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”
Improve 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
  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

- **LECTURES**: 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)**

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

Textbook: Mazur, Principles & Practice of Physics (Chapters 1 – 15, not 14)
<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Course organization doesn’t follow textbook</th>
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</thead>
<tbody>
<tr>
<td>1-3</td>
<td>Forces and Equilibrium/Problem Solving (Vectors, All forces including friction, spring, buoyancy)</td>
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<tr>
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<td>Chapter: 1.1, 3.1-.5, .12, 13.1, 4.10</td>
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<tr>
<td>4</td>
<td>Torque and Equilibrium</td>
<td>Biomechanics 1</td>
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<td>Chapter: 4.1, .2, .4 – .9</td>
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<tr>
<td>5-8</td>
<td>Force, Energy Transfer, and Conservation of Energy (Energy in all systems including fluid flow)</td>
<td>Energy use 4</td>
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<tr>
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<td>Chapter: 1.1 –1.3, 6.1- .6, .9, .11, 13.2 - .8</td>
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<tr>
<td>9-10</td>
<td>Energy, Systems &amp; Cycles (including fluid circularity system, thermodynamics)</td>
<td>Energy use &amp; energy cycles 6</td>
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<td>Chapter: 14.4, 12.3 - .7, 10.1- .6, 11.1 - .2, .7</td>
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<tr>
<td>11-12</td>
<td>Entropy &amp; Free Energy (entropy as probability)</td>
<td>Entropy driven processes 10</td>
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<td>Notes, Chapter: 11.3</td>
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<tr>
<td>13-14</td>
<td>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)</td>
<td>Complex motion 9</td>
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<tr>
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<td>Chapter: 1, 2, 3.6 - .8, .12, 5.1, 5.2, 9, 14.5</td>
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<td>15</td>
<td>Review</td>
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<td>16</td>
<td>Final Exam</td>
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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
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

<table>
<thead>
<tr>
<th>Undesirable behavior</th>
<th>Desirable behavior</th>
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<tr>
<td>1) -</td>
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Prioritize!

Encourage desired behavior.
Discourage undesirable behavior.

Grading must align with your priorities.
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 -

Unfortunately institutions often do this

Class, I have been teaching you to solve problems by making your own decisions.

Those decisions result in a complex process based on a few basic physics principles. And now your learning will be measured.

With a multiple choice test

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

Martinez, Phi Delta Kappan, April, 1998
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.
Control Equations: Only these are allowed

Useful Mathematical Relationships:

For a right triangle: \( \sin \theta = \frac{a}{c}, \cos \theta = \frac{b}{c}, \tan \theta = \frac{a}{b} \),
\[ a^2 + b^2 = c^2, \quad \sin^2 \theta + \cos^2 \theta = 1 \]
For a circle: \( C = 2\pi R, \quad A = \pi R^2 \)

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

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

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

Fundamental Concepts, Principles, and Definitions:

<table>
<thead>
<tr>
<th>( \sum \vec{F} = ma )</th>
<th>( \rho = \frac{m}{V} )</th>
<th>( \tau = rF_\perp )</th>
<th>( \vec{t} = \vec{r} \times \vec{F} )</th>
<th>( a_x = \frac{dv_x}{dt} )</th>
<th>( v_x = \frac{dx}{dt} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma = \frac{F}{A} )</td>
<td>( \epsilon = \frac{\Delta \ell}{\ell} )</td>
<td>( KE = \frac{1}{2}mv^2 )</td>
<td>( \frac{dE_{\text{transfer}}}{dx} = F_x )</td>
<td>( E_f - E_i = E_{\text{input}} - E_{\text{output}} )</td>
<td></td>
</tr>
<tr>
<td>( X_f - X_i = X_{\text{input}} - X_{\text{output}} )</td>
<td>( \frac{du}{dx} = -F_x )</td>
<td>( P = \frac{F}{A} )</td>
<td>( \epsilon = \frac{E_{\text{desired}}}{E_{\text{input}}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \rho = \frac{dE}{dt} )</td>
<td>( S = k \ln \Omega )</td>
<td>( \mathcal{F} = \mathcal{U} - TS )</td>
<td></td>
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</tbody>
</table>

Under Certain Conditions:

<table>
<thead>
<tr>
<th>( \sum F_x = 0 )</th>
<th>( F = mg )</th>
<th>( F = -kx )</th>
<th>( F = \mu_k n )</th>
<th>( F \leq \mu_s n )</th>
<th>( \sum \tau = 0 )</th>
<th>( F = -bv )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{du}{dT} = cm )</td>
<td>( \frac{du}{dT} = cn )</td>
<td>( Q = Av )</td>
<td>( \Delta P = QR )</td>
<td>( \mathcal{P} = Q\Delta P )</td>
<td>( PV = NRT )</td>
<td>( PV = nkT )</td>
</tr>
</tbody>
</table>

\( W = -T \Delta S \) 

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 \( m = 2.5 \text{ kg} \) starts from rest and slides down a frictionless ramp that makes an angle of \( \theta = 25^\circ \) 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 \( v = 12 \text{ m/s} \).

(a) Draw a diagram, labeling \( \theta \) 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
A block of mass $m = 2.5 \text{ kg}$ starts from rest and slides down a frictionless ramp that makes an angle of $\theta = 25^\circ$ 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 $v = 12 \text{ m/s}$.

(a) Draw a diagram, labeling $\theta$ 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
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

STEP 1
Recognize the Problem
What's going on and what do I want?

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?

email received June, 2012

G. Polya, 1945

Not a linear sequence. Requires continuous reflection and iteration.

“...
Problem Solving Decision Framework Details

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

**STEP 5**
Evaluate the solution
- Did you answer the question?
- Justify that your answer is not unreasonable? If it is, find the mistake.

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

**STEP 1**
Focus the Problem
- Instructor needs to continually show how to use this framework in class

**STEP 2**
Describe the physics
- Instructor needs to continually show how to use this framework in class

**STEP 3**
Plan a solution
- Instructor needs to continually show how to use this framework in class

**STEP 4**
Execute the plan
- Instructor needs to continually show how to use this framework in class

**STEP 5**
Evaluate the solution
- Instructor needs to continually show how to use this framework in class

The only math solving a problem requires many decisions and takes time.

Requires conceptual knowledge

Requires an organized method

Solving a problem requires many decisions and takes time.
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: $\Delta V$
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: $\Delta V$
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.
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.
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Assume:
The motor and the resistive wire are ohmic. The voltage drop across them is proportional to the current through them.
Plan

Find $I_m$

$I_b = I_1 + I_m$  [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 $R_2$

$\Delta V_2 = I_b R_2$  [4]  $\Delta V_2$

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

\[ I_b \]
\[ \Delta V \]
\[ R_w \]
\[ I_1 \]
\[ R_1 \]
\[ \Delta V_1 \]
\[ I_m \]
\[ \Delta V_m \]

Target: \( I_m \)

Know:
\( \Delta V \quad r = R_1/R_2 \)
\( R_m \quad R_w \)

Plan

Find \( I_m \)
\( I_b = I_1 + I_m \) \[1\]

Find \( I_1 \)
\( \Delta V_1 = I_1 R_1 \) \[2\]

Find \( R_1 \)
\( R_w = R_1 + R_2 \) \[3\]

Find \( R_2 \)
\( r = R_1/R_2 \) \[4\]

Find \( \Delta V_1 \)
\( \Delta V = \Delta V_1 + \Delta V_2 \) \[5\]

Find \( \Delta V_2 \)
\( \Delta V = \Delta V_m + \Delta V_2 \) \[6\]

Find \( \Delta V_m \)
\( \Delta V_m = I_m R_m \) \[7\]

Find \( I_b \)
\( \Delta V_2 = I_b R_2 \) \[8\]

8 unknowns, 8 equations OK to solve

Quantitative relationships:
Conservation of charge: \( I_b = I_1 + I_m \) \( \checkmark \)
Conservation of energy:
\( \Delta V = \Delta V_1 + \Delta V_2 \) \( \checkmark \)
\( \Delta V = \Delta V_m + \Delta V_2 \) \( \checkmark \)
\( \Delta V_1 = I_1 R_1 \) \( \checkmark \)
\( \Delta V_2 = I_b R_2 \) \( \checkmark \)
\( \Delta V_m = I_m R_m \) \( \checkmark \)
\( R_w = R_1 + R_2 \) \( \checkmark \)
\( r = R_1/R_2 \) \( \checkmark \)
**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.

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**Diagram**

- **Target & knows**
  - Target: \( I_m \)
  - Know: \( \Delta V \) \( \frac{r}{R_m} = \frac{R_1}{R_2} \)
  - Know: \( R_w = R_1 + R_2 \)

- **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
    - \( \Delta V = \Delta V_1 + \Delta V_2 \)
    - \( \Delta V = \Delta V_m + \Delta V_2 \)
Moving contact resistive wire called a potentiometer or pot.

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: \( \Delta V = \Delta V_1 + \Delta V_2 \)

Know:

- \( \Delta V = \Delta V_m + \Delta V_2 \)
- \( r = \frac{R_1}{R_2} \)
- \( R_w = R_1 + R_2 \)

Plan

- Find \( I_m \)
- \( I_b = I_1 + I_m \) [1]
- Find \( I_1 \)
- \( \Delta V_1 = I_1 R_1 \) [2]
- Find \( R_1 \)
- \( R_w = R_1 + R_2 \) [3]
- Find \( R_2 \)
- \( r = \frac{R_1}{R_2} \) [4]
- Find \( \Delta V_1 \)
- \( \Delta V = \Delta V_1 + \Delta V_2 \) [5]
- Find \( \Delta V_2 \)
- \( \Delta V = \Delta V_m + \Delta V_2 \) [6]
- Find \( \Delta V_m \)
- \( \Delta V_m = I_m R_m \) [7]
- Find \( I_b \)
- \( \Delta V_2 = I_b R_2 \) [8]

8 unknowns, 8 equations OK to solve

Solve
Plan
Find $I_m$
$I_b = I_1 + I_m$ \[1\]

Find $I_1$
$\Delta V_1 = I_1 R_1$ \[2\]

Find $R_1$
$R_w = R_1 + R_2$ \[3\]

Find $R_2$
$r = R_1/R_2$ \[4\]

Find $\Delta V_1$
$\Delta V = \Delta V_1 + \Delta V_2$ \[5\]

Find $\Delta V_2$
$\Delta V = \Delta V_m + \Delta V_2$ \[6\]

Find $\Delta V_m$
$\Delta V_m = I_m R_m$ \[7\]

Find $I_b$
$\Delta V_2 = I_b R_2$ \[8\]

8 unknowns, 8 equations OK to solve

Solve

Solve [8] for $I_b$
$\Delta V_2 = I_b R_2$

Put into [1]

$\frac{V_2}{R_2} = I_b$

Solve [7] for $\Delta V_m$
$\Delta V_m = I_m R_m$

Put into [6]

Solve [6] for $\Delta V_2$
$\Delta V = I_m R_m + \Delta V_2$

Put into [1] and [5]

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

Solve [5] for $\Delta V_1$
$V = V_1 + \left( V - I_m R_m \right)$

$I_m R_m = V_1$

Put into [2]

$I_m R_m = I_1 R_1$

Solve [4] for $R_2$
$r = R_1/R_2$

Put into [1] and [3]

$R_2 = R_1/r$
Solve [8] for $I_b$
$\Delta V_2 = I_b R_2$
\[
\frac{V_2}{R_2} = I_b \quad \text{Put into [1]}
\]

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

Solve [7] for $\Delta V_m$
$\Delta V_m = I_m R_m$ \quad \text{Put into [6]}

Solve [6] for $\Delta V_2$
$\Delta V = I_m R_m + \Delta V_2$
\[
V - I_m R_m = V_2 \quad \text{Put into [1] and [5]}
\]

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

Solve [5] for $\Delta V_1$
$V = V_1 + \left( V - I_m R_m \right)$
\[
I_m R_m = V_1 \quad \text{Put into [2]}
\]

[2] \[ I_m R_m = I_1 R_1 \]

Solve [4] for $R_2$
$r = R_1/R_2$
\[
R_2 = R_1/r \quad \text{Put into [1] and [3]}
\]

[1] \[ \frac{V - I_m R_m}{R_1} = I_1 + I_m \quad \text{Find } R_1 \]

$R_w = R_1 + R_1/r$

\[
R_w = R_1(1 + \frac{1}{r})
\]

Put into [1] and [2]

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

\[
I_m R_m = I_1 \frac{R_w}{(1 + \frac{1}{r})}
\]

Put into [1]
\[
\begin{align*}
\left[1\right] \quad \frac{V-I_mR_m}{R_1} &= I_1 + I_m \\
\text{Solve \left[2\right] for } I_1 \\
I_mR_m &= I_1 \frac{R_w}{(1+\frac{1}{r})} \\
I_mR_m(1+\frac{1}{r}) &= I_1 \\
& \quad \text{Put into \left[1\right]} \\
\left[3\right] \quad R_w &= R_1 + \frac{R_1}{r} \\
& \quad \text{Find } R_1 \\
\left[2\right] \quad \frac{V-I_mR_m}{R_w} &= \frac{I_mR_m(1+\frac{1}{r})}{1+\frac{1}{r}} + I_m \\
\text{Put into \left[1\right]} \\
\text{Solve \left[1\right] for } I_m \\
r \frac{V-I_mR_m}{R_w} &= \frac{I_mR_m(1+\frac{1}{r})}{1+\frac{1}{r}} + I_m \\
\text{Find } R_w = R_1 + R_2 \\
r \frac{V-rI_mR_m}{R_w} &= I_m + rI_m \frac{R_w}{r+1} \\
r \frac{V}{R_m + r \frac{R_w}{r+1} + rR_m} &= I_m \\
\frac{rV}{(r \frac{R_w}{r+1} + (1+r)R_m)} &= I_m
\end{align*}
\]
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.

Know:
\[ \Delta V \quad r = \frac{R_1}{R_2} \]
\[ R_m \quad R_w \]

The target is expressed only in terms of known quantities

Check units:
\[ \left[ \frac{[V]}{[V]} \right] = \left[ \frac{[V]}{[V]} \right] = [\text{A}] \]

Amps is the correct units for current

Evaluate

Solve [1] for \( I_m \)
\[
\frac{r}{1+\frac{1}{r}} \frac{V-I_m R_m}{R_w} = \frac{I_m R_m (1+\frac{1}{r})}{R_w} + I_m
\]

\[
r \ V - rI_m R_m = \frac{R_w}{1+\frac{1}{r}} \frac{I_m R_m (1+\frac{1}{r})}{R_w} + I_m \frac{R_w}{1+\frac{1}{r}}
\]

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

\[
r \ V = I_m R_m + rI_m \frac{R_w}{r+1} + rI_m R_m
\]

\[
r \ V = I_m \left( R_m + r \frac{R_w}{r+1} + rR_m \right)
\]

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

\[
\frac{r \ V}{(r \frac{R_w}{r+1} + (1+r)R_m)} = I_m
\]
**Worksheet to help organize for Quiz 1**

<table>
<thead>
<tr>
<th>FOCUS on the PROBLEM</th>
<th>PLAN the SOLUTION</th>
<th>EXECUTE the PLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture and Given Information</td>
<td>Construct Specific Equations</td>
<td>Follow the Plan</td>
</tr>
</tbody>
</table>

**Question(s)**

**Approach**

---

**DESCRIBE the PHYSICS**

Diagram(s) and Define Quantities

---

**Target Quantity(ies)**

**Quantitative Relationships**

---

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

**DANGER**

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.

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

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

Johnson & Johnson, 1978
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**
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
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."

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

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)
Class 1

Extensive Support program for TAs

Class 2

5 problems each graded by a different TA

TA Grading Compared to Expert Rubric Grading

Correlation: 0.91

Correlation: 0.90
The End

Please visit our website for more information:
http://groups.physics.umn.edu/physed/

The best is the enemy of the good.
"le mieux est l'ennemi du bien"

Voltaire

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