The Link to Improved Physics Instruction through Research on Student Learning

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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

- Overview of goals and methods of PER

Investigation of Students' Reasoning:

- Students' reasoning in thermodynamics
- Diverse representational modes in student learning

Curriculum Development:

- Instructional methods and curricular materials for large-enrollment physics classes

Assessment of Instruction:

- Measurement of learning gain

Ongoing and Future Projects

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

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Research Group

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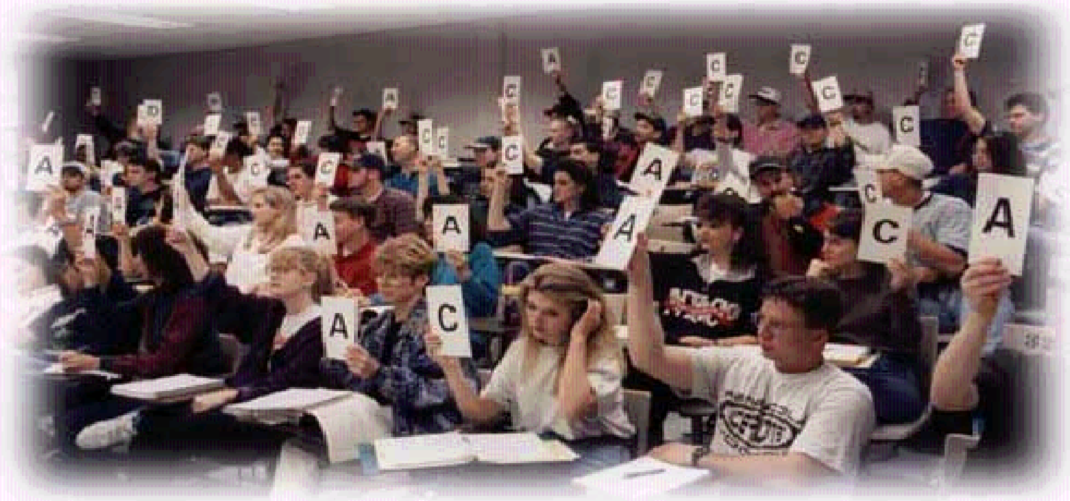

Department of Physics and Astronomy
Iowa State University
Ames, Iowa

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Research-Based Curriculum Development

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

Addressing Learning Difficulties: A Model Problem

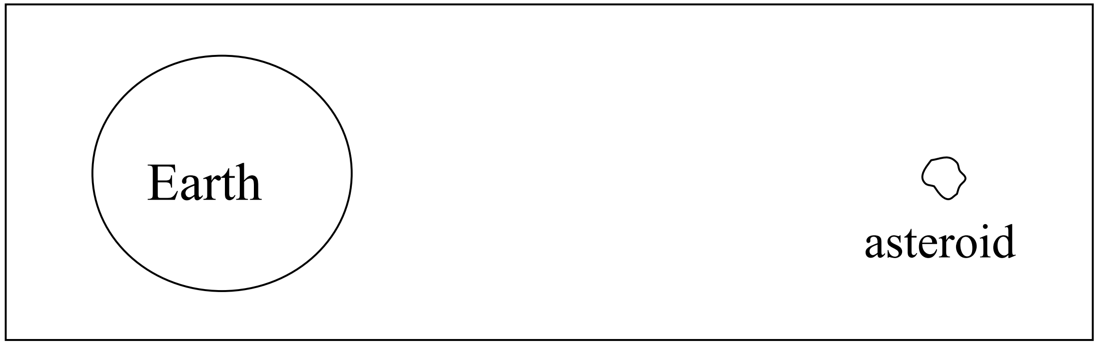
Student Concepts of Gravitation

[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.]

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________________________

Gravitation Worksheet
Physics 221

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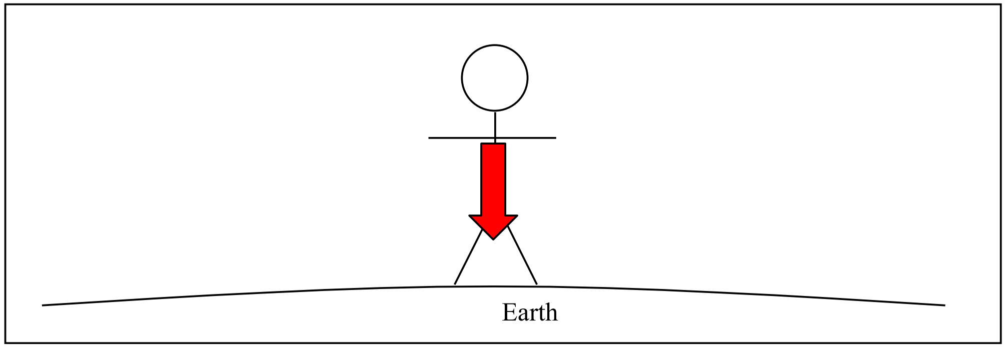

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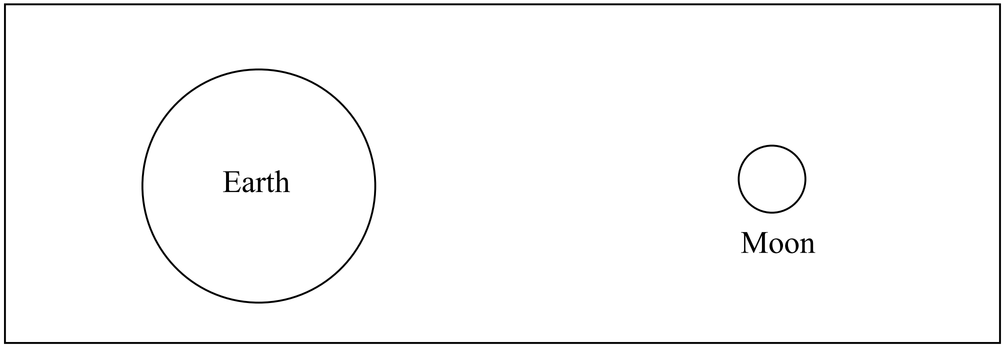

c) Now, in the same picture (above), draw an arrow which represents the force exerted ***by*** the Moon ***on*** the Earth. Label this arrow **(c)**. Remember to draw the arrow with the correct length and direction as compared to the arrow you drew in **(b)**.

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

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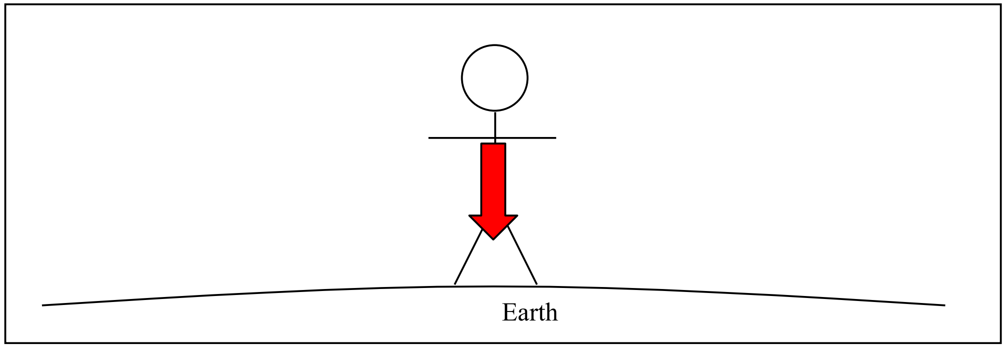

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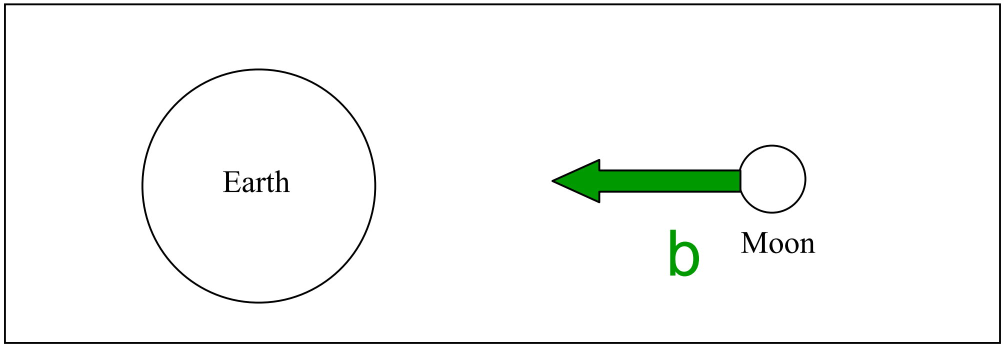

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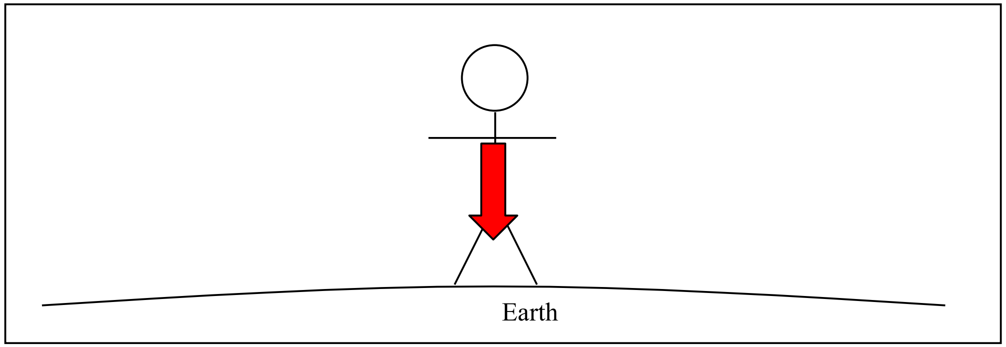

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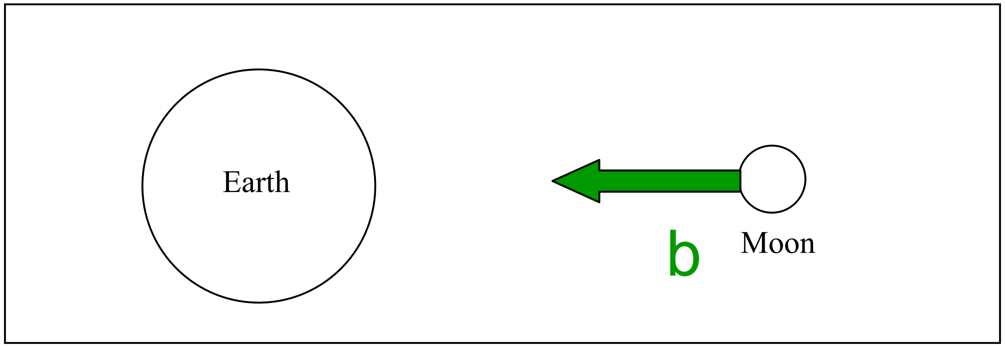

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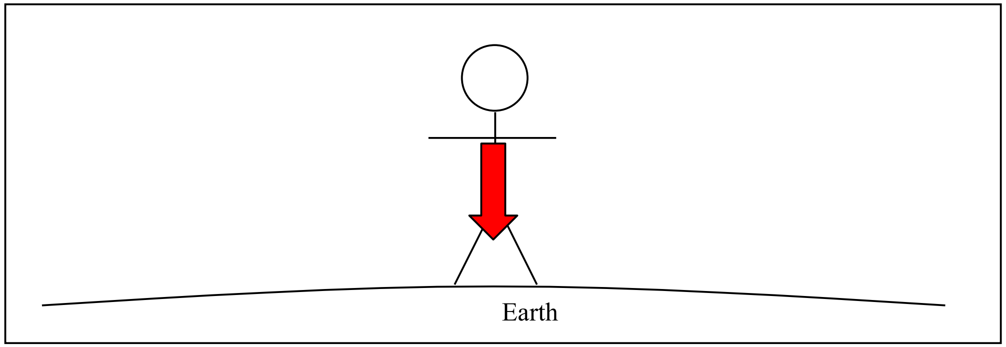

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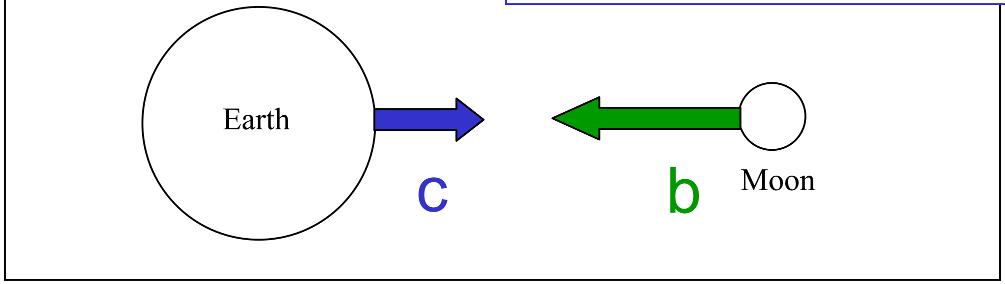
common student response



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e) Consider the magnitude of the gravitational force in (b). Write down an algebraic expression for the strength of the force. (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.

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?

h) Check your answers to (b) and (c) to see if they are consistent with (e) and (f). If necessary, make changes to the arrows in (b) and (c).

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$$F_b = G\frac{M_e M_m}{r^2}$$

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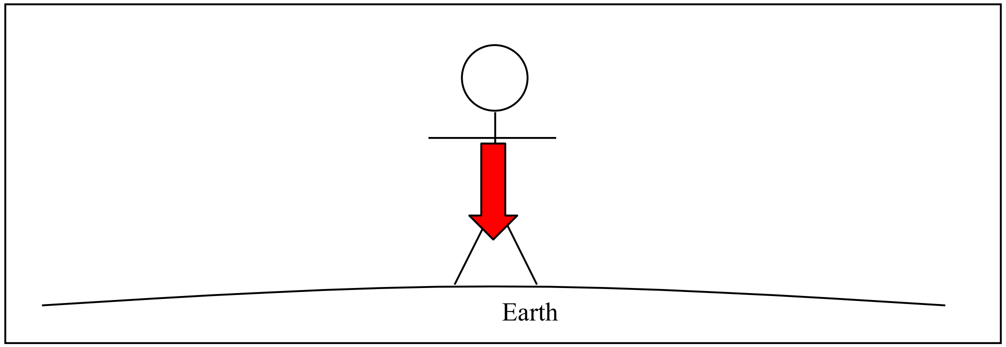

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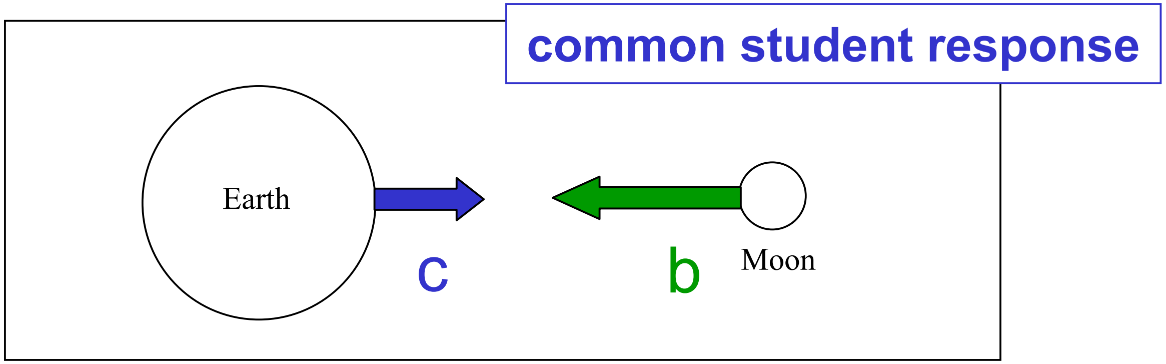

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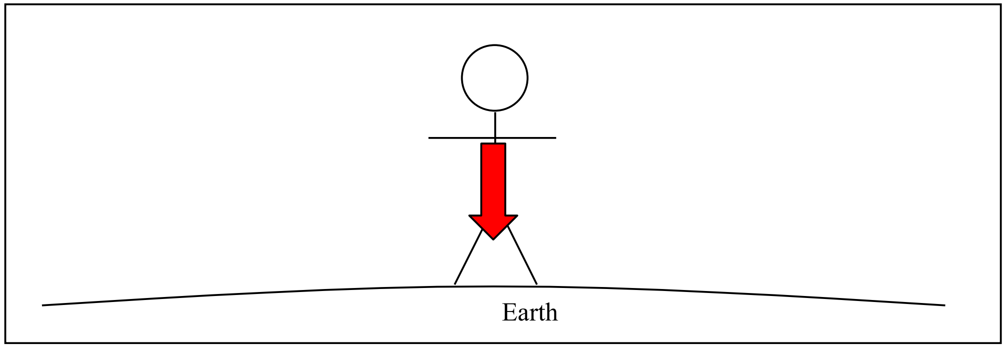

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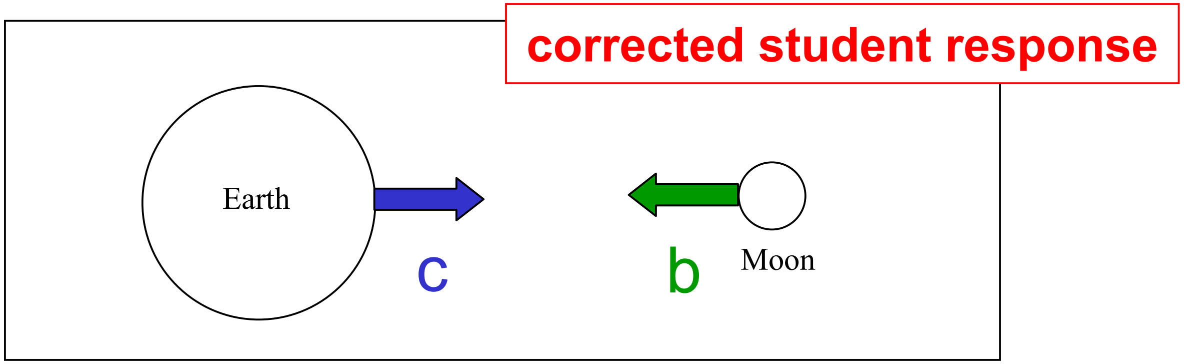

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Post-test Question (Newton's third law)

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)

Outline

- Overview of goals and methods of PER

Investigation of Students' Reasoning:

- Students' reasoning in thermodynamics
- Diverse representational modes in student learning

Curriculum Development:

- Instructional methods and curricular materials for large-enrollment physics classes

Assessment of Instruction:

- Measurement of learning gain

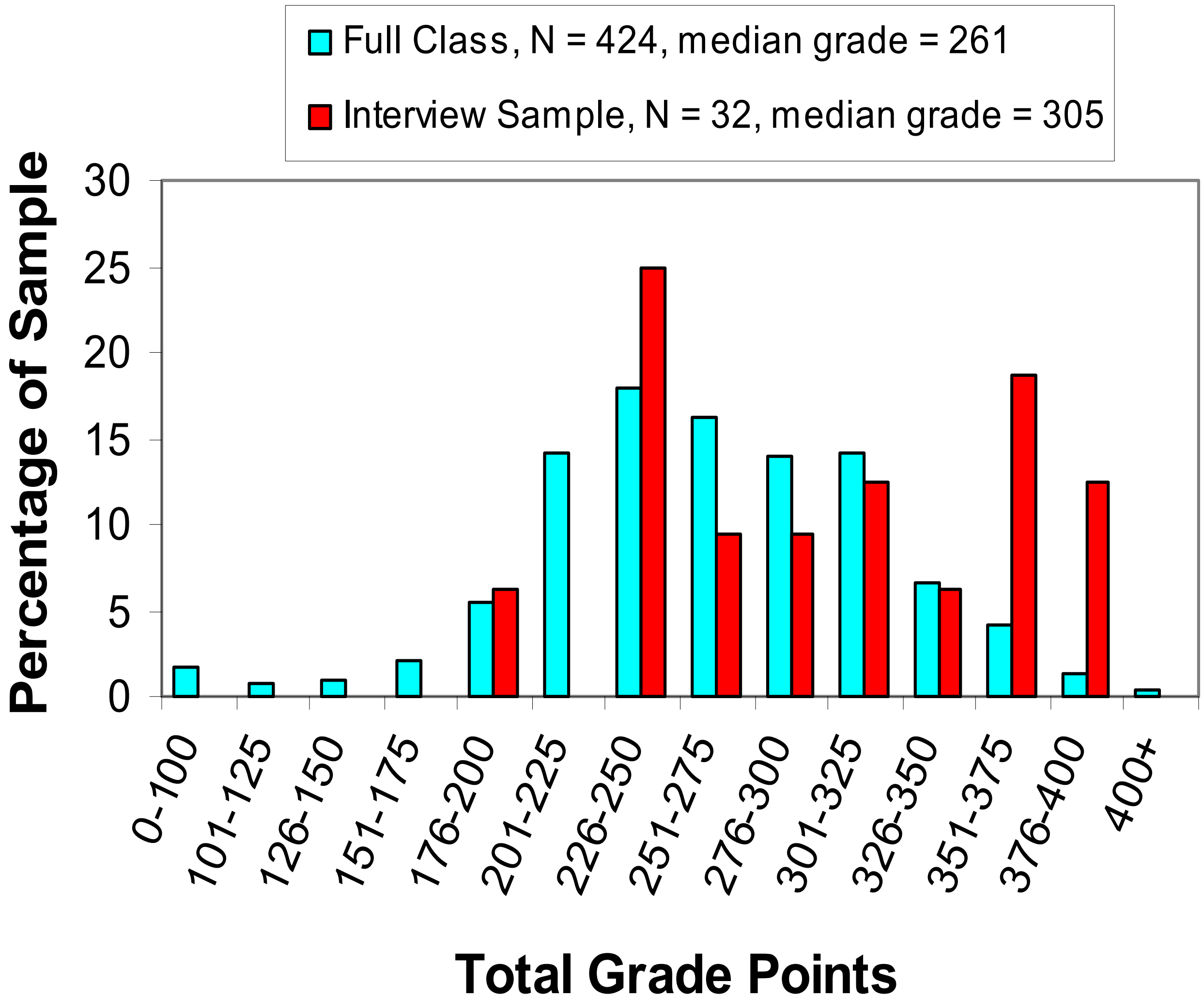
Ongoing and Future ProjectsI broader impact of

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]

Grade Distributions: Interview Sample vs. Full Class



***Interview Sample*:**

34% above 91st percentile; 50% above 81st percentile

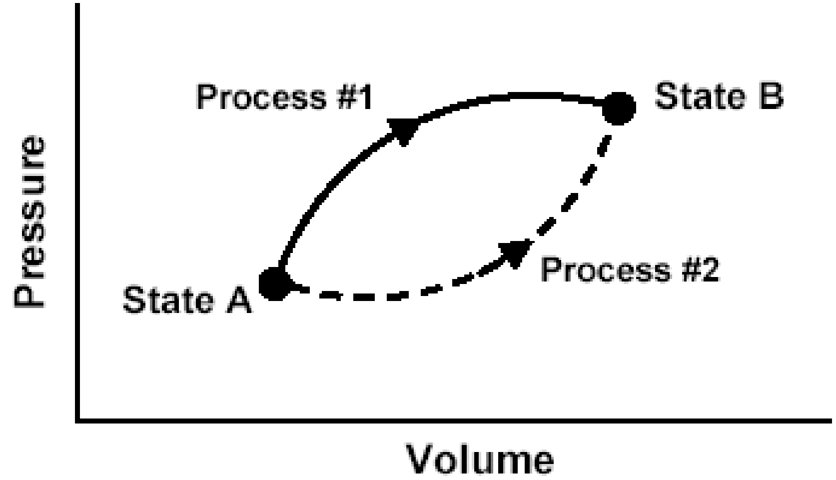
Predominant Themes of Students' Reasoning

1. Understanding of concept of state function in the context of energy.
2. Belief that work is a state function.
3. Belief that heat is a state function.
4. Belief that net work done and net heat absorbed by a system undergoing a cyclic process are zero.
5. Inability to apply the first law of thermodynamics.

Understanding of Concept of State Function in the Context of Energy

- Diagnostic question: two different processes connecting identical initial and final states.
- Do students realize that only initial and final states determine change in a state function?

This *P-V* diagram represents a system consisting of a fixed amount of ideal gas that undergoes two ***different*** processes in going from state A to state B:



[In these questions, ***W*** represents the work done ***by*** the system during a process; ***Q*** represents the heat ***absorbed*** by the system during a process.]

1. Is *W* for Process #1 ***greater than, less than***, or ***equal to*** that for Process #2? Explain.

2. Is *Q* for Process #1 ***greater than, less than***, or ***equal to*** that for Process #2?

3. Which would produce the largest change in the total energy of all the atoms in the system: ***Process #1, Process #2,*** or ***both processes produce the same change?***

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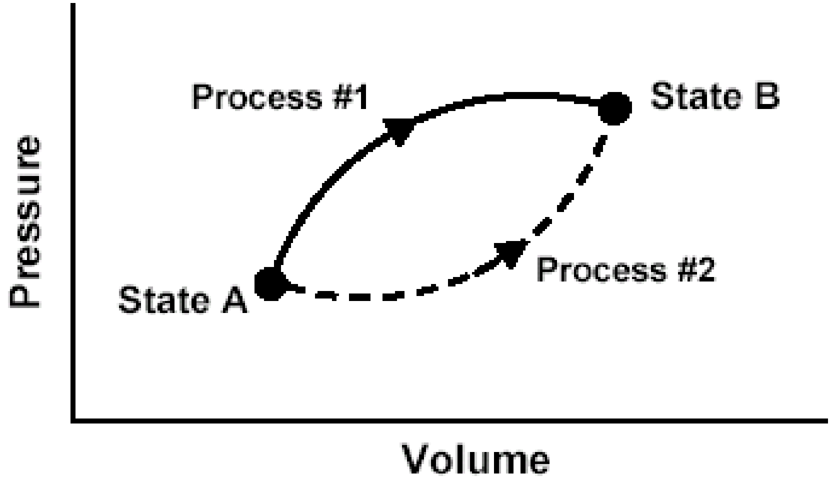
$\Delta U_1 = \Delta U_2$



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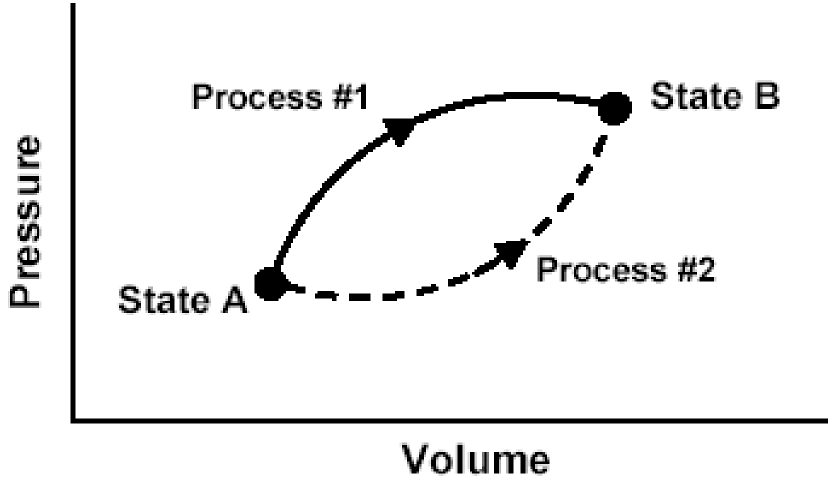

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Students seem to have adequate grasp of state-function concept

- Consistently high percentage (70-90%) of correct responses on relevant questions, with good explanations.

- Interview subjects displayed good understanding of state-function idea.

➡ Students' major conceptual difficulties stemmed from ***overgeneralization*** of state-function concept. **Details to follow . . .**

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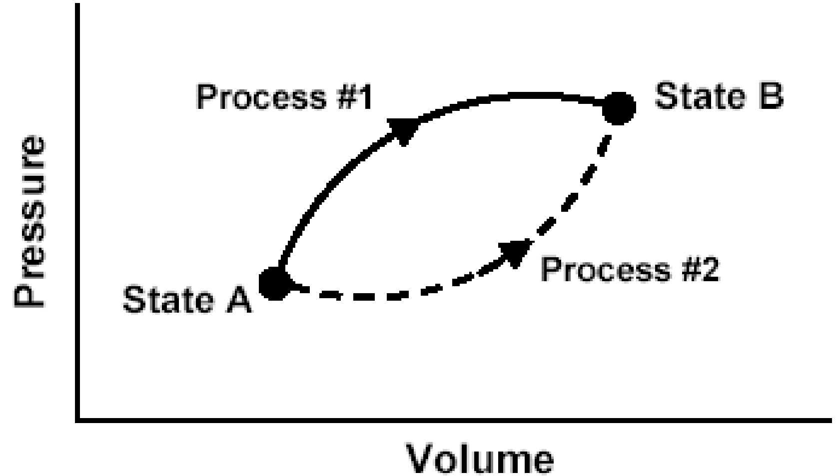

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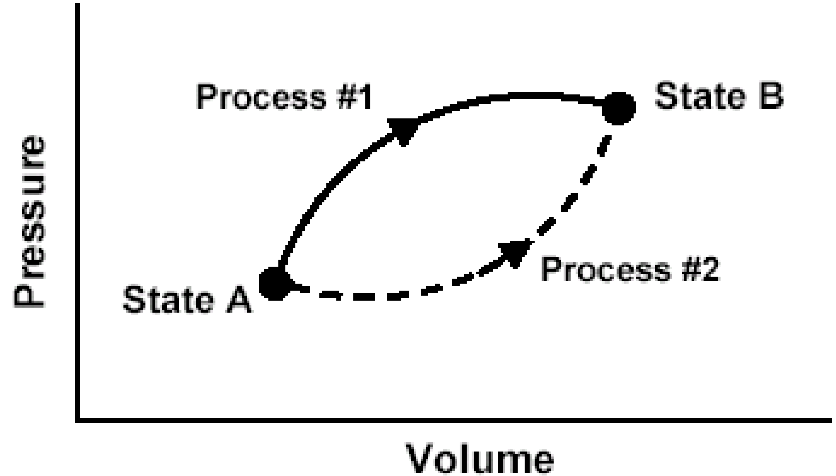
$$W = \int_{V_A}^{V_B} P\,dV$$



$$W_1 > W_2$$

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Responses to Diagnostic Question #1

(Work question)

	1999 (*N*=186)	**2000** (*N*=188)	**2001** (*N*=279)	**2002** Interview Sample (*N*=32)
$W_1 = W_2$	**25%**	**26%**	**35%**	**22%**
Because work is independent of path	*	14%	23%	22%
Other reason, or none	*	12%	13%	0%

*explanations not required in 1999

Explanations Given by Interview Subjects to Justify $W_1 = W_2$

- "*Work is a state function*."
- "*No matter what route you take to get to state B from A, it's still the same amount of work*."
- "*For work done take state A minus state B; the process to get there doesn't matter*."

Many students come to associate work with properties (and descriptive phrases) only used by instructors in connection with state functions.

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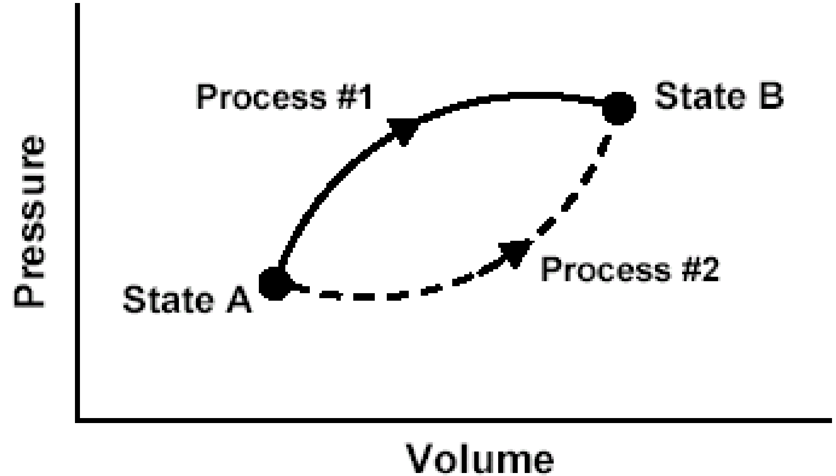

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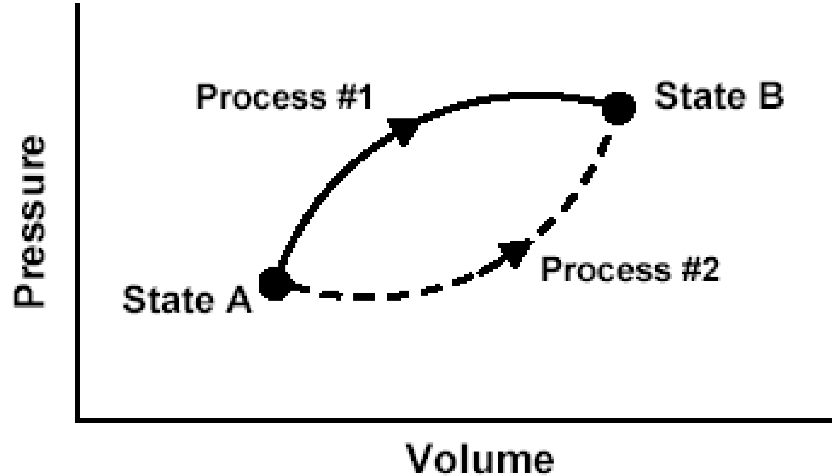
3. Which would produce the largest change in the total energy of all the atoms in the system: ***Process #1, Process #2,*** or ***both processes produce the same change?***

This *P-V* diagram represents a system consisting of a fixed amount of ideal gas that undergoes two ***different*** processes in going from state A to state B:

Change in internal energy is the same for Process #1 and Process #2.



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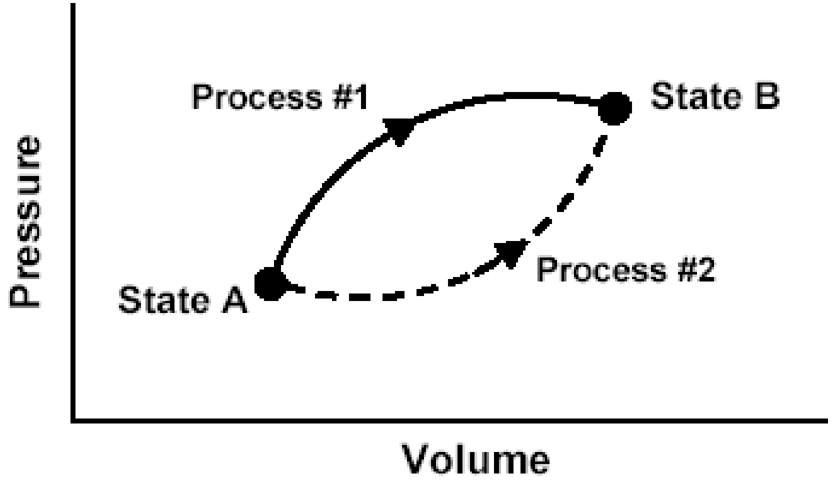
The system does more work in Process #1, so it must absorb more heat to reach same final value of internal energy:
$Q_1 > Q_2$



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This *P-V* diagram represents a system consisting of a fixed amount of ideal gas that undergoes two ***different*** processes in going from state A to state B:

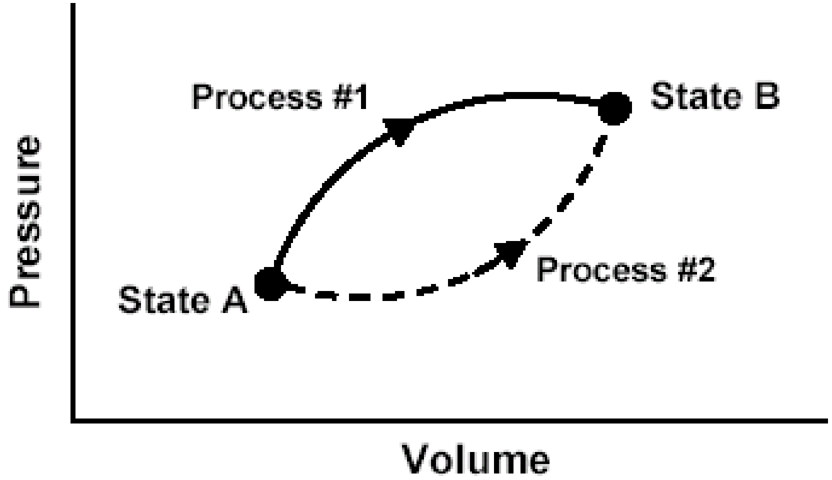
Algebraic Method:

$$\Delta U_1 = \Delta U_2$$

$$Q_1 - W_1 = Q_2 - W_2$$

$$W_1 - W_2 = Q_1 - Q_2$$

$$W_1 > W_2 \Rightarrow Q_1 > Q_2$$



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3. Which would produce the largest change in the total energy of all the atoms in the system: ***Process #1, Process #2,*** or ***both processes produce the same change?***

Responses to Diagnostic Question #2
(Heat question)

	1999 (*N*=186)	**2000** (*N*=188)	**2001** (*N*=279)	**2002** Interview Sample (*N*=32)
$Q_1 = Q_2$	**31%**	**43%**	**41%**	**47%**
Because heat is independent of path	**21%**	**23%**	**20%**	**44%**
Other explanation, or none	**10%**	**18%**	**20%**	**3%**

Explanations Given by Interview Subjects to Justify $Q_1 = Q_2$

- "*I believe that heat transfer is like energy in the fact that it is a state function and doesn't matter the path since they end at the same point*."

- "*Transfer of heat doesn't matter on the path you take*."

- "*They both end up at the same PV value so . . . They both have the same Q or heat transfer*."

➢ **Almost 150 students offered arguments similar to these either in their written responses or during the interviews.**

Predominant Themes of Students' Reasoning

1. Understanding of concept of state function in the context of energy.
2. Belief that work is a state function.
3. Belief that heat is a state function.
4. Belief that net work done and net heat absorbed by a system undergoing a cyclic process are zero.
5. Inability to apply the first law of thermodynamics.

Interview Questions

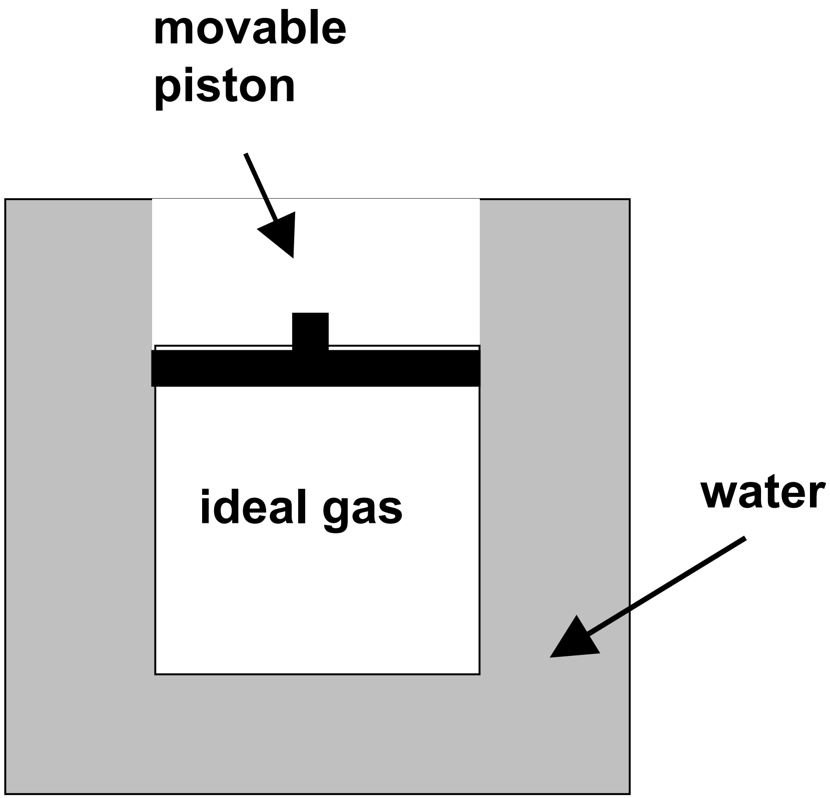
A fixed quantity of ideal gas is contained within a metal cylinder that is sealed with a movable, frictionless, insulating piston.

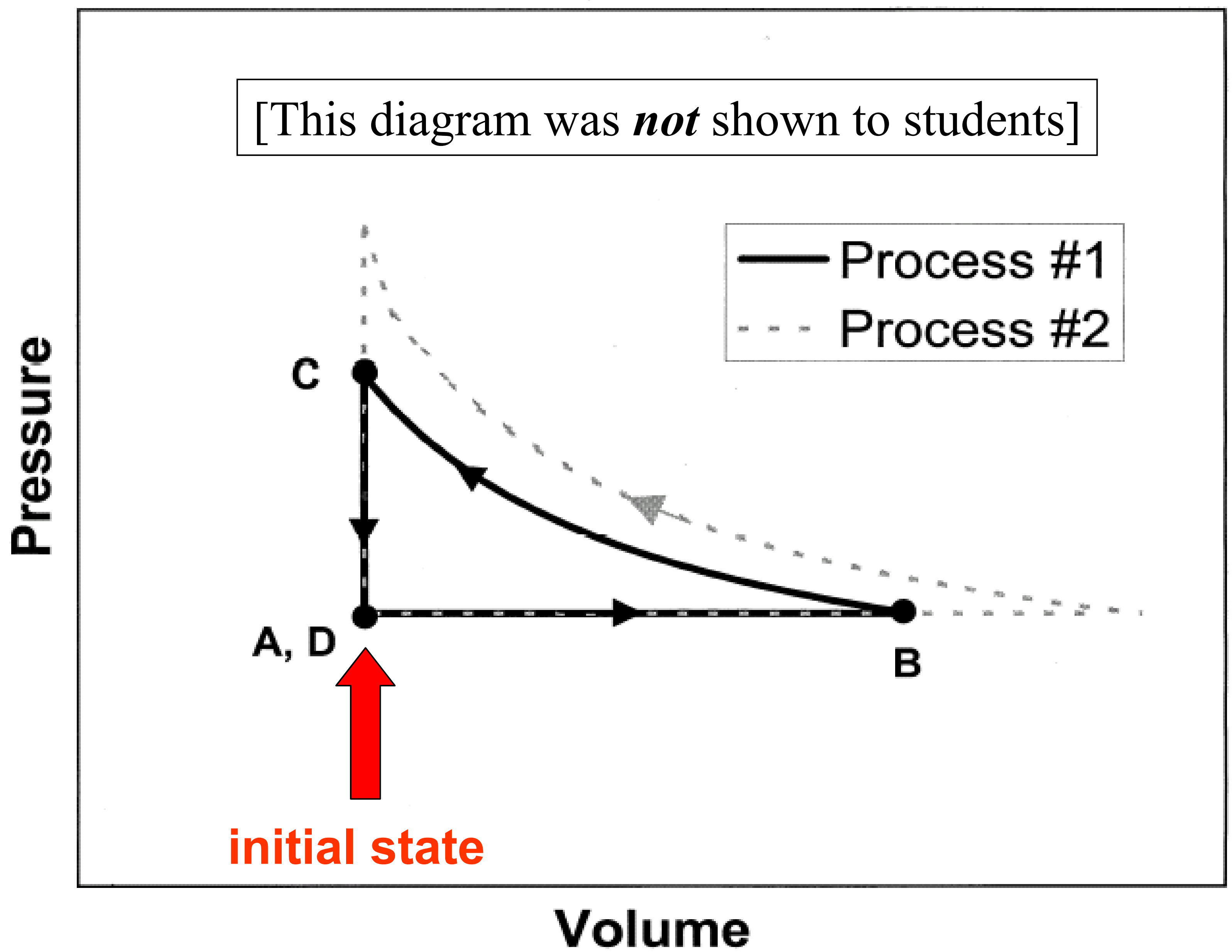
The cylinder is surrounded by a large container of water with high walls as shown. We are going to describe two separate processes, Process #1 and Process #2.

At initial time *A*, the gas, cylinder, and water have all been sitting in a room for a long period of time, and all of them are at room temperature

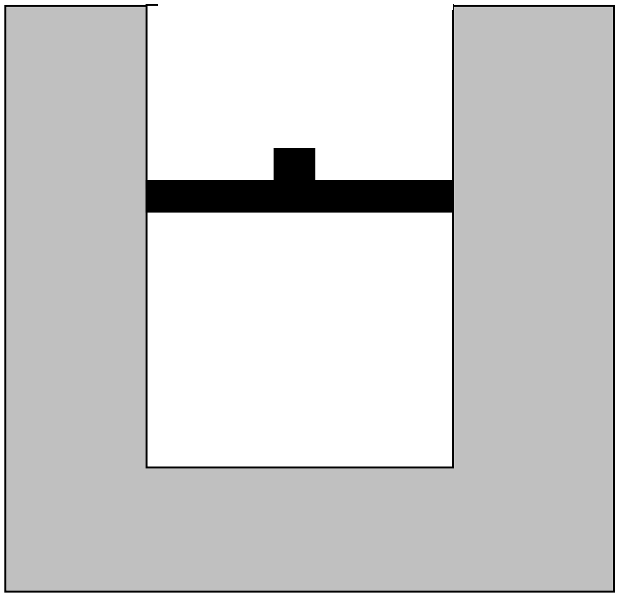
Time *A*

Entire system at room temperature.




[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
initial state
Pressure
Volume

Step 1. We now begin Process #1: The water container is gradually heated, and the piston *very slowly* moves upward. At time *B* the heating of the water stops, and the piston stops moving when it is in the position shown in the diagram below:

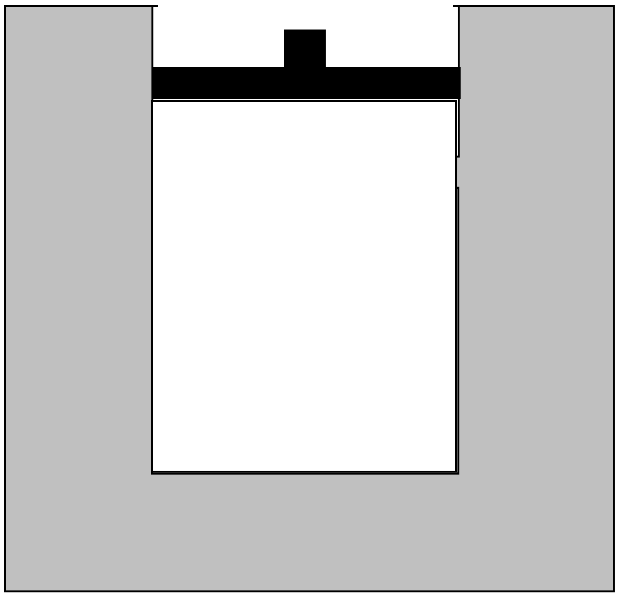


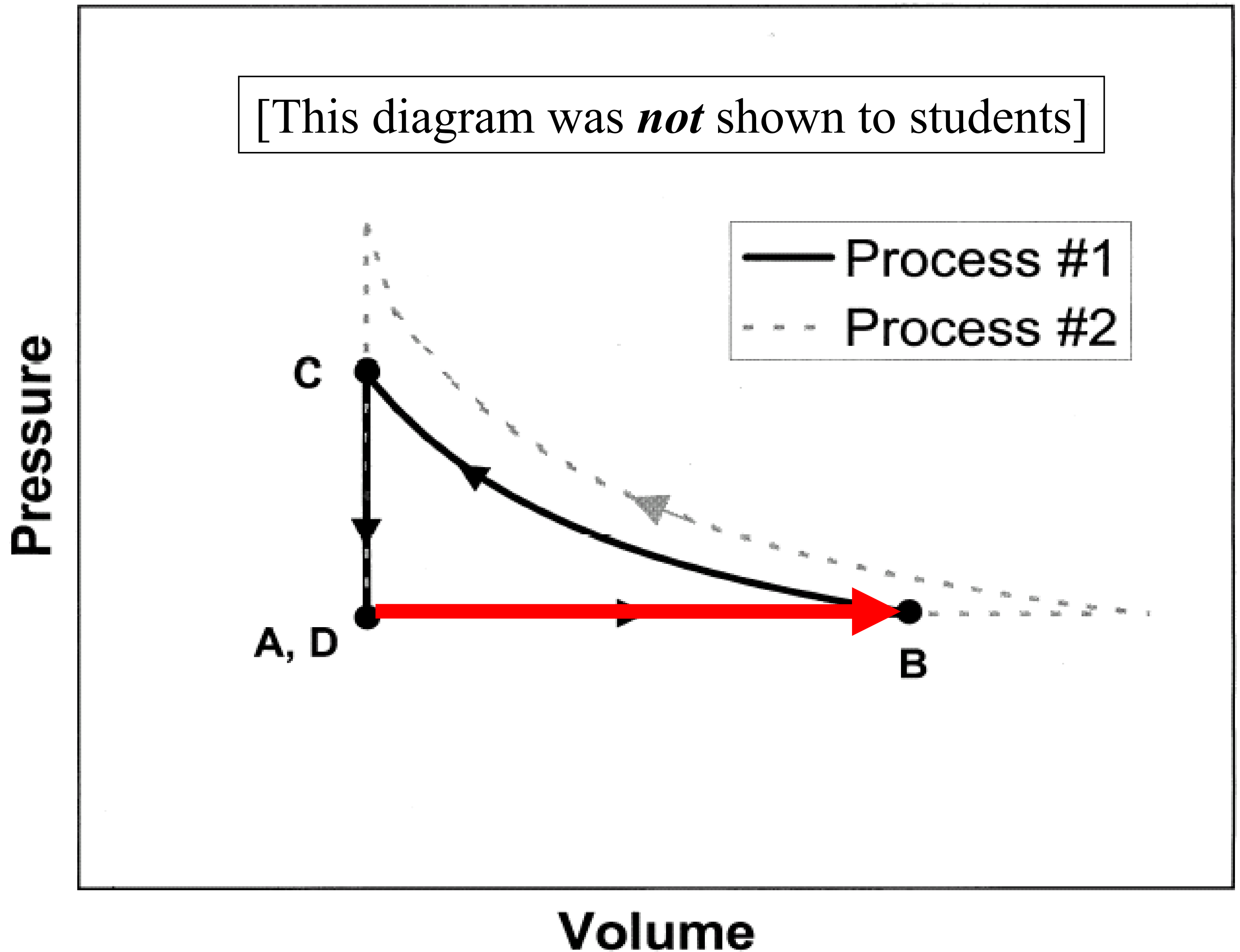
Step 1. We now begin Process #1: The water container is gradually heated, and the piston *very slowly* moves upward. At time *B* the heating of the water stops, and the piston stops moving when it is in the position shown in the diagram below:

Time *B*

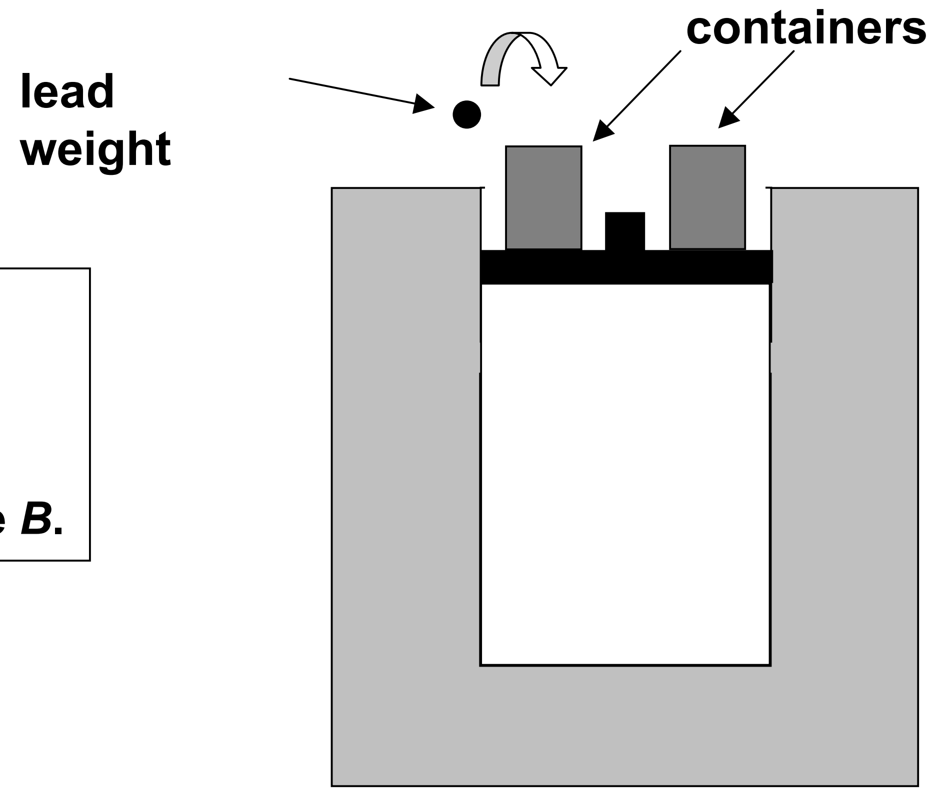
Piston in new position.

Temperature of system has changed.




[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
Pressure
Volume

Step 2. Now, empty containers are placed on top of the piston as shown. Small lead weights are gradually placed in the containers, one by one, and the piston is observed to move down slowly. While this happens, the temperature of the water is nearly unchanged, and the gas temperature remains practically *constant*. (That is, it remains at the temperature it reached at time *B,* after the water had been heated up.)



weights being added

Piston moves down slowly.

Temperature remains same as at time *B*.

Step 2. Now, empty containers are placed on top of the piston as shown. Small lead weights are gradually placed in the containers, one by one, and the piston is observed to move down slowly. While this happens, the temperature of the water is nearly unchanged, and the gas temperature remains practically *constant*. (That is, it remains at the temperature it reached at time *B,* after the water had been heated up.)

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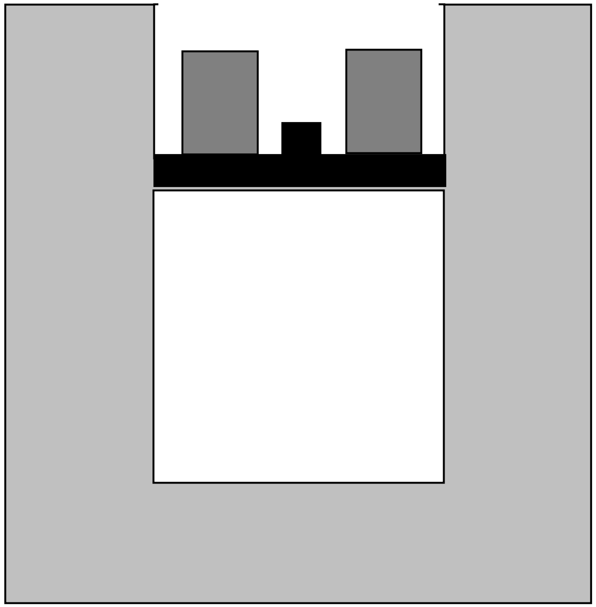
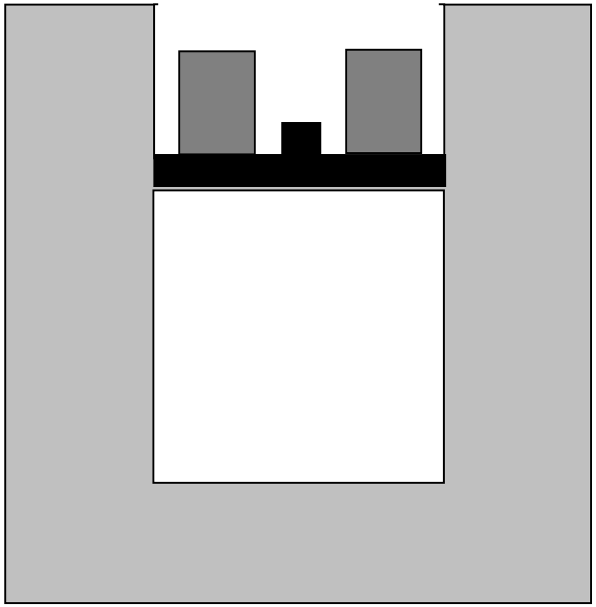


Step 3. At time *C* we stop adding lead weights to the container and the piston stops moving. (The weights that we have already added up until now are still in the containers.) The piston is now found to be at *exactly the same position it was at time* ***A*** .



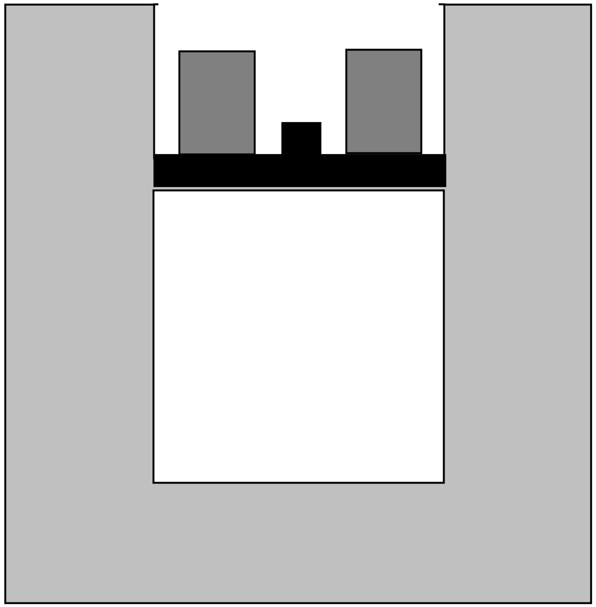
Step 3. At time *C* we stop adding lead weights to the container and the piston stops moving. (The weights that we have already added up until now are still in the containers.) The piston is now found to be at *exactly the same position it was at time **A*** .

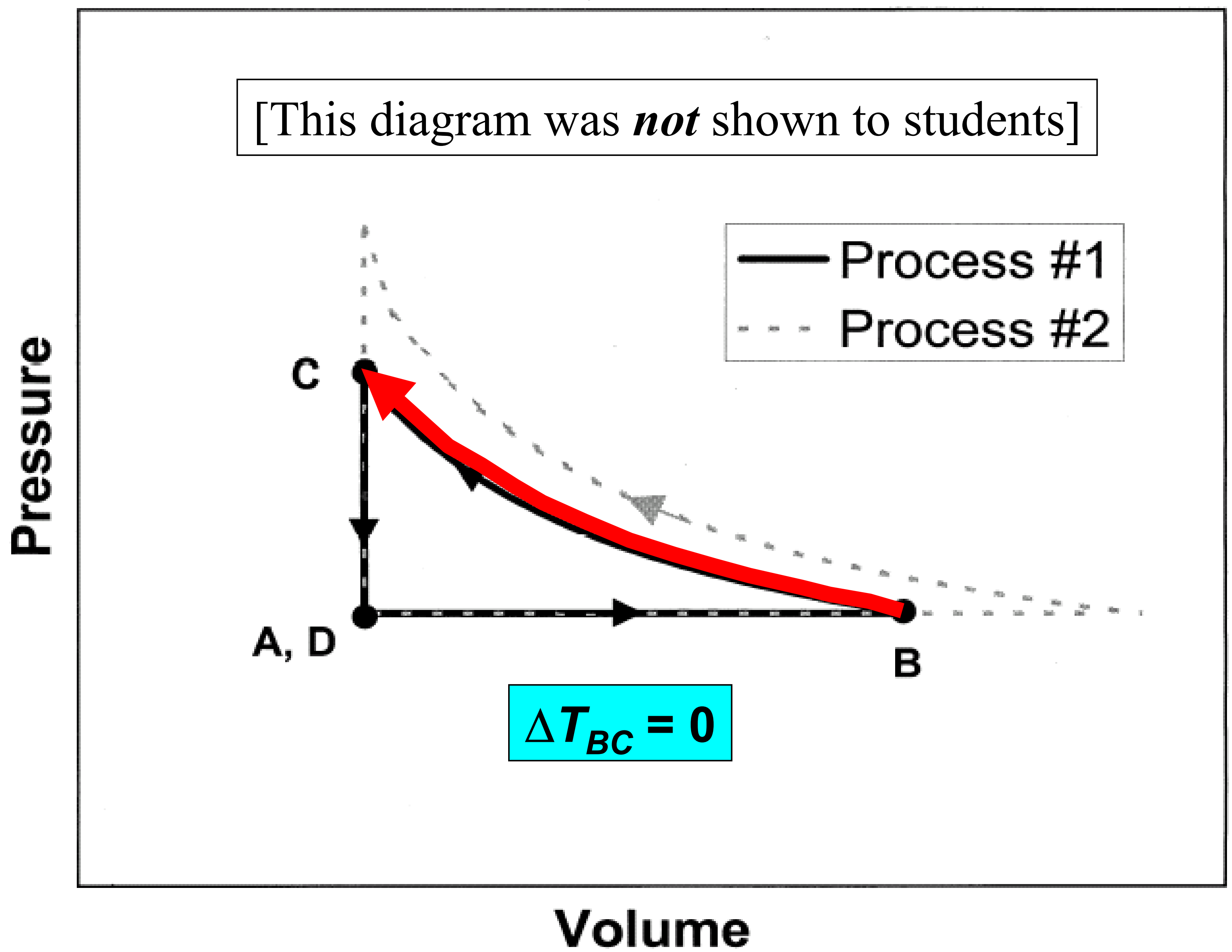
Time *C*

Weights in containers.

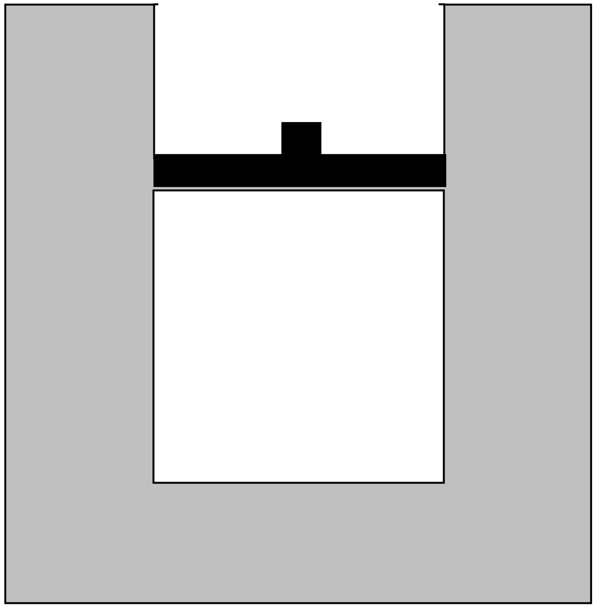
Piston in same position as at time *A*.

Temperature same as at time *B*.




[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
$\Delta T_{BC} = 0$
Pressure
Volume

Step 4. Now, the piston is locked into place so it *cannot move*; the weights are removed from the piston. The system is left to sit in the room for many hours, and eventually the entire system cools back down to the same room temperature it had at time *A.* When this finally happens, it is time *D*.



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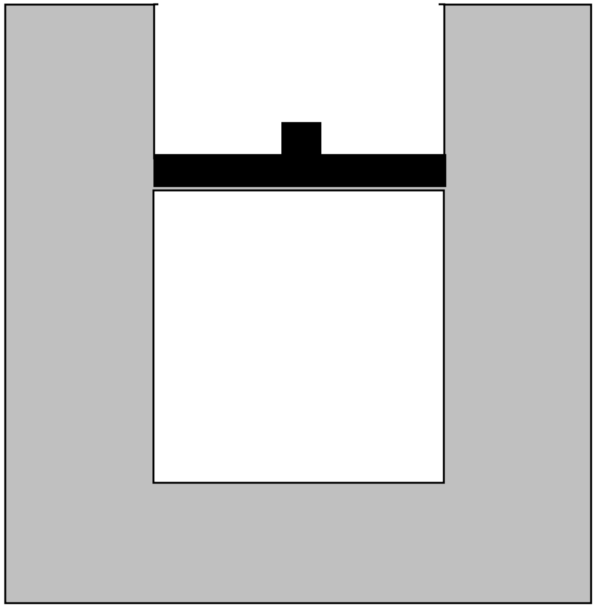
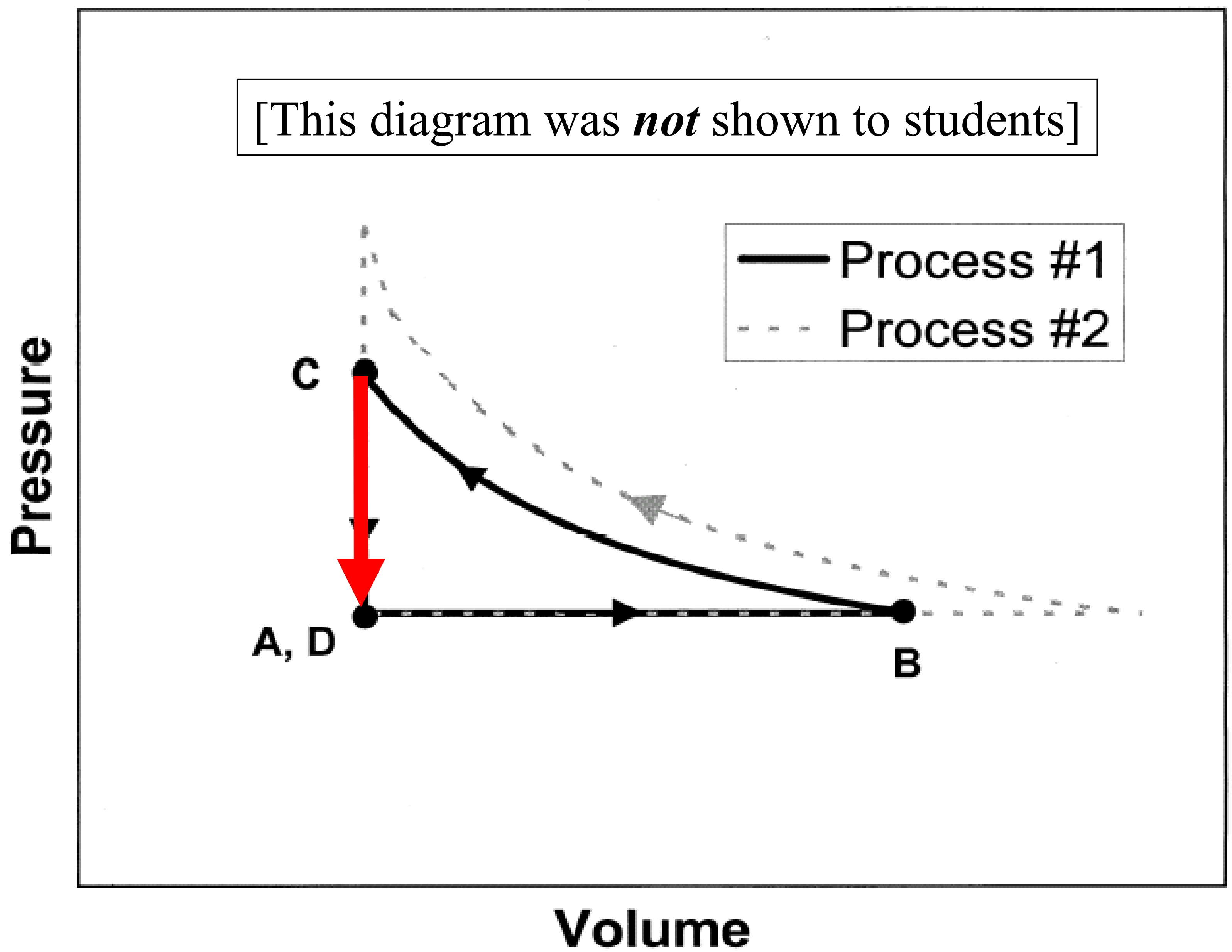
Time *D*

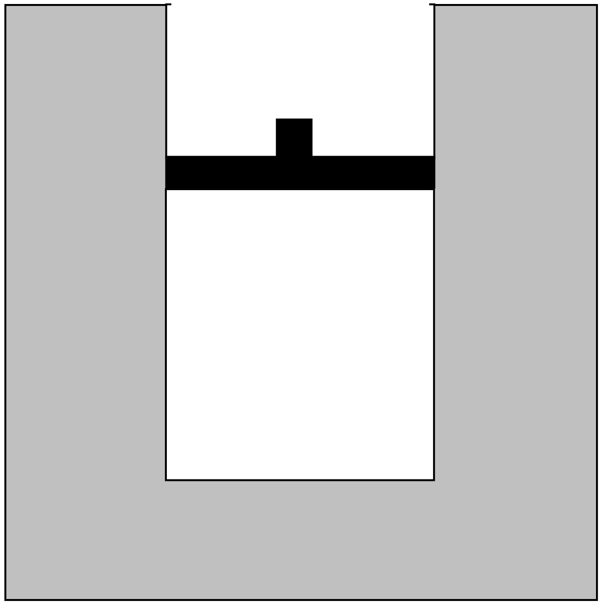
Piston in same position as at time *A*.

Temperature same as at time *A*.





[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
Pressure
Volume



Time *D*

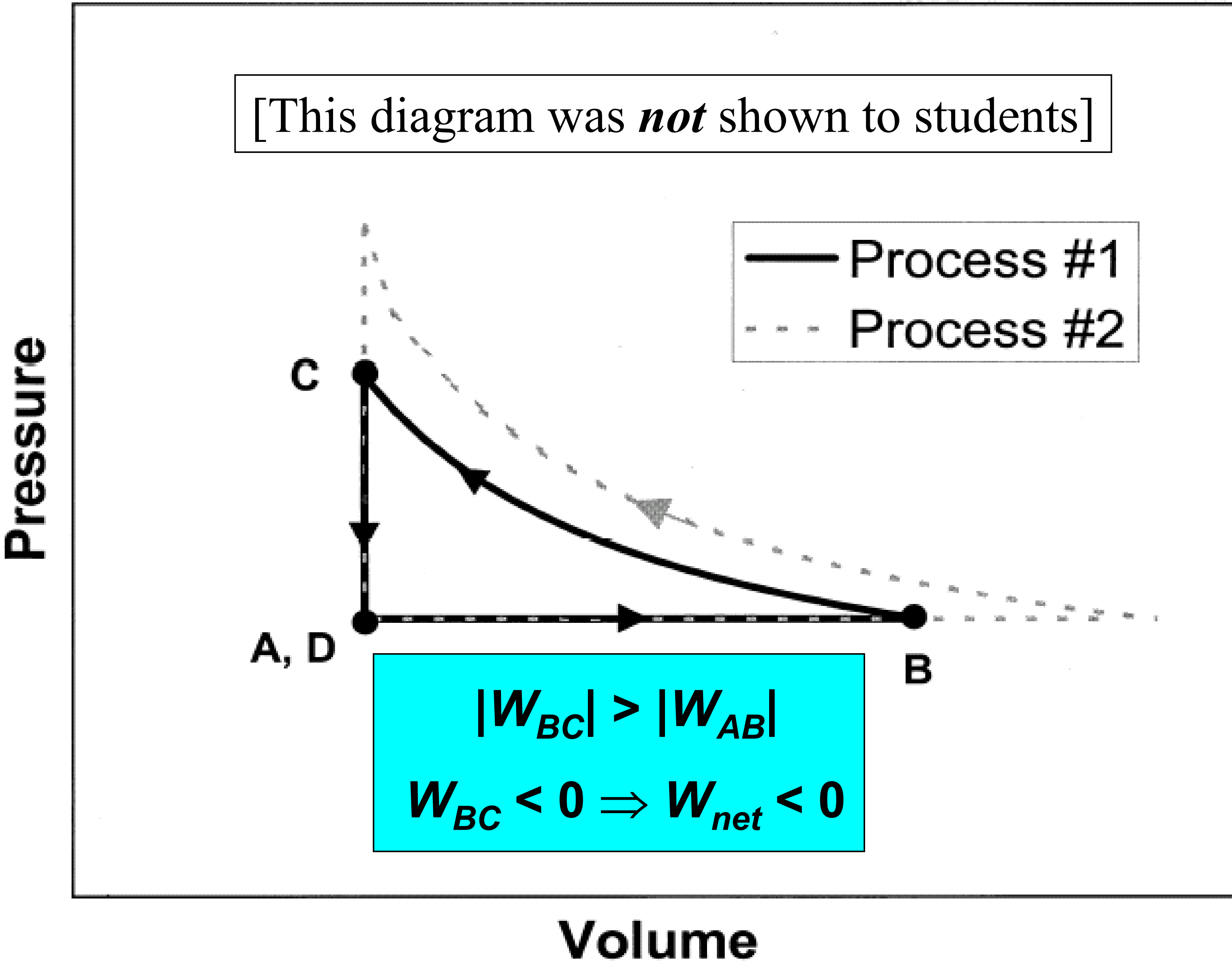
Piston in same position as at time *A*.

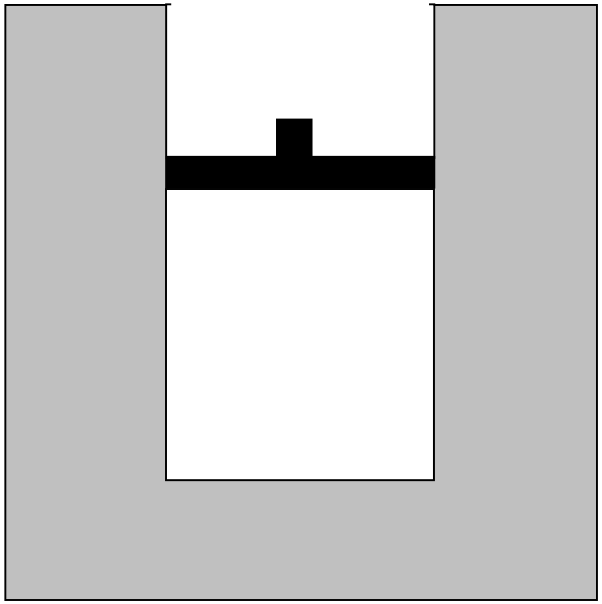
Temperature same as at time *A*.

Question #6: Consider ***the entire process*** from time *A* to time *D*.

(i) Is the net work done *by* the gas on the environment during that process (a) greater than zero, (b) equal to zero, or (c) less than zero?

(ii) Is the total heat transfer to the gas during that process (a) greater than zero, (b) equal to zero, or (c) less than zero?


[This diagram was *not* shown to students]
Process #1
Process #2
Pressure
Volume
C
A, D
B
$|W_{BC}| > |W_{AB}|$
$W_{BC} < 0 \Rightarrow W_{net} < 0$



Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.

Question #6: Consider ***the entire process*** from time *A* to time *D*.

(i) Is the net work done *by* the gas on the environment during that process (a) greater than zero, (b) equal to zero, or (c) less than zero?

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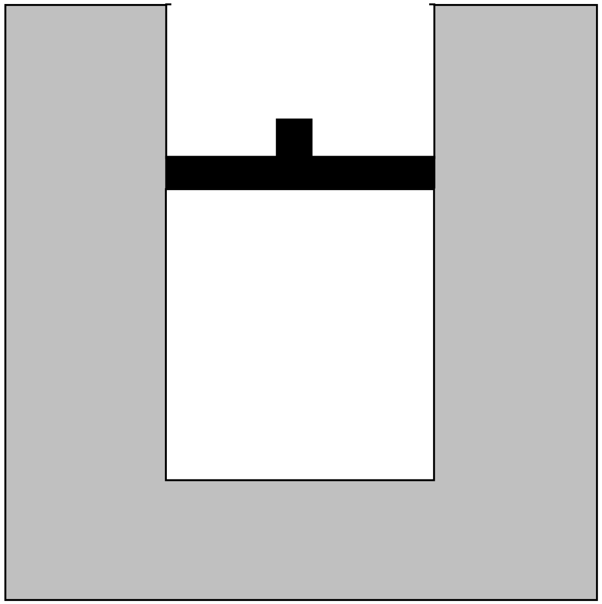


Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.

Question #6: Consider ***the entire process*** from time *A* to time *D*.

(i) Is the net work done *by* the gas on the environment during that process (a) greater than zero, (b) equal to zero, or **(c) less than zero?**

(ii) Is the total heat transfer to the gas during that process (a) greater than zero, (b) equal to zero, or (c) less than zero?

Results on Interview Question #6 (i)

$N = 32$

(a) $W_{net} > 0$: 16%

(b) $W_{net} = 0$: 63%

(c) $W_{net} < 0$: 19% ***[correct]***

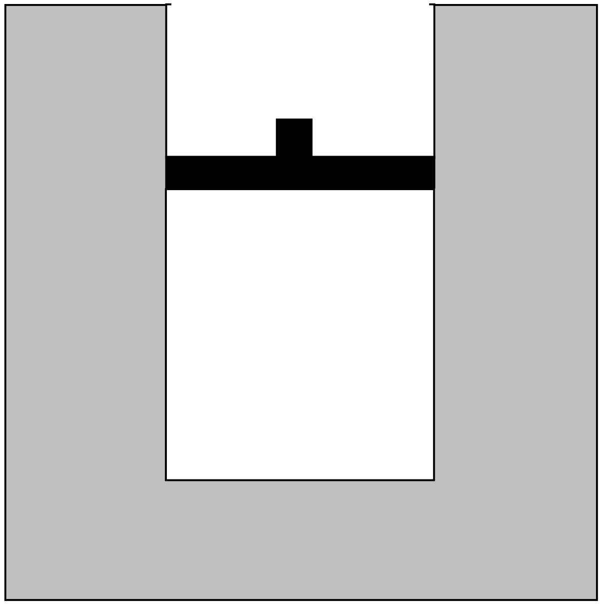
No response: 3%

Even after being asked to draw a *P-V* diagram for Process #1, nearly two thirds of the interview sample believed that net work done was equal to zero.

Explanations offered for W_{net} = 0

“[Student #1:] *The physics definition of work is like force times distance. And basically if you use the same force and you just travel around in a circle and come back to your original spot, technically you did zero work*.”

“[Student #2:] *At one point the volume increased and then the pressure increased, but it was returned back to that state . . . The piston went up so far and then it’s returned back to its original position, retracing that exact same distance*.”



Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.

Question #6: Consider ***the entire process*** from time *A* to time *D*.

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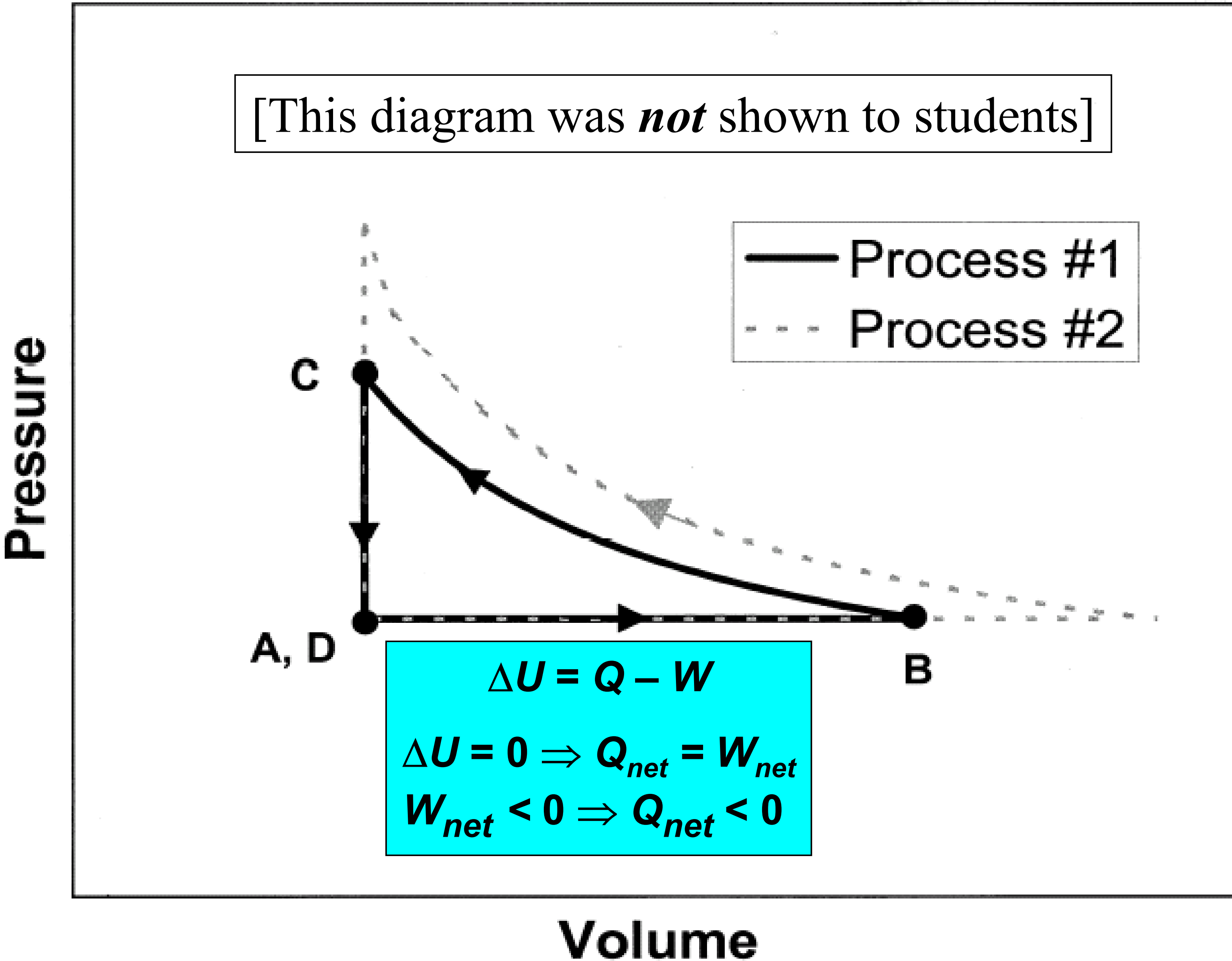
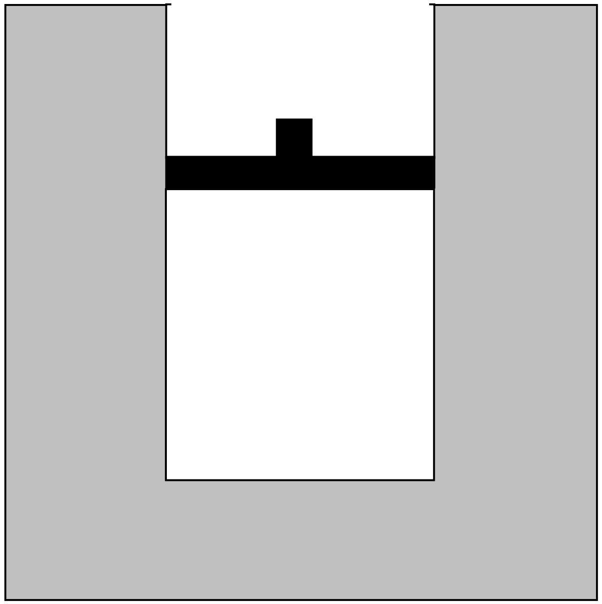

[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
Pressure
Volume
$\Delta U = Q - W$
$\Delta U = 0 \Rightarrow Q_{net} = W_{net}$
$W_{net} < 0 \Rightarrow Q_{net} < 0$



Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.

Question #6: Consider ***the entire process*** from time *A* to time *D*.

(i) Is the net work done *by* the gas on the environment during that process (a) greater than zero, (b) equal to zero, or **(c) less than zero?**

(ii) Is the total heat transfer to the gas during that process (a) greater than zero, (b) equal to zero, or **(c) less than zero?**

Results on Interview Question #6 (ii)

$N = 32$

(a) $Q_{net} > 0$	**9%**	
(b) $Q_{net} = 0$	**69%**	
(c) $Q_{net} < 0$	**16%**	***[correct]***

with correct explanation: ***13%***

with incorrect explanation: ***3%***

Uncertain: **6%**

More than two thirds of the interview sample believed that net heat absorbed was equal to zero.

Explanation offered for $Q_{net} = 0$

"*The heat transferred to the gas . . . is equal to zero . . . . The gas was heated up, but it still returned to its equilibrium temperature. So whatever energy was added to it was distributed back to the room.*"

Most students thought that both Q_{net} and W_{net} are equal to zero

- 56% believed that both the net work done ***and*** the total heat transferred would be zero.
- Only three out of 32 students (9%) answered both parts of Interview Question #6 correctly.

Predominant Themes of Students' Reasoning

1. Understanding of concept of state function in the context of energy.
2. Belief that work is a state function.
3. Belief that heat is a state function.
4. Belief that net work done and net heat absorbed by a system undergoing a cyclic process are zero.
5. Inability to apply the first law of thermodynamics.

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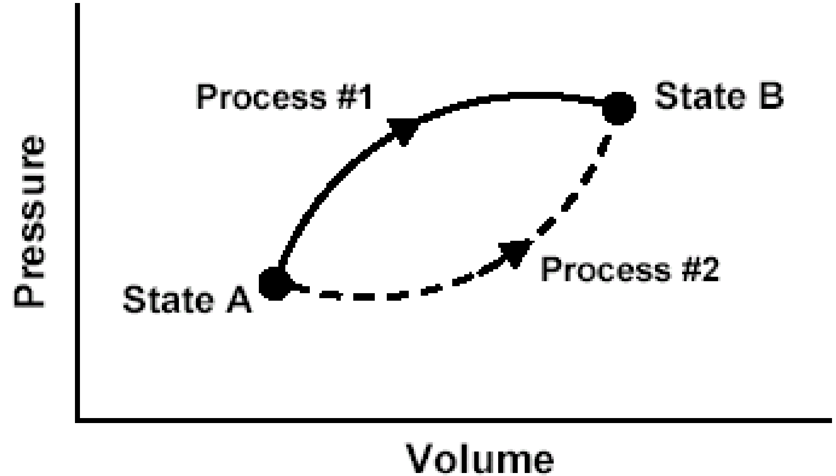

[In these questions, ***W*** represents the work done ***by*** the system during a process; ***Q*** represents the heat ***absorbed*** by the system during a process.]

1. Is *W* for Process #1 ***greater than, less than****,* or ***equal to*** that for Process #2? Explain.

2. Is Q for Process #1 ***greater than, less than****,* or ***equal to*** that for Process #2?

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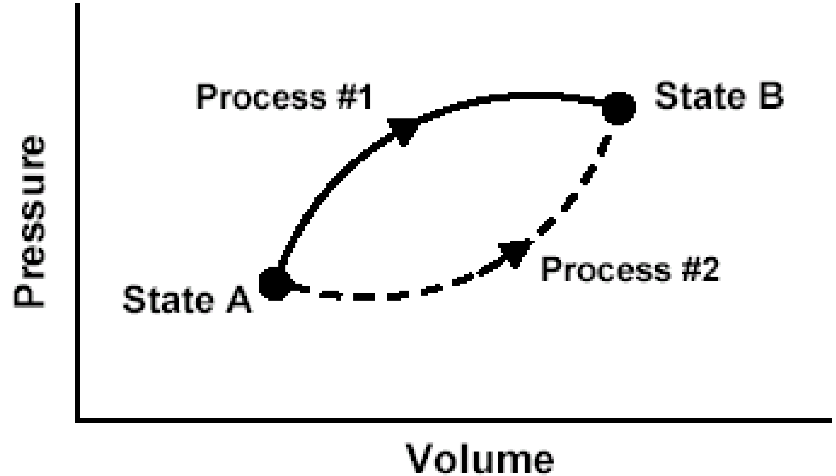

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1. Is *W* for Process #1 ***greater than, less than***, or ***equal to*** that for Process #2? Explain.

2. Is *Q* for Process #1 ***greater than, less than***, or ***equal to*** that for Process #2?

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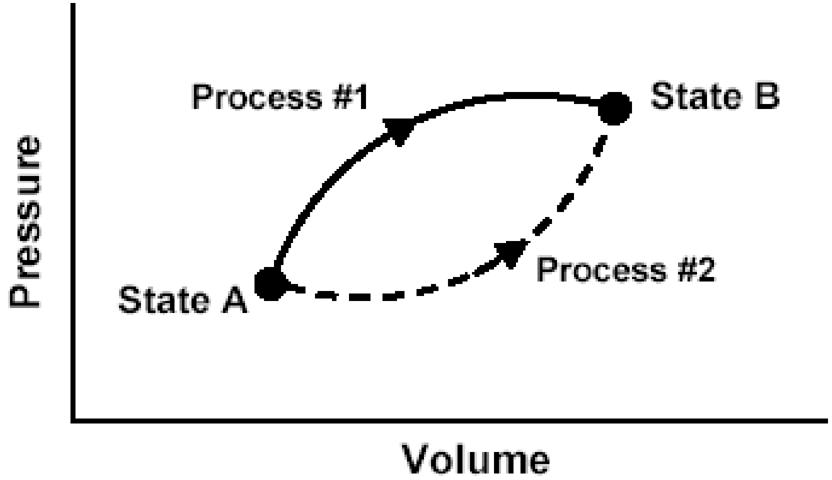
The system does more work in Process #1, so it must absorb more heat to reach same final value of internal energy: $Q_1 > Q_2$



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1. Is *W* for Process #1 ***greater than, less than***, or ***equal to*** that for Process #2? Explain.

2. Is Q for Process #1 ***greater than, less than***, or ***equal to*** that for Process #2?

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Responses to Diagnostic Question #2
(Heat question)

	1999 (*N*=186)	**2000** (*N*=188)	**2001** (*N*=279)	**2002** Interview Sample (*N*=32)
$Q_1 > Q_2$ (disregarding explanations)	**56%**	**40%**	**40%**	**34%**

Examples of "Acceptable" Student Explanations for $Q_1 > Q_2$

"$\Delta U = Q - W$. *For the same* ΔU, *the system with more work done must have more* Q *input so process #1 is greater*."

"Q *is greater for process one because it does more work; the energy to do this work comes from the* Q_{in}."

Responses to Diagnostic Question #2
(Heat question)

	1999 (*N*=186)	**2000** (*N*=188)	**2001** (*N*=279)	**2002** Interview Sample (*N*=32)
$Q_1 > Q_2$	**56%**	**40%**	**40%**	**34%**
Correct or partially correct explanation	**14%**	**10%**	**10%**	**19%**
Incorrect, or missing explanation	**42%**	**30%**	**30%**	**15%**

Fewer than 20% of Students are Able to Apply First Law

- Fewer than 20% of students overall could explain why $Q_1 > Q_2$.
- 13% of students in interview sample were able to use first law to correctly answer Question #6(ii).

➡ **Large majority of students finish general physics course unable to apply first law of thermodynamics.**

Consistent with results of Loverude, Kautz, and Heron, Am. J. Phys. (2002), for Univ. Washington, Univ. Maryland, and Univ. Illinois

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→ **Students very often attribute state-function properties to process-dependent quantities.**

Some Strategies for Instruction

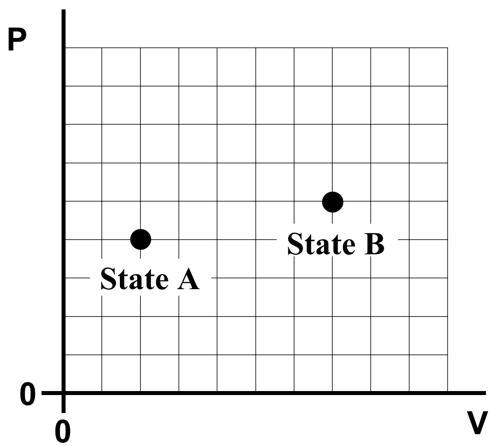
- Try to build on students' understanding of state-function concept.
- Focus on meaning of heat as ***transfer*** of energy, ***not*** quantity of energy residing in a system.
- Develop concept of work as energy transfer mechanism.

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.

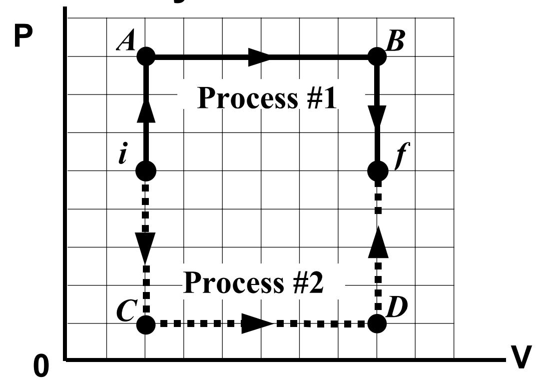


3. If a system starts with an initial internal energy of $U_{initial}$ and ends up with U_{final} some time later, we symbolize the *change* in the system's internal energy by ΔU and define it as follows: $\Delta U = U_{final} - U_{initial}$.

   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 Worksheet



7. Rank the *temperature* of the gas at the six points *i*, *A*, *B*, *C*, *D*, and *f*. (Remember this is an *ideal* gas.)

8. Consider all sub-processes represented by straight-line segments. For each one, state whether the work is positive, negative, or zero. In the second column, rank all six processes according to their ΔU. (Pay attention to the sign of ΔU.) If two segments have the same ΔU, give them the same rank. In the last column, state whether heat is added *to* the gas, taken *away* from the gas, or is *zero* (i.e., *no* heat transfer). ***Hint:*** **First determine *U* for each point using the result of #1 on page 1.**

Process	**Is *W* +, –, or 0?**	**rank according to ΔU**	**heat added *to*, taken *away*, or *zero*?**
$i \rightarrow A$			
$A \rightarrow B$			
$B \rightarrow f$			
$i \rightarrow C$			
$C \rightarrow D$			
$D \rightarrow f$			

9. Consider **only** the sub-processes that have $W = 0$. Of these, which has the *greatest* absolute value of heat transfer Q? Which has the *smallest* absolute value of Q?

10. Rank the six segments in the table above according to the absolute value of their W. *Hint:* For processes at constant pressure, $W = P\,\Delta V$.

11. Using your answers to #8 and #10, explain whether W_1 is *greater than*, *less than*, or *equal to* W_2. [Refer to definitions, page 3.] Is there also a way to answer this question using an "area" argument?

12. Is Q_1 *greater than*, *less than*, or *equal to* Q_2? Explain. *Hint:* Compare the magnitude of ΔU_1 and ΔU_2, and make use of the answer to #6.

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

Related Work on Calorimetry

- Investigate students' understanding of chemical calorimetry
  - *with T. J. Greenbowe, ISU Chemistry Dep't.*
- Probe understanding of students in physics courses
  - *with N.-L. Nguyen and Warren Christensen*
- Develop and test worksheets for both physics and chemistry

Student Learning of Thermochemical Concepts

T. J. Greenbowe and DEM, Int. J. Sci. Educ. *25, 779 (2003)*

- Investigated students' misunderstanding of role of bond breaking and forming in determining heats of reaction
  - *student belief that heat flows <u>from</u> one reactant <u>to</u> the other*
- Uncovered students' misinterpretation of role of mass in relationship $Q = mc\Delta T$
  - *strong tendency to associate "m" with reactants only, instead of with total mass undergoing temperature change*

Thermochemistry Tutorial

The textbook (p. 161) describes an experiment in which Silver Nitrate ($AgNO_3$) solution is mixed with hydrochloric acid (HCl) solution in a constant-pressure calorimeter. (We assume that the calorimeter loses only a negligible quantity of heat.) The temperature of the resulting solution is observed to increase, due to the following reaction:

$$AgNO_3(aq) + HCl(aq) \rightarrow AgCl(s) + HNO_3(aq)$$

2. Three students are discussing this experiment. Here is part of their discussion:

Mary: The silver nitrate was originally a solid. When it's put into solution along with the HCl, I think that heat flows out from the $AgNO_3$ and into the HCl solution, and that's why the temperature increases.

Bob: Well, the hydrochloric acid is the more powerful reactant; it's a strong acid, so it must be the one that reacts most strongly. I think that the heat must come out of the HCl.

Lisa: I don't really think that the heat flows into either of those two. I think heat flows out of both the silver nitrate *and* the hydrochloric acid solution, and that's why the temperature rises.

Mary: But how could heat flow out of *both* of the reactants? Where is it coming from then? Doesn't that violate conservation of energy?

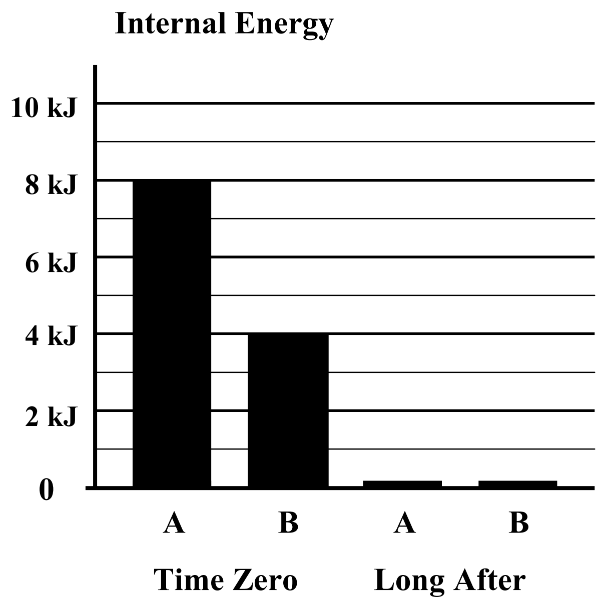
Comment on the students' statements. Do you agree with one of them more than the others? If so, explain why. If you don't think that any of them are completely correct, give your own opinion.

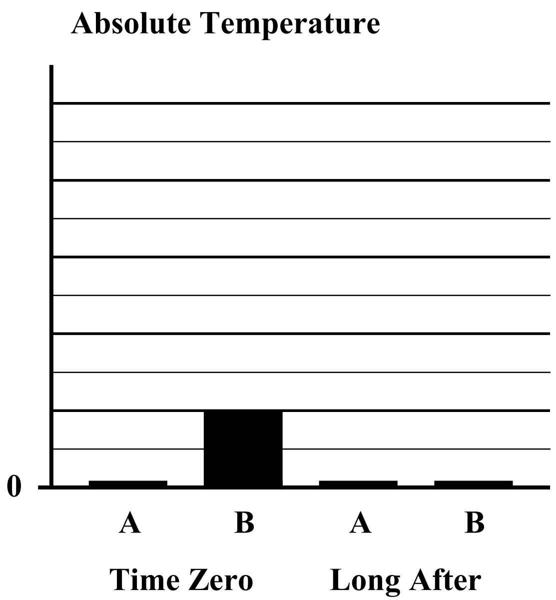
Related Work on Calorimetry

- Investigate students' understanding of chemical calorimetry
  - *with T. J. Greenbowe, ISU Chemistry Dep't.*
- Probe understanding of students in physics courses
  - *with N.-L. Nguyen and Warren Christensen*
- Develop and test worksheets for both physics and chemistry

Calorimetry Worksheet

Complete the bar charts by finding the "Long After" values for temperature and internal energy, and also the amounts of energy transferred to each sample. (This is the net transfer that occurs between time zero and the time "long after.") If any quantity is zero, label that quantity as zero on the bar chart. Explain your reasoning below. *NOTE: The missing values – indicated by a thick line on the horizontal axis – are not necessarily zero – you need to determine whether or not they are actually zero!*





Outline

- Overview of goals and methods of PER

Investigation of Students' Reasoning:

- Students' reasoning in thermodynamics
- Diverse representational modes in student learning

Curriculum Development:

- Instructional methods and curricular materials for large-enrollment physics classes

Assessment of Instruction:

- Measurement of learning gain

Ongoing and Future Projectsl broader impact of PER on undergraduate education

Investigation of Diverse Representational Modes in the Learning of Physics and Chemistry

Supported by *NSF "Research on Learning and Education" program, Co-PI: T. J. Greenbowe*

- Probe students' reasoning with widely used representations
  - e.g., force-vector, free-body, *P*-*V*, and field-vector diagrams [*N.-L. Nguyen and DEM,* Am. J. Phys. ***70****, 630 (2003)]*
- Compare student reasoning with different forms of representation of same concept
  - e.g., verbal, diagrammatic, mathematical/symbolic, graphical

"Multiple-Representation" Quiz

- Same or similar question asked in more than one form of representation
  - e.g., verbal [words only], diagrammatic, mathematical, etc.

- Comparison of responses yields information on students' reasoning patterns with diverse representations

Must ensure that students have first had extensive practice with each form of representation

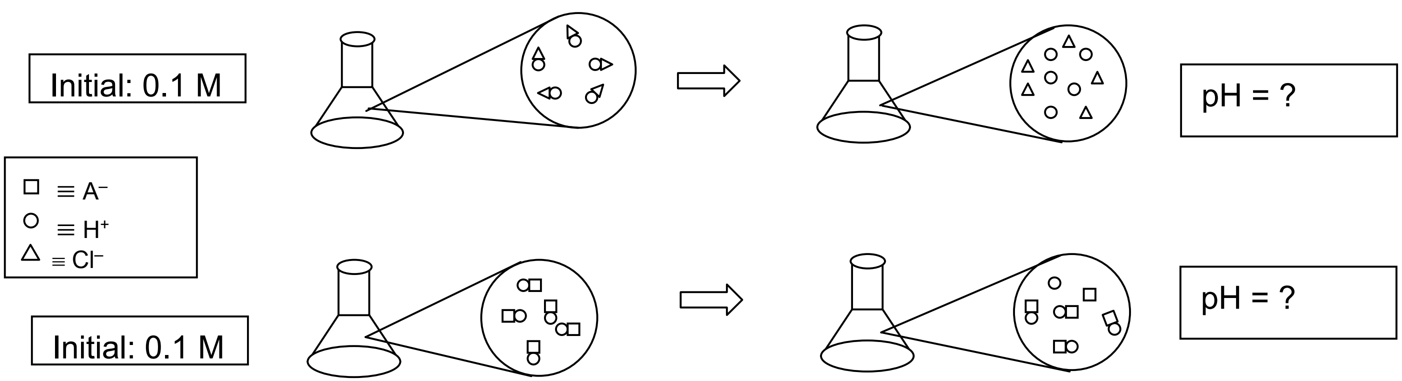
[Chemistry Multi-representation Quiz]

1. Hydrogen chloride gas is bubbled into water, resulting in a one-tenth molar hydrochloric acid solution. In that solution, after dissociation, all of the chlorine atoms become chloride ions, and all of the hydrogen atoms become hydronium ions. In a separate container, HA acid is added to water creating an initial concentration of one-tenth molar HA-acid solution. In that solution (at equilibrium), twenty percent of the H atoms becomes hydronium ions, and twenty percent of the A atoms become A^- ions.

(a) Find the pH of the hydrochloric acid solution and explain your reasoning

(b) Find the pH of the HA-acid solution and explain your reasoning

2. (a) Given these two samples below, find the pH of each solution



(b) Explain the reasoning you used to come to this conclusion.

Investigation of Physics Students' Understanding of Representations

- Second-semester, algebra-based general physics course at Iowa State University.
- Data collected during five separate years (1998-2002).

Example: Quiz on Gravitation

- 11-item quiz given on second day of class (all students have completed study of mechanics)

- Two questions on quiz relate to Newton's third law in astronomical context
  - verbal version and diagrammatic version

#1. The mass of the sun is about 3 x 10^5 times the mass of the earth. How does the magnitude of the gravitational force exerted by the sun on the earth compare with the magnitude of the gravitational force exerted by the earth on the sun?

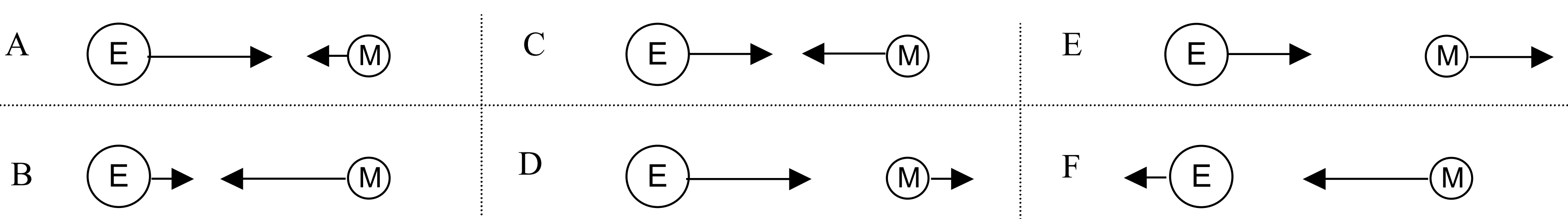
The force exerted by the sun on the earth is:

A. about 9 x 10^{10} times larger
B. about 3 x 10^5 times larger
C. exactly the same
D. about 3 x 10^5 times smaller
E. about 9 x 10^{10} times smaller

"verbal"

#8. Which of these diagrams most closely represents the gravitational forces that the earth and moon exert ***on each other***? (Note: The mass of the earth is about 80 times larger than that of the moon.)

"diagrammatic"



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C. exactly the same
D. about 3 x 10^5 times smaller
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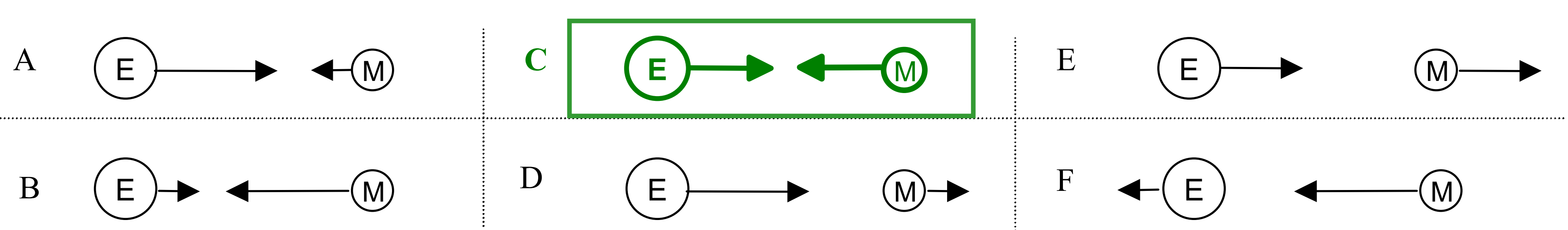
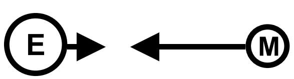
#8. Which of these diagrams most closely represents the gravitational forces that the earth and moon exert ***on each other***? (Note: The mass of the earth is about 80 times larger than that of the moon.)



Results of Quiz on Gravitation

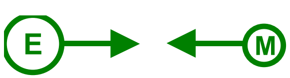
	1998-2002	
#1. force by sun is:	*N = 408*	
larger	**79%**	
*** the same**	**16%**	***(s.d. = 5%)***
smaller	**5%**	

#8. earth/moon force

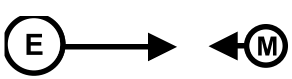


48%

*



9% ***(s.d. = 3%)***



41%

[wrong direction] 2%

Comparison of Responses

- Proportion of correct responses on diagrammatic version of question is consistently lower than on verbal version.
- Pattern of incorrect responses is dramatically different on two versions of question:
  - most common response on verbal version: *force exerted by more massive object has larger magnitude*
  - on diagrammatic version: *force exerted by more massive* ***<u>or</u>*** *less massive object has larger magnitude*

Students' written explanations confirm that most believed that more massive object exerts larger force.

Comparison of Responses

- Proportion of correct responses on diagrammatic version of question is consistently lower than on verbal version.
- Pattern of incorrect responses is dramatically different on two versions of question:
  - most common response on verbal version: *force exerted by more massive object has larger magnitude*
  - on diagrammatic version: *force exerted by more massive* ***or*** *less massive object has larger magnitude*

Apparently, many students have difficulty translating phrase "*force exerted on*" into vector diagram form.

Students' Problem-Solving Performance and Representational Mode

DEM, submitted to *Am. J. Phys.* (2003)

- Significant discrepancy between student responses on Newton's third-law questions in "verbal" and "diagrammatic" representations

Coulomb's Law Quiz in Multiple Representations

IF YOU WANT A QUESTION GRADED OUT OF THREE POINTS (–1 [MINUS ONE] FOR WRONG ANSWER!!) WRITE "3" IN SPACE PROVIDED ON EACH QUESTION.

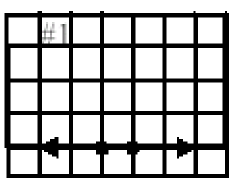
1. When two identical, isolated charges are separated by two centimeters, the magnitude of the force exerted by each charge on the other is eight newtons. If the charges are moved to a separation of eight centimeters, what will be the magnitude of that force now?

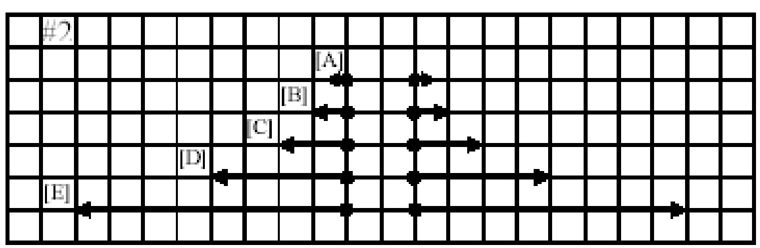
A. one-half of a newton
B. two newtons
C. eight newtons
D. thirty-two newtons
E. one hundred twenty-eight newtons

Grade out of three? Write "3" here: ______

V [verbal]

2. Figure #1 shows two identical, isolated charges separated by a certain distance. The arrows indicate the forces exerted by each charge on the other. The same charges are shown in Figure #2. Which diagram in Figure #2 would be correct?





A.
B.
C.
D.
E.

Grade out of three? Write "3" here: ______

D [diagrammatic]

3. Isolated charges q_1 and q_2 are separated by distance r, and each exerts force F on the other. $q_1^{initial} = q_1^{final}$ and $q_2^{initial} = q_2^{final}$; $r^{initial} = 10m$; $r^{final} = 2m$. $F^{initial} = 25N$; $F^{final} = ?$

A. 1 N
B. 5 N
C. 25 N
D. 125 N
E. 625 N

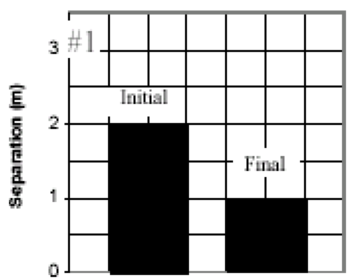
Grade out of three? Write "3" here: ____

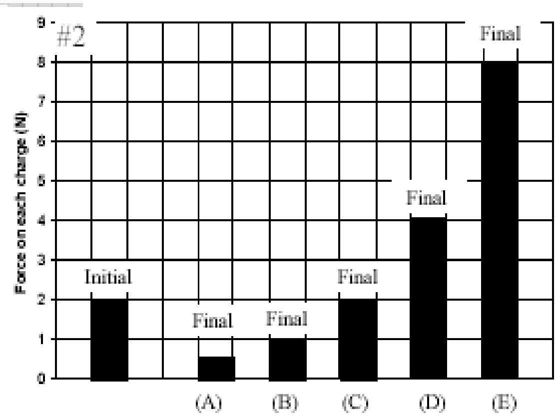
M [mathematical/symbolic]

4. Graph #1 refers to the initial and final separation between two identical, isolated charges. Graph #2 refers to the initial and final forces exerted by each charge on the other. Which bar is correct?

Grade out of three? Write "3" here: ____

A.
B.
C.
D.
E.





G [graphical]

DC Circuits Quiz

1. In a parallel circuit, a three-ohm resistor and a six-ohm resistor are connected to a battery. In a series circuit, a four-ohm and an eight-ohm resistor are connected to a battery that has the ***same*** voltage as the battery in the parallel circuit. What will be the ratio of the current through the six-ohm resistor to the current through the four-ohm resistor? Current through six-ohm resistor divided by current through four-ohm resistor is:

   A. greater than one

   B. equal to one

   C. less than one

   D. equal to negative one

   E. cannot determine without knowing the battery voltage

   Grade out of 3? Write "3" here: _____

V

2. Parallel circuit: $R_A = 6\ \Omega;\ R_B = 9\ \Omega$.
   Series circuit: $R_C = 7\ \Omega;\ R_D = 3\ \Omega$.
   $\Delta V_{bat}(series) = \Delta V_{bat}(parallel)$

M

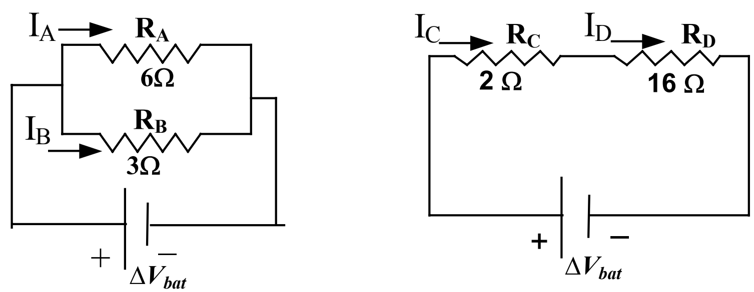
   A. $\frac{I_B}{I_C} > 1$ B. $\frac{I_B}{I_C} = 1$ C. $\frac{I_B}{I_C} < 1$ D. $\frac{I_B}{I_C} = -1$ E. need ΔV_{bat}

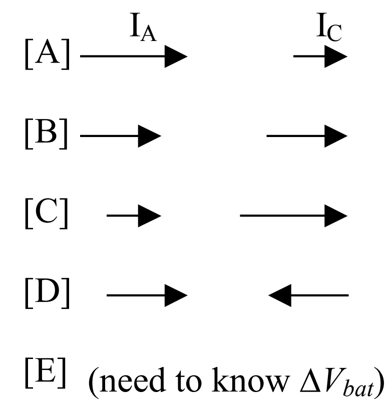
   Grade out of 3? Write "3" here: _____

D

3. The arrows represent the magnitude and direction of the current through resistors A and C. Choose the correct diagram.

A.
B.
C.
D.
E. need to know ΔV_{bat}



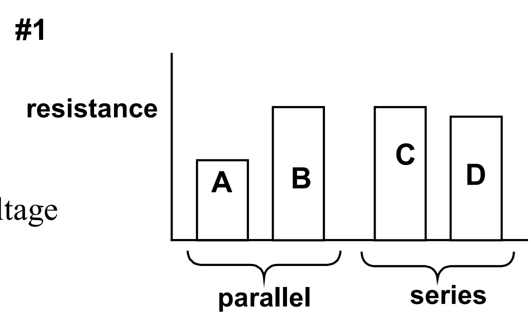


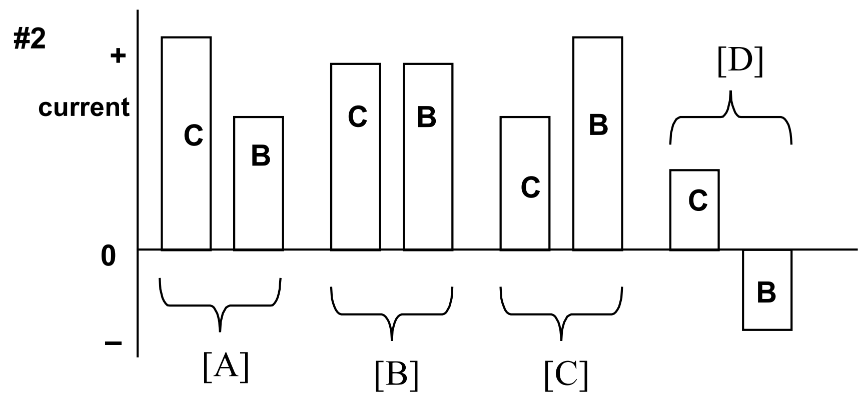
Grade out of 3? Write "3" here: _____

G

4. Graph #1 represents the relative resistances of resistors A, B, C, and D. Resistors A and B are connected in a parallel circuit. Resistors C and D are connected in a series circuit. The battery voltage in both circuits is the same. Graph #2 represents the currents in resistors C and B respectively. Which pair is correct?

A.
B.
C.
D.
E. need to know voltage





Students' Problem-Solving Performance and Representational Mode

DEM, submitted to *Am. J. Phys.* (2003)

- Significant discrepancy between student responses on Newton's third-law questions in "verbal" and "diagrammatic" representations
- Even after identical instruction, consistent discrepancy between female and male performance on circuit-diagram questions
  - *50% higher error rates for female students in algebra-based physics*

Outline

- Overview of goals and methods of PER

Investigation of Students' Reasoning:

- Students' reasoning in thermodynamics
- Diverse representational modes in student learning

Curriculum Development:

- Instructional methods and curricular materials for large-enrollment physics classes

Assessment of Instruction:

- Measurement of learning gain

Ongoing and Future Projectsl broader impact

Keystones of Innovative Pedagogy

- 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

“Fully Interactive” Physics Lecture

DEM and K. Manivannan, Am. J. Phys. ***70,*** *639 (2002)*

V

Transforming the lecture-hall environment: The fully interactive physics lecture

David E. Meltzer[a)]

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(Received 19 September 2001; accepted 29 January 2002)

Numerous reports suggest that learning gains in introductory university physics courses may be increased by "active-learning" instructional methods. These methods engender greater mental engagement and more extensive student–student and student–instructor interaction than does a typical lecture class. It is particularly challenging to transfer these methodologies to the large-enrollment lecture hall. We report on seven years of development and testing of a variant of Peer Instruction as pioneered by Mazur that aims at achieving virtually continuous instructor–student interaction through a "fully interactive" physics lecture. This method is most clearly distinguished by instructor–student dialogues that closely resemble one-on-one instruction. We present and analyze a detailed example of such classroom dialogues, and describe the format, procedures, and curricular materials required for creating the desired lecture-room environment. We also discuss a variety of assessment data that indicate strong gains in student learning, consistent with other researchers. We conclude that interactive-lecture methods in physics instruction are practical, effective, and amenable to widespread implementation.

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[DOI: 10.1119/1.1463739]

I. INTRODUCTION

Numerous investigations in recent years have shown active-learning methods to be effective in increasing student learning of physics concepts. These methods aim at promoting substantially greater engagement of students during in-class activities than occurs, for instance, in a traditional physics lecture. A long-standing problem has been that of

The basic elements of an interactive lecture strategy have been described by Mazur.[1] In this paper we broaden and extend that discussion, explaining in detail how the lecture component in large-classroom instruction may be almost eliminated. Depending on the preferences of the instructor and the specific student population, this strategy may yield worthwhile learning outcomes. To carry out the rapid back-and-forth dialogue observed in one-on-one instruction in large-enrollment classes requires a variety of specific instruc-

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“Fully Interactive” Physics Lecture

DEM and K. Manivannan, Am. J. Phys. ***70,*** *639 (2002)*

- Very high levels of student-student and student-instructor interaction (*Simulate one-on-one dialogue of instructor’s office*)
- Use numerous structured question sequences, focused on specific concept: small conceptual “step size”
- Use student response system to obtain instantaneous responses from all students simultaneously (e.g., “flash cards”)

v


IOWA STATE

Curriculum Requirements for Fully Interactive Lecture

- Many question sequences employing multiple representations, covering full range of topics
- Free-response worksheets adaptable for use in lecture hall
- Text reference ("Lecture Notes") with strong focus on conceptual and qualitative questions

→ *Workbook for Introductory Physics (DEM and K. Manivannan, CD-ROM, 2002)*

Supported by NSF under "Assessment of Student Achievement" program

Curriculum Development on the Fast Track

- Need curricular materials for complete course $\Rightarrow$ must create, test, and revise "on the fly"
- Daily feedback through in-class use aids assessment
- Pre- and post-testing with standardized diagnostics helps monitor progress

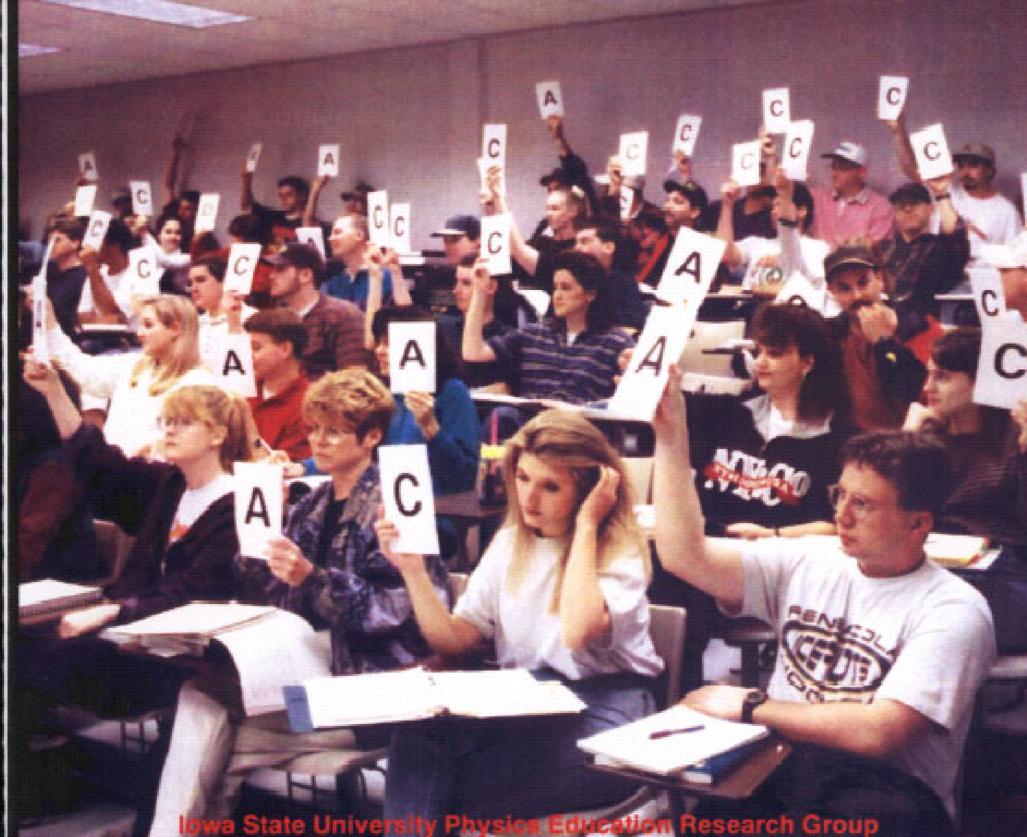
Workbook for Introductory Physics

(CD-ROM; $\approx$ 400 pages)

Workbook for Introductory Physics

Part II: Electricity and Magnetism, Optics, and Modern Physics

David E. Meltzer and Kandiah Manivannan



Iowa State University Physics Education Research Group

Workbook for Introductory Physics

(CD-ROM; ≈ 400 pages)

- Conceptual-Question Sequences for Interactive Lecture (“Flash-card Questions”)
- Worksheets (tutorial-style, for group work)
- Lecture notes (text-style reference)
- Quizzes, Exams, Solution Sets
- Video of Class

Chapter 1 Electrical Forces

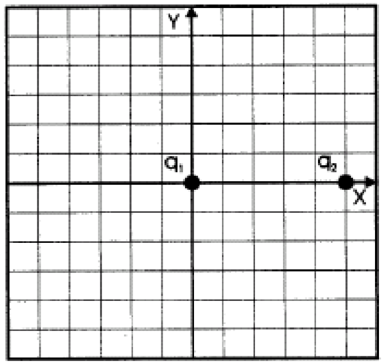
"Flash-Card" Questions

In-Class Questions

Prerequisite Concepts:

- **Positive and negative charges; Coulomb's law: $F = kq_1q_2/r^2$**
- **Protons (+) and electrons (–)**
- **Superposition principle: $F_{net}=F_1+F_2 + \ldots + F_n$**
- **Vector addition: $F_{netx}=F_{1x} + F_{2x} + \ldots F_{nx}$**
- **Newton's second law, a = F/m**

Questions #1–2 refer to the figure below. Charge q_1 is located at the origin, and charge q_2 is located on the positive x axis, five meters from the origin. There are no other charges anywhere nearby.



1. If q_1 is positive and q_2 is negative, what is the direction of the electrical force on q_1?

   A. in the positive x direction
   B. in the negative x direction
   C. in the positive y direction
   D. in the negative y direction
   E. the force is not directed precisely along any of the coordinate axes, but at some angle
   F. there is no force in this case

2. If q_1 is positive and q_2 is positive, what is the direction of the electrical force on q_1?

   A. in the positive x direction
   B. in the negative x direction
   C. in the positive y direction
   D. in the negative y direction
   E. the force is not directed precisely along any of the coordinate axes, but at some angle
   F. there is no force in this case

"Flash-Card" Questions

3. In this figure, a proton is located at the origin, and an electron is located at the point (3m, 3m). What is the direction of the electrical force on the proton?

A. 

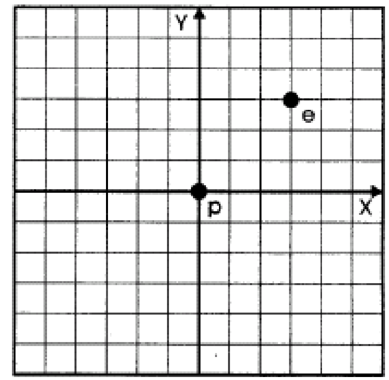
B. 

C. 

D. 

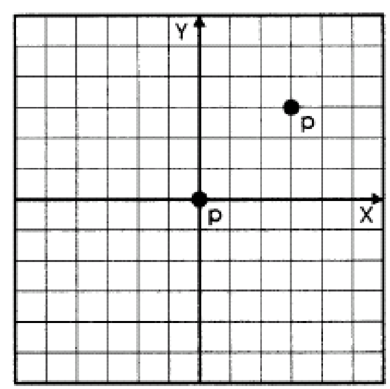
E. 

F. 



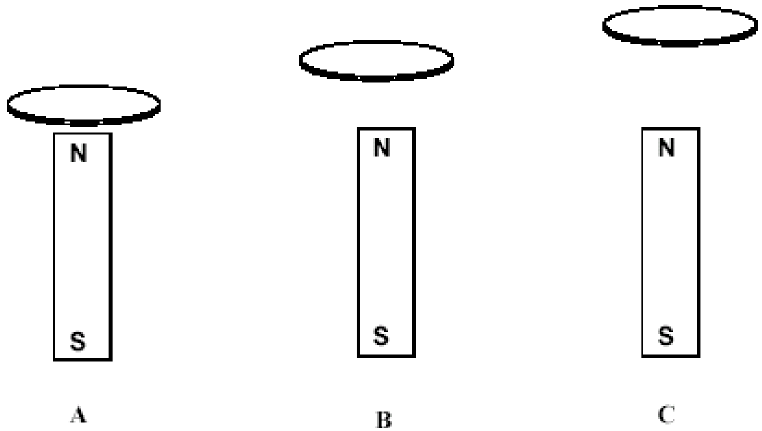
4. In this figure, a proton is located at the origin, and a proton is located at the point (3m, 3m). The vector representing the electrical force on the proton *at the origin* makes what angle with respect to the positive x axis?

A. 0°
B. 45°
C. 90°
D. 135°
E. 225°
F. 270°



Magnetic Induction Worksheet

1. In diagrams A, B, and C, three identical bar magnets and three identical wire loops are shown. ***All three loops remain fixed in the positions shown.***



Worksheets (free-response)

a) Is there any magnetic flux in:

Loop A? ________

Loop B? ________

Loop C? ________

b) Rank the magnitude of the magnetic flux in loops A, B, and C. If all three are zero, state that explicitly. Explain your answer.

c) Is there any current flowing in:

Loop A? ________

Loop B? ________

Loop C? ________

d) Rank the magnitude of the current flowing in loops A, B, and C. If all three currents are zero, state that explicitly. Explain your answer.

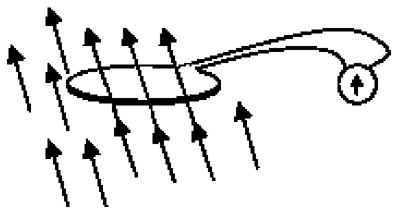
Chapter 10 Notes: Magnetic Induction

Lecture Notes

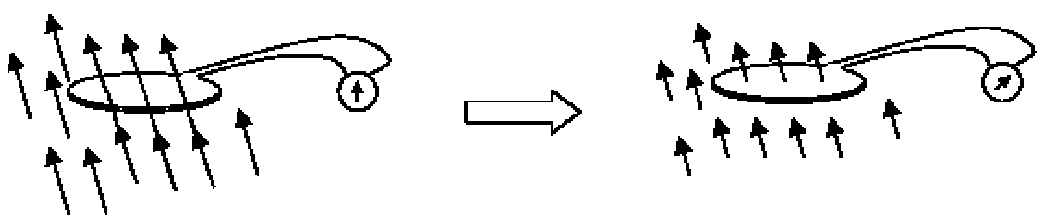
How can a changing magnetic field cause an electric current to flow?

Eleven years after the connection between magnetism and electricity was first reported by Oersted, the British scientist Michael Faraday made one of the most important discoveries in the history of physics. Oersted had found that an electric current could influence the motion of a compass needle; this showed that an electric current produced a magnetic field. Faraday found that, under certain specific circumstance, a magnet (such as a large compass needle) could itself *produce* an electric current (i.e., it could cause charges to begin to move). Although an electric current ***always*** produces a magnetic field, Faraday found that a magnet could only produce an electric current under one or more of three basic conditions: (1) the magnetic field varied in ***magnitude***; (2) the magnetic field varied in ***direction***; (3) the conducting path (which would carry the current) ***varied in shape***.

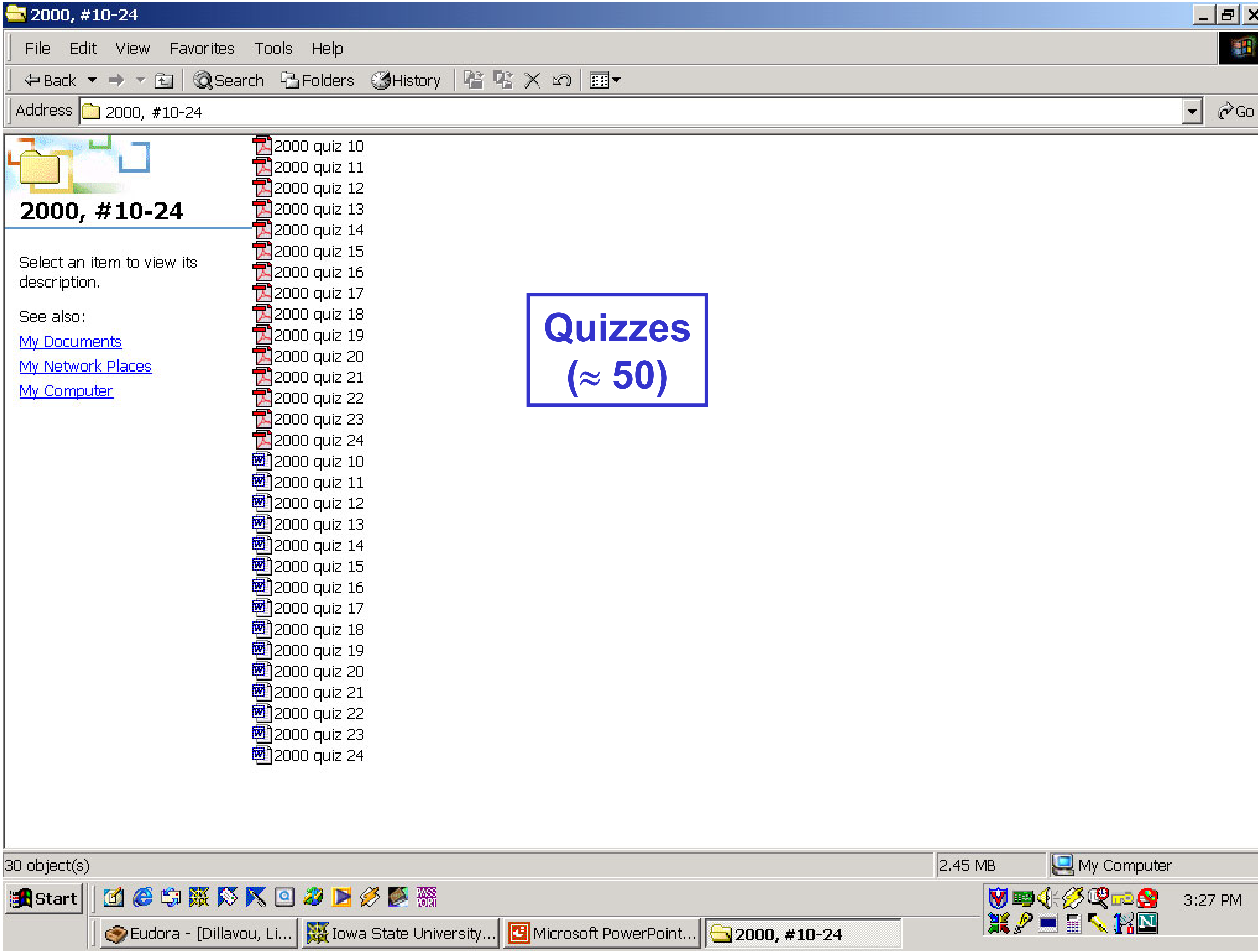
These situations can be illustrated by three different experiments, all involving a magnetic field and a closed loop of conducting material. We could connect a galvanometer (a current-detecting device) to the loop to determine whether or not a current is flowing. We could use a permanent magnet to produce the magnetic field, or instead use the uniform field inside a solenoid. In the diagram below, we have placed a conducting loop in a uniform magnetic field (indicted by the arrows); the loop is connected to a galvanometer. The needle of the galvanometer will deflect (move away from its initial position) if a current if produced in the loop. If the needle is in its initial position (as shown here), there is ***no*** current flowing in the loop.



In the ***initial*** situation shown above, where neither the loop nor the magnetic field is changing in any way, ***no current*** is observed to flow in the loop. However, if we ***change the magnitude*** of the magnetic field – either an increase or a decrease – then a current ***does*** flow in the loop, as shown here:



However, if the magnetic field magnitude ***stops changing***, the current will abruptly cease flowing and the galvanometer needle will go back to its initial position (again indicating "zero current"):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Select an item to view its description.
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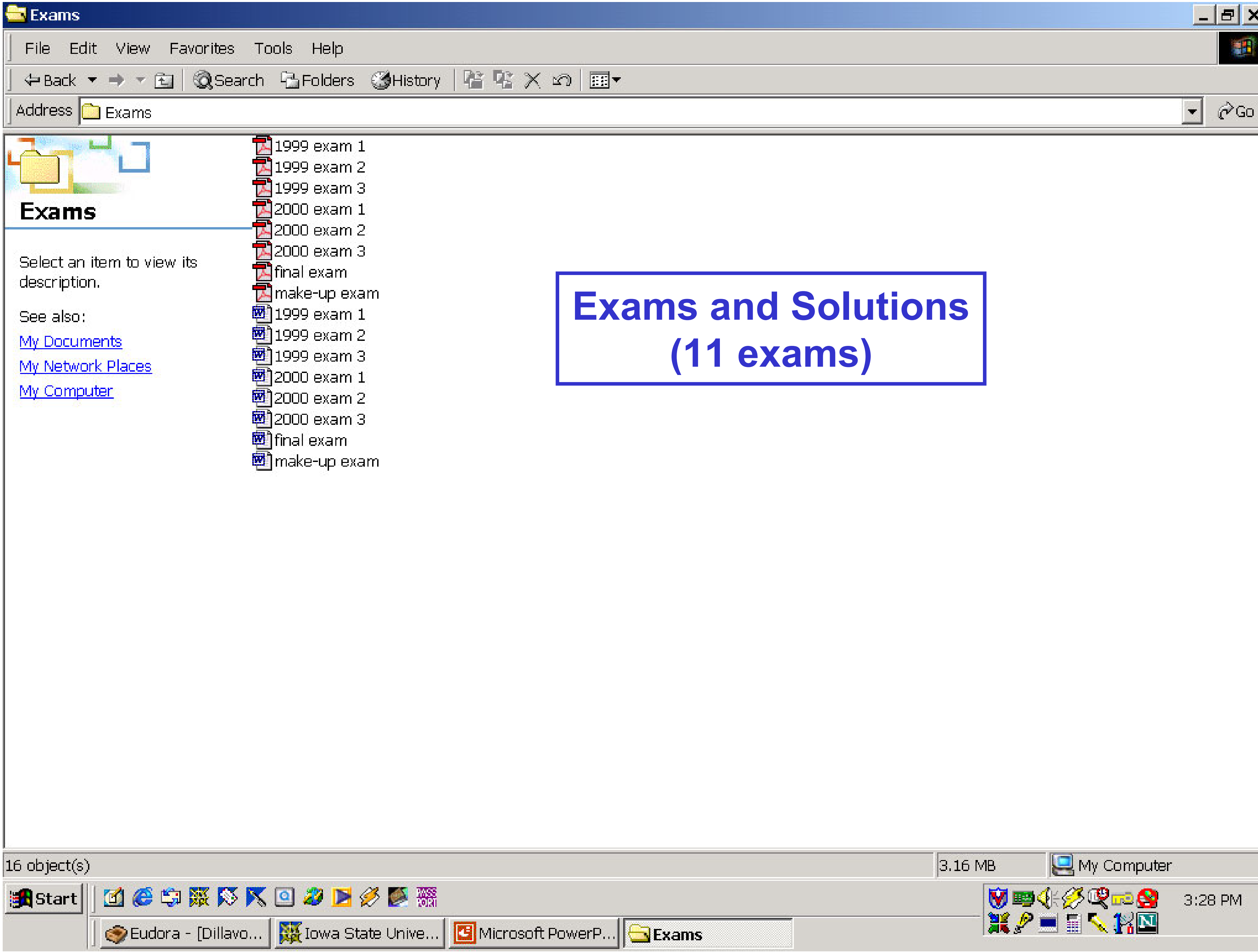
Exams and Solutions (11 exams)



Assessment Data

Scores on Conceptual Survey of Electricity and Magnetism, 14-item electricity subset

Sample	*N*	Mean pre-test score	Mean post-test score	<g>
National sample (algebra-based)	402	**27%**	**43%**	**0.22**
National sample (calculus-based)	1496	**37%**	**51%**	**0.22**
ISU 1998	70	**30%**	**75%**	**0.64**
ISU 1999	87	**26%**	**79%**	**0.71**
ISU 2000	66	**29%**	**79%**	**0.70**

Quantitative Problem Solving: Are skills being sacrificed?

ISU Physics 112 compared to ISU Physics 221 (calculus-based), numerical final exam questions on electricity

	N	**Mean Score**
Physics 221: F97 & F98 ***Six final exam questions***	*320*	56%
Physics 112: F98 **Six final exam questions**	*76*	77%
Physics 221: F97 & F98 **Subset of three questions**	*372*	59%
Physics 112: F98, F99, F00 **Subset of three questions**	*241*	78%

Ongoing Curricular Development

(Projects starting 2003)

- "Formative Assessment Materials for Large-Enrollment Physics Lecture Classes"

  Funded through NSF's "Assessment of Student Achievement" program

- "Active-Learning Curricular Materials for Fully Interactive Physics Lectures"

  Funded through NSF's "Course, Curriculum, and Laboratory Improvement – Adaptation and Implementation" program

Outline

- Overview of goals and methods of PER

Investigation of Students' Reasoning:

- Students' reasoning in thermodynamics
- Diverse representational modes in student learning

Curriculum Development:

- Instructional methods and curricular materials for large-enrollment physics classes

Assessment of Instruction:

- Measurement of learning gain

Ongoing and Future Projects

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.*

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

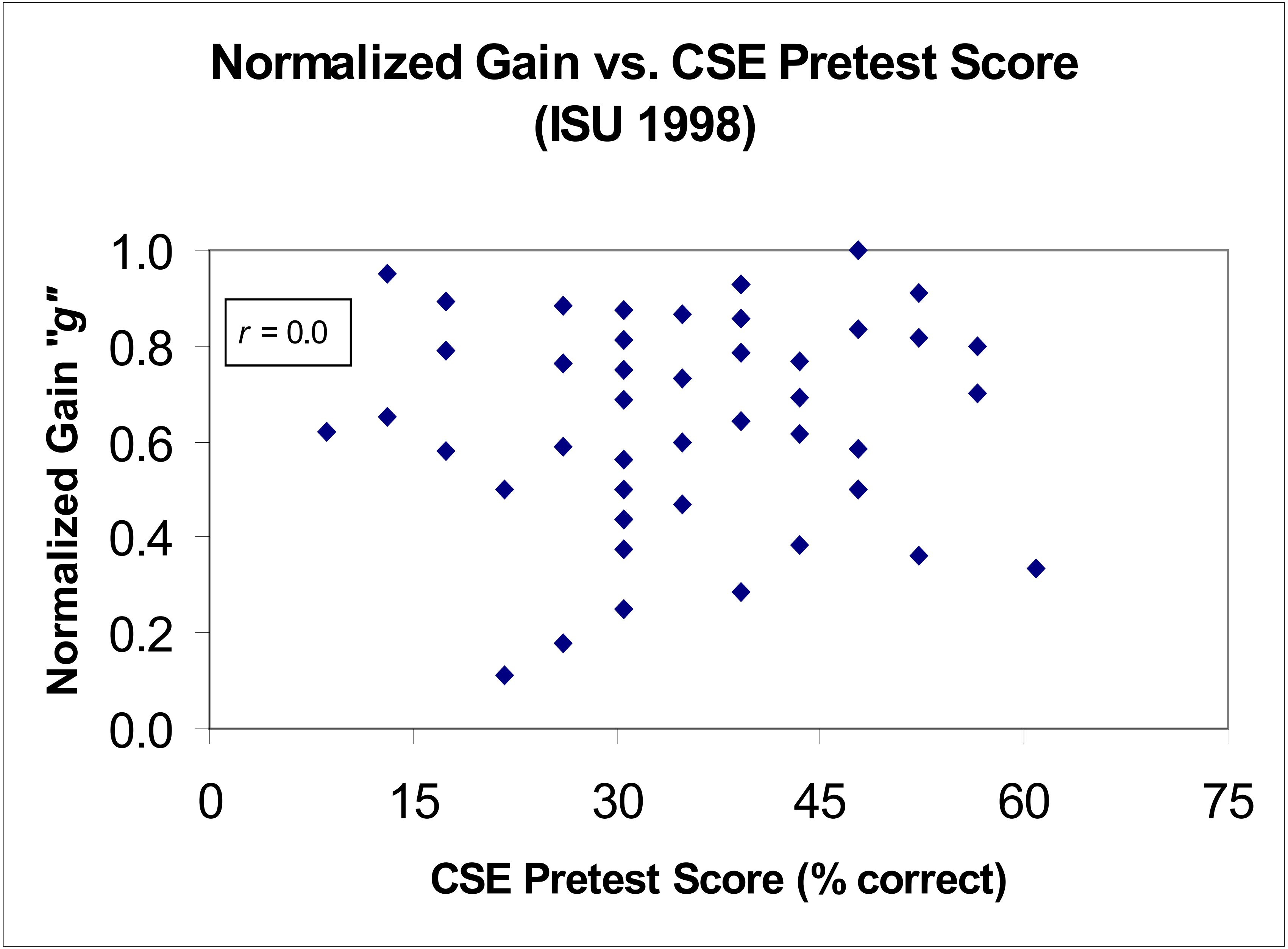
But is *g* really independent of pre-instruction state?

Possible “hidden variables” in students’ pre-instruction mental state

Relationship between Mathematical Ability and Learning Gains in Physics

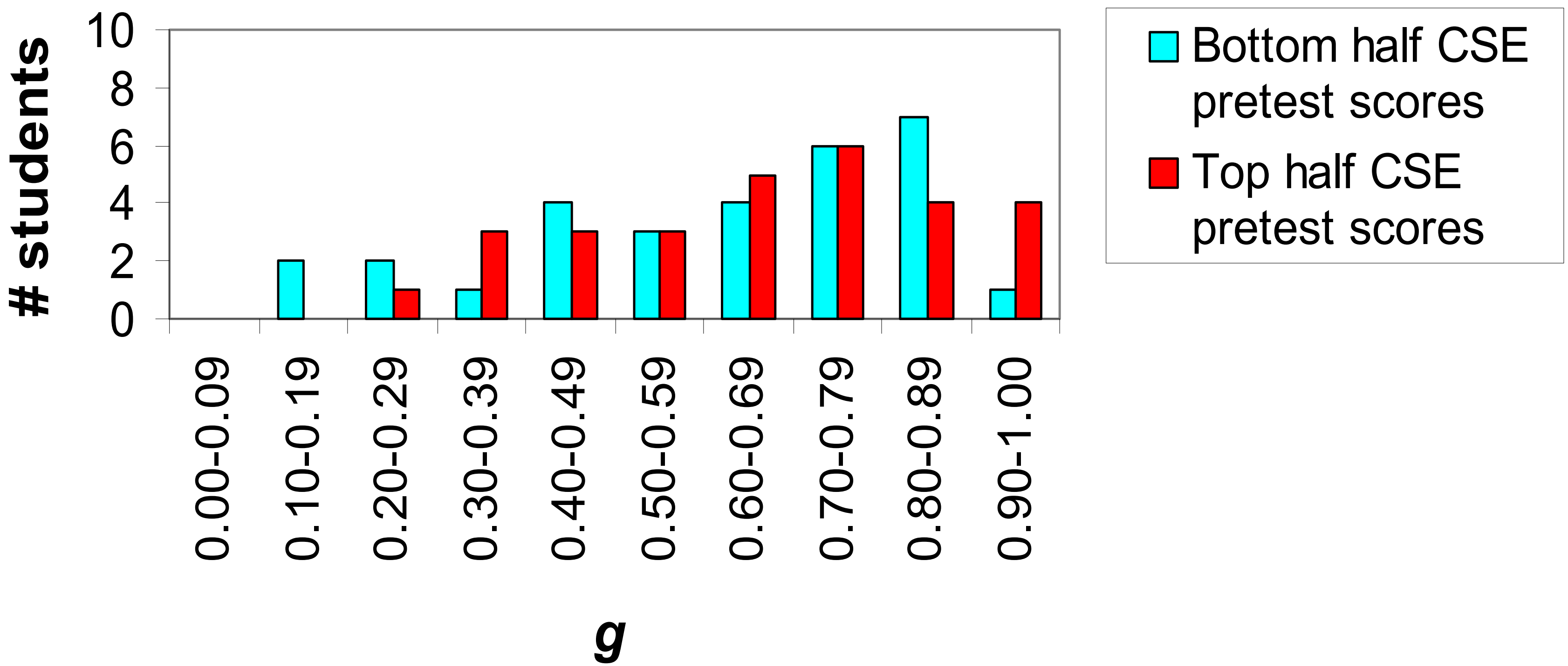
DEM, Am. J. Phys. ***70****, 1259 (2002)*

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

Distribution of Gains: ISU 1998

(high and low CSE pretest scores)



Relationship between Mathematical Ability and Learning Gains in Physics

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- 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")*
- 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?

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

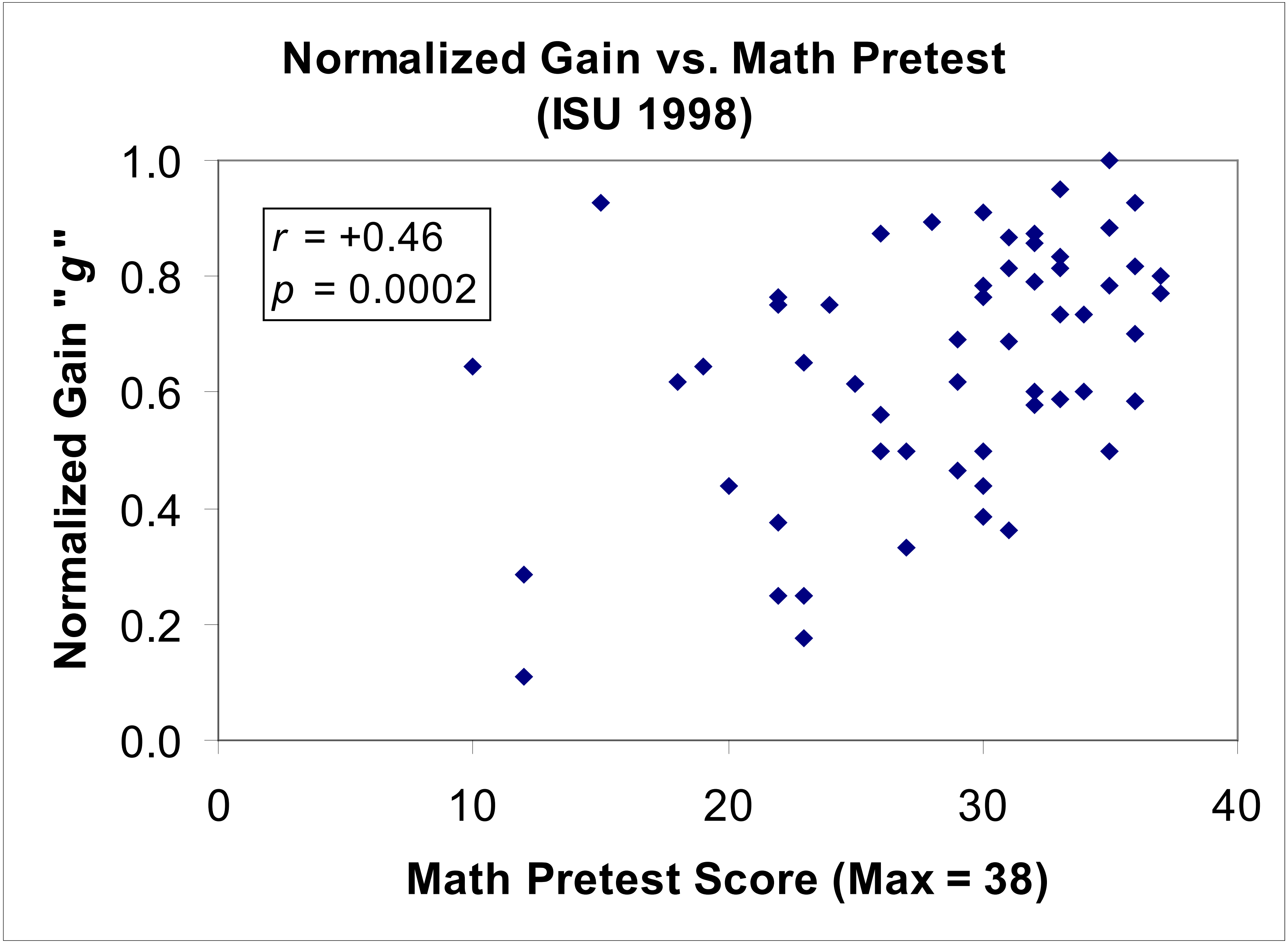
a. -2/9 b. 2 c. 1/2 d. 4 e. 1/4

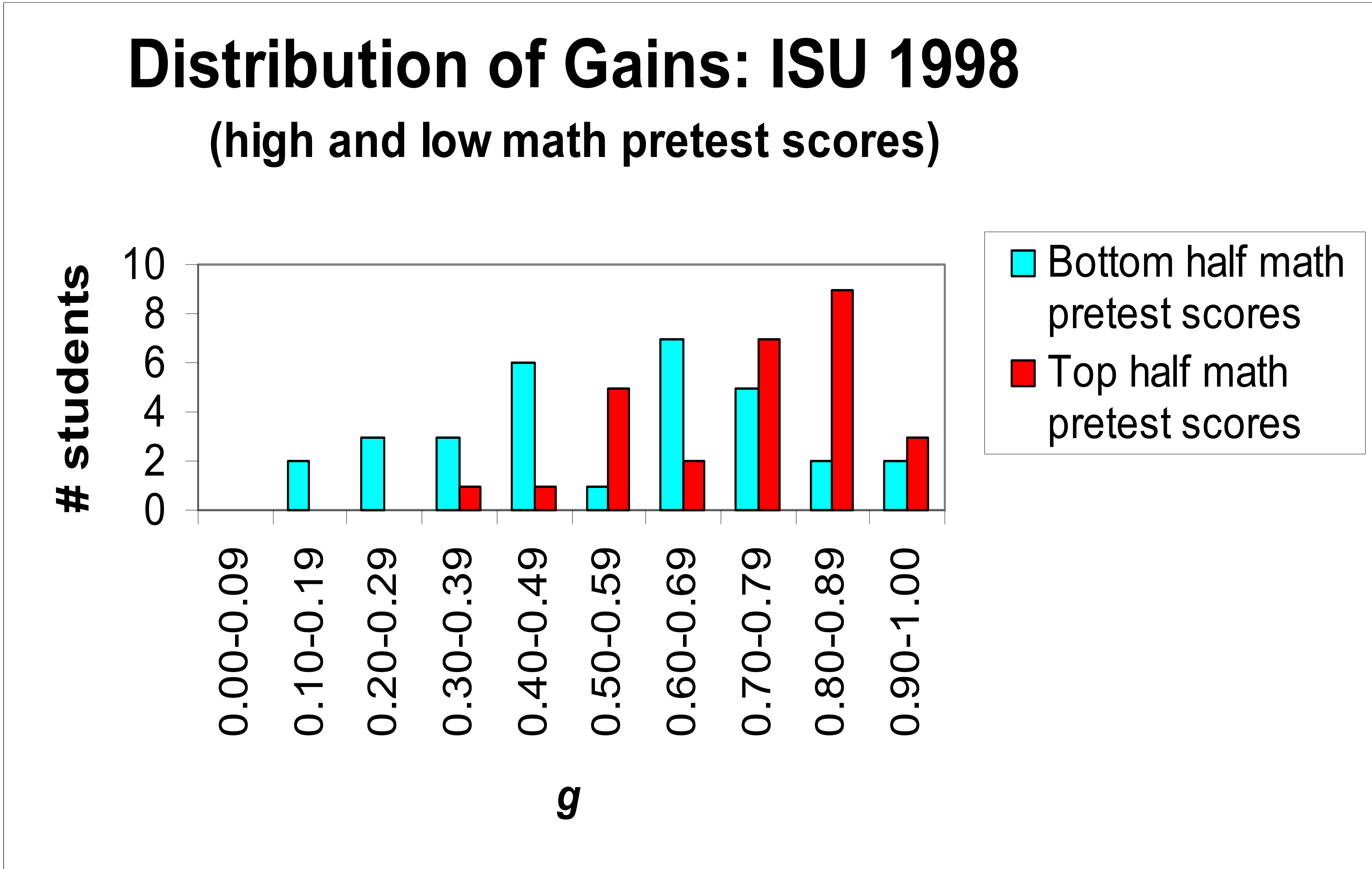
6. Find y as a function of x from the following equations.

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

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)
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

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Ongoing and Future Projects

Ongoing and Future Projects

- Continued curricular development for large-enrollment physics classes

Formative Assessment Materials for Large-Enrollment Physics Lecture Classes

Detailed assessment of previously developed conceptual-question sequences; begin development of new materials

Primary Objectives:

1) *analyze reliability and validity of materials through student interviews*
2) *acquire baseline data regarding student performance through use of electronic response systems*

[Supported by NSF "CCLI-ASA" program]

Active-Learning Curricular Materials for Fully Interactive Physics Lectures

- Development of new conceptual-question sequences for interactive lectures
  - *focus on materials for first-semester topics*
  - *carry out class testing*
  - *build response database with use of electronic response system*
- Test at other institutions

[Supported by NSF "CCLI-A&I" program]

Ongoing and Future Projects

- Continued curricular development for large-enrollment physics classes
- Further investigation into role of representations in student learning
- Extension of research on student understanding of thermodynamics to advanced topics in thermal and statistical physics

Summary

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

  e.g. curricular materials in thermodynamics

- Probing deep-seated learning issues can lead toward more precise targeting of instruction

  e.g., understanding students' difficulties with diverse representations

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