Improved Pedagogy for Introductory Physics Instruction

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Memorization of facts → Development of critical thinking skills

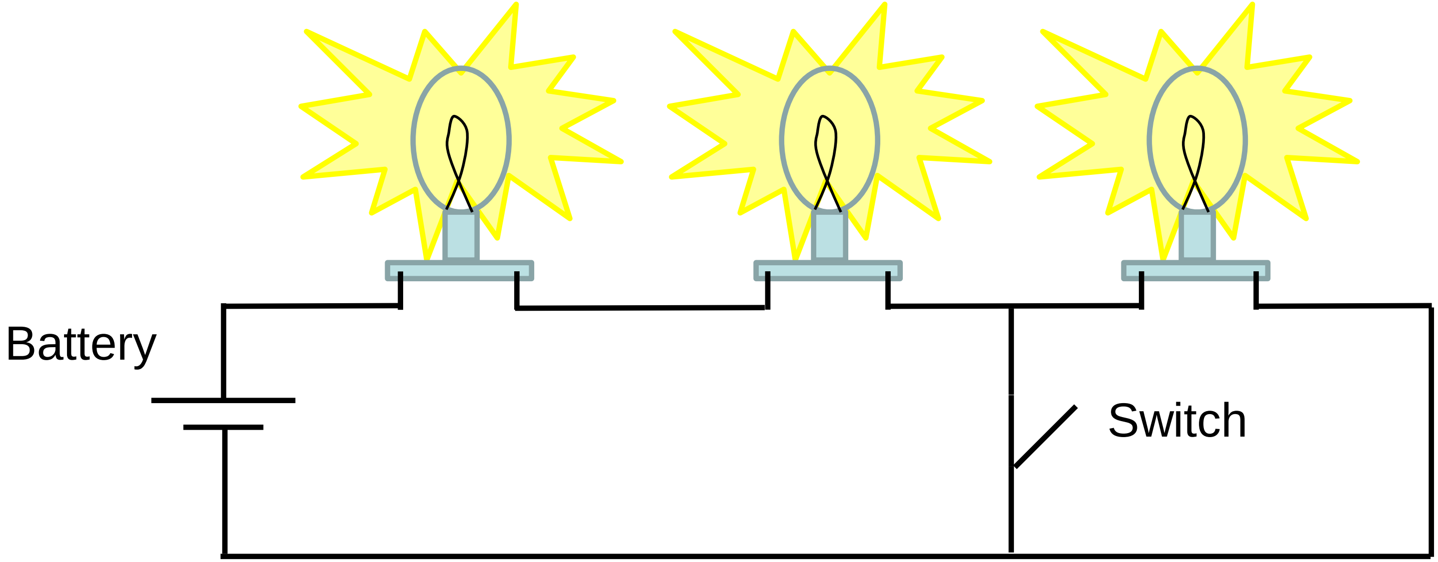
A Long History of Physics Education Research

Conducted by physicists in physics departments.

Quantitative investigations of student learning started in the 70’s and took off in the 90’s.

Arnold Arons – University of Washington
Richard Hake – Indiana University
David Hestenes – Arizona State University
Lillian McDermott – University of Washington
Priscilla Laws – Dickinson College
Eric Mazur – Harvard
Edward Redish – University of Maryland
Patricia Heller – University of Minnesota
C. Wieman – University of British Columbia
and many more …

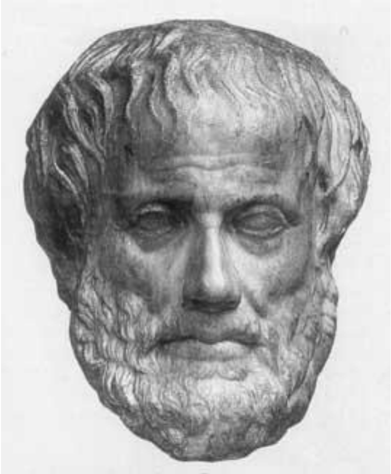
Misconceptions Regarding Electricity



What happens when the switch is closed?

- Current is “used up” as it moves through a circuit.
- A battery is a source of constant and unchanging current.
- Current divides equally when it reaches a junction.

Aristotle's View of Classical Mechanics



- Every motion has a cause-namely, a force. In the absence of any force, an object immediately comes to rest.
- Forces come in two types-contact forces and inherent forces, which are the tendencies of objects to seek their natural place. Inherent force is a property of the object instead of an action on the object.
- Gravity (an inherent force) is the tendency of a heavy object to fall.
- Heavy bodies fall faster than lighter bodies in proportion to their weight. (Aristotle had a concept of speed, but not acceleration.)
- A medium, such as air, has a motive power to propel objects through it. Since all motion must have causes, this was how an arrow, shot horizontally continues to move.

We have three calculus-based sequences that cover introductory physics. Average lecture has 200-270 students.

Physics 2 series

- 3 quarter sequence (classical mechanics – modern physics)
- Lab is separate course (not required, but most take it)
- Taken by life-science majors
- ~600 students take this series each year.

Physics 40 series

- 3 quarter sequence (classical mechanics – E&M)
- lab integrated into course
- Taken by chemistry and engineering majors
- ~500 students take this series each year.

Physics 41 series (new)

- 3 quarter sequence (classical mechanics – modern physics)
- 8 units – 12 contact hours per week (MWF 9-11, TTh 9-12).
- Integrated lecture/discussion/lab
- Taken by physics majors
- ~25 students take this series each year.

Force Concept Inventory Exam

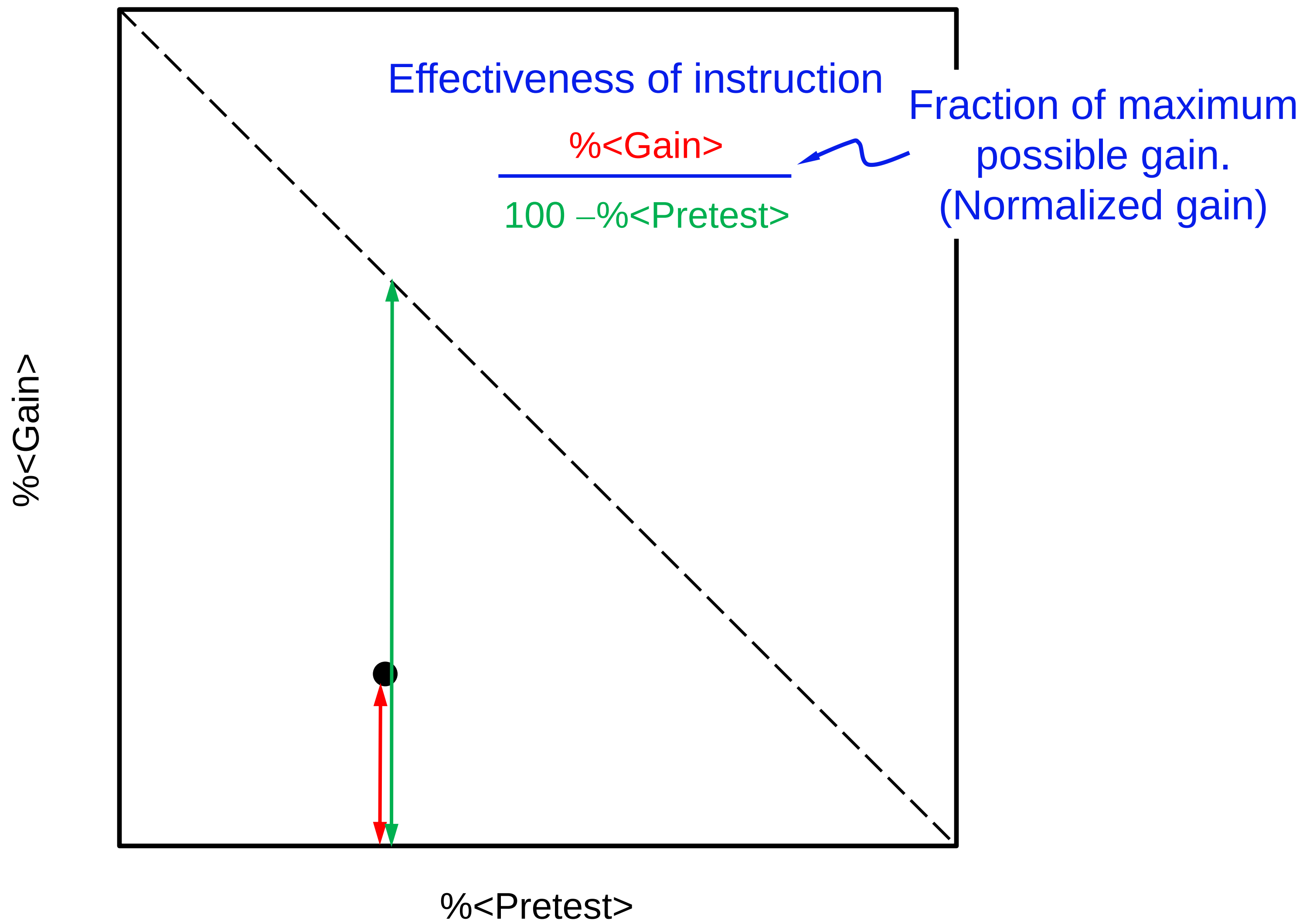
- Developed by D. Hestenes, M. Wells, G. Swackhamer at ASU in 1992, and later modified by Halloun, Hake and Mosca in 1995.
- 30 multiply-choice question exam, students have 30 minutes to complete.
- Qualitative questions on basic principles in classical mechanics.
- Given as a pre and post instruction test. Can be administered using Blackboard.
- Can obtain FCI from modeling.asu.edu.

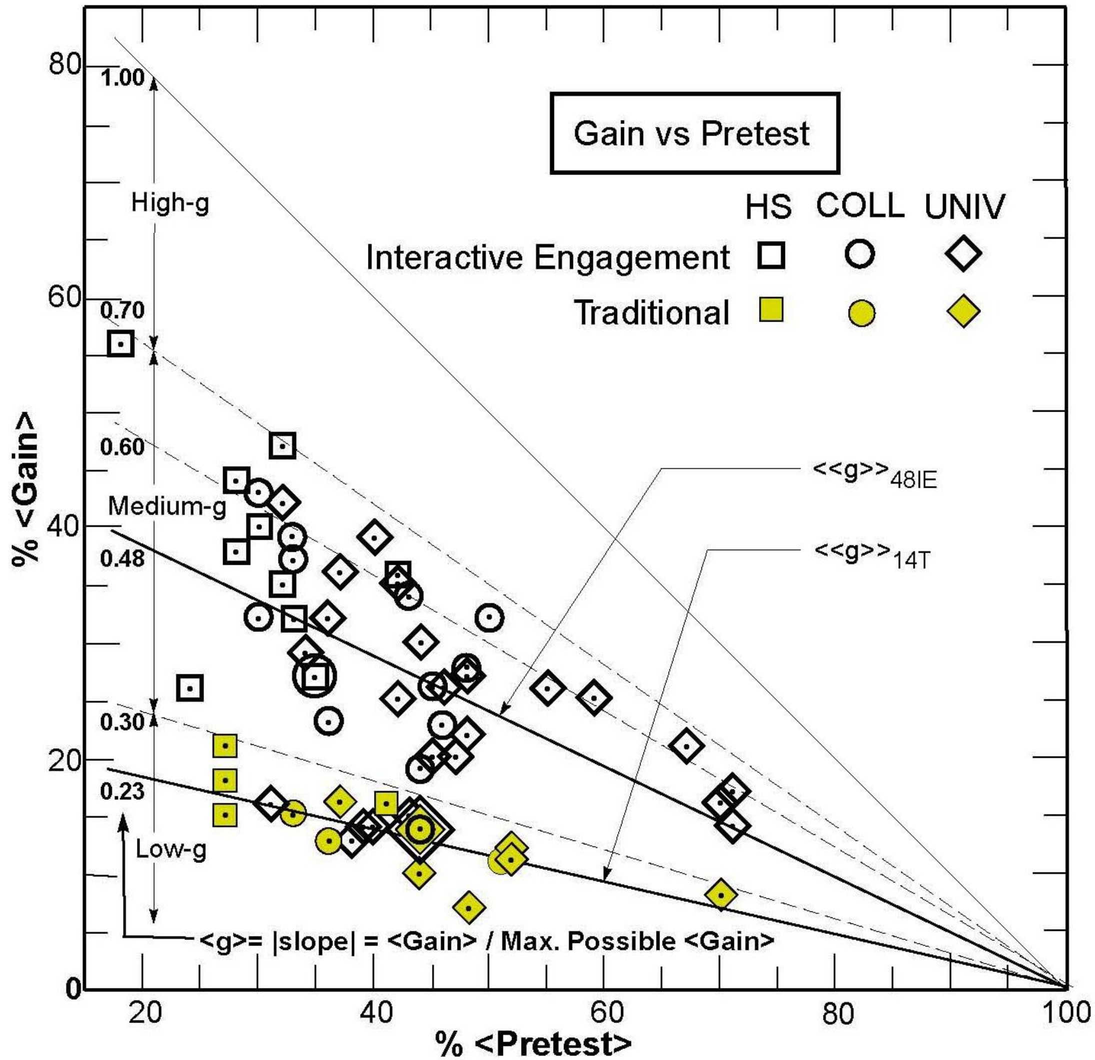
Sample Question

Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same time. The time it takes the balls to reach the ground below will be:

a) about half as long for the heavier ball as for the lighter one.
b) about half as long for the lighter ball as for the heavier one.
c) about the same for both balls.
d) considerably less for the heavier ball, but not necessarily half as long.
e) considerably less for the lighter ball, but not necessarily half as long.

%<Gain> = %<Post-test>–%<Pretest>





FCI tests for 62 courses enrolling a total N = 6542 students: 14 traditional (T) courses (N = 2084) which made little or no use of interactive engagement (IE) methods, and 48 IE courses (N = 4458) which made considerable use of IE methods.

R. Hake, AJP **66**, 64 (1998)

%<Gain> = %<Posttest>–%<Pretest>

Interactive Engagement

The common IE methods used in 48 courses for this study, ranked in order of popularity.

1. Collaborative Peer Instruction (CPI): 48
2. Microcomputer-Based Labs: 35
3. Concepts Tests (Peer Instruction): 20
4. Modeling: 19
5. Overview/Case Studies or Active-Learning Problem Sets: 17
6. Physics-Research-Based Text /No Text: 13
7. Socratic-Dialogue-Inducing Labs: 9

- Based on the Constructivists teaching philosophy: Students must construct their knowledge through interaction with ideas and the material, instead of simply receiving knowledge.

- Students actively engaged in doing, thinking, and talking about the material, not listening to lecture.
- Students interact with their peers.
- Students receive immediate feedback.
- The instructor is more a facilitator, less a conveyor of knowledge.
- Students take responsibility for their knowledge (participating in activities, studying the text, and completing assignments).

15% IE > 200

IU94S = 388

EM94C = 216

~15% of IE did not realize significant gains.

What is mechanism?

Impedance mismatch

Educational transformer

Recent Study Supporting IE

Science **332**, 862 (2011) Louis Deslauriers, Ellen Schelew, Carl Wieman

Compared learning effectiveness in 2 sections taught using different instructional approaches.

The intervention occurred during the 12th week in the 2nd semester of a standard physics sequence taken by Engineering undergraduates at UBC, and it covered 12 topics on electromagnetic waves.

Control Section (267 students)

Standard 50 min. lecture delivered 3 times a week by a seasoned and popular instructor.

Experimental Section (271 students)

Instruction during the 3 lectures was given by two inexperienced instructors (postdoc and grad student) trained in IE techniques.

- Pre-class reading assignments
- Pre-class reading quizzes
- In-class clicker questions in a peer-instruction format
- Targeted in-class instructor feedback

BEMA: Brief Electricity and Magnetism Assessment.
CLASS: Colorado Learning Attitude about Science Survey

Table 1. Measures of student perceptions, behaviors, and knowledge.

	Control section	Experimental section
Number of students enrolled	267	271
Mean BEMA score (*13*) (week 11)	47 ± 1%	47 ± 1%
Mean CLASS score (*14*) (start of term) (agreement with physicist)	63 ± 1%	65 ± 1%
Mean midterm 1 score	59 ± 1%	59 ± 1%
Mean midterm 2 score	51 ± 1%	53 ± 1%
Attendance before experiment*	55 ± 3%	57 ± 2%
Attendance during experiment	53 ± 3%	75 ± 5%
Engagement before experiment*	45 ± 5%	45 ± 5%
Engagement during experiment	45 ± 5%	85 ± 5%

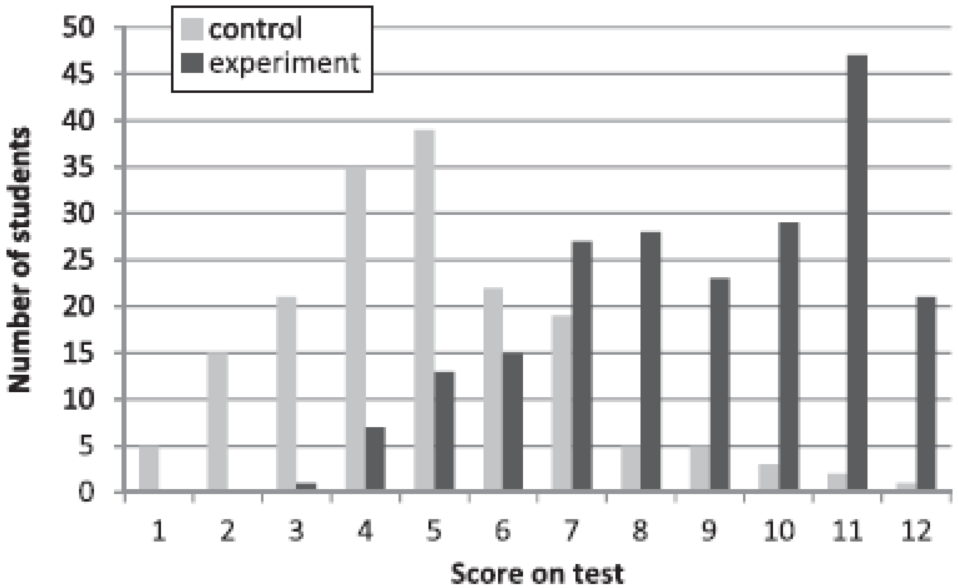
*Average value of multiple measurements carried out in a 2-week interval before the experiment. Engagement also varies over location in the classroom; numbers given are spatial and temporal averages.

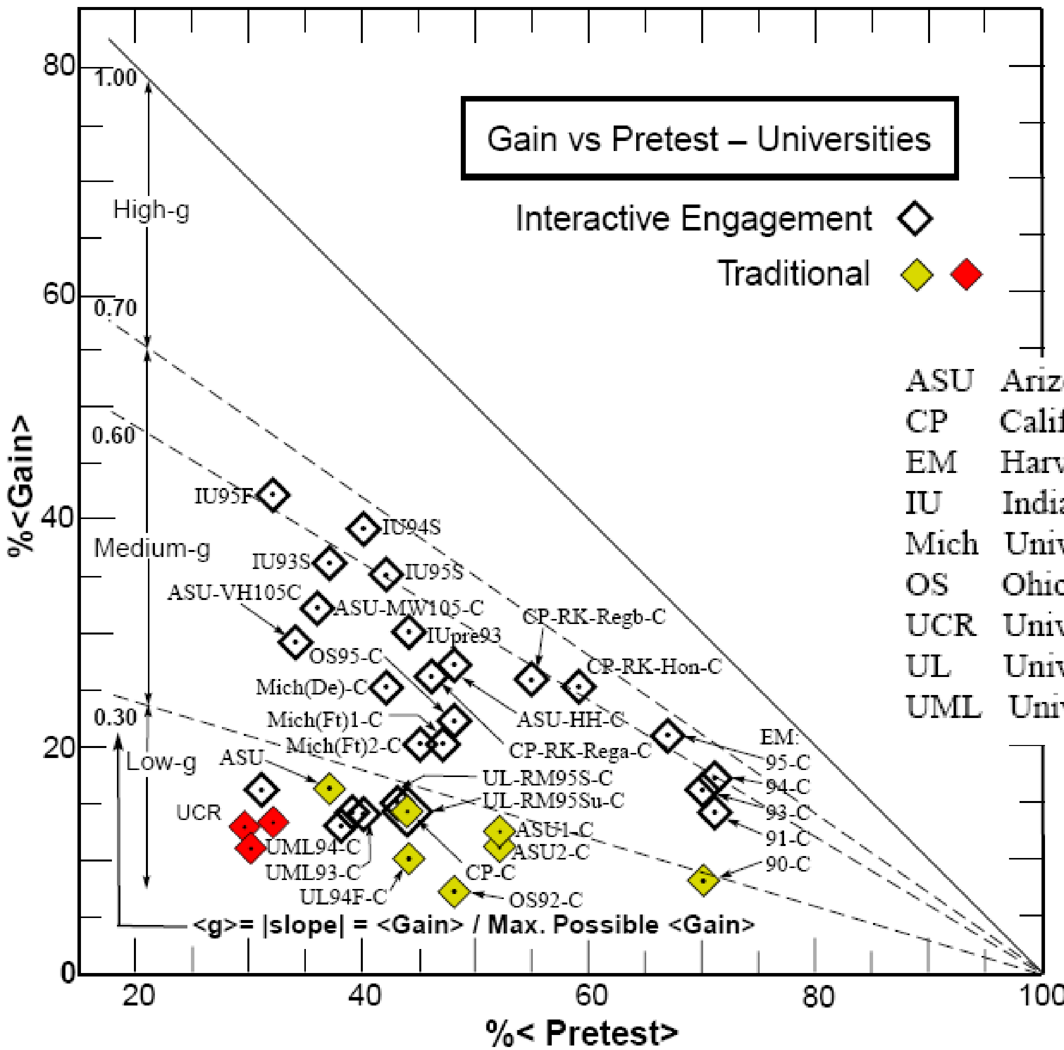
Results from exam given in first class after 3-hour unit.

Average score in control group: 41%

Average score in experimental group: 74%

Improvement in experimental group is 2.5 standard deviations above the control group!





ASU Arizona State University
CP California Polytechnic State University (San Luis Obispo)
EM Harvard (Eric Mazur)
IU Indiana University
Mich University of Michigan (Flint & Dearborn)
OS Ohio State
UCR University of California Riverside (Physics 2A - Fall 2005)
UL University of Louisville
UML University of Massachusetts at Lowell

%<Gain> vs %<Pretest> score on the conceptual MD or FCI tests for 32 university courses enrolling a total N = 4832 students. The course code "-C" indicates a calculus-based course.

What have we done in Physics 2 to improve learning?

1. Web-based homework ~2002.
2. On-line access to course material (Blackboard) ~2002.
3. Web-based discussion forum (Blackboard) ~2003.
4. PowerPoint ~2004
5. Clickers (reading/lecture quizzes and peer instruction) ~2004.
6. Better balance of conceptual & quantitative material. (Deal directly with student's misconceptions.) Emphasize problem-solving strategy ~2004.
7. Absolute assessment (Absolute grading scale & pre- and post-class FCI) ~2005.
8. Workshops with cooperative groups (CPI) ~2007.
9. Early warning notification system ~2008.

Lately, many of these ideas have been adopted in the Physics 40ABC series. Also, in 2010, a new introductory series (Physics 41ABC) was started for just our majors. This new series uses a workshop format where the lecture, discussion and lab are more integrated with an inquiry-based teaching philosophy.

Problem-Solving Strategy

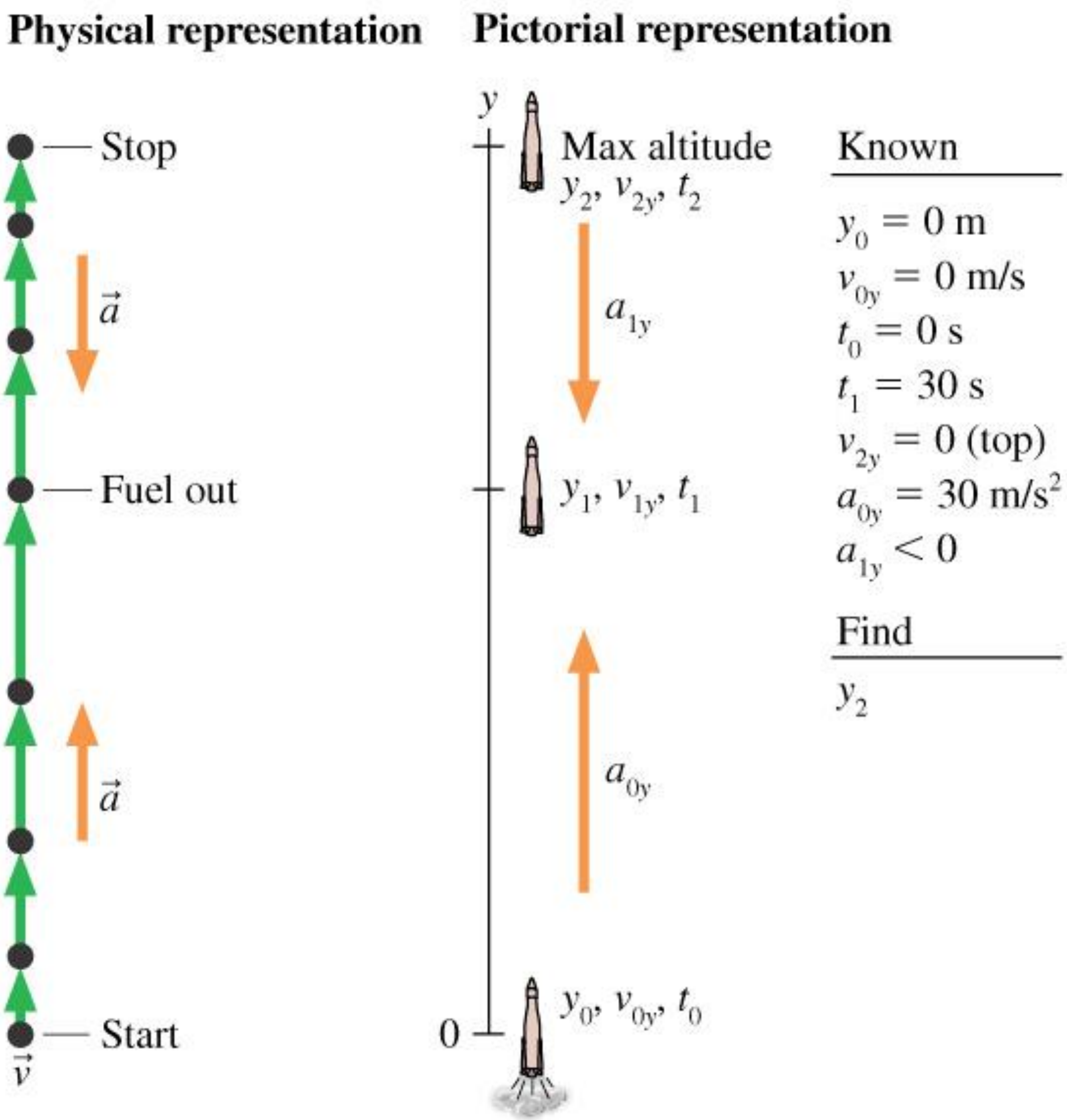
Model – Think about what information is given and what you want to find. (i.e., what are the relevant parts of the problem.) What are the simplifying assumptions (i.e., particle model)?

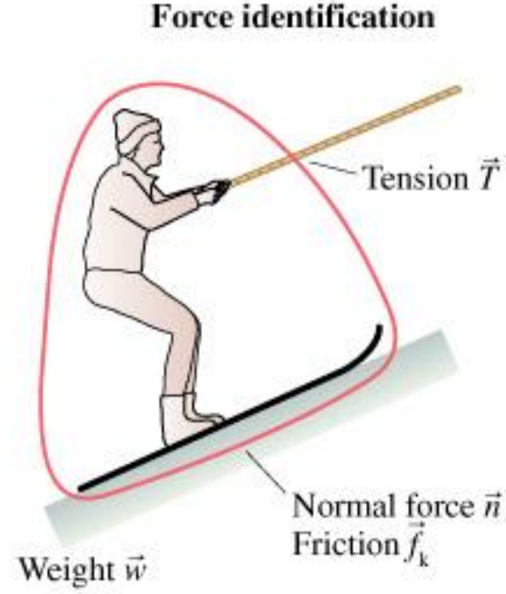
Visualize – Draw a pictorial & physical representation of the problem. You can go back and forth between these representations.

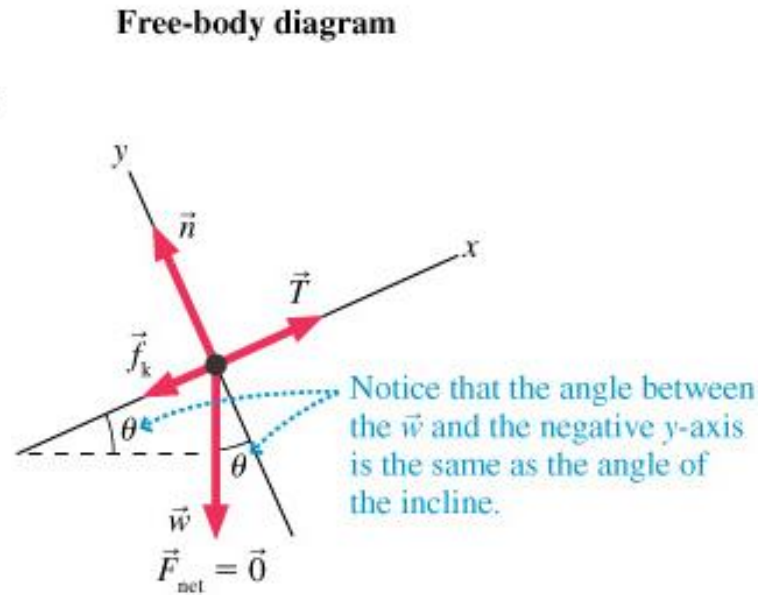
Solve – Develop a mathematical representation. The visualization step should help with this process. This is where students usually want to start.

Assess – Crap detection. After you are done, step back and ask "Does it make sense?" Are the units correct?

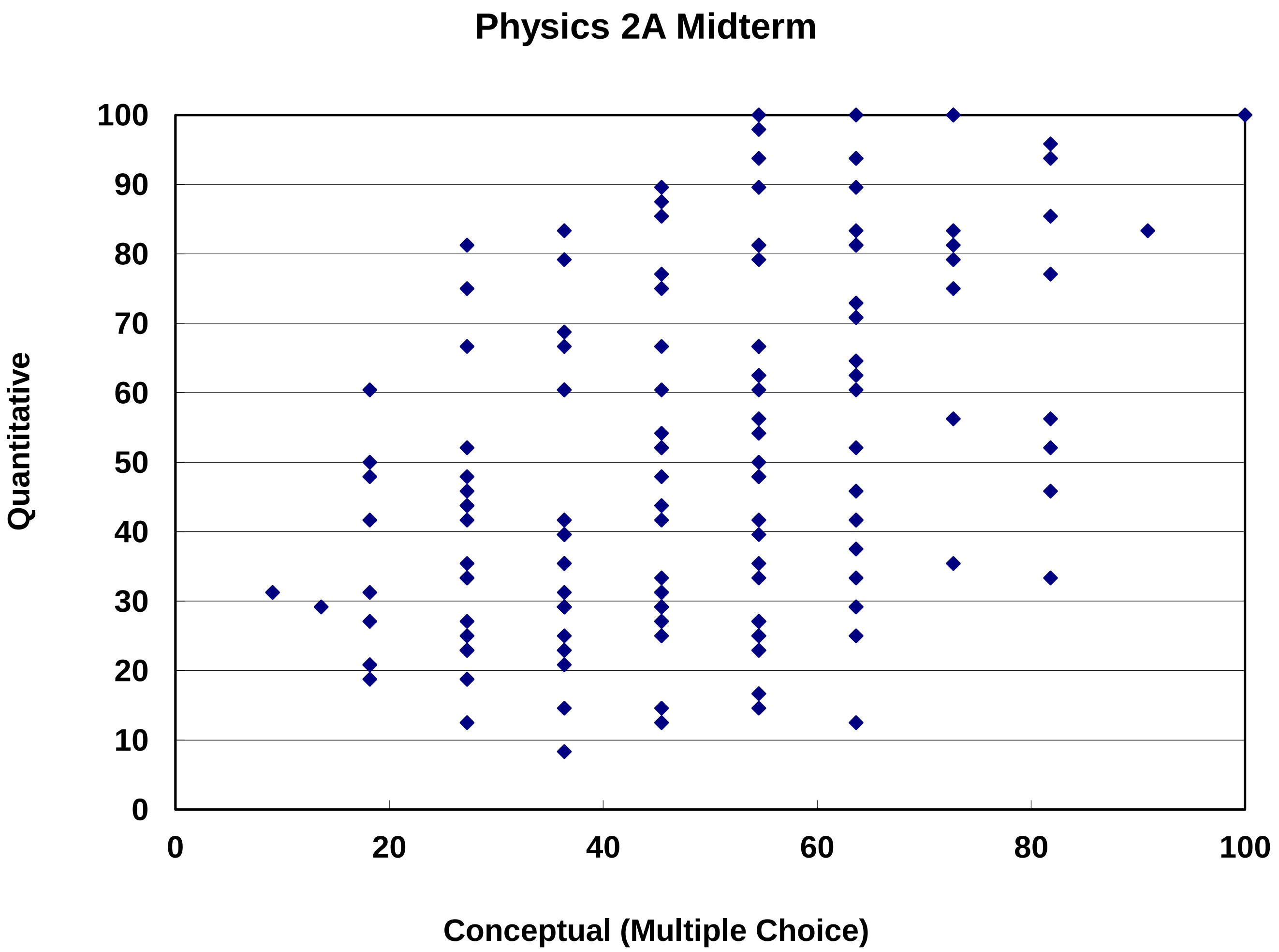
Visualizations





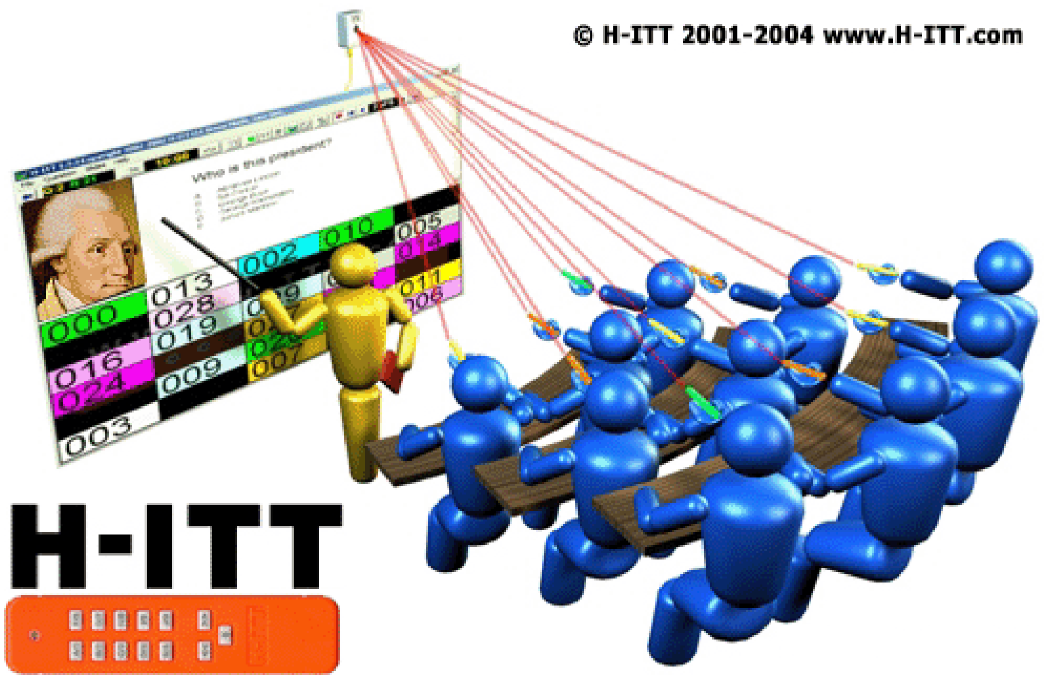


Balance Conceptual and Quantitative Material



Electronic Personal Response System (Clickers)

- Started in Psychology in Spring 2004.
- Adopted by Physics in Fall 2004 (with text book change).
- All general-assignment classrooms are wired.
- ~5% of the faculty and courses now use clickers (~8000 students/quarter).
- More popular in select departments and for introductory courses.
- Added benefit of increasing attendance. (From ~50% to above 80%.)

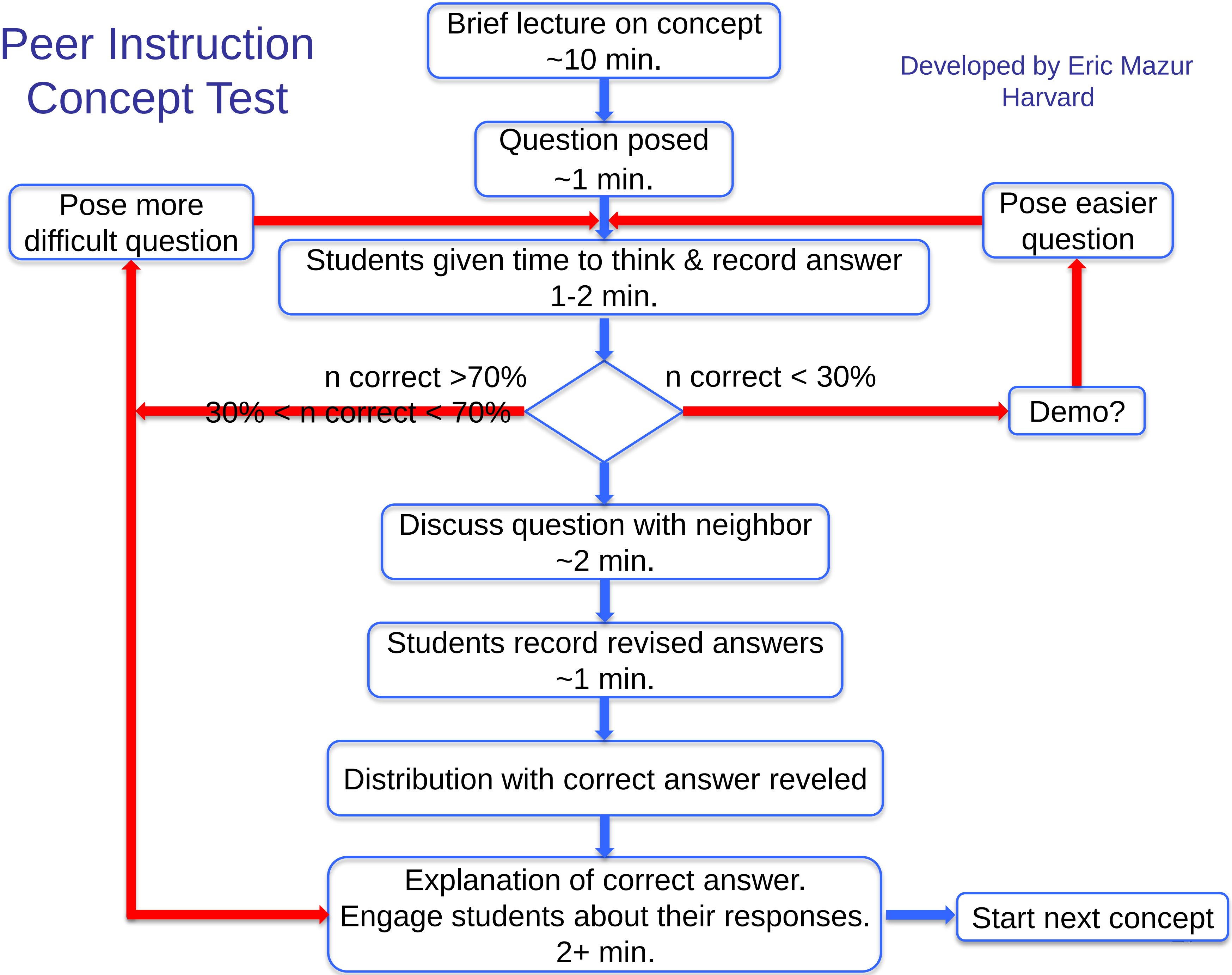


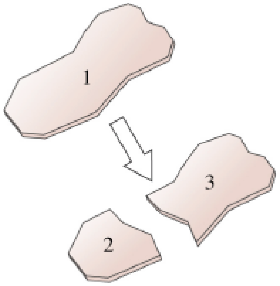
How it is used in Physics

- Reading Quizzes
- Synchronous JiTT
- Peer Instruction

Peer Instruction
Concept Test

Developed by Eric Mazur
Harvard

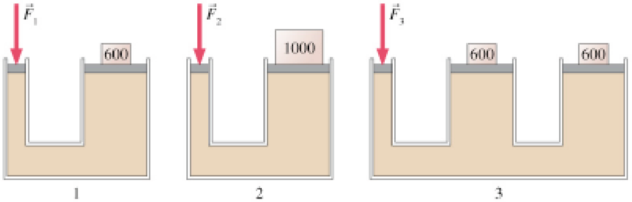




A piece of glass is broken into two pieces of different sizes. Rank in order the mass densities of each piece.

A. $\rho_1 > \rho_3 > \rho_2$
B. $\rho_2 > \rho_3 > \rho_1$
C. $\rho_1 > \rho_3 = \rho_2$
D. $\rho_1 = \rho_2 = \rho_3$

77% → 89%



Rank the forces necessary to balance the masses (given in kg)

A. $F_1 < F_2 < F_3$
B. $F_1 > F_2 > F_3$
C. $F_1 < F_3 < F_2$
D. $F_1 > F_2 = F_3$
E. $F_2 > F_1 = F_3$

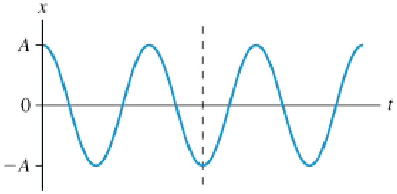
34% → 50%

A metal weight is fastened to the top of a large solid piece of Styrofoam that floats in a container of water. If the piece of Stryofoam is turned upside down, so that the weight is now suspended underneath it (and is thus submerged), the water level in the container

A. rises.
B. drops.
C. remains the same.

48% → 62%

This is the position graph of a mass on a spring. What can you say about the velocity and the force at the instant indicated by the dotted line?

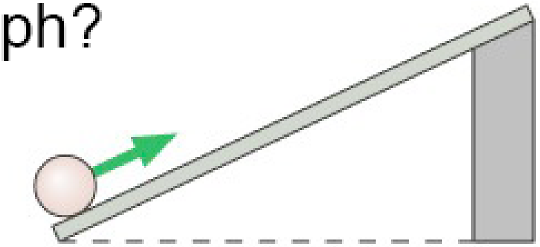


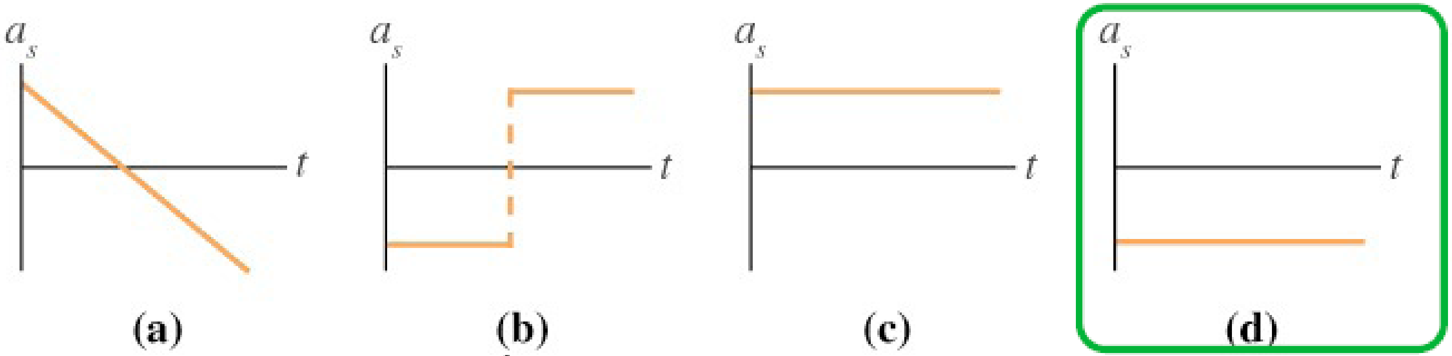
A. Velocity is positive; force is to the right.
B. Velocity is negative; force is to the right.
C. Velocity is zero; force is to the right.
D. Velocity is zero; force is to the left.
E. Velocity is positive; force is zero.

55% → 82%

Sometimes discussion doesn't help...

The ball rolls up the ramp and then back down. Which is the correct acceleration graph?

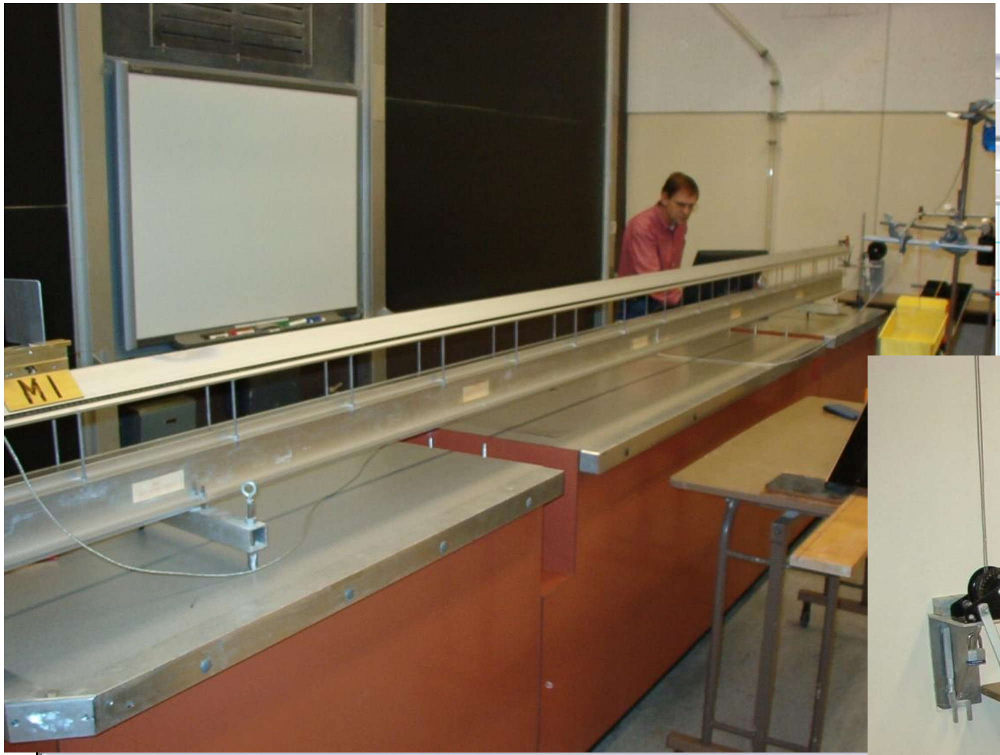


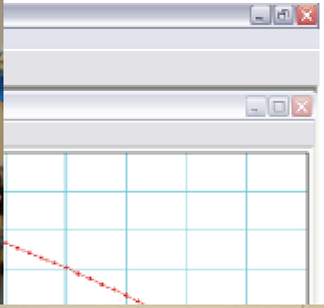


9% /1% | 64% /74% | 11% /5% | 16% /20%

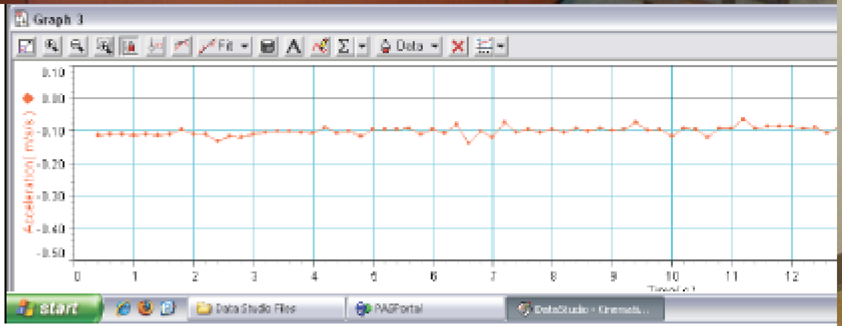
Demonstrations come in ***very*** handy at this point.

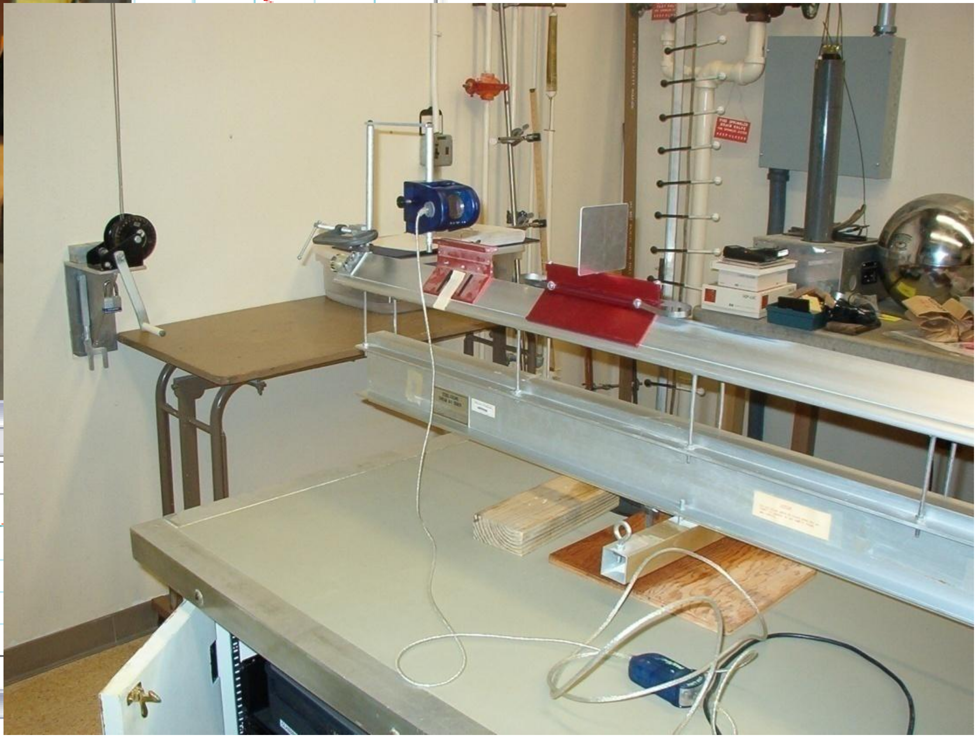
Slanted Air Track Demo





Position





Cooperative Groups in Discussion Sections

- Based on what Patricia Heller does at University of Minnesota.
- Students organized into groups of four.
- Groups are balanced by ability (one from each quartile) and reshuffled several times during the quarter.
- Groups work on 3-6 exercises (2-5 conceptual and 1 content-rich problem).
- After each exercise, one group is selected to present to class.

Problem – Difficulty getting students to engage with each other.

- Need good TAs. (TA training is very important.)
- Specialized rooms (lots of board space).

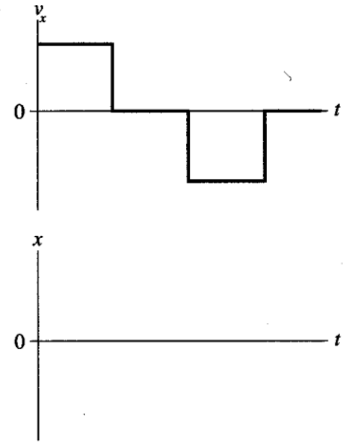
Conceptual Problems

Below are shown four velocity-versus-time graphs. For each:

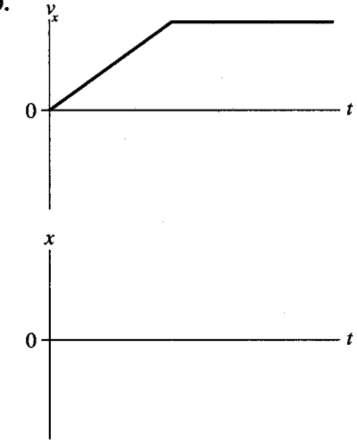
- Draw the corresponding position-versus-time graph.
- Give a written description of the motion.

Assume that the motion takes place along a horizontal line and that $x_0 = 0$.

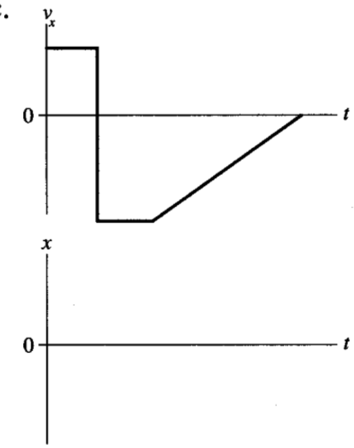
a.



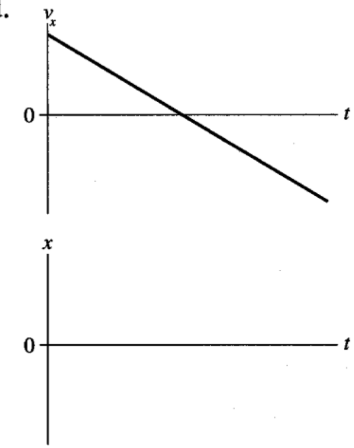
b.



c.

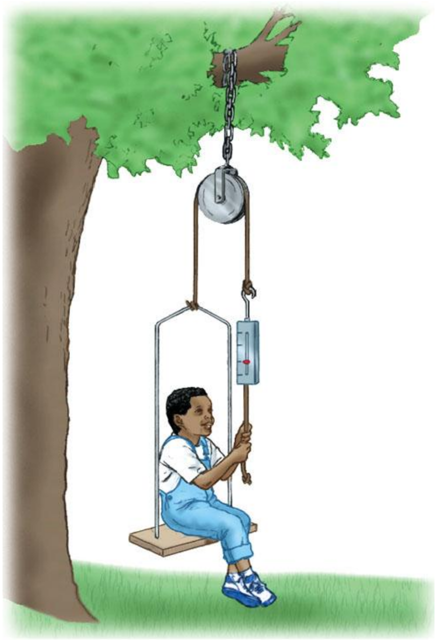


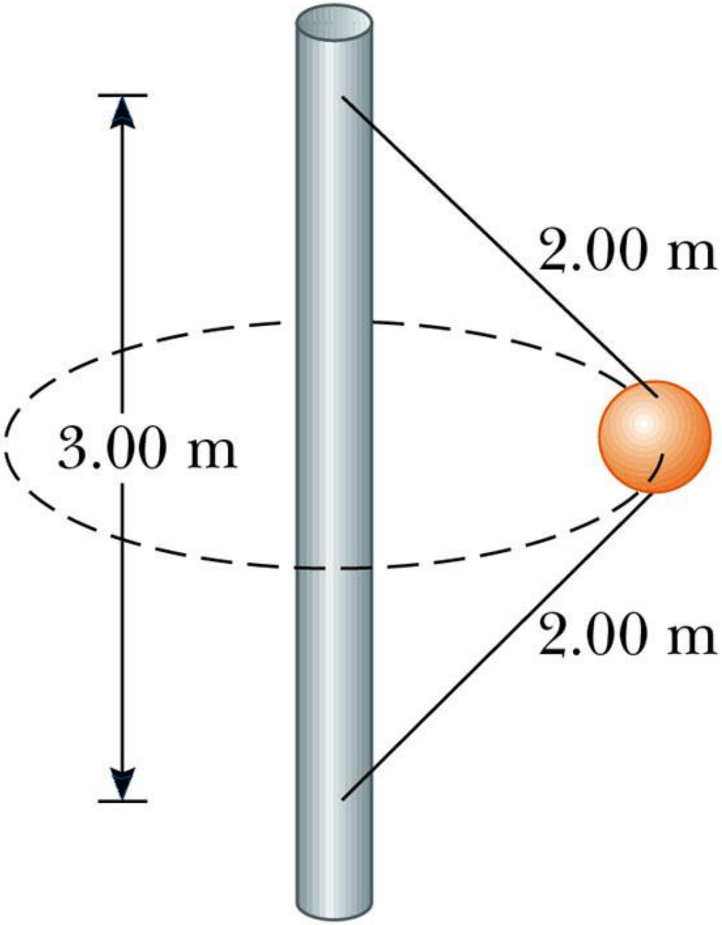
d.



Traditional Problems

A 4.00-kg object is attached to a vertical rod by two strings as shown in the figure. The object rotates in a horizontal circle at constant speed 6.00 m/s. Find the tension in (a) the upper string and (b) the lower string.





Content-Rich Problems

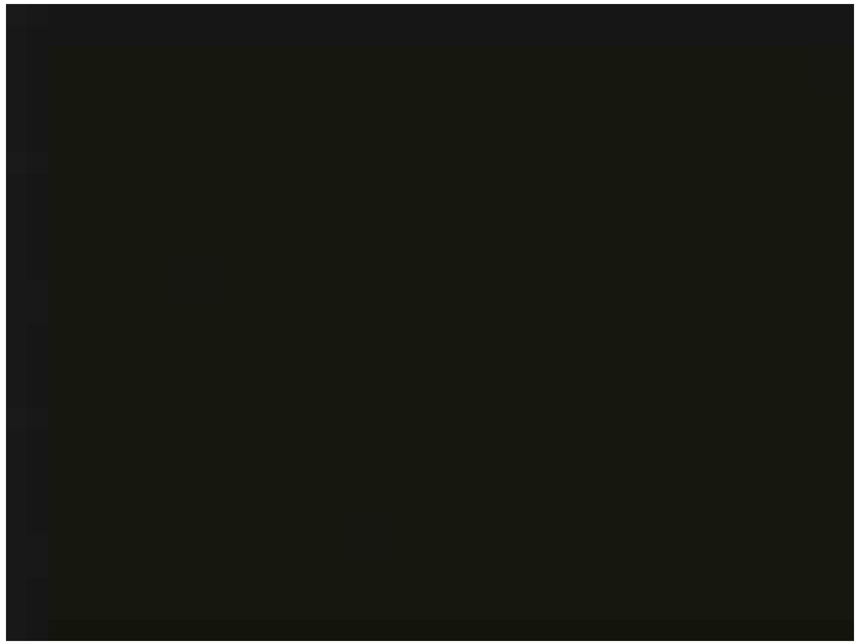
They are set in context of a short story that establishes a reason for the problem.

They generally do not specify the unknown, often contain irrelevant information, and sometimes are missing information, so the student needs to estimate.

Example of Content-Rich Problem

You are planning to build a log cabin in the San Bernardino Mountains. You will pull the logs up a long, smooth hill to the building site by means of a rope attached to a winch. You need to buy a rope for this task, which will be strong enough. You know that the logs weigh at most 200 kg. You measure that the hill is at an angle of 30° with respect to the horizontal, and the coefficients of static and kinetic friction between a log and the hill are 0.90 and 0.70, respectively. When pulling a log up the hill, you will make sure that the rope stays parallel to the surface of the hill and the acceleration of the log is never more than 0.80 m/s^2. How strong a rope should you buy?

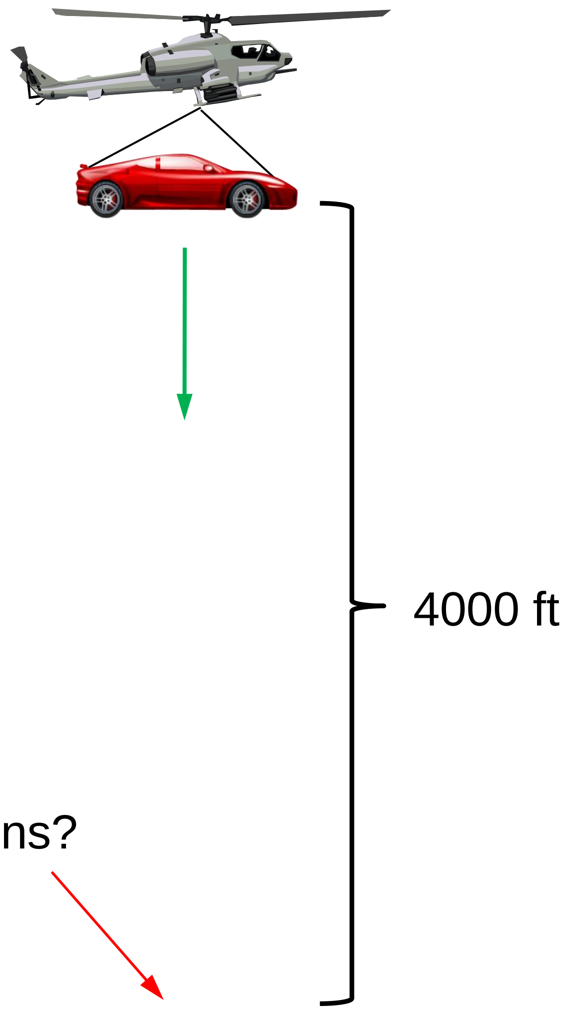
Lexus Commercial



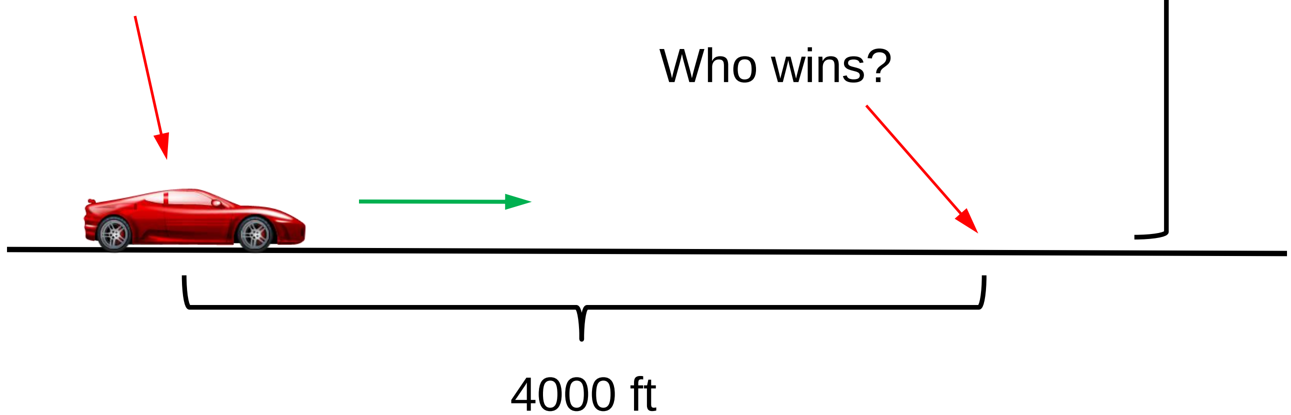
Lexus Commercial

Real or a Hollywood stunt?

Emphasizes the process of scientific inquiry.

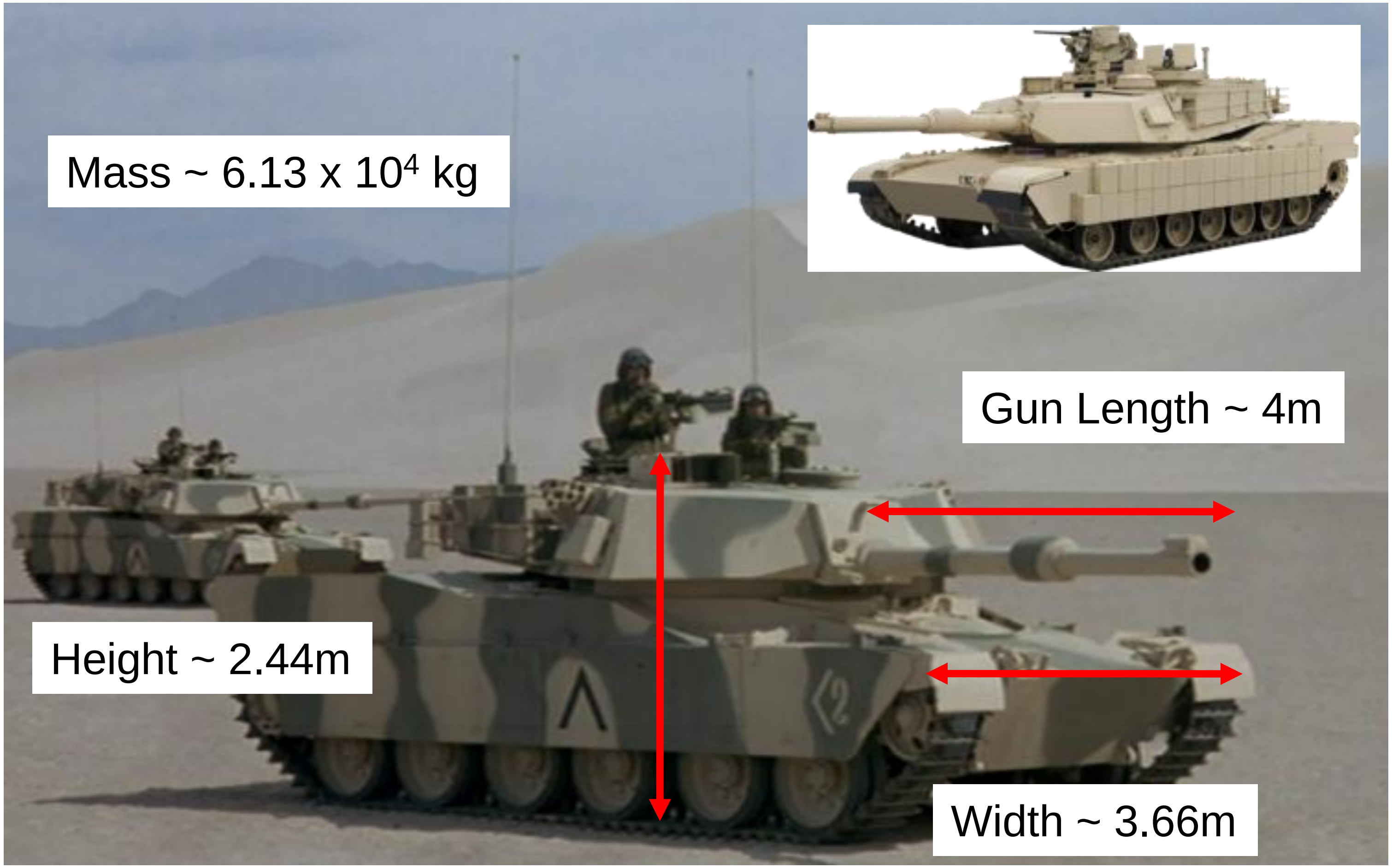


Does this car start from rest, or is it already moving when it is here?

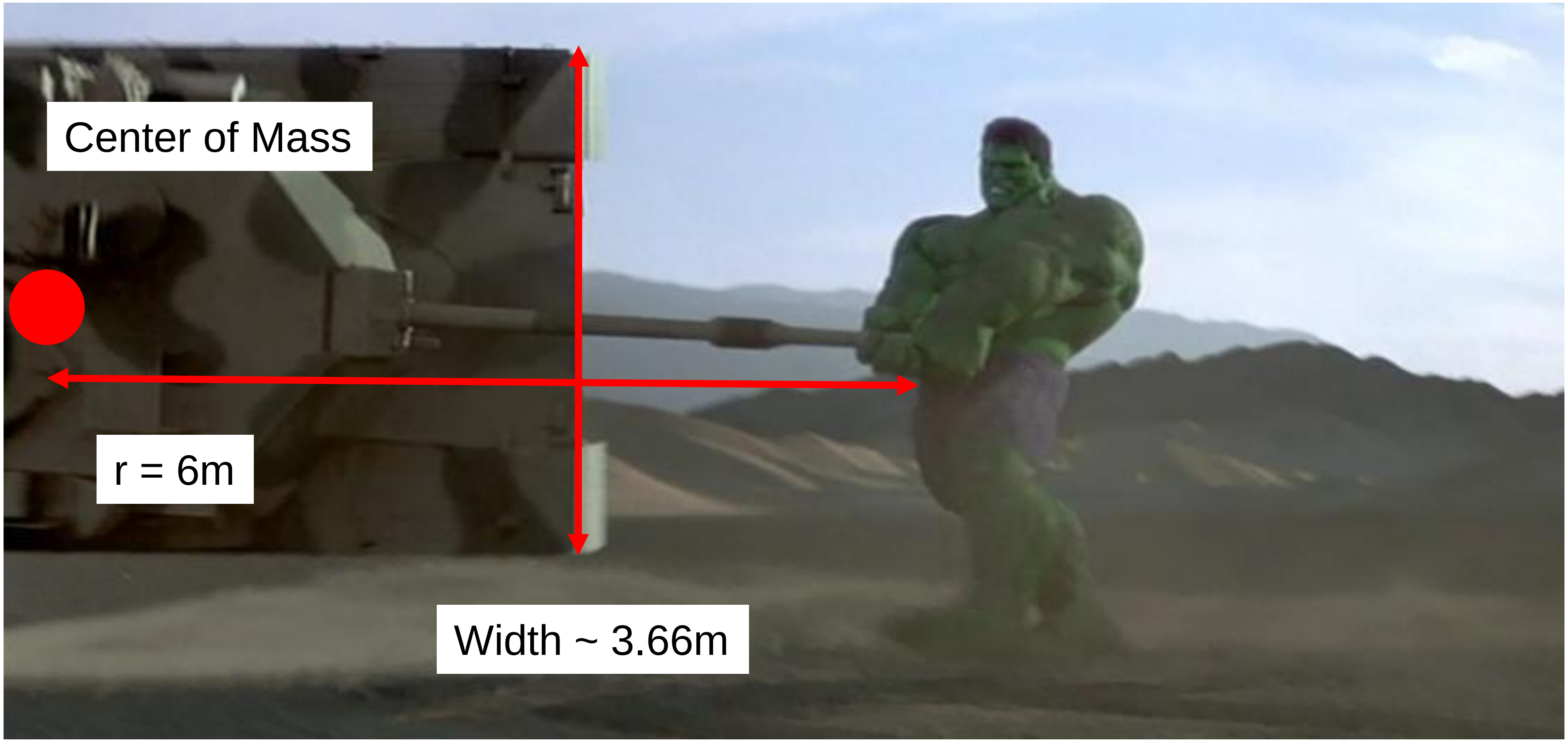


The Incredible Hulk Movie - 2003

M1A2 Abrams



From David Mast, University of Cincinnati



Estimate rotational period with stop watch or frame rate.

From the distances and times, calculate velocities and accelerations.

Mechanics: Laws of motion, forces, work and energy

Tangential velocity, angular velocity, centripetal acceleration, etc.

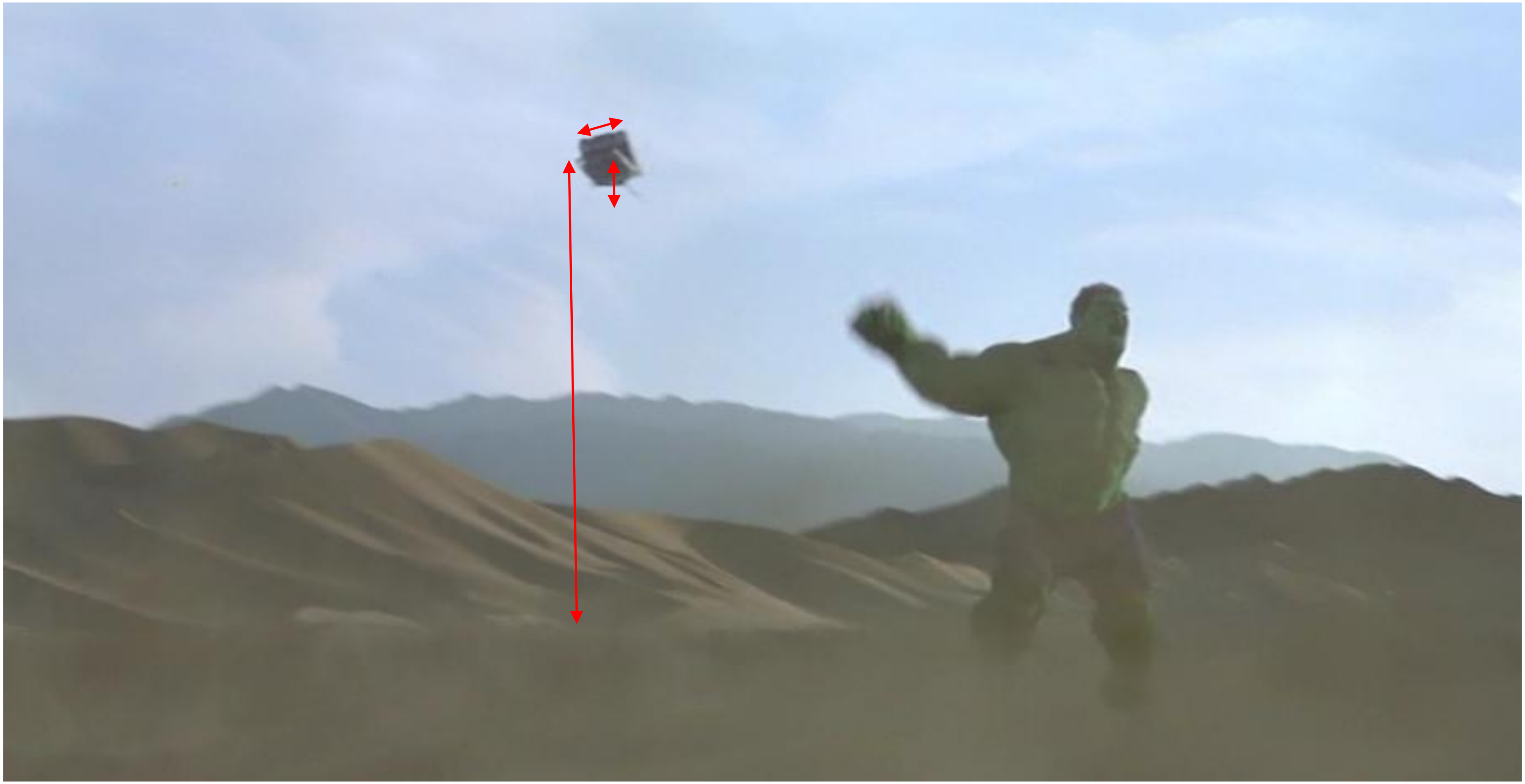
Projectile Motion

Velocity and angle at the time of release.


Initial Position

Intermediate Conditions

Maximum Height ~50 m



Trajectory

Work and Energy

~1.5×10^8 J ~5×10^7 W

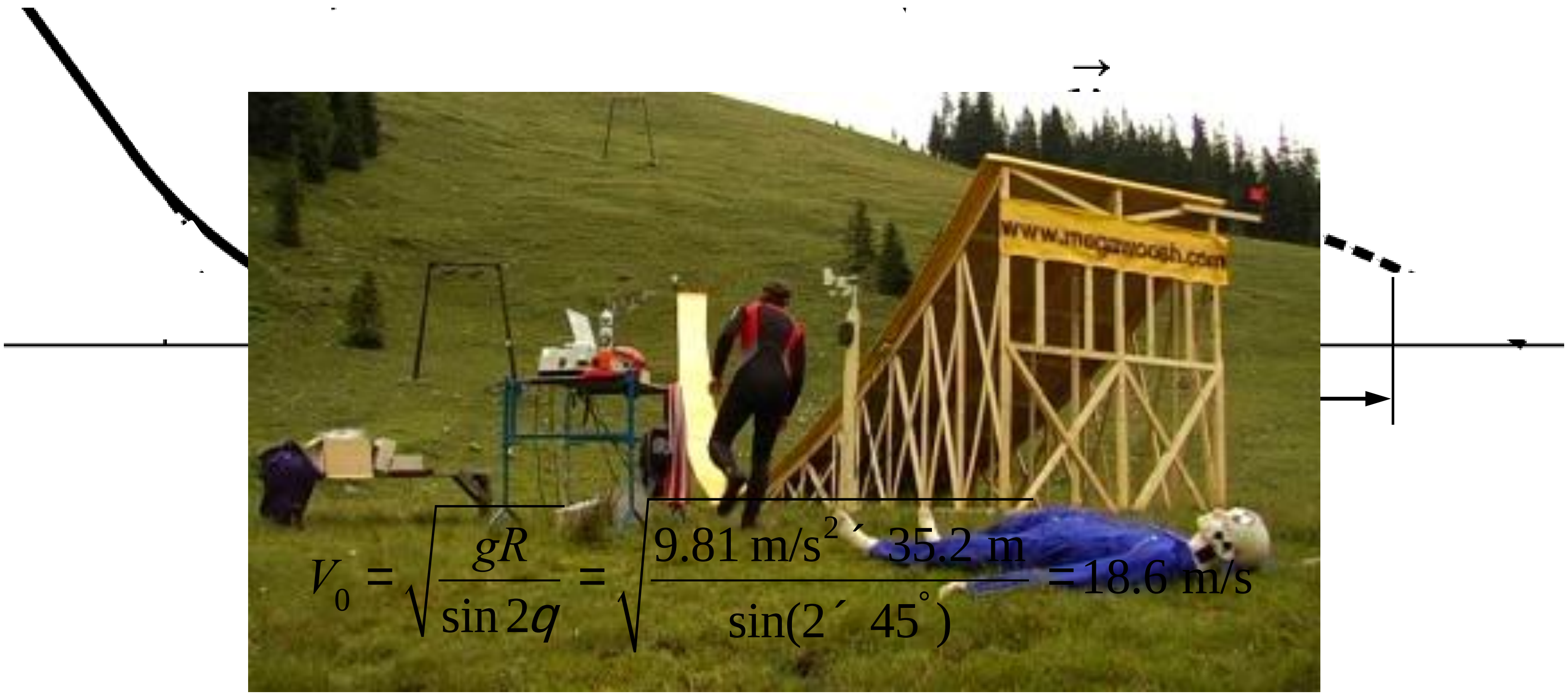
Engineering Questions?

What is the coefficient of friction between his hands and the barrel?

Would the barrel survive this maneuver?

Bruno Kammerl's Punktlandung

(www.megawoosh.com)

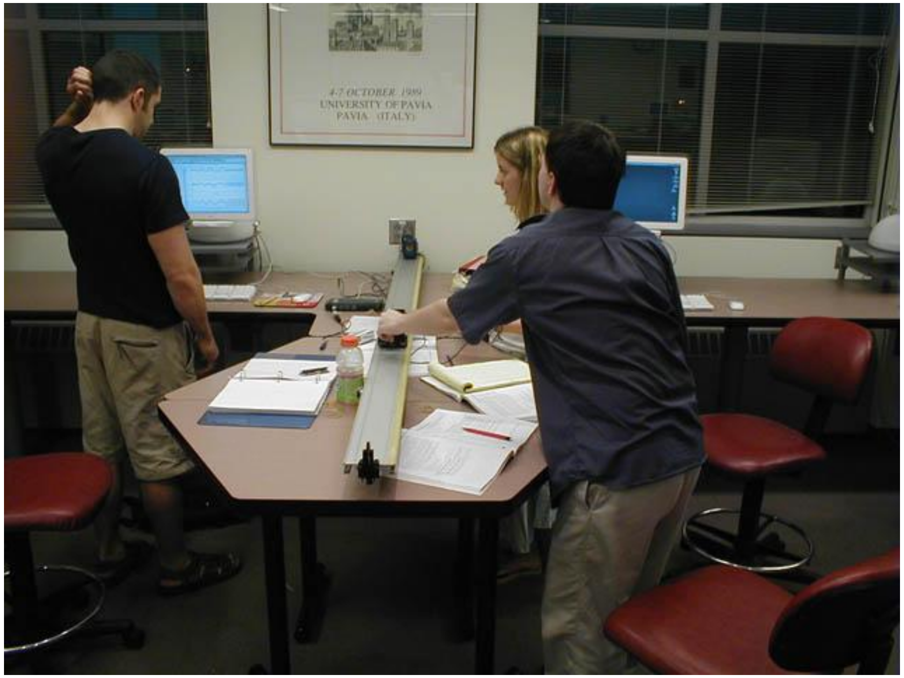


$$V_0 = \sqrt{\frac{gR}{\sin 2\theta}} = \sqrt{\frac{9.81\ \text{m/s}^2 \times 35.2\ \text{m}}{\sin(2 \times 45^\circ)}} = 18.6\ \text{m/s}$$

$$v_f^2 = v_i^2 + 2a\Delta s \quad \Rightarrow \quad a = \frac{v_f^2 - v_i^2}{2\Delta s} = \frac{0 - \left(18.6\ \text{m/s}\right)^2}{2 \times 1.00\ \text{m}} = -173\ \text{m/s}^2\ \left(\sim 18\ \text{g}\right)$$

Priscilla Laws at Dickinson College gets normalized FCI gains of ~0.70 using Workshop Physics !

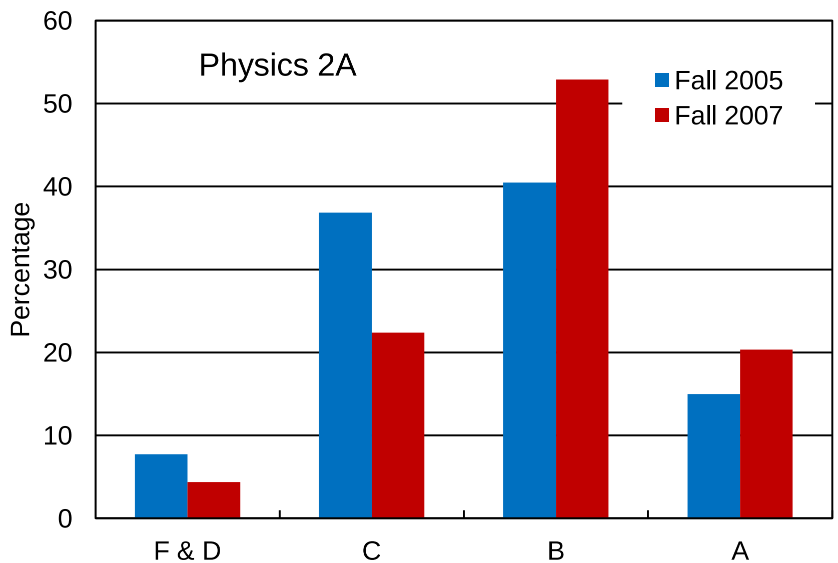
- No formal lectures.
- Reduce content and concentrate of the process of scientific inquiry.
- Emphasize directly observable phenomena.

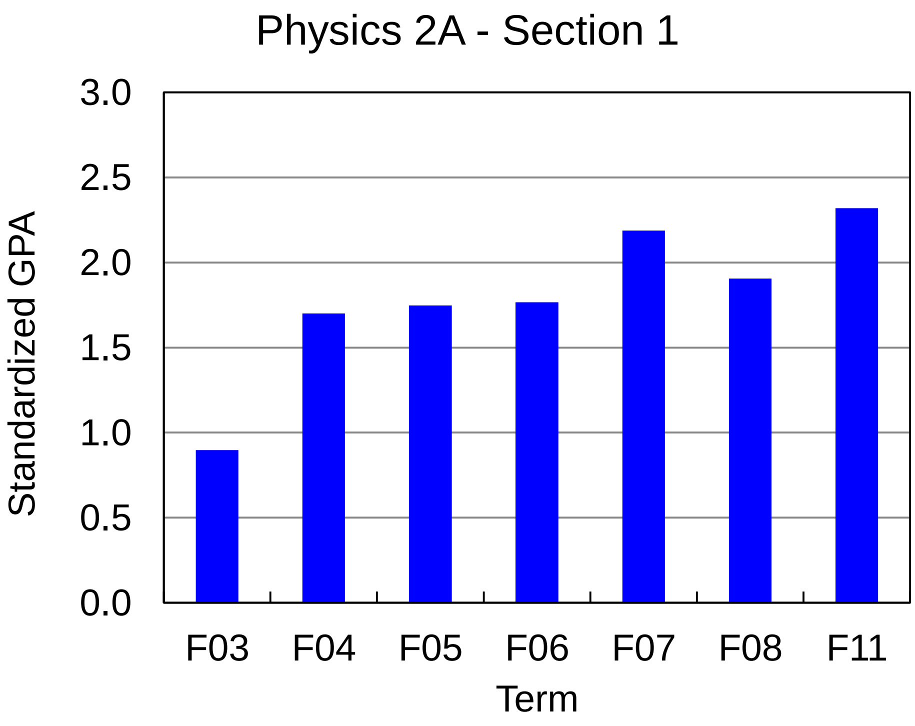


Quantitative Assessment

	Physics 2A				Physics 2B			
	Fall 03	Fall 05	Fall 07	Fall 08	Winter 04	Winter 06	Winter 08	Winter 09
Normalized FCI Gain	-	0.18	0.24	0.23	NA	NA	NA	NA
D & F's	19.4%	7.7%	4.4%	9.3%	16.2%	5.6%	2.8%	2.7%
Course GPA	2.32	2.60	2.86	2.53	2.47	2.56	2.84	2.78

	Fall 05	Fall 07	Fall 08
C– cutoff	26	35	38
B cutoff	54	59	60

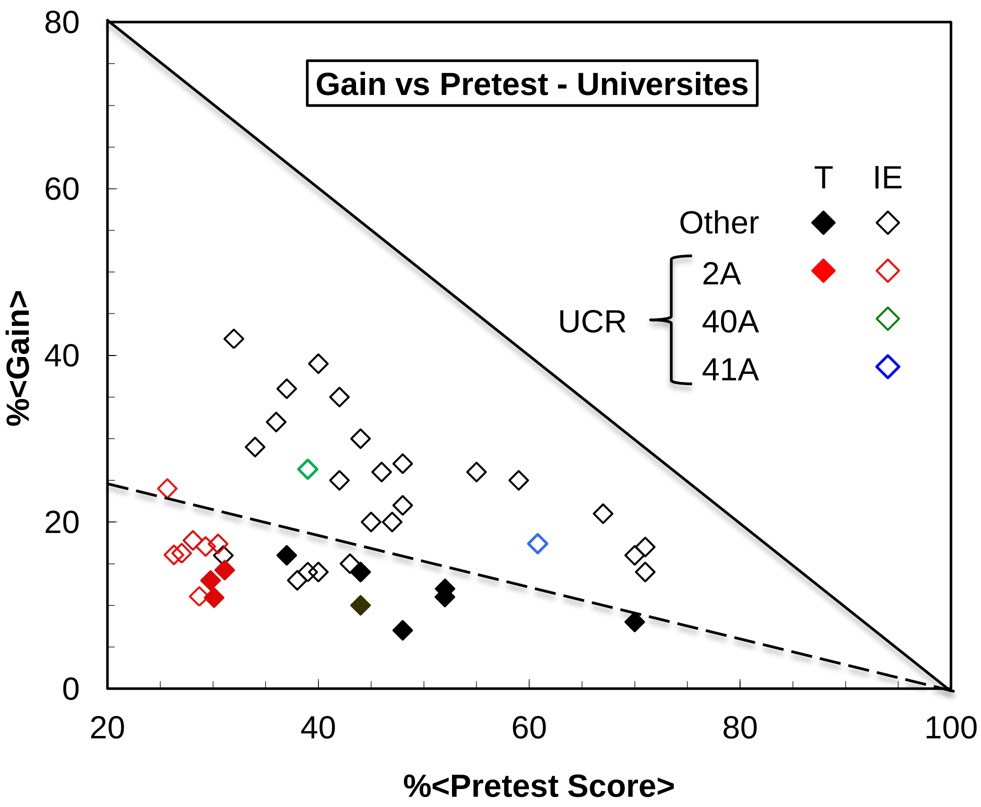




Some Quantitative Improvement

- Students retain more material from previous quarter.
- Higher levels of student interaction in lecture.
- Higher student satisfaction (class evaluations).

How about the FCI?



Some Conclusions

- A large body of literature shows that pedagogies based on IE significantly improve teaching effectiveness. Technology alone will not solve our problem; however, as a tool, it can be helpful for implementing effective pedagogies.
- There are many different implementations of IE, designed for different teaching environments (i.e. large classrooms, small classrooms, discussion sections, and laboratory.)
- Good quantitative (absolute) assessments are important for implementing IE.
- Peer instruction using a classroom response system and cooperative group instruction in discussion sections are two implementations of IE that have improved learning at UCR.
- A workshop style physics instruction like the one used in our Physics 41 series may be even more effective.