Physics Education Research:
Laying the Basis for Improved Physics Instruction

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Division of Undergraduate Education
Division of Research, Evaluation and Communication

ISU Center for Teaching Excellence

Miller Faculty Fellowship 1999-2000 (with T. Greenbowe)
CTE Teaching Scholar 2002-2003

Outline

Physics Education as a Research Problem

- Goals and Methods of Physics Education Research
- Some Specific Issues

Research-Based Curriculum Development

- Principles of research-based curriculum development
- Examples

Research-Based Instructional Methods

- Principles of research-based instruction
- Examples of research-based instructional methods

Assessment of Instruction

- Measurement of learning gain

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Physics Education As a Research Problem

Within the past 25 years, physicists have begun to treat the teaching and learning of physics as a research problem

- Systematic observation and data collection; reproducible experiments
- Identification and control of variables
- In-depth probing and analysis of students' thinking

Physics Education Research ("PER")

Goals of PER

- Improve effectiveness and efficiency of physics instruction
  - measure and assess *learning* of physics (not merely *achievement*)
- Develop instructional methods and materials that address obstacles which impede learning
- Critically assess and refine instructional innovations

Methods of PER

- Develop and test diagnostic instruments that assess student understanding
- Probe students' thinking through analysis of written and verbal explanations of their reasoning, supplemented by multiple-choice diagnostics
- Assess learning through measures derived from pre- and post-instruction testing

What PER Can NOT Do

- Determine “philosophical” approach toward undergraduate education
  - focus on majority of students, or on subgroup?
- Specify the goals of instruction in particular learning environments
  - proper balance among “concepts,” problem-solving, etc.

Active PER Groups in Ph.D.-granting Physics Departments

> 10 yrs old	6-10 yrs old	< 6 yrs old
*U. Washington	U. Maine	Oregon State U.
*Kansas State U.	Montana State U.	Iowa State U.
*Ohio State U.	U. Arkansas	City Col. N.Y.
*North Carolina State U.	U. Virginia	Texas Tech U.
*U. Maryland		U. Central Florida
*U. Minnesota		U. Colorado
*San Diego State U. [joint with U.C.S.D.]		U. Illinois
*Arizona State U.		U. Pittsburgh
U. Mass., Amherst		Rutgers U.
Mississippi State U.		Western Michigan U.
U. Oregon		Worcester Poly. Inst.
U. California, Davis		U. Arizona
		New Mexico State U.

*leading producers of Ph.D.'s

Primary Trends in PER

- Research into Student Understanding
- Research-based Curriculum Development
- Assessment of Instructional Methods
- Preparation of K-12 Physics and Science Teachers

Major Curriculum Development Projects

- **U.S. Air Force Academy**
  - Just-in-Time Teaching [large classes]
- **U. Arizona; Montana State**
  - Lecture Tutorials for Introductory Astronomy
- **Arizona State U.**
  - Modeling Instruction [primarily high-school teachers]
- **Davidson College**
  - Physlets
- **Harvard**
  - ConcepTests ["Peer Instruction"]
- **Indiana University**
  - Socratic-Dialogue Inducing Labs
- **Iowa State U.**
  - Workbook for Introductory Physics
- **Kansas State U.**
  - Visual Quantum Mechanics
- **U. Massachusetts, Amherst**
  - Minds-On Physics [high school]

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Major Curriculum Development Projects [cont'd]

- **U. Maryland; U. Maine; CCNY**
  - New Model Course in Quantum Physics; Activity-based Physics Tutorials
- **U. Minnesota**
  - Cooperative Group Problem Solving
- **U. Nebraska; Texas Tech U.**
  - Physics with Human Applications
- **North Carolina State; U. Central Florida**
  - SCALE-UP [large classes]; Matter and Interactions
- **Oregon State U.**
  - Paradigms in Physics [upper-level]
- **Rutgers; Ohio State U.**
  - Investigative Science Learning Environment
- **San Diego State U.**
  - Constructing Physics Understanding
- **Tufts; U. Oregon; Dickinson College**
  - Real-time Physics; Workshop Physics ["MBL"]
- **U. Wash**
  - Physics by Inquiry; Tutorials in Introductory Physics

Types of Curriculum Development
(lots of overlaps)

- Lab-based
- Large-class (interactive lectures)
- Small-class (group learning)
- High-School
- Technology-based
- Upper-level
- Teacher Preparation

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(lots of overlaps)

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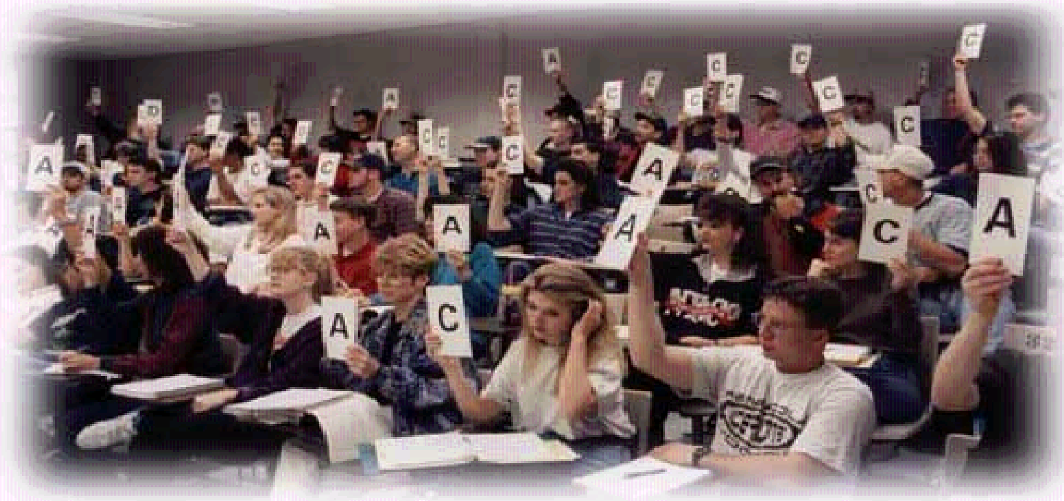
*ISU PER projects

Major PER Research Trends

- Students’ conceptual understanding
- Development of assessment instruments
- Students’ attitudes toward and beliefs about learning physics
- Analysis of students’ knowledge structure (context-dependence of students’ knowledge)
- Assessment of students’ problem-solving skills

Physics Education
Research Group



Department of Physics and Astronomy
Iowa State University
Ames, Iowa

Welcome to the website for Iowa State University's Physics Education Research Group! Follow the links on the navigation bar to find out more about our teaching and research.

About Us
Learn about the purpose and goals of Iowa State's PERG.

Members
Find contact information for students and faculty involved in the PERG.

Media
Watch physics education in action at Iowa State.

Links
Find other physics education resources on the web.

Current Projects
Explore the PERG's latest projects.

Publications and Preprints

www.physics.iastate.edu/per/

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Some Specific Issues

Many (if not most) students:

- develop weak ***qualitative*** understanding of concepts
  - don’t use qualitative analysis in problem solving
  - lacking quantitative problem solution, can’t reason “physically”

- lack a **“*functional*”** understanding of concepts (which would allow problem solving in unfamiliar contexts)

Origins of Learning Difficulties

- Students hold many firm ideas about the physical world that may conflict strongly with physicists' views.

  Examples:

  - **An object in motion *must* be experiencing a force**
  - **A given battery always produces the *same* current in *any* circuit**
  - **Electric current gets "used up" as it flows around a circuit**

- Most introductory students need much guidance in scientific reasoning employing abstract concepts.

- Most introductory students lack "active learning" skills that would permit more efficient mastery of physics concepts.

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Research-Based Curriculum Development

- Investigate student learning with standard instruction; probe learning difficulties
- Develop new materials based on research
- Test and modify materials
- Iterate as needed

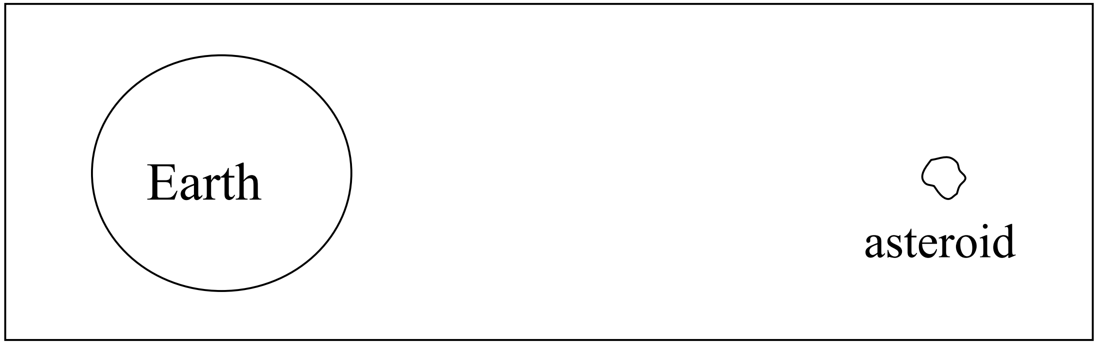
Addressing Learning Difficulties: A Model Problem

Student Concepts of Gravitation

[Jack Dostal and DEM]

- 10-item free-response diagnostic administered to over 2000 ISU students during 1999-2000.
  - *Newton's third law in context of gravity; direction and superposition of gravitational forces; inverse-square law.*
- Worksheets developed to address learning difficulties; tested in calculus-based physics course Fall 1999

Example: Newton's Third Law in the Context of Gravity



Is the magnitude of the force exerted **by the asteroid on the Earth** *larger than, smaller than, or the same as the magnitude of the force exerted* **by the Earth on the asteroid***? Explain the reasoning for your choice.*

[Presented during first week of class to all students taking calculus-based introductory physics at ISU during Fall 1999.]

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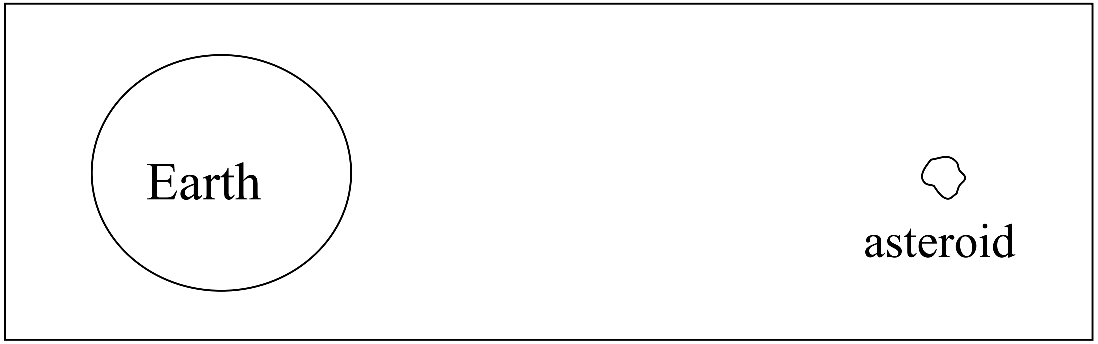

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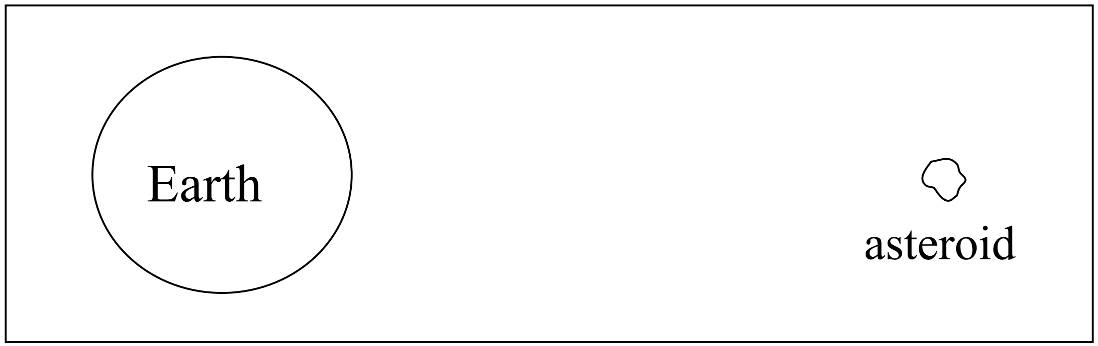

Is the magnitude of the force exerted **by the asteroid on the Earth** *larger than, smaller than, or the same as the magnitude of the force exerted* **by the Earth on the asteroid*?*** *Explain the reasoning for your choice.*

[Presented during first week of class to all students taking calculus-based introductory physics at ISU during Fall 1999.]

First-semester Physics *(N = 546)*: ***15% correct responses***

Second-semester Physics *(N = 414)*: ***38% correct responses***

Most students claim that Earth exerts greater force because it is larger

Implementation of Instructional Model

"Elicit, Confront, Resolve" *(U. Washington)*

- Guide students through reasoning process in which they tend to encounter targeted conceptual difficulty
- Allow students to commit themselves to a response that reflects conceptual difficulty
- Guide students along alternative reasoning track that bears on same concept
- Direct students to compare responses and resolve any discrepancies

Implementation of Instructional Model

"Elicit, Confront, Resolve" (U. Washington)

→ *One of the central tasks in curriculum reform is development of "Guided Inquiry" worksheets*

- Worksheets consist of sequences of closely linked problems and questions
  - *focus on conceptual difficulties identified through research*
  - *emphasis on qualitative reasoning*
- Worksheets designed for use by students working together in small groups (3-4 students each)
- Instructors provide guidance through "Socratic" questioning

Example: Gravitation Worksheet

(Jack Dostal and DEM)

- Design based on research (interviews + written diagnostic tests), as well as instructional experience
- Targeted at difficulties with Newton's third law, and with use of proportional reasoning in inverse-square force law

Protocol for Testing Worksheets
(Fall 1999)

- 30% of recitation sections yielded half of one period for students to do worksheets
- Students work in small groups, instructors circulate
- Remainder of period devoted to normal activities
- No net additional instructional time on gravitation
- Conceptual questions added to final exam with instructor's approval

Name________________________

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Physics 221

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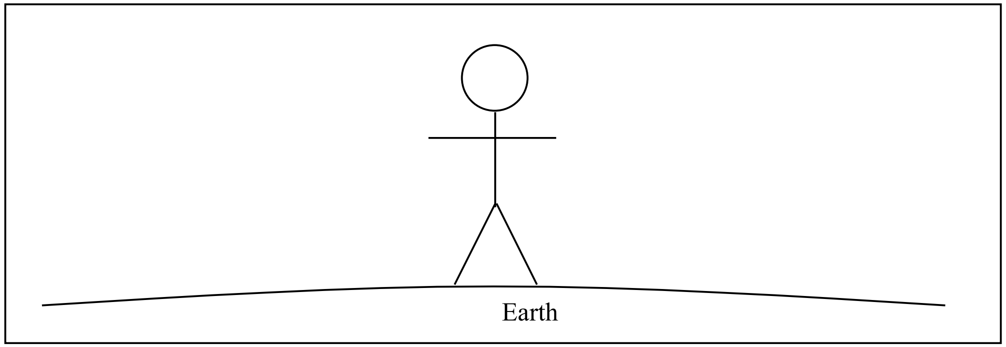

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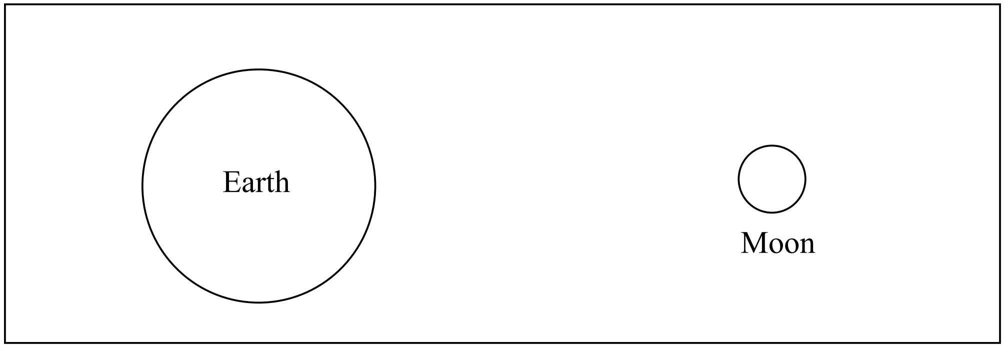

c) Now, in the same picture (above), draw an arrow which represents the force exerted ***by*** the Moon ***on*** the Earth. Label this arrow **(c)**. Remember to draw the arrow with the correct length and direction as compared to the arrow you drew in **(b)**.

d) Are arrows **(b)** and **(c)** the same size? Explain why or why not.

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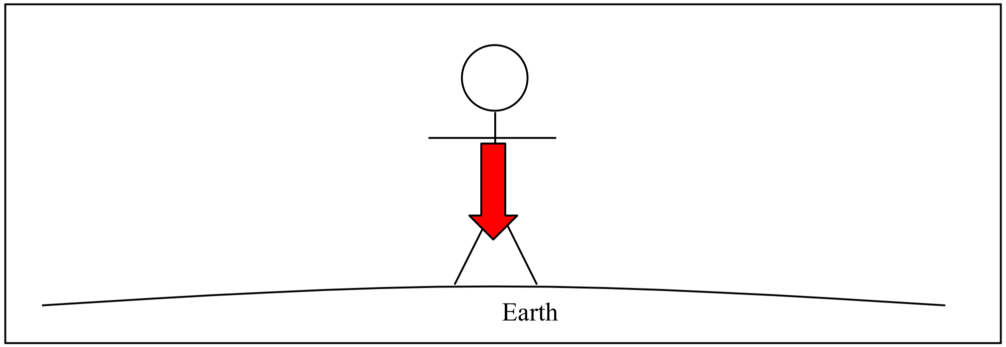

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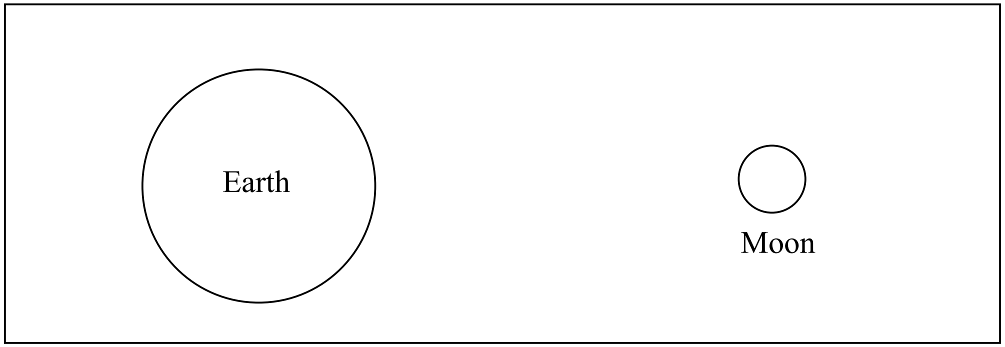

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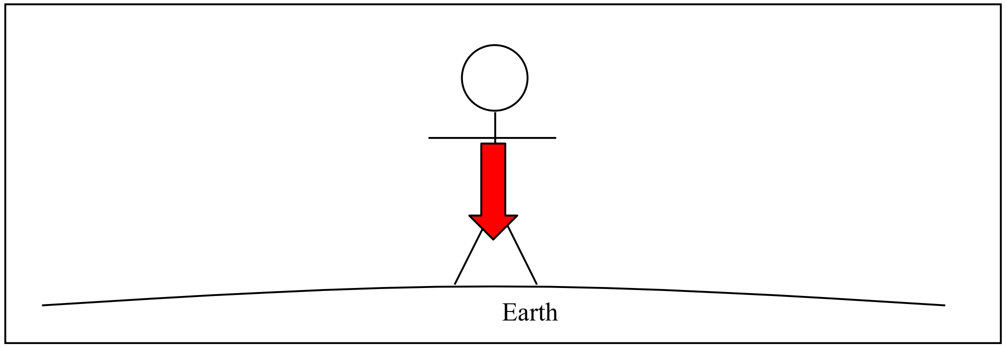

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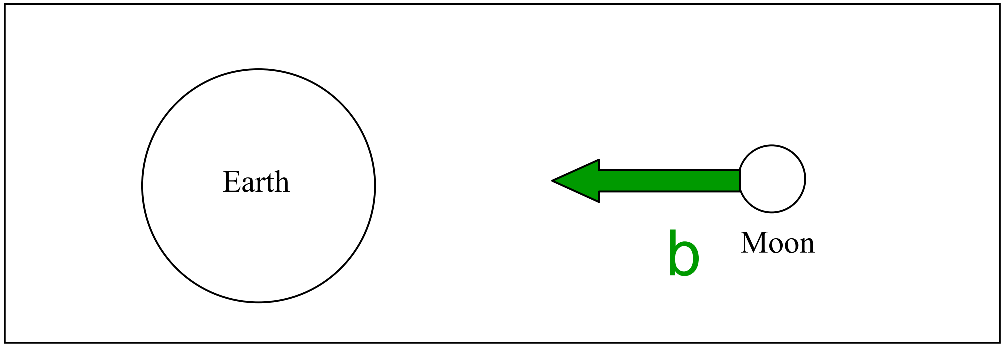

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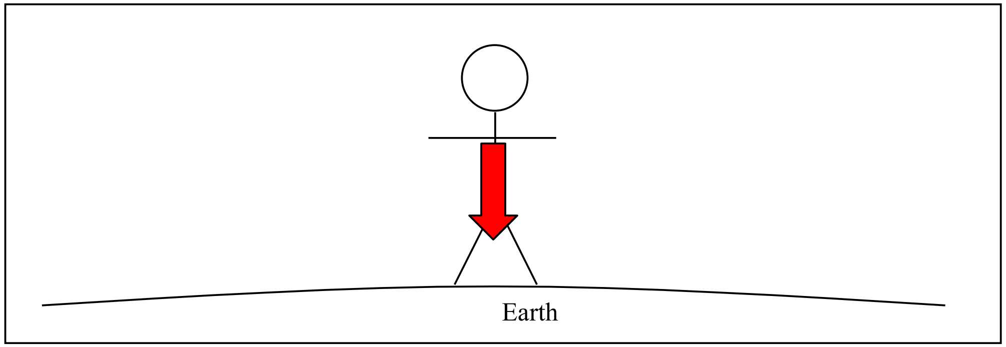

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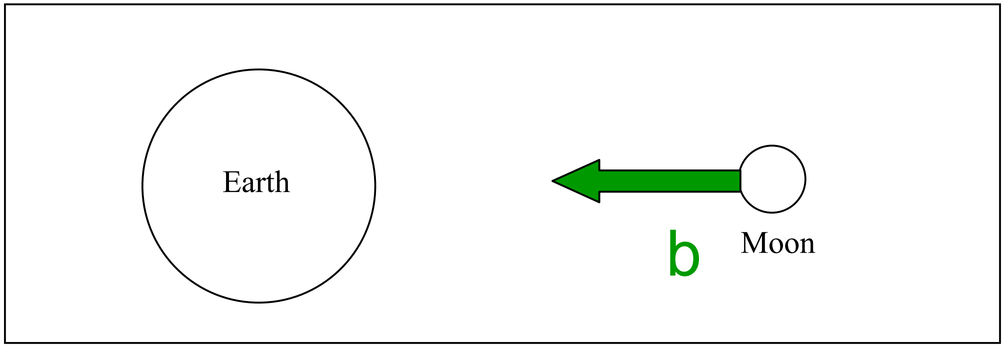

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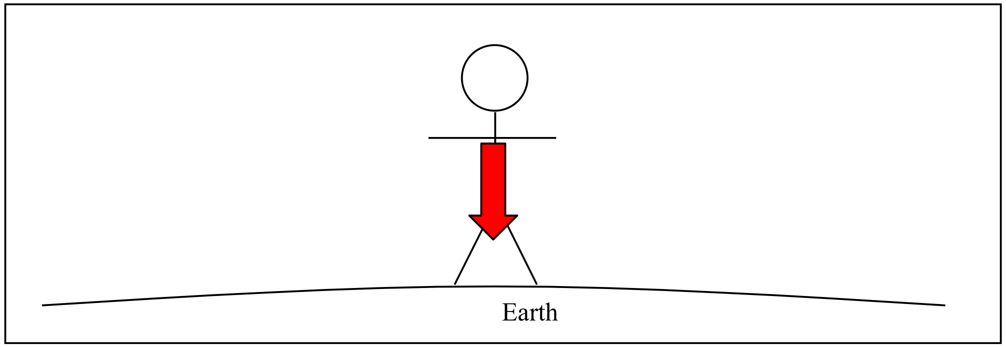

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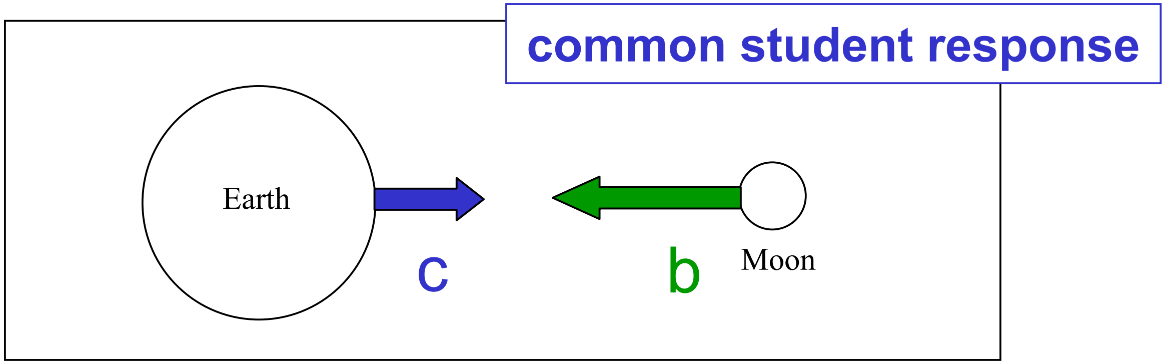

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f) Consider the magnitude of the gravitational force in (c). Write down an algebraic expression for the strength of the force. (Again, refer to Newton's Universal Law of Gravitation at the top of the previous page.) Use M_e for the mass of the Earth and M_m for the mass of the Moon.

g) Look at your answers for (e) and (f). Are they the same?

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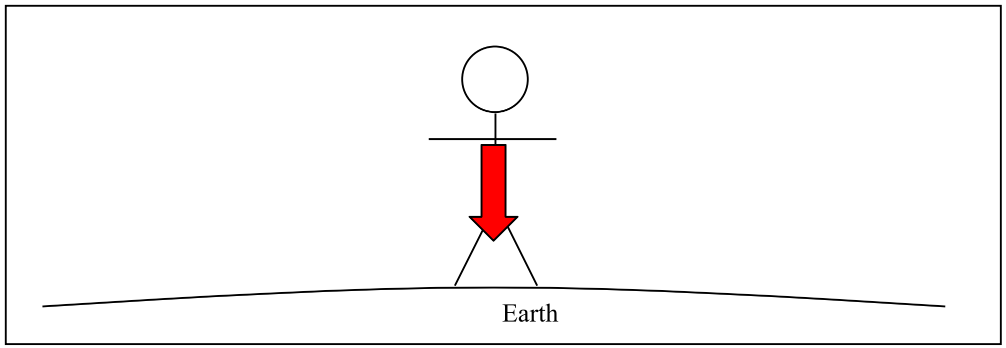

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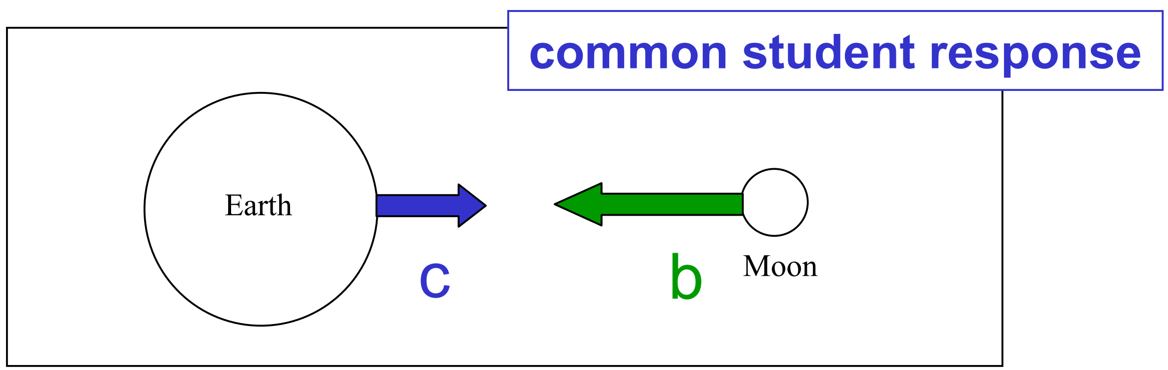

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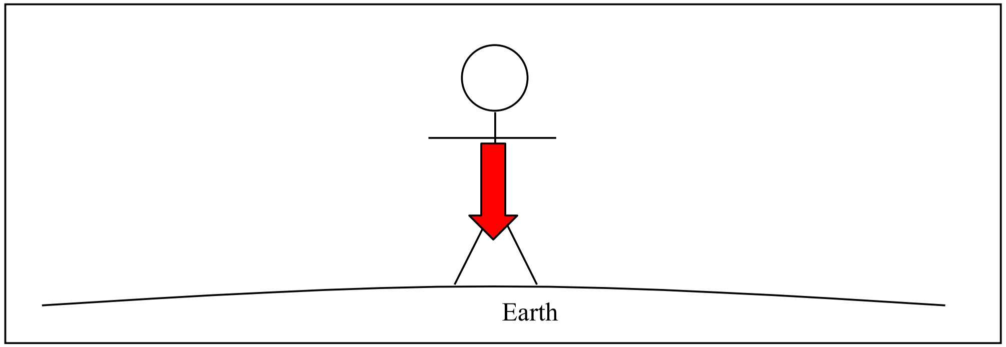

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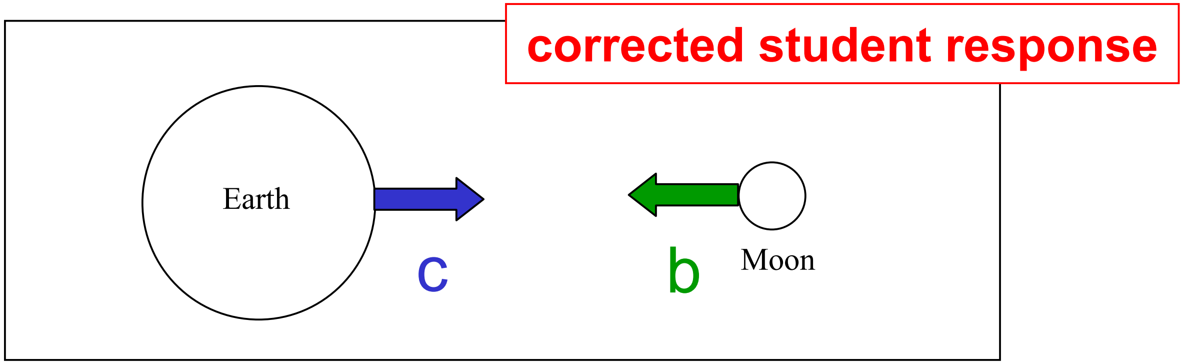

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Diagram (i): In this figure, two equal spherical masses (mass = "M") are shown. Draw the vectors representing the gravitational forces the masses exert on each other. Draw your *shortest* vector to have a length equal to *one* of the grid squares.

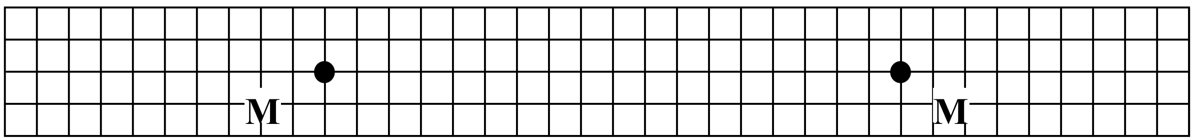


Diagram (ii): Now, one of the spheres is replaced with a sphere of mass 2M. Draw a new set of vectors representing the mutual gravitational forces in this case.

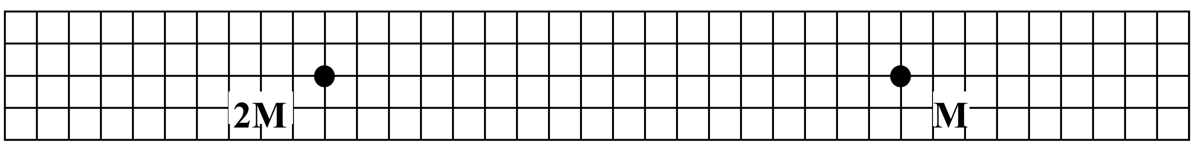
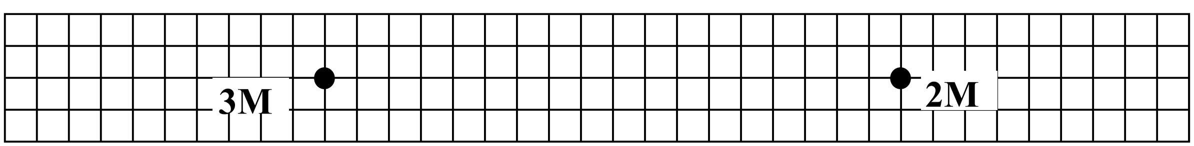


Diagram (iii): In this case, the spheres have masses 2M and 3M. Again, draw the vectors representing the mutual gravitational forces.



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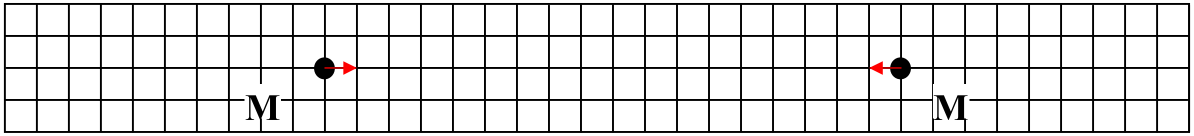

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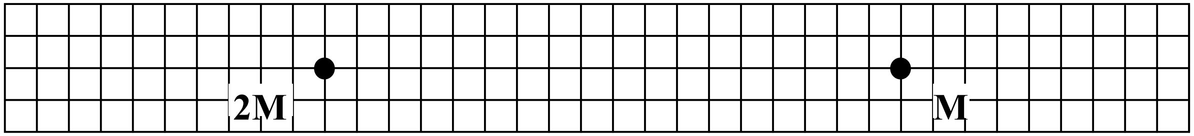
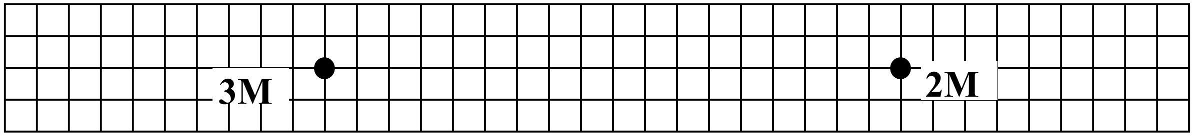
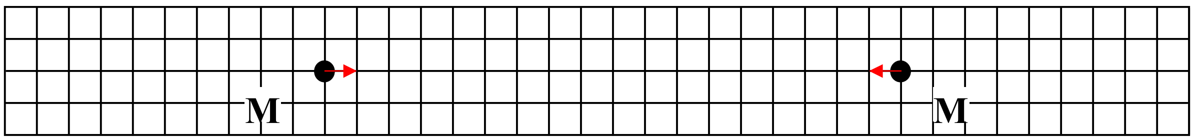


Diagram (iii): In this case, the spheres have masses 2M and 3M. Again, draw the vectors representing the mutual gravitational forces.



2) In the following diagrams, draw arrows representing force vectors, such that the length of the arrow is proportional to the magnitude of the force it represents.

Diagram (i): In this figure, two equal spherical masses (mass = "M") are shown. Draw the vectors representing the gravitational forces the masses exert on each other. Draw your *shortest* vector to have a length equal to *one* of the grid squares.



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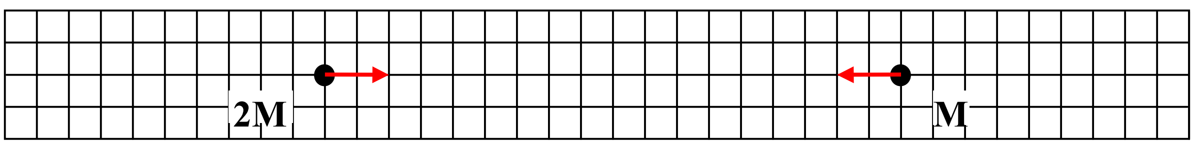

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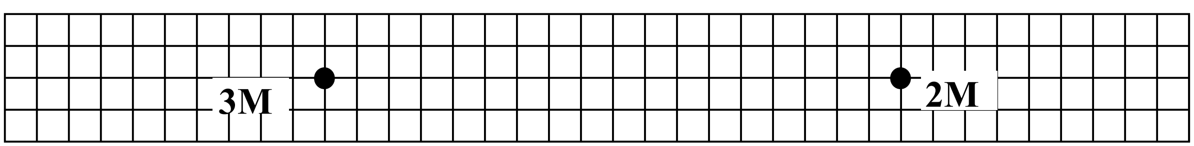

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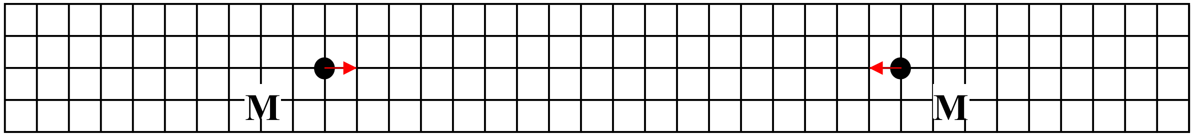

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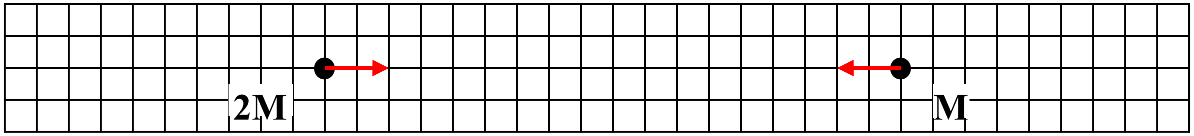

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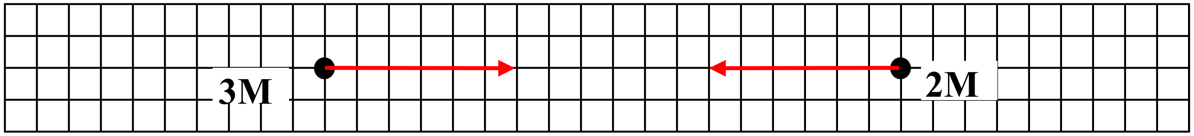

Post-test Question (Newton's third law)

The rings of the planet Saturn are composed of millions of chunks of icy debris. Consider a chunk of ice in one of Saturn's rings. Which of the following statements is true?

A. The gravitational force exerted by the chunk of ice on Saturn is **greater than** the gravitational force exerted by Saturn on the chunk of ice.

➡ B. The gravitational force exerted by the chunk of ice on Saturn is **the same magnitude as** the gravitational force exerted by Saturn on the chunk of ice.

C. The gravitational force exerted by the chunk of ice on Saturn is **nonzero, and less than** the gravitational force exerted by Saturn on the chunk of ice.

D. The gravitational force exerted by the chunk of ice on Saturn is zero.

E. Not enough information is given to answer this question.

Results on Newton's Third Law Question

(All students)

	N	Post-test Correct
Non-Worksheet	*384*	61%
Worksheet	*116*	87%

(Fall 1999: calculus-based course, first semester)

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Assessment of Instruction

- Measurement of learning gain

Research Basis for Curriculum Development *(NSF CCLI Project with T. Greenbowe)*

- Investigation of second-semester calculus-based physics course (mostly engineering students).
- Written diagnostic questions administered last week of class in 1999, 2000, and 2001 (N_{total} = 653).
- Detailed interviews (avg. duration ≥ one hour) carried out with 32 volunteers during 2002 (total class enrollment: 424).
  - *interviews carried out after all thermodynamics instruction completed*
  - *final grades of interview sample far above class average*

[two course instructors, ≈ 20 recitation instructors]

Findings: Student Learning Difficulties

1. Belief that work is a state function.
2. Belief that heat is a state function.
3. Failure to recognize “work” as a mechanism of energy transfer.
4. Belief that net work done and net heat transferred during a cyclic process are zero.
5. Inability to apply the first law of thermodynamics.

. . . etc.

Some Strategies for Instruction

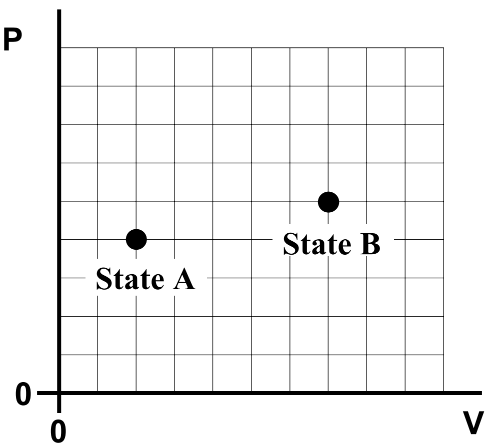
- Focus on meaning of heat as ***transfer*** of energy, ***not*** quantity of energy residing in a system.
- Develop concept of work as energy transfer mechanism.
- Guide students to make increased use of *PV*-diagrams and similar representations.

Thermodynamics Worksheet

For an ideal gas, the internal energy U is directly proportional to the temperature T. (This is because the internal energy is just the total kinetic energy of all of the gas molecules, and the temperature is defined to be equal to the *average* molecular kinetic energy.) For a monatomic ideal gas, the relationship is given by $U = \frac{3}{2}nRT$, where n is the number of moles of gas, and R is the universal gas constant.

1. Find a relationship between the internal energy of n moles of ideal gas, and pressure and volume of the gas. Does the relationship change when the number of moles is varied?

2. Suppose that m moles of an ideal gas are contained inside a cylinder with a movable piston (so the volume can vary). At some initial time, the gas is in state A as shown on the PV-diagram in Figure 1. A thermodynamic process is carried out and the gas eventually ends up in State B. Is the internal energy of the gas in State B *greater than*, *less than*, or *equal to* its internal energy in State A? (That is, how does U_B compare to U_A?) Explain.



3. If a system starts with an initial internal energy of $U_{initial}$ and ends up with U_{final} some time later, we symbolize the *change* in the system's internal energy by ΔU and define it as follows: $\Delta U = U_{final} - U_{initial}$.

   a. For the process described in #2 (where the system goes from State A to State B), is ΔU for the gas system *greater than zero*, *equal to zero*, or *less than zero*?

   b. During this process, was there any energy transfer between the gas system and its surrounding environment? Explain.

Thermodynamics Curricular Materials

- Preliminary versions and initial testing of worksheets for:
  - calorimetry
  - thermochemistry
  - first-law of thermodynamics
  - cyclic processes
  - Carnot cycle
  - entropy
  - free energy

Preliminary testing in general physics and in junior-level thermal physics course

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But … ***some*** students learn efficiently . . .

- Highly successful physics students are ***"active learners."***
  - they continuously probe their own understanding

    [*pose their own questions; scrutinize implicit assumptions; examine varied contexts; etc.]*
  - they are sensitive to areas of confusion, and have the confidence to confront them directly

- Majority of introductory students are unable to do efficient active learning on their own: they don't know "which questions they need to ask"
  - they require considerable prodding by instructors, aided by appropriate curricular materials

Active-Learning Pedagogy
(“*Interactive Engagement*”)

- problem-solving activities during class time
- deliberately elicit and address common learning difficulties
- guide students to “figure things out for themselves” as much as possible

“Interactive Engagement”

“Interactive Engagement” methods require an <u>active learning</u> classroom:

- Very high levels of interaction between students and instructor
- Collaborative group work among students during class time
- ***<u>Intensive</u>*** active participation by students in focused learning activities during class time

Elicit Students' Pre-existing Knowledge Structure

- Have students predict outcome of experiments***.***
- Require students to give written explanations of their reasoning.
- Pose specific problems that trigger learning difficulties. ***(Based on research)***
- Structure subsequent activities to confront difficulties that were elicited.

“Inquiry-based” Learning

Students are guided through investigations to “discover” concepts

- Targeted concepts are generally ***not*** told to the students in lectures before they have an opportunity to investigate (or ***think*** about) the idea

- Can be implemented in the instructional laboratory where students are guided to form conclusions based on observational evidence

- Can be implemented in “lecture” or recitation, by guiding students through chains of reasoning utilizing printed worksheets

Example: Force and Motion

A cart on a low-friction surface is being pulled by a string attached to a spring scale. The velocity of the cart is measured as a function of time.

The experiment is done three times, and the pulling force is varied each time so that the spring scale reads 1 N, 2 N, and 3 N for trials #1 through #3, respectively. (The mass of the cart is kept the same for each trial.)

On the graph below, sketch the appropriate lines for velocity versus time for the three trials, and label them #1, #2, and #3.

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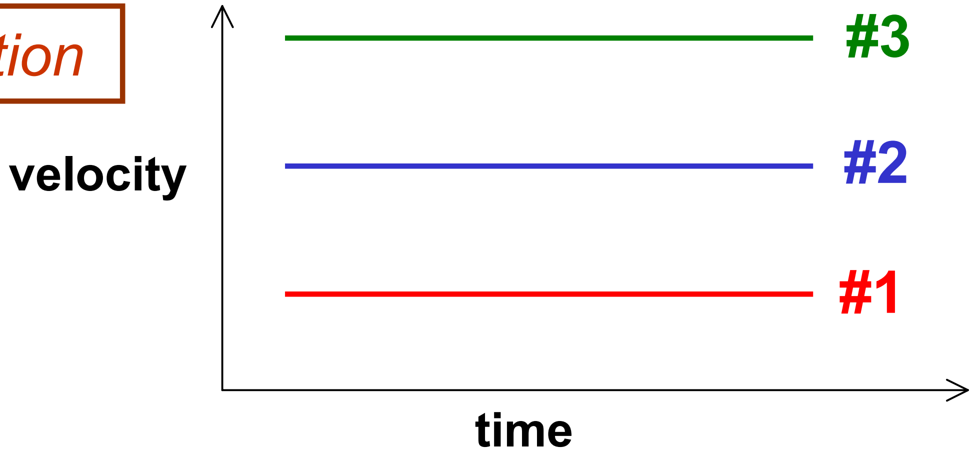
common student prediction



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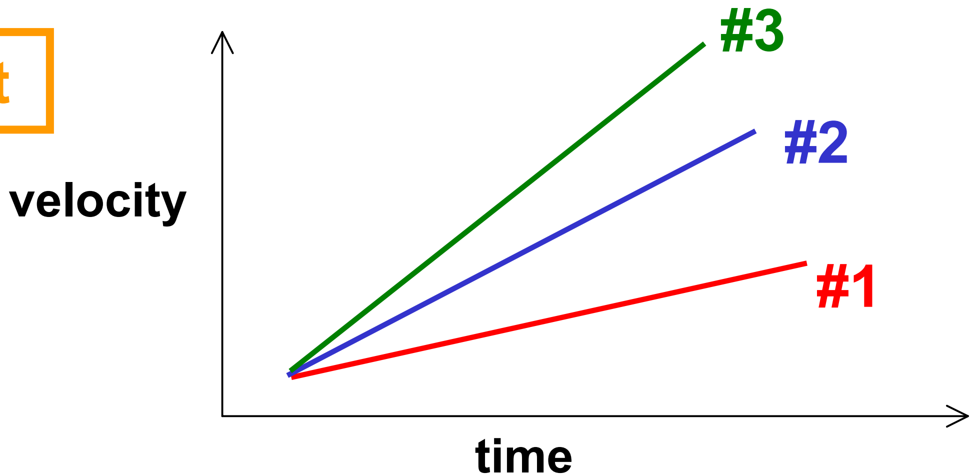
result of measurement



Key Themes of Research-Based Instruction

- Emphasize qualitative, non-numerical questions to reduce unthoughtful “plug and chug.”

- Make extensive use of multiple representations to deepen understanding.

  (Graphs, diagrams, words, simulations, animations, etc.)

- Require students to *explain their reasoning* (verbally or in writing) to more clearly expose their thought processes.

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New Approaches to Instruction on Problem Solving

- **A. Van Heuvelen**: Require students to use multiple representations (pictures, diagrams, graphs, etc.).
- **P. and K. Heller:** Use “context rich” problems posed in natural language.
- **F. Reif et al.:** Require students to construct problem-solving strategies.
- **P. D’Allesandris:** Use “goal-free” problems with no explicitly stated unknown.
- **J. Mestre, W. Gerace, W. Leonard, R. Dufresne:** Emphasize student generation of qualitative problem-solving strategies.

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Difficulties in Changing Representations or Contexts

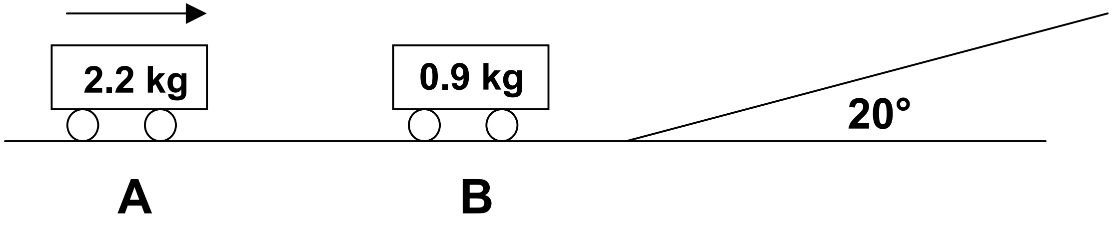
- Students are often ***unable*** to solve the same problem when posed in a different representation.
- Students are often able to solve problems in a "physics" context (e.g., a textbook problem), but ***unable*** to solve the same problem in a "real world" context.

Changing Contexts:

Textbook Problems and "Real" Problems

- **"Standard" Textbook Problem:**

Cart A, which is moving with a constant velocity of 3 m/s, has an inelastic collision with cart B, which is initially at rest as shown in Figure 8.3. After the collision, the carts move together up an inclined plane. Neglecting friction, determine the vertical height *h* of the carts before they reverse direction.



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- **"Context-Rich" Problem (K. and P. Heller):**

You are helping your friend prepare for the next skate board exhibition. For her program, she plans to take a running start and then jump onto her heavy-duty 15-lb stationary skateboard. She and the skateboard will glide in a straight line along a short, level section of track, then up a sloped concrete wall. She wants to reach a height of at least 10 feet above where she started before she turns to come back down the slope. She has measured her maximum running speed to safely jump on the skateboard at 7 feet/second. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned. She tells you that she weighs 100 lbs.

New Instructional Methods: Active-Learning Laboratories

- **"Microcomputer-based Labs"** *(P. Laws, R. Thornton, D. Sokoloff)*: Students make predictions and carry out detailed investigations using real-time computer-aided data acquisition, graphing, and analysis. *"Workshop Physics" (P. Laws)* is ***entirely*** lab-based instruction.

- **"Socratic-Dialogue-Inducing" Labs** *(R. Hake)*: Students carry out and analyze activities in detail, aided by "Socratic Dialoguist" instructor who asks leading questions, rather than providing ready-made answers.

New Instructional Methods: Active Learning Text/Workbooks

- ***Matter & Interactions (Vols. I and II)***, R. Chabay and B. Sherwood, Wiley, 1995-2003.
- ***Understanding Basic Mechanics***, F. Reif, Wiley, 1995.
- ***Physics: A Strategic Approach***, R. Knight, Addison-Wesley, 2003.
- ***Six Ideas That Shaped Physics***, T. Moore, McGraw-Hill, 1998.

Research-based Software/Multimedia

- ***Simulation Software:*** *ActivPhysics (*Van Heuvelen and d'Allesandris); *Visual Quantum Mechanics* (Zollman, Rebello, Escalada)

- ***"Intelligent Tutors":*** *"Freebody," (*Oberem); *"Photoelectric Effect," (*Oberem and Steinberg)

- ***"Reciprocal Teacher":*** *"Personal Assistant for Learning," (*Reif and Scott)

New Instructional Methods: University of Washington Model

"Elicit, Confront, Resolve"

Most thoroughly tested and research-based physics curricular materials; based on 20 years of ongoing work

- ***"Physics by Inquiry":*** 3-volume lab-based curriculum, primarily for elementary courses, which leads students through extended group investigations. Instructors provide "leading questions" only.

- ***"Tutorials for Introductory Physics":*** Extensive set of worksheets, designed for use by general physics students working in groups of 3 or 4. Instructors provide guidance and probe understanding with "leading questions." Aimed at eliciting deep conceptual understanding of frequently misunderstood topics.

New Instructional Methods: Active Learning in Large Classes

- ***"Active Learning Problem Sheets"*** (A. Van Heuvelen): Worksheets for in-class use, emphasizing multiple representations (verbal, pictorial, graphical, etc.)
- ***"Interactive Lecture Demonstrations"*** (R. Thornton and D. Sokoloff): students make written predictions of outcomes of demonstrations.
- ***"Peer Instruction"*** (E. Mazur): Lecture segments interspersed with challenging conceptual questions; students discuss with each other and communicate responses to instructor.
- ***"Workbook for Introductory Physics"*** (D. Meltzer and K. Manivannan): combination of multiple-choice questions for instantaneous feedback, and sequences of free-response exercises for in-class use.

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Active Learning in Large Classes

- **Drastic de-emphasis of lecturing**; Instead, ask students to respond to many questions.
- Use of communication systems (e.g., “Flash Cards”) to obtain **instantaneous feedback** from entire class.
- Cooperative **group work** using carefully structured free-response worksheets (e.g., *“Workbook for Introductory Physics”)*

Goal: *Transform large-class learning environment into “office” learning environment (i.e., instructor + one or two students)*

Challenges to Implementation

- Many (most?) students are comfortable and familiar with more passive methods of learning science. ***Active learning methods are always challenging, and frequently frustrating for students. Some (many?) react with anger.***

- Active learning methods and curricula are not "instructor proof." Training, experience, energy and commitment are needed to use them effectively.

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Measures of Learning Gain

- Single exam measures only instantaneous knowledge state, but instructors are interested in improving *learning*, i.e., transitions between states.
- Need a measure of learning gain that has maximum dependence on *instruction*, and minimum dependence on students' *pre-instruction* state.

$\Rightarrow$ *search for measure that is correlated with instructional activities, but has minimum correlation with pretest scores.*

A Figure of Merit: "Normalized" Gain [*g*]

- Practical problem: maximum score = 100%, so if students have different pretest scores their maximum ***possible*** gain is different.
- One solution: Use ***normalized gain "g"*** (introduced by R. Hake)

$$g = \frac{\text{gain}}{\text{maximum possible gain}}$$

$$= \frac{[\textit{posttest score} - \textit{pretest score}]}{[100\% - \textit{pretest score}]}$$

→ ***Normalized gain yields a gain score that corrects for pretest score.***

Normalized Learning Gain "*g*"

R. R. Hake, Am. J. Phys. ***66****, 64 (1998)*

$$g \equiv \frac{posttest\ score - pretest\ score}{maximum\ possible\ score - pretest\ score} = \frac{gain}{maximum\ possible\ gain}$$

In a study of 62 mechanics courses enrolling over 6500 students, Hake found that mean normalized gain <*g*> on the Force Concept Inventory is:

- virtually independent of class mean pretest score (r = +0.02);
- highly correlated with instructional method

Effectiveness of Active-Learning Instruction

Results on "Force Concept Inventory" (diagnostic exam for mechanics concepts)

Survey of 4500 students in 48 "interactive engagement" courses showed g = 0.48 ± 0.14

→ ***highly significant improvement compared to non-Interactive-Engagement classes (g = 0.23 ± 0.04)***

(R. Hake, *Am. J. Phys.* **66**, 64 [1998])

Survey of 281 students in 4 courses using "MBL" labs showed g = 0.34 (range: 0.30 - 0.40)

(non-Interactive-Engagement: g = 0.18)

(E. Redish, J. Saul, and R. Steinberg, *Am. J. Phys.* **66**, 64 [1998])

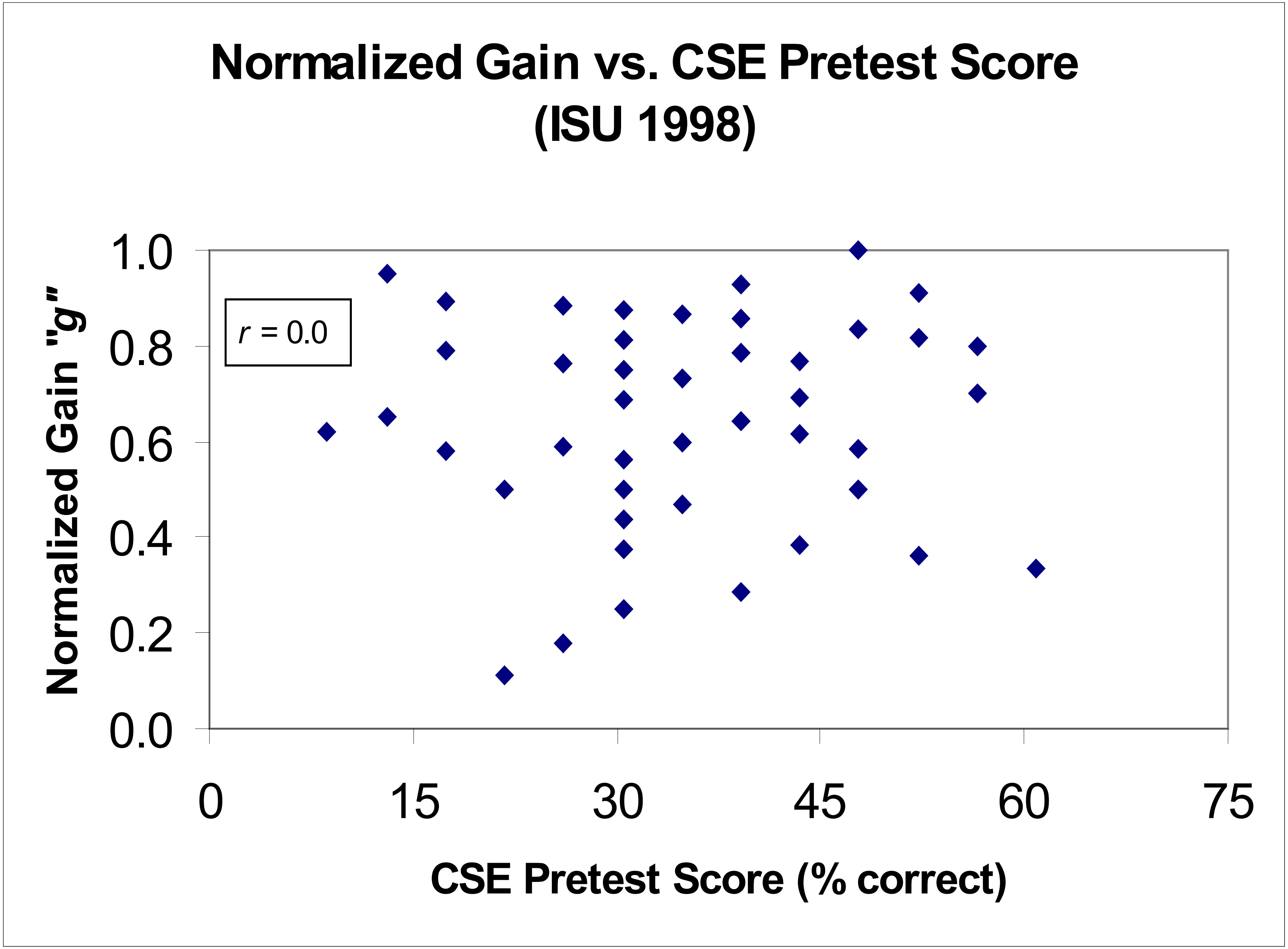
But is *g* really independent of pre-instruction state?

Possible "hidden variables" in students' pre-instruction mental state

Relationship between Mathematical Ability and Learning Gains in Physics

DEM, Am. J. Phys. ***70****, 1259 (2002)*

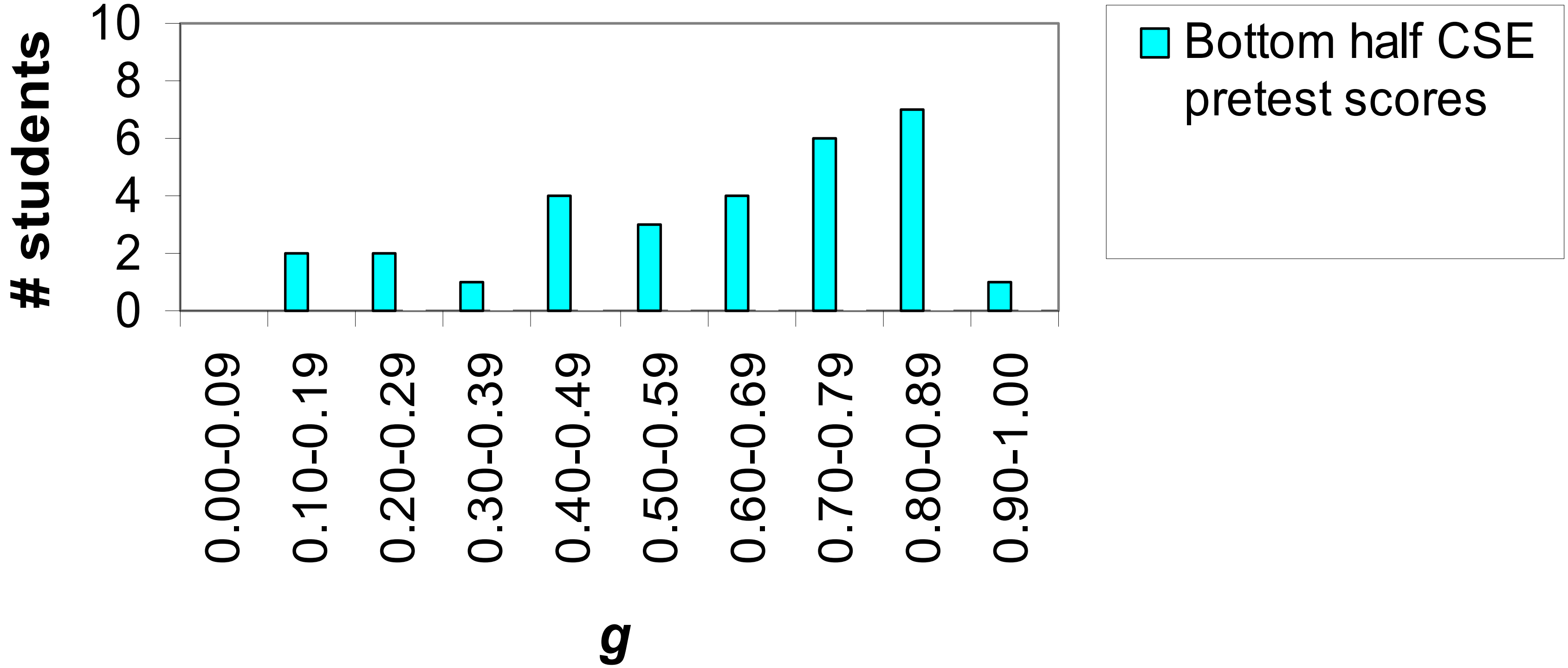
- Investigation of four separate introductory E & M courses (algebra-based, second semester)
- No correlation between individual students' normalized learning gain *g* and their pre-instruction score on physics concept test *(Conceptual Survey of Electricity, "CSE")*



Normalized Gain vs. CSE Pretest Score
(ISU 1998)
1.0
0.8
0.6
0.4
0.2
0.0
Normalized Gain "g"
r = 0.0
0
15
30
45
60
75
CSE Pretest Score (% correct)

Distribution of Gains: ISU 1998

(high and low CSE pretest scores)



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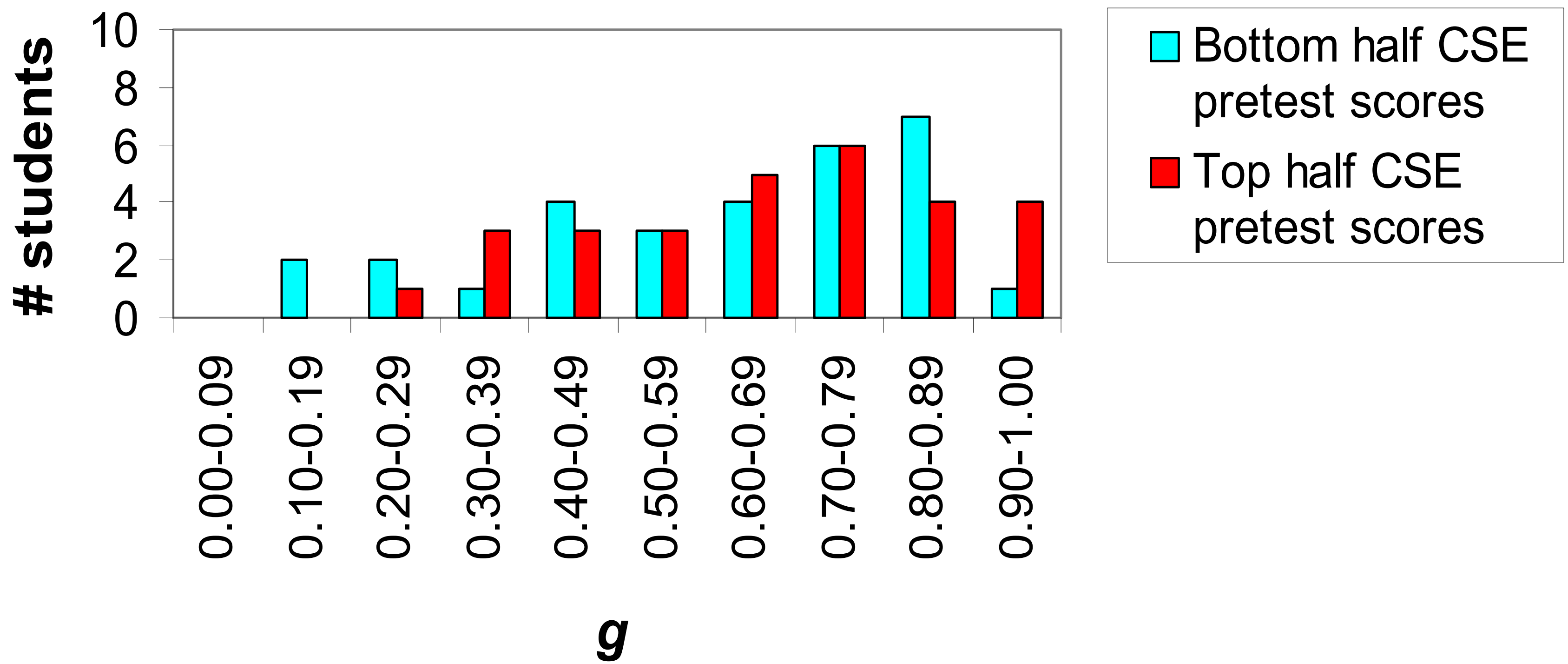

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- Significant correlation (r = +0.30 – +0.46) between individual students' *g* and their pre-instruction score on algebra/trigonometry skills test *(ACT Math Test and ISU Math Diagnostic)*

DIAGNOSTIC TEST

1. What is the value of x in the expression

$$x = p(p + q) + 4$$

if p = -2 and q = 5?

a. -2 b. -3 c. 4 d. -6 e. 18

2. Given $x + 2 = 2(x - 3)$, what is the value of x?

a. 2 b. 3 c. 4 d. 6 e. 8

3. $\sqrt{15^2 - 9^2}$ = ________.

a. 6 b. $\sqrt{6}$ c. 12 d. $\sqrt{12}$ e. $\sqrt{135}$

4. Express a speed of 30 kilometers per hour in meters/second.

a. 108,000 b. 0.008 c. 0.03 d. 3.0 e. 8.3

5. What is the value of x in the following equations?

$$x + 4t = 2$$
$$2x - 2 = t + 2$$

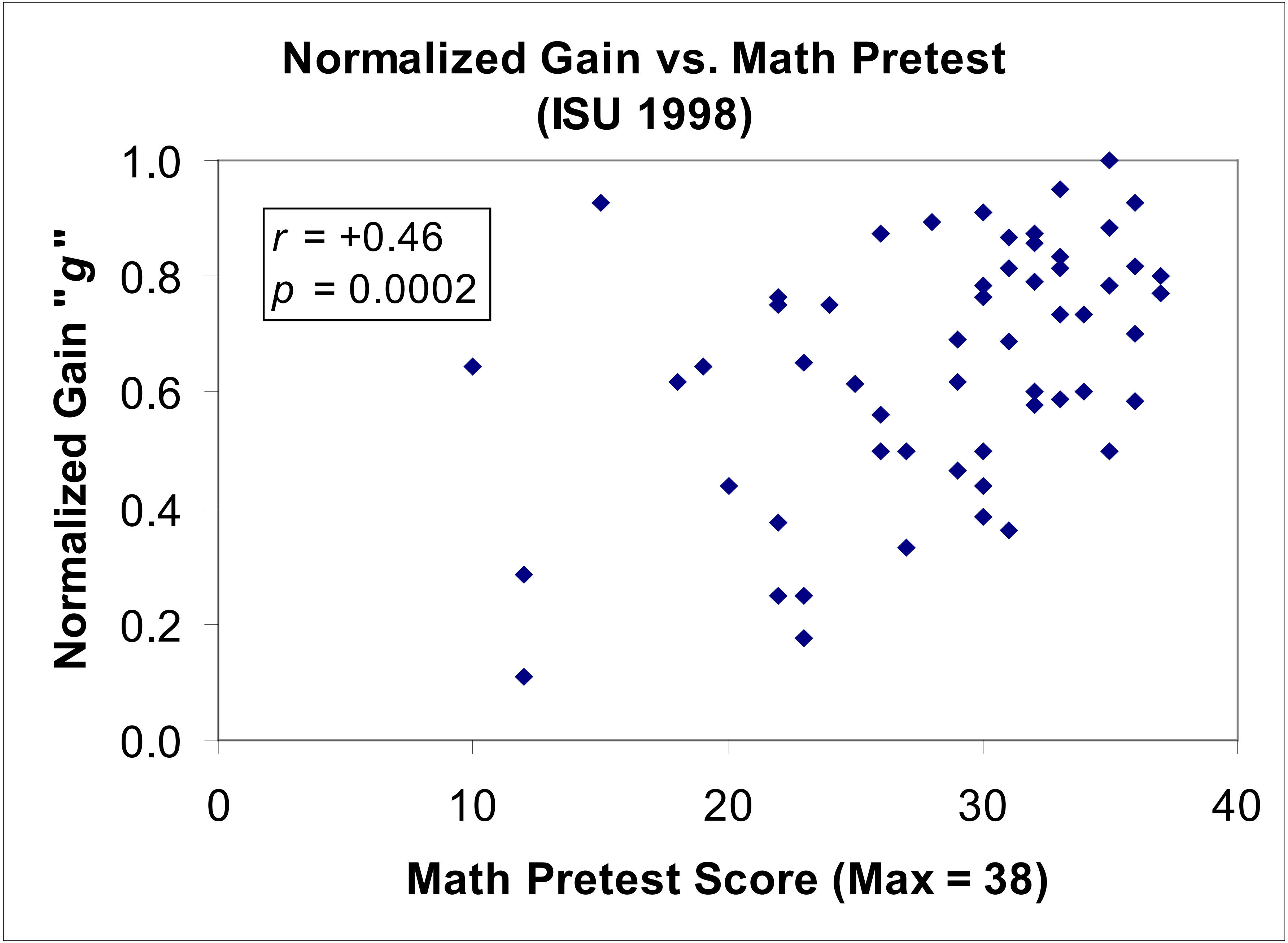
a. -2/9 b. 2 c. 1/2 d. 4 e. 1/4

6. Find y as a function of x from the following equations.

$$2x - t = 2$$
$$y - 4 = 3t$$

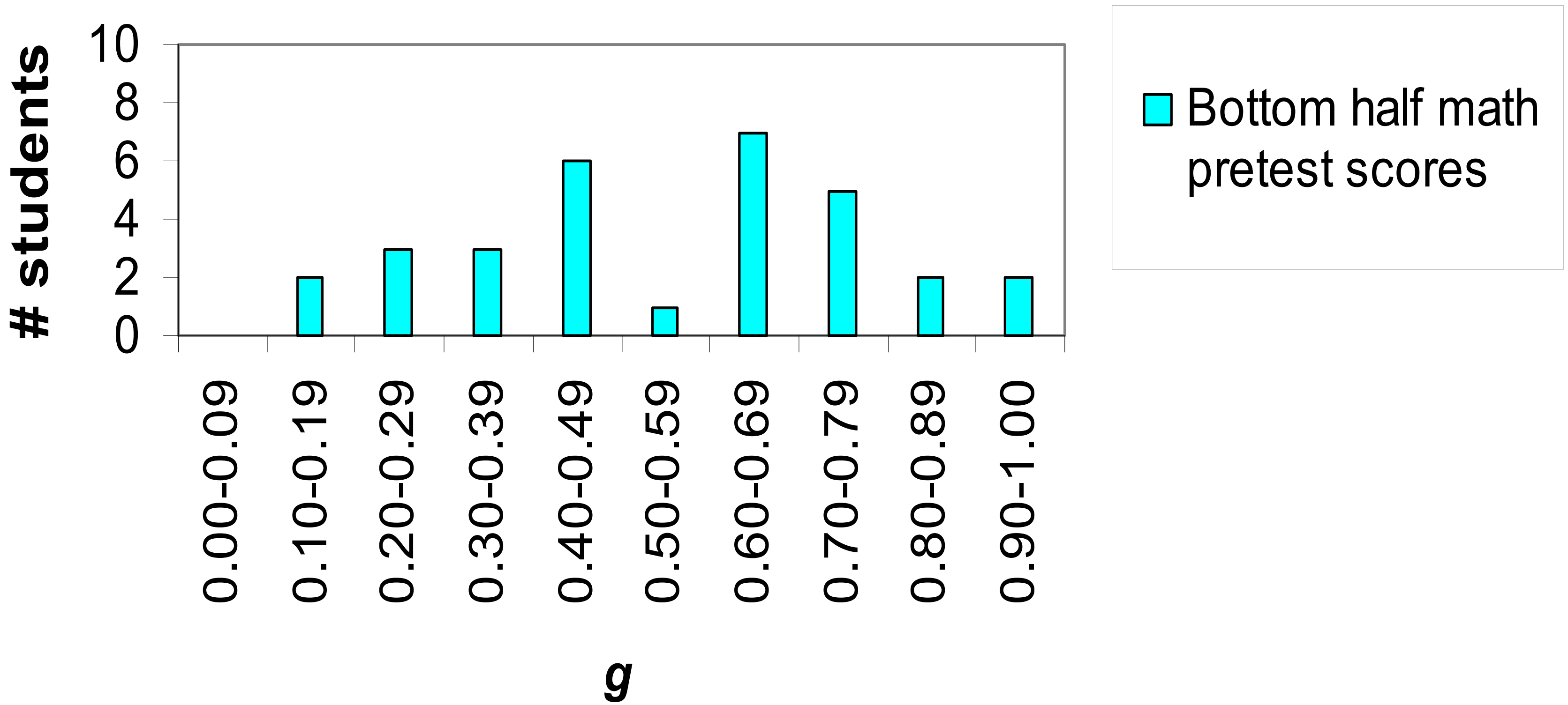
a. $y = 3x + 4$ b. $y = 10 - 3x$ c. $y = 3x + 6$

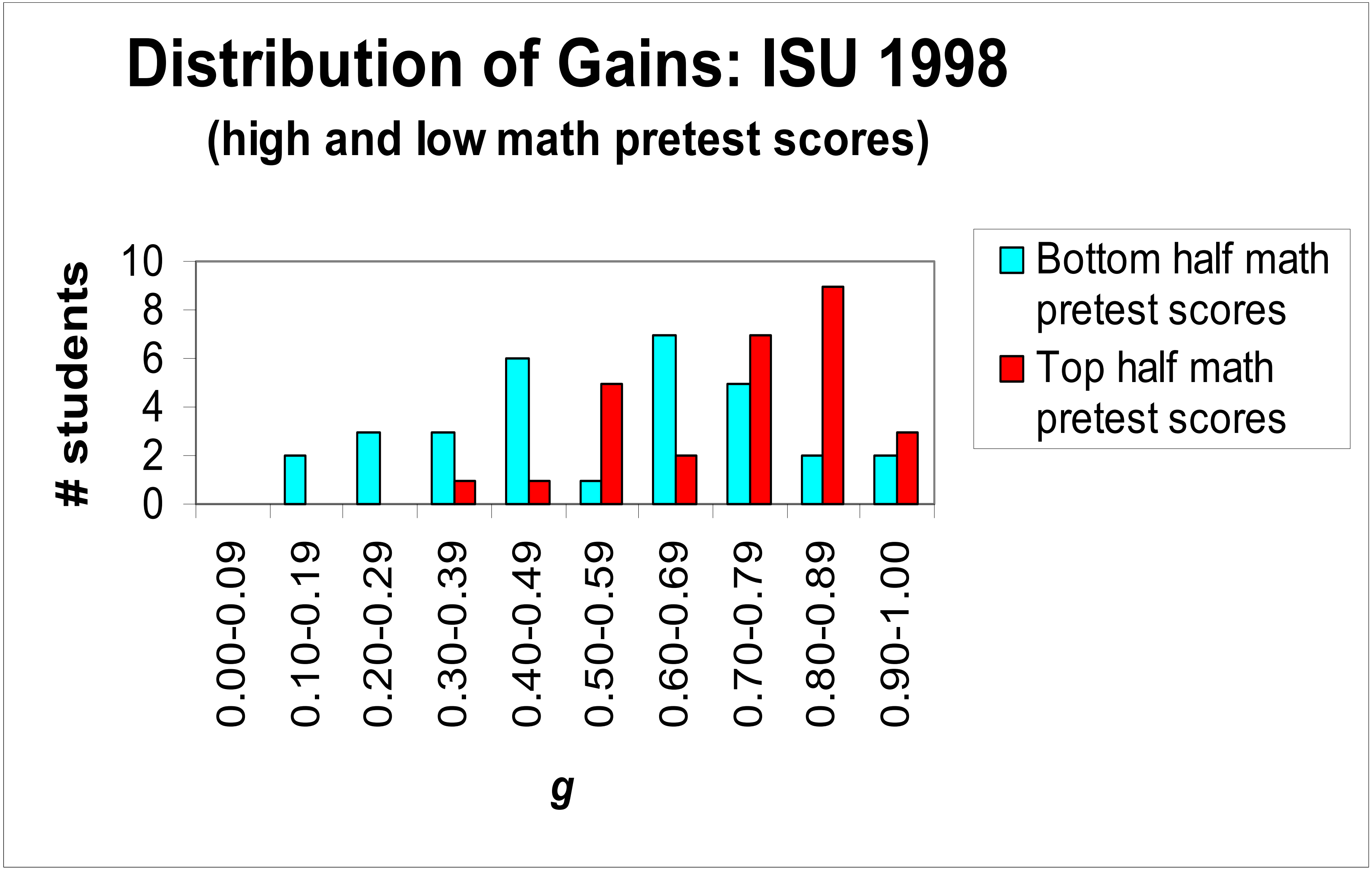
d. $y = 4 - 6x$ e. $y = 6x - 2$


Normalized Gain vs. Math Pretest
(ISU 1998)
r = +0.46
p = 0.0002
Normalized Gain "g"
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
Math Pretest Score (Max = 38)

Distribution of Gains: ISU 1998

(high and low math pretest scores)





Distribution of Gains: ISU 1998
(high and low math pretest scores)
students
10
8
6
4
2
0
0.00-0.09
0.10-0.19
0.20-0.29
0.30-0.39
0.40-0.49
0.50-0.59
0.60-0.69
0.70-0.79
0.80-0.89
0.90-1.00
g
Bottom half math pretest scores
Top half math pretest scores

Second-Order Effects on *g*

- Normalized gain *g* not correlated with pre-instruction ***physics*** knowledge
- Normalized gain *g* ***is*** correlated with pre-instruction math skill
- When comparing *g* for diverse student populations, may need to take into account students' pre-instruction state

Summary

- Investigation of students' reasoning lays the basis for improved curriculum

  e.g. curricular materials in thermodynamics

- Use of "interactive engagement" instructional methods can improve student learning

  e.g., active learning in large classes

- Continual process of development and assessment of research-based curriculum holds promise for sustained improvements in learning.