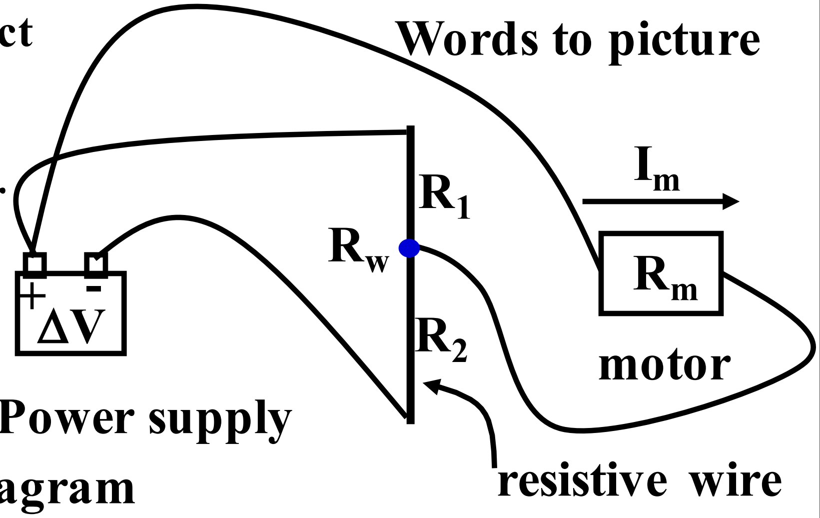
Other information

$$r = R_1/R_2$$

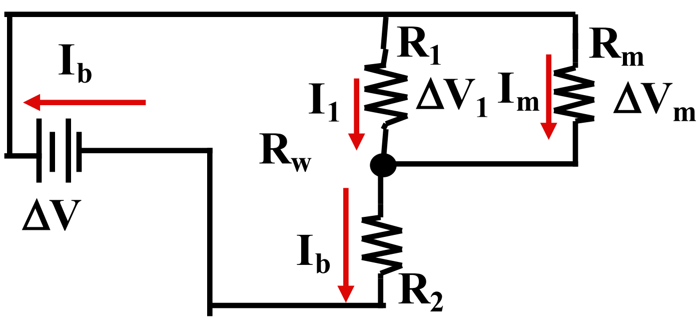
$$R_w = R_1 + R_2$$

Moving contact resistive wire called a potentiometer or pot.

Words to picture



Picture to diagram



Target & knowns

Physics

Target: I_m

Ohm's law

$\Delta V_m = I_m R_m$

$\Delta V_1 = I_1 R_1$

$\Delta V_2 = I_b R_2$

Conservation of charge

$I_b = I_1 + I_m$

Conservation of energy

$\Delta V = \Delta V_1 + \Delta V_2$

$\Delta V = \Delta V_m + \Delta V_2$

Know:

ΔV	$r = R_1/R_2$
R_m	R_w

Other information

$r = R_1/R_2$

$R_w = R_1 + R_2$

Plan

Plan		unknowns
Find I_m		I_m
$I_b = I_1 + I_m$	[1]	I_b, I_1
Find I_1		
$\Delta V_1 = I_1 R_1$	[2]	ΔV_1, R_1
Find R_1		
$R_w = R_1 + R_2$	[3]	R_2
Find R_2		
$r = R_1/R_2$	[4]	
Find ΔV_1		
$\Delta V = \Delta V_1 + \Delta V_2$	[5]	ΔV_2
Find ΔV_2		
$\Delta V = \Delta V_m + \Delta V_2$	[6]	ΔV_m
Find ΔV_m		
$\Delta V_m = I_m R_m$	[7]	
Find I_b		
$\Delta V_2 = I_b R_2$	[8]	

8 unknowns, 8 equations OK to solve

Solve

Plan — unknowns

Find I_m — I_m

$I_b = I_1 + I_m$ [1] — I_b, I_1

Find I_1

$\Delta V_1 = I_1 R_1$ [2] — $\Delta V_1, R_1$

Find R_1

$R_w = R_1 + R_2$ [3] — R_2

Find R_2

$r = R_1/R_2$ [4]

Find ΔV_1

$\Delta V = \Delta V_1 + \Delta V_2$ [5] — ΔV_2

Find ΔV_2

$\Delta V = \Delta V_m + \Delta V_2$ [6] — ΔV_m

Find ΔV_m

$\Delta V_m = I_m R_m$ [7]

Find I_b

$\Delta V_2 = I_b R_2$ [8]

8 unknowns, 8 equations OK to solve

Solve

Solve [8] for I_b

$\Delta V_2 = I_b R_2$

$\frac{V_2}{R_2} = I_b$ Put into [1]

[1] $\frac{V_2}{R_2} = I_1 + I_m$

Solve [7] for ΔV_m

$\Delta V_m = I_m R_m$ Put into [6]

Solve [6] for ΔV_2

$\Delta V = I_m R_m + \Delta V_2$

$V - I_m R_m = V_2$ Put into [1] and [5]

[1] $\frac{V - I_m R_m}{R_2} = I_1 + I_m$

Solve [5] for ΔV_1

$V = V_1 + \left(V - I_m R_m \right)$

$I_m R_m = V_1$ Put into [2]

[2] $I_m R_m = I_1 R_1$

Solve [4] for R_2

$r = R_1/R_2$

$R_2 = R_1 / r$ Put into [1] and [3]

Solve [8] for I_b

$\Delta V_2 = I_b R_2$

$$\frac{V_2}{R_2} = I_b$$ Put into [1]

[1] $$\frac{V_2}{R_2} = I_1 + I_m$$

Solve [7] for ΔV_m

$\Delta V_m = I_m R_m$ Put into [6]

Solve [6] for ΔV_2

$\Delta V = I_m R_m + \Delta V_2$

$$V - I_m R_m = V_2$$ Put into [1] and [5]

[1] $$\frac{V - I_m R_m}{R_2} = I_1 + I_m$$

Solve [5] for ΔV_1

$$V = V_1 + \left(V - I_m R_m \right)$$

$$I_m R_m = V_1$$ Put into [2]

[2] $I_m R_m = I_1 R_1$

Solve [4] for R_2

$r = R_1/R_2$

$R_2 = R_1/r$ Put into [1] and [3]

[1] $$\frac{V - I_m R_m}{\frac{R_1}{r}} = I_1 + I_m$$

Find R_1

$R_w = R_1 + R_2$ [3]

Solve [3] for R_1

$R_w = R_1 + R_1/r$

$$R_w = R_1\left(1 + \frac{1}{r}\right)$$

$$\frac{R_w}{\left(1 + \frac{1}{r}\right)} = R_1$$ Put into [1] and [2]

[1] $$r\frac{V - I_m R_m}{\frac{R_w}{1 + \frac{1}{r}}} = I_1 + I_m$$

Solve [2] for I_1

$$I_m R_m = I_1 \frac{R_w}{\left(1 + \frac{1}{r}\right)}$$

$$\frac{I_m R_m \left(1 + \frac{1}{r}\right)}{R_w} = I_1$$ Put into [1]

[1] $$\frac{V - I_m R_m}{\frac{R_1}{r}} = I_1 + I_m$$

Solve [3] for R_1

Find R_1

$R_w = R_1 + R_2$ [3]

$$R_w = R_1 + R_1/r$$

$$R_w = R_1\left(1+\frac{1}{r}\right)$$

$$\frac{R_w}{\left(1+\frac{1}{r}\right)} = R_1$$

Put into [1] and [2]

[1] $$r\,\frac{V - I_m R_m}{\frac{R_w}{1+\frac{1}{r}}} = I_1 + I_m$$

Solve [2] for I_1

$$I_m R_m = I_1 \frac{R_w}{\left(1+\frac{1}{r}\right)}$$

$$\frac{I_m R_m\left(1+\frac{1}{r}\right)}{R_w} = I_1$$

Put into [1]

Solve [1] for I_m

$$r\,\frac{V - I_m R_m}{\frac{R_w}{1+\frac{1}{r}}} = \frac{I_m R_m\left(1+\frac{1}{r}\right)}{R_w} + I_m$$

$$r\;\; V - rI_m R_m = \frac{R_w}{1+\frac{1}{r}}\,\frac{I_m R_m\left(1+\frac{1}{r}\right)}{R_w} + I_m\,\frac{R_w}{1+\frac{1}{r}}$$

$$r\;\; V - rI_m R_m = I_m R_m + rI_m\,\frac{R_w}{r+1}$$

$$r\;\; V = I_m R_m + rI_m\,\frac{R_w}{r+1} + rI_m R_m$$

$$r\;\; V = I_m\left(R_m + r\,\frac{R_w}{r+1} + rR_m\right)$$

$$\frac{r\;\; V}{\left(R_m + r\,\frac{R_w}{r+1} + rR_m\right)} = I_m$$

$$\boxed{\frac{r\;\; V}{\left(r\,\frac{R_w}{r+1} + (1+r)R_m\right)} = I_m}$$

Solve [1] for I_m

$$r\frac{\frac{V-I_mR_m}{R_w}}{1+\frac{1}{r}}=\frac{I_mR_m(1+\frac{1}{r})}{R_w}+I_m$$

$$r\ V-rI_mR_m=\frac{R_w}{1+\frac{1}{r}}\frac{I_mR_m(1+\frac{1}{r})}{R_w}+I_m\frac{R_w}{1+\frac{1}{r}}$$

$$r\ V-rI_mR_m=I_mR_m+rI_m\frac{R_w}{r+1}$$

$$r\ V=I_mR_m+rI_m\frac{R_w}{r+1}+rI_mR_m$$

$$r\ V=I_m(R_m+r\frac{R_w}{r+1}+rR_m)$$

$$\frac{r\ V}{(R_m+r\frac{R_w}{r+1}+rR_m)}=I_m$$

$$\boxed{\frac{r\ V}{(r\frac{R_w}{r+1}+(1+r)R_m)}=I_m}$$

Know:

ΔV $\quad r = R_1/R_2$

R_m $\quad R_w$

The target is expressed only in terms of known quantities

Check units:

$$\frac{[V]}{[\ \ ]+[\ \ ]}=\frac{[V]}{[\ \ ]}=[A]$$

Amps is the correct units for current

Evaluate

In the final equation, if the power supply voltage is increased, the current through the motor is increased. It is reasonable that a higher voltage power supply would give a higher voltage across the motor and thus cause more current to go through the motor.

Worksheet to help organize for Quiz 1

FOCUS on the PROBLEM
Picture and Given Information

Question(s)

Approach

DESCRIBE the PHYSICS
Diagram(s) and Define Quantities

Target Quantity(ies)

Quantitative Relationships

PLAN the SOLUTION
Construct Specific Equations

EXECUTE the PLAN
Follow the Plan

Check Units

Calculate Target Quantity(s)

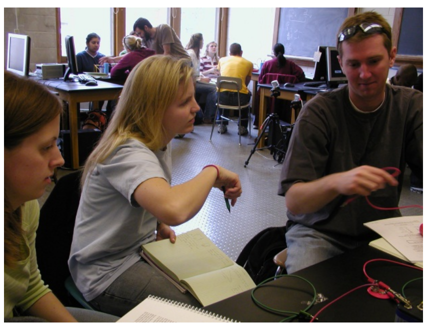
EVALUATE the ANSWER
Is The Question Answered?

Is Answer Unreasonable?

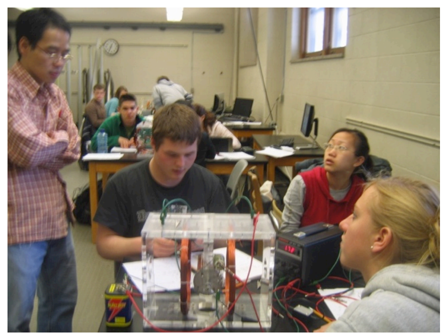
Necessary Elements of Course

1. **Tests** that Require Students to Solve Complex Problems Using an Organized Framework.
2. **Grading** that Reinforces Problem Solving Using Fundamental Physics
3. **Lectures** that Demonstrate Using an Organized Framework for Making Problem Solving Decisions
4. **Coaching** Students While They Solve Problems – labs, discussion sections, lectures
5. **Out of class work** – homework from text (can be non-graded), textbook reading quiz (on computer), prelecture questions (JITT, on computer), office hours, computer problem solving coach.

Groups Can Be Effective for Coaching



Peer coaching



Instructor coaching

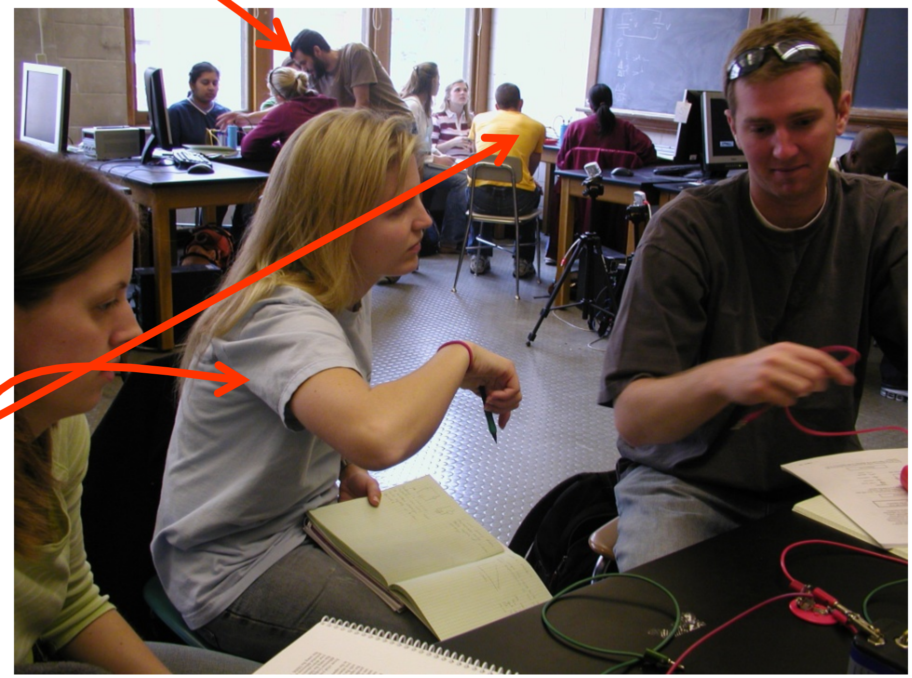
Most students do not benefit from working in unstructured groups

Effective Coaching Using Cooperative Groups

Discussion Section & Lab Environment

- Students work on an appropriate task in small groups.
- Students coach each other.
- Instructor coaches a group as needed.

TA Coaching One Group



Groups Discussing Physics

However, having just students work together in groups is not beneficial

- Groups must have a collaborative structure
- Groups must be actively managed by the instructor
- Task must be appropriate for group work (Context-rich problems are)

What are Cooperative Groups

Provide peer coaching and facilitate expert coaching

Allow success solving complex problems with an organized framework from the beginning of the course.

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

Johnson & Johnson, 1978

Email 8/24/05

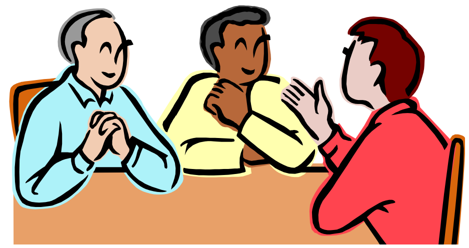
"Another good reason for cooperative group methods: this is how we solve all kinds of problems in the real world - the real academic world and the real business world. I wish they'd had this when I was in school. Keep up the great work."

Vice President,

Hewlett Packard

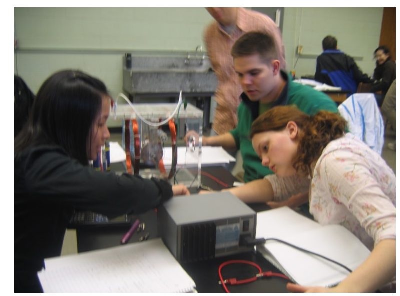
Structure and Management of Groups

1. **What is the "optimal" group size?**
   - Three (or occasionally four) for novices



2. **What should be the gender and performance composition of cooperative groups?**
   - Heterogeneous groups:
     - one from top third
     - one from middle third
     - one from bottom third

     based on past test performance.
   - Two women with one man, or same-gender groups
   - Students never choose their own groups



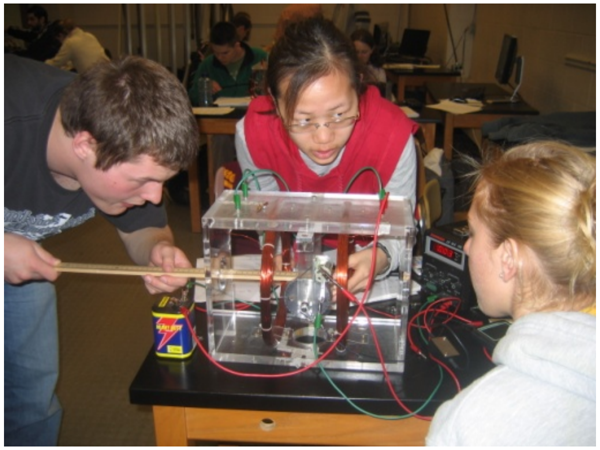
Structure and Management of Groups

3. How often should the groups be changed?

- 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 per semester

Tell students at the beginning of term how often groups will be changed.

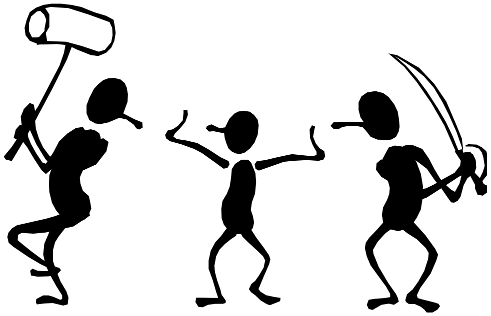
- reassure students at the beginning that they will not be “stuck” with the same people.
- combat resistance at first group change.



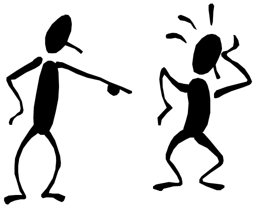
Structure and Management of Groups

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 for all members. Working well together has consequences.
- Assign and rotate roles:
  - Manager
  - Skeptic
  - Checker/Recorder
  - Summarizer

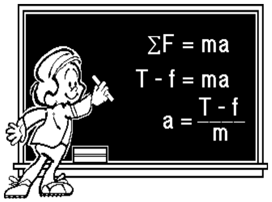


- Most of grade is based on individual problem solving.
- Occasional class time for students to discuss how they worked together and how they could be more effective.



Structure and Management of Groups

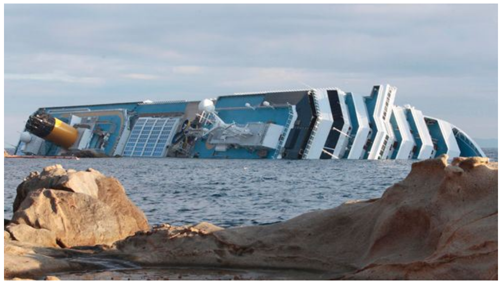
5. How can individual accountability be addressed?



- assign and rotate roles, occasional group functioning self-assessment;
- seat arrangement -- eye-to-eye, knee-to-knee;
- individual students randomly called on to present group results;
- a group problem counts as a test question -- if group member was absent the weeks before, he or she cannot take group test unless OKed by the instructor and the group;
- most of the test is taken individually. The final exam is all individual. All lab reports are individual with each group member reporting on a different lab problem

Other situations that prevent effective group work

- Allowing books or notes
- Working individually and comparing results
- Allowing one student to do the work



Cooperative Group Problem Solving Is Not Just for Intro. Physics

After introduction in algebra based physics – U of M faculty began using it in other courses

Algebra-based Intro Physics (24 different majors) 1987

Calculus-based Intro Physics (88% engineering majors) 1993

Intro Physics for Biology Majors Course 2003

Upper Division Physics Major Courses 2002

- Analytic Mechanics
- Electricity & Magnetism
- Quantum Mechanics

Graduate Courses 2007

- Quantum Mechanics

Budget constraints prevented additional expansion in physics courses although faculty has requested it in other courses

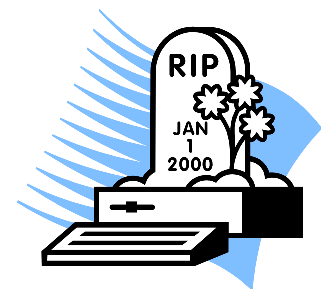
Mechanical Engineering Department 2010

Caution: Learning is Difficult

Changing a deeply held way of thinking is traumatic

That trauma is the death of successful ideas and practices.

New information conflicts with old ideas



Response to emotional trauma
such as dying (Elisabeth Kubler-Ross)

Stages of trauma

- denial
- anger
- bargaining
- depression
- acceptance

5 stages of reacting to a traumatic event : Learning Expert-like Problem Solving!

DENIAL --- "I don't really have to do all that. My way will work! I'll just have to be more careful. I've missed something so I'll work harder."

ANGER --- "%$@^##& professor!", "I shouldn't have to take this course. It's such a weird way of teaching. This has nothing to do with what I need. These problems are tricky and unclear."

BARGAINING --- "Can I do something for extra credit? Just make the problems clearer and give us more time to solve them."

DEPRESSION --- "What am I going to do. I'll never be able to well in this rotten course. I hope I can get lucky enough to just pass".

ACCEPTANCE --- "Ok. I really need to have a logical and organized process to solve problems. These problems really are the kind of thing I need to be able to solve. I actually use this in my other classes and my internship."

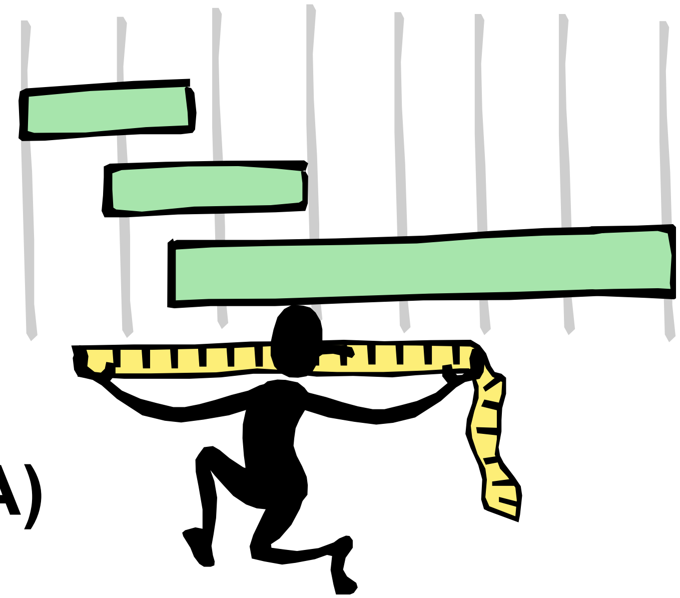
Adapted from Counseling For Loss & Life Changes (1997)
http://www.counselingforloss.com/article8.htm

Email after Introductory Physics for Biology & Pre-Medical Students May, 2013

I am one of your former students in PHYS 1201. I would like to thank you for your efforts in teaching us physics and guiding us through many difficult problems. I am currently studying for the MCAT and realized that your course, even though I hated it in the beginning, has helped me think critically and work through problems in an organized manner.

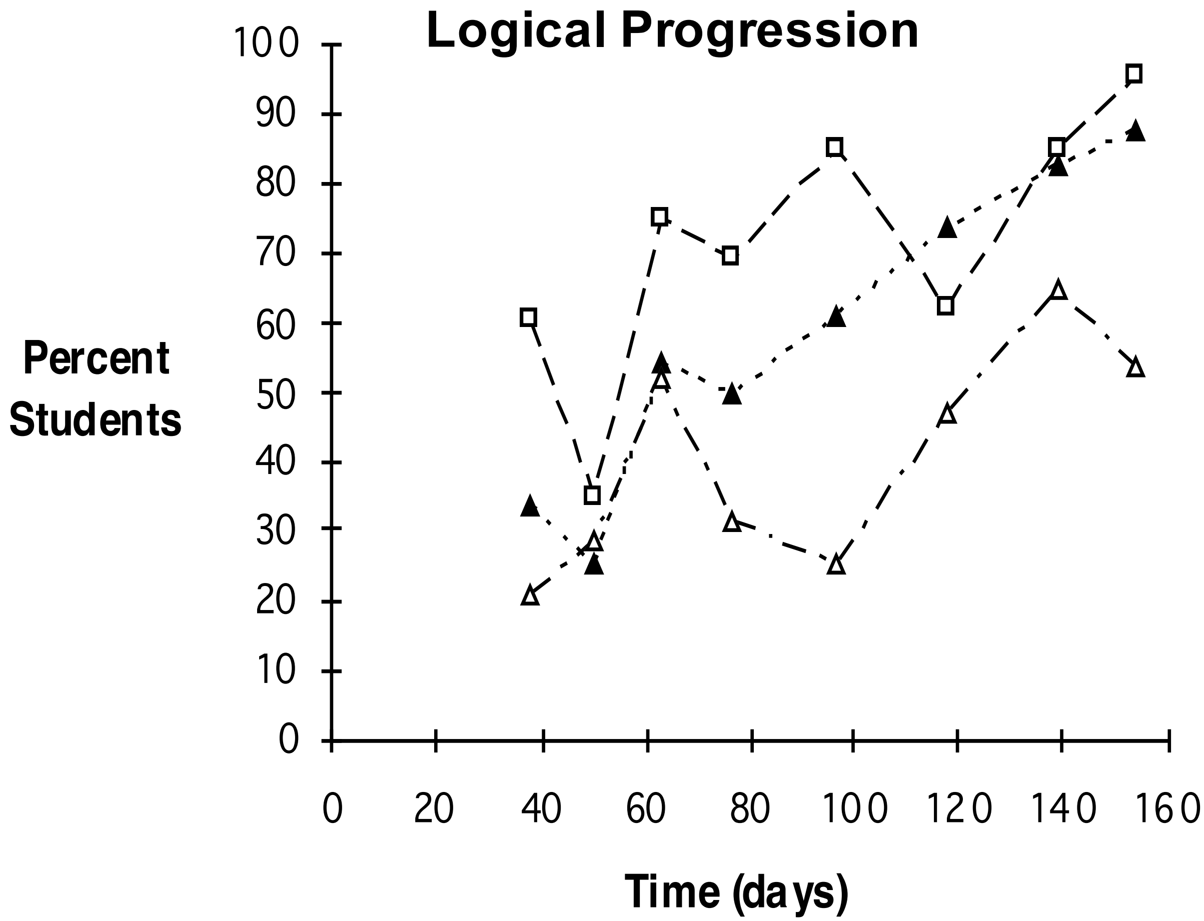
Have a great summer and best wishes,

Assessment



- Problem Solving Skill
- Drop out rate
- Failure rate
- National concept tests (FCI, BEMA)
- National attitude survey (CLASS)
- Math skills test
- What students value in the course
- Engineering student longitudinal study
- Faculty use
- Adoption by other institutions and other disciplines

Improvement in Problem Solving



Algebra based physics 1991

Heller, Keith, and Anderson
Am. J. Phys., Vol. 60, No. 7, July 1992

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?

Measuring Expert-like Problem Solving

Almost Independent Dimensions

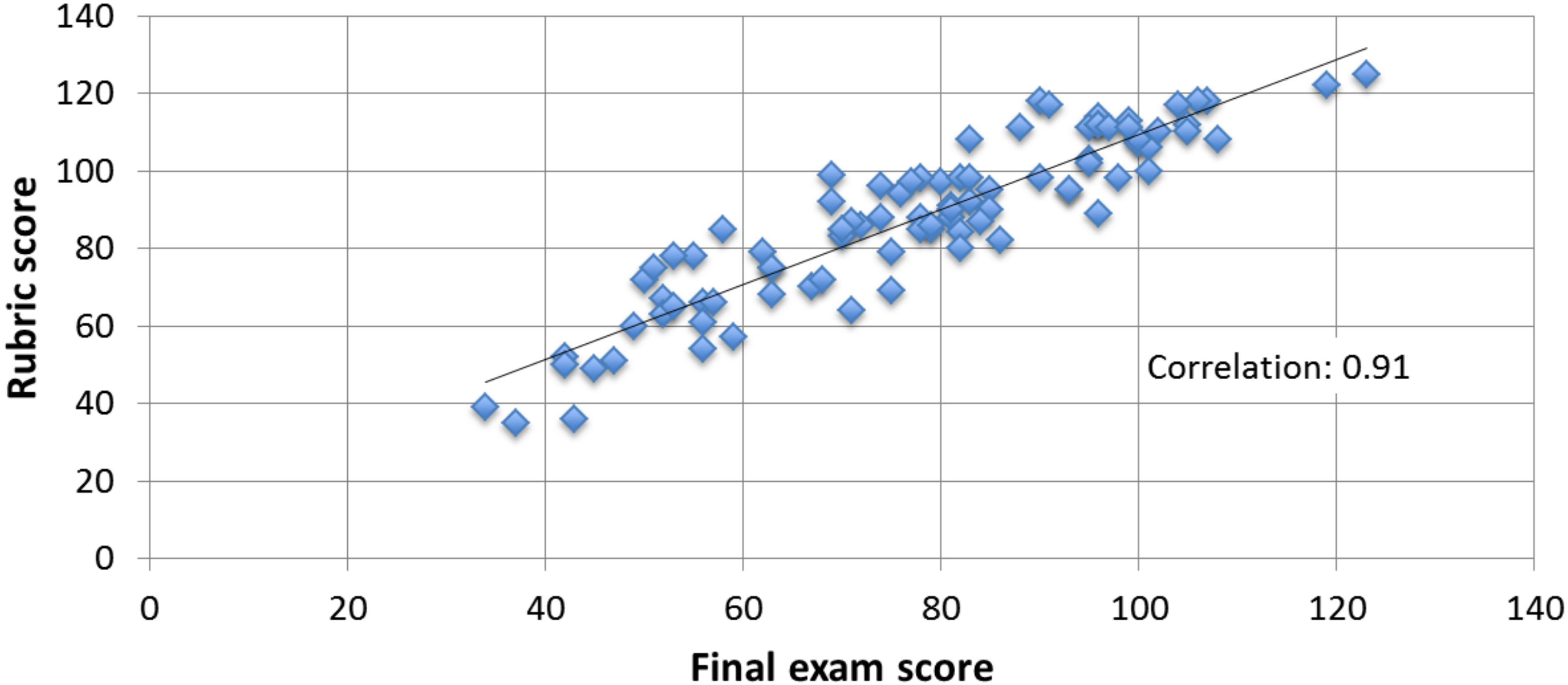
- **Useful Description**
  - organize information from the problem statement symbolically, visually, and/or in writing.
- **Physics Approach**
  - select appropriate physics concepts and principles
- **Specific Application of Physics**
  - apply physics approach to the specific conditions in problem
- **Mathematical Procedures**
  - follow appropriate & correct math rules/procedures
- **Logical Progression**
  - overall the solution progresses logically; it is coherent, focused toward a goal, and consistent (not necessarily linear)

J. Docktor (2009) based on previous work by:

J. Blue (1997); T. Foster (2000); T. Thaden-Koch (2005);

P. Heller, R. Keith, S. Anderson (1992)

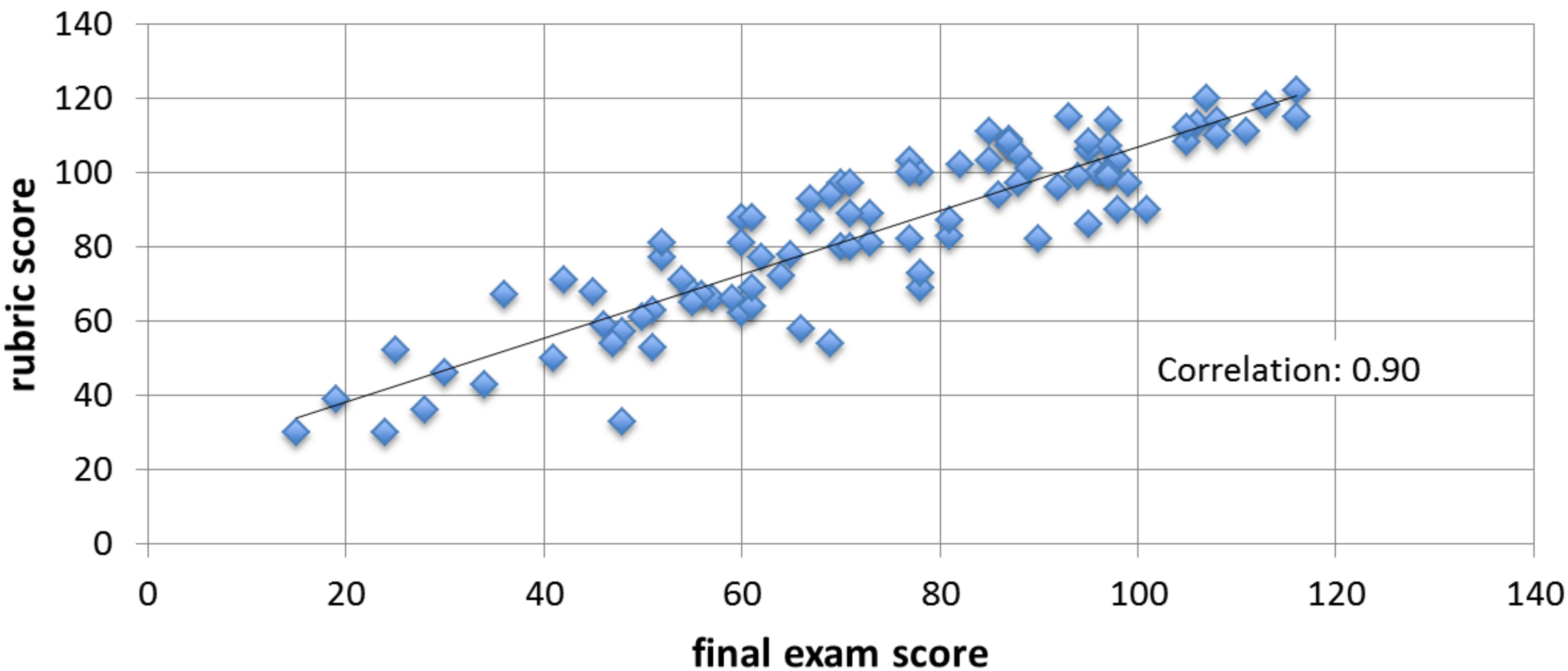
TA Grading Compared to Expert Rubric Grading



5 problems each graded by a different TA

Class 1

Extensive Support program for TAs



Class 2

The End

Please visit our website for more information:

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

PER group reunion
18 years of alumni who contributed to this research.

The best is the enemy of the good.

"le mieux est l'ennemi du bien"

Voltaire