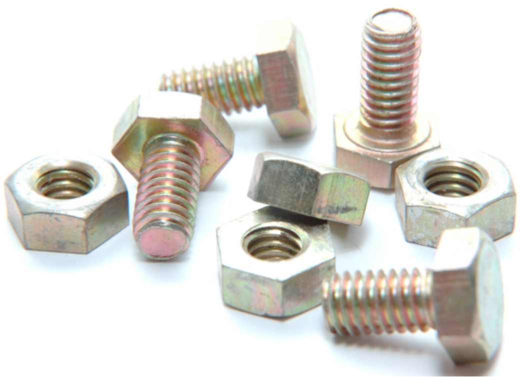
Helping Your Students Develop Expertise in Problem Solving – While Learning Physics



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

Ken Heller

School of Physics and Astronomy
University of Minnesota

What – Why - How

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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What is Problem Solving

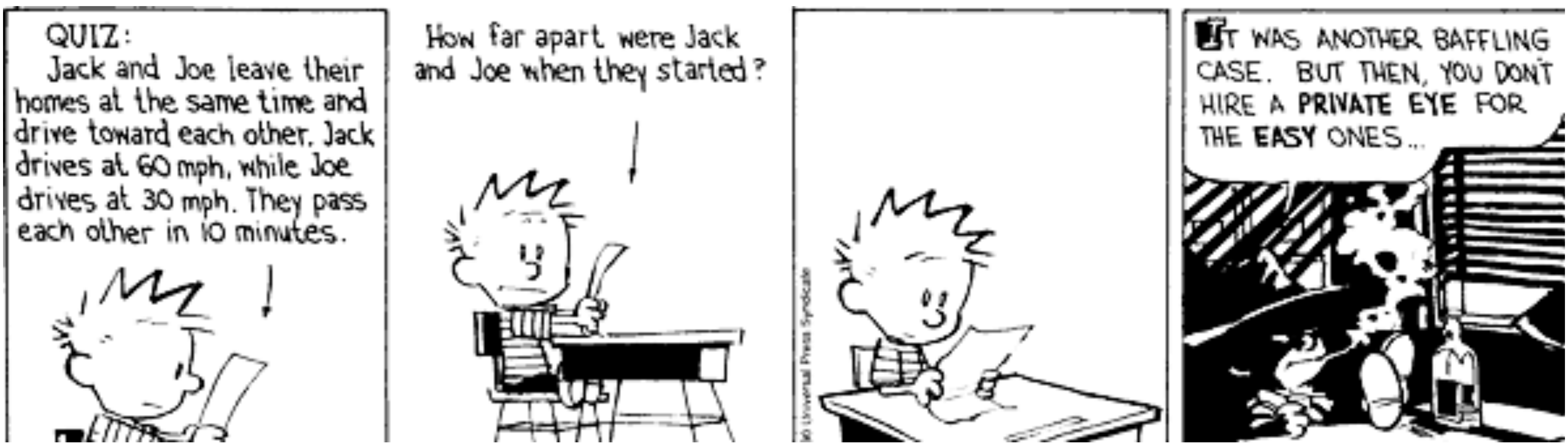
A problem is a situation that you do not know how to resolve.

If you know how to do it, it is not a problem.

Solving a problem requires making decisions about connecting what you know in new ways.

Problem solving requires error and uncertainty

M. Martinez, <u>Phi Delta Kappan</u>, April, 1998



The Nature of Physics is Problem Solving

"All science is either physics or stamp collecting"

(quantitative problem solving) (cataloging information)

Every science requires quantitative problem solving based on a universal set of fundamental principles

Awarded the 1908 Nobel Prize in Chemistry

"I must confess I am very startled at my metamorphosis into a chemist."

Ernest Rutherford

In science, concepts are invented to solve problems.

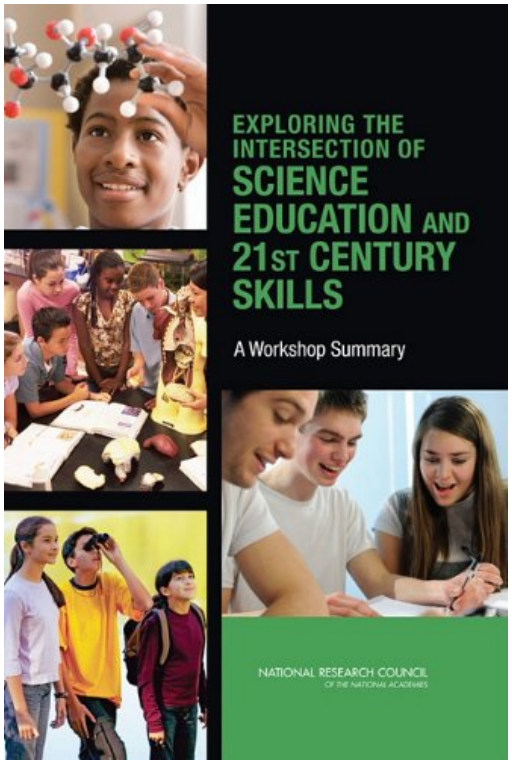
- How do the Sun, Moon, Stars, Planets move around the Earth?
- How does an arrow fly through the air?
- How can an atom be stable?
- What happened to the antimatter in our Universe?

Those concepts are connected by a theoretical framework that can be used to solve other problems and uncovers new problems.

To be science, problem solving is constrained by certain rules

- Logic
- Mathematics
- Testability
- Consistency
- Universality

Problem Solving is Necessary



NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES (2010)

21st Century Skills

- **Adaptability:**
- **Complex communication/social skills:**
- **Self-management/self-development:**
- **Systems thinking:**
- **Nonroutine problem solving:**
- **Diagnose the problem.**
- **Link information.**
- **Reflect on solution strategy.**
- **Switch strategy if necessary.**
- **Generate new solutions.**
- **Integrate seemingly unrelated information.**

University of Minnesota Strategic Planning - 2007

At the time of receiving a bachelor's degree, students will demonstrate the following qualities:

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1. the ability to identify, define, and solve problems
2. the ability to locate and evaluate information
3. mastery of a body of knowledge and mode of inquiry
4. an understanding of diverse philosophies and cultures in a global society
5. the ability to communicate effectively
6. an understanding of the role of creativity, innovation, discovery, and expression in the arts and humanities and in the natural and social sciences
7. skills for effective citizenship and life-long learning.

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

Accredited ABET Engineering Accreditation Commission

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

(5 pt scale)

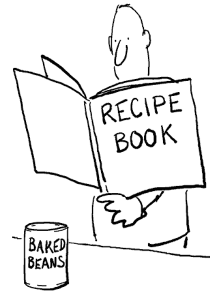
- 4.7 Basic principles behind all physics
- 4.2 General qualitative problem solving skills
- 4.2 Overcome misconceptions about physical world
- 4.0 General quantitative problem solving skills
- 4.0 Apply physics topics covered to new situations

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

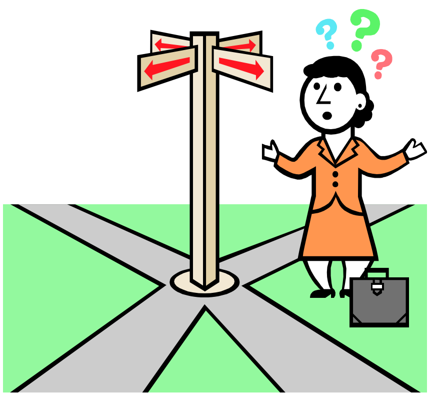
Solving Physics Problems

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.



Novice: Solving a problem requires a following a recipe that connects the situation to the goal. Every type of situation has its own recipe.

Experts have an organized way of making decisions:



Doing this requires metacognition (active control of your thought processes)

- **Planning**
- **Monitoring**
- **Evaluating**

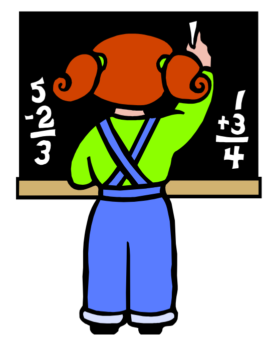
Novice Problem-solving Framework

- **What Kind of Problem is This?**
  Which pattern does it match?

- **What Equations Are Needed?**
  One should match this situation

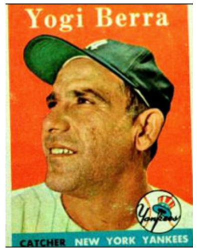
- **Do Some Math**
  Plug in numbers

- **Do Some More Math**
  Manipulate equations to get an answer.

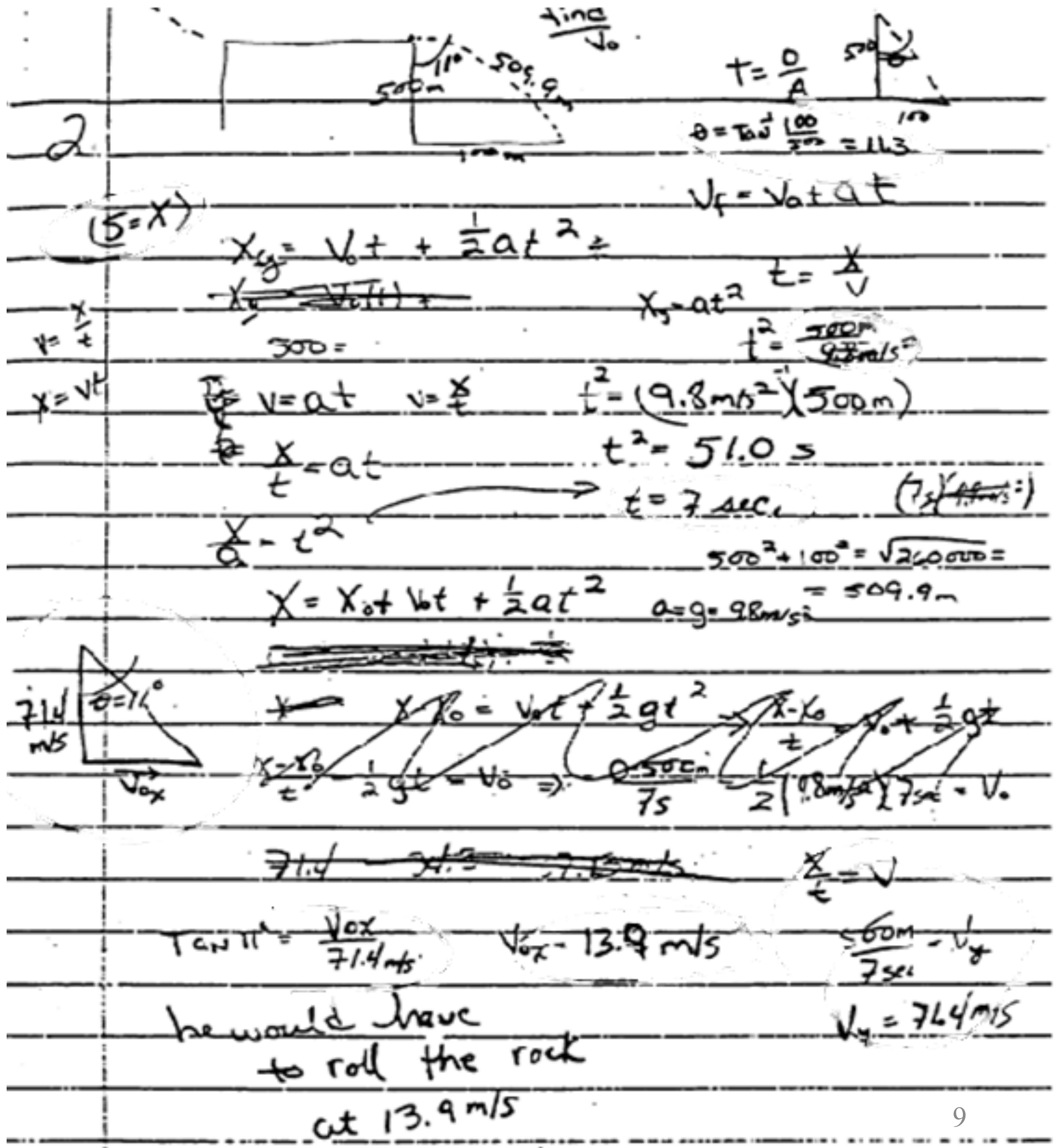


- **Is It Done?**
  Did I get an answer?

"You can observe a lot by watching"



Novice 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.

We are not happy.
Neither are our students.

Solution

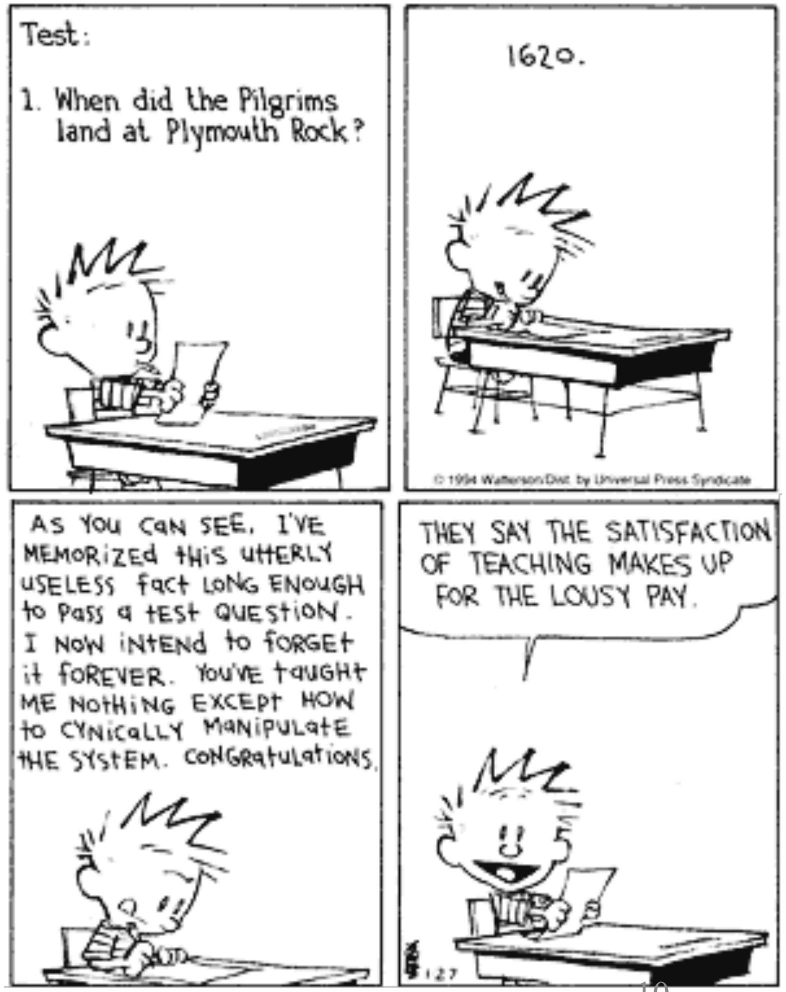
- **Get better students**
- **Get better teachers**
- **Do things differently**

How to Do Things Differently

"When you have eliminated the impossible, whatever remains, *however improbable*, must be the truth"

Sherlock Holmes

Eliminate What Makes Learning Problem Solving Impossible

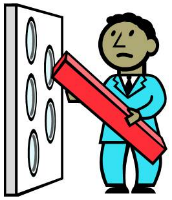


Too much, too fast

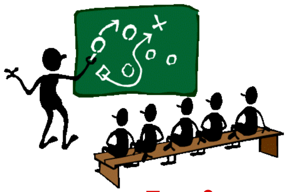
Inappropriate assessment

- **Only or primarily multiple choice tests**
- **Emphasis on getting the right answer**

Inappropriate tasks for practice

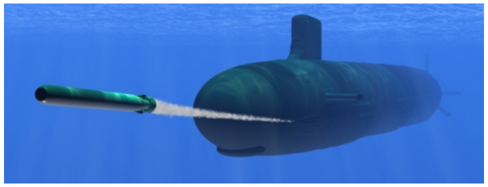


Insufficient demonstration of problem solving



Insufficient coaching of problem solving

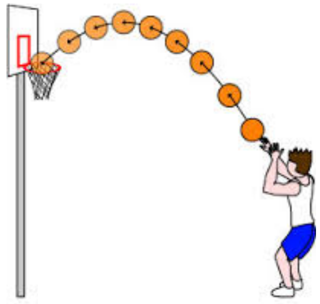
Subverting Problem Solving



Any problem solution can be reduced to a recipe.

This often starts at the beginning of the course with the "Kinematics Equations"

Equation	x	a	v	v_0	t
$v = v_0 + at$	—	✓	✓	✓	✓
$x = \frac{1}{2}(v_0 + v)t$	✓	—	✓	✓	✓
$x = v_0 t + \frac{1}{2}at^2$	✓	✓	—	✓	✓
$v^2 = v_0^2 + 2ax$	✓	✓	✓	✓	—



Identify one unknown quantity and three known quantities.
Use the table to look up the equation that is the solution

Typical textbooks and "helpful" websites.

When we "derive" an equation to show an interesting relationship, students hear:

- **The equation we end with is what is important. It is the recipe.**
- **To succeed you must remember all those equations or remember their derivation.**

"Do we have to derive the formulas on the test?"

Subverting student problem solving is supported by allowing students to bring in their own "cheat sheet" to tests. List of recipes.

Mapping Teaching Components to Course Structural Constraints

Can be combined in studio style class (SCALE-UP, TEAL, ALC, one-room schoolhouse, …)

Lectures

- **Well suited for modeling: fundamental principles to solve problems**
- **Useful for some peer coaching: concepts, problem solving**

Discussion sections and laboratory

- **Well suited for coaching groups – must structure group process**
- **Not efficient for modeling**

Most students do not benefit from working in unstructured groups

Instructor office hours

- **Coaching individuals**

Instructor problem solutions

- **Modeling**

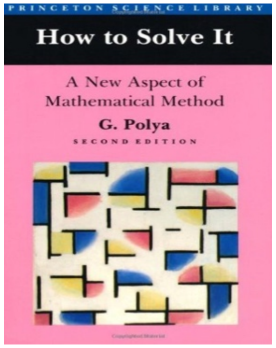
Fading (outside of class)

- **Tests**
- **Homework**
- **Reading tests**
- **Lab warm-up questions**
- **Pre-lecture questions**

Individual Coaching (outside of class)

- **Tutor room**

Problem Solving Framework
Used by experts in all fields



G. Polya, 1945

Not a linear sequence. Requires continuous reflection and iteration.

- **Recognize the Problem**

  What's going on and what do I want?

- **Describe the problem in terms of the field**

  What does this have to do with ……. ?

- **Plan a solution**

  How do I get what I want?

- **Execute the plan**

  Let's get the answer.

- **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

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.

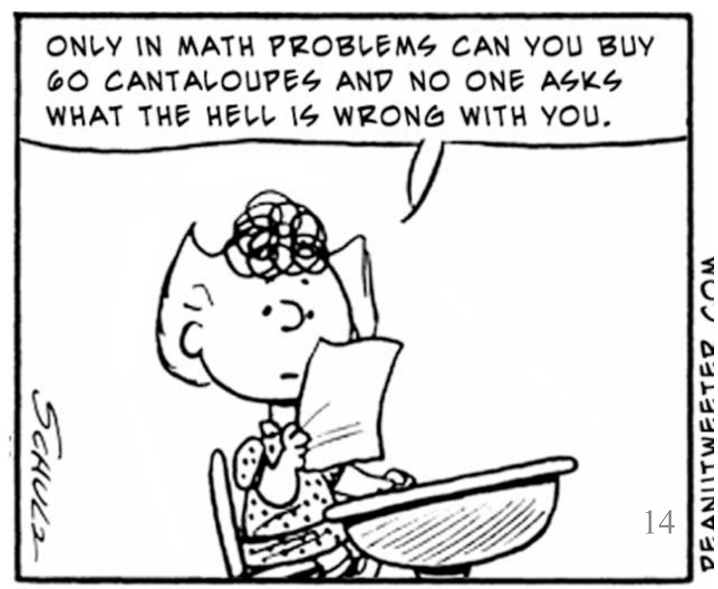
(a) Draw a diagram, labeling θ and d.

(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

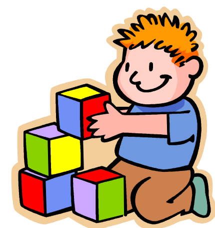
The Dilemma

Start with complex problems so novice problem solving framework fails

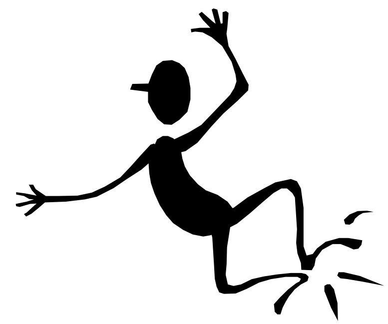
Students have difficulty using an expert-like problem solving framework with challenging problems.

Why change?

Start with simple problems to learn expert-like problem solving framework.



Students have success using novice framework.



Why change?

Cooperative groups is the ingredient that allows students to successfully solve complex problems that require practicing an expert-like framework.

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

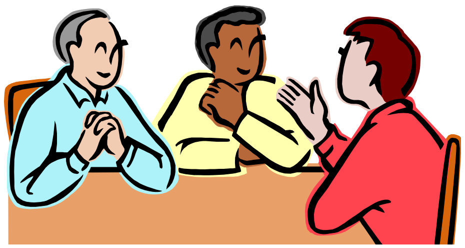
"Another good reason for cooperative group methods: this is how we solve all kinds of problems in the real world - the real academic world and the real business world. I wish they'd had this when I was in school. Keep up the great work."

Vice President,

Hewlett Packard

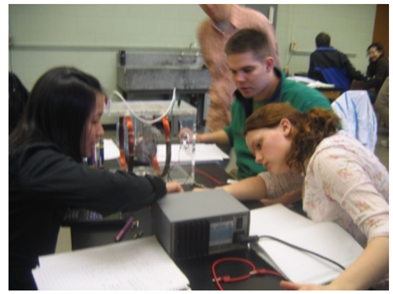
Structure and Management of Groups

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



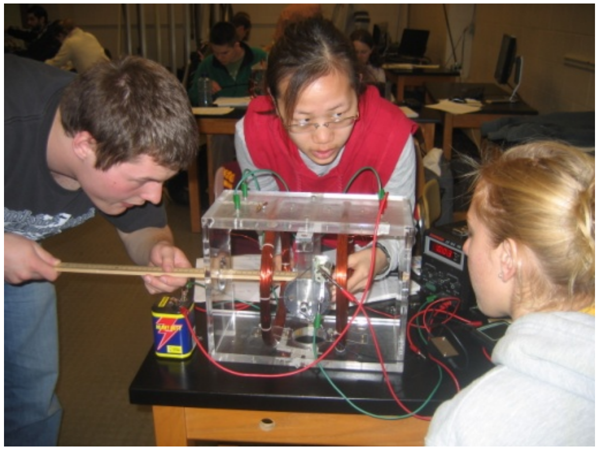
Structure and Management of Groups

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.

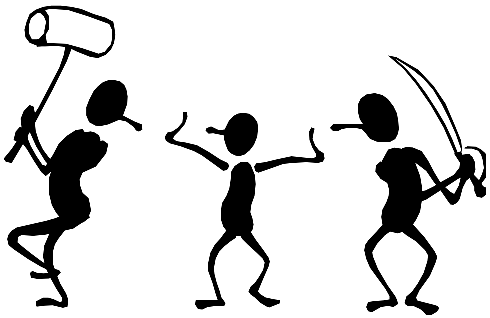
- reassure students at the beginning that they will not be “stuck” with the same people.
- combat resistance at first group change.



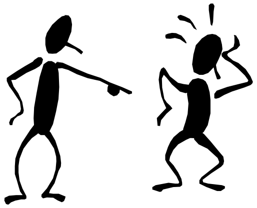
Structure and Management of Groups

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.



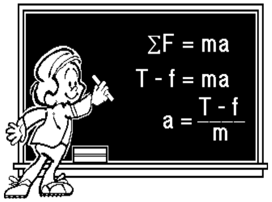
- Assign and rotate roles:
  - Manager
  - Skeptic
  - Checker/Recorder
  - Summarizer
- Most of grade is based on individual problem solving.



- Occasional class time for students to discuss how they worked together and how they could be more effective.

Structure and Management of Groups

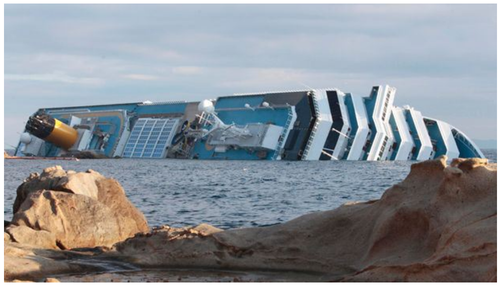
5. How can individual accountability be addressed?



- 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

Situations that prevent effective group work

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

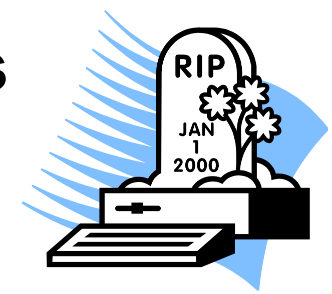


Caution: Learning is Difficult

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,

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

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

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