Research in Physics Education and the Development of Improved Instruction

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Outline

Physics Education as a Research Problem

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

Research-Based Instructional Methods

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

Research-Based Curriculum Development

- Principles of research-based curriculum development
- Examples

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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
  - e.g., 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

> 11 yrs old	7-11 yrs old	< 7 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

Physics Education
Research Group

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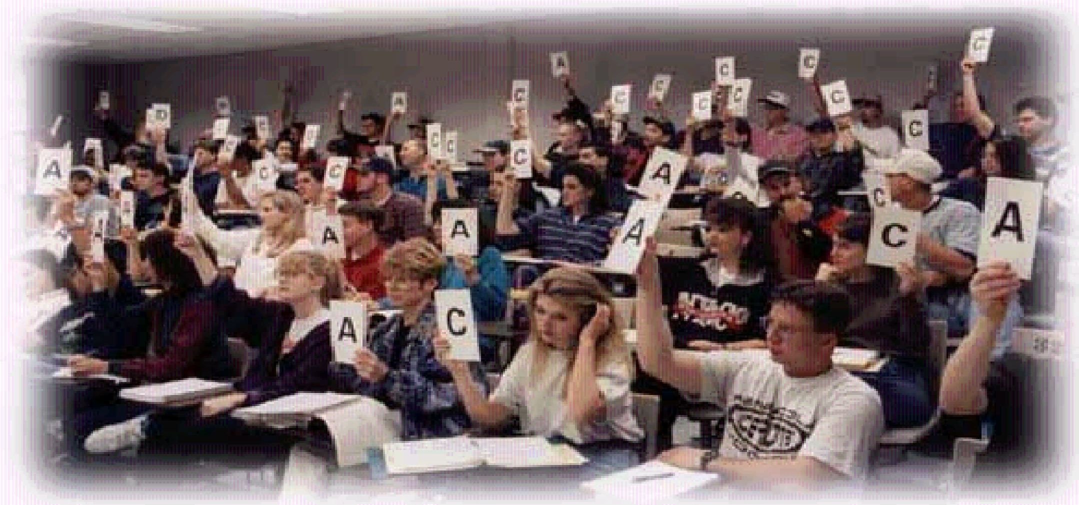

Department of Physics and Astronomy
Iowa State University
Ames, Iowa

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.

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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)

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 assistance from instructors, aided by appropriate curricular materials

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Research in physics education suggests that:

- "Teaching by telling" has only limited effectiveness
  - listening and note-taking have relatively little impact
- Problem-solving activities with rapid feedback yield improved learning gains
  - student group work
  - frequent question-and-answer exchanges with instructor

Goal:* *Guide students to "figure things out for themselves" as much as possible

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

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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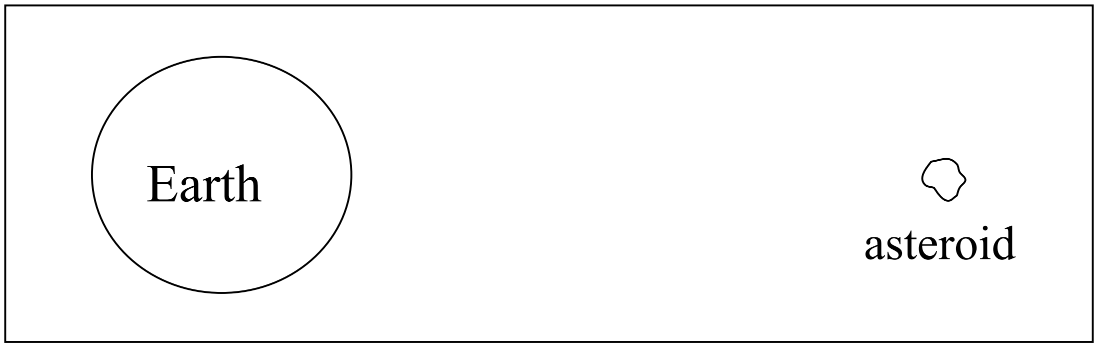
Research-Based Curriculum Development

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

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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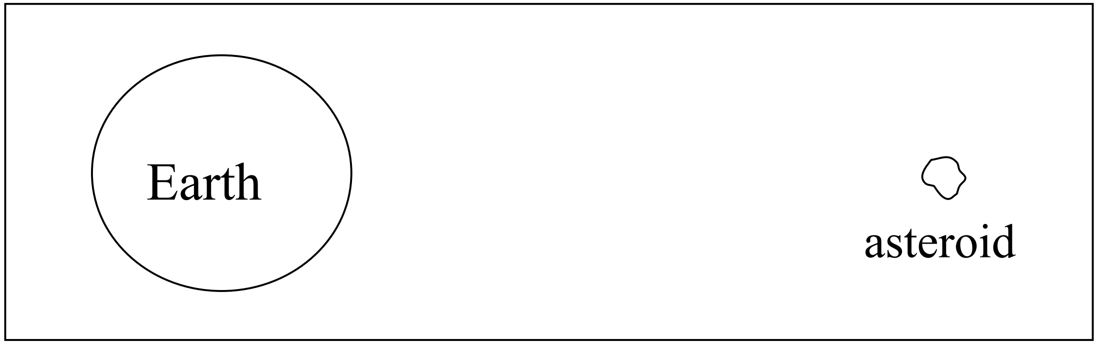

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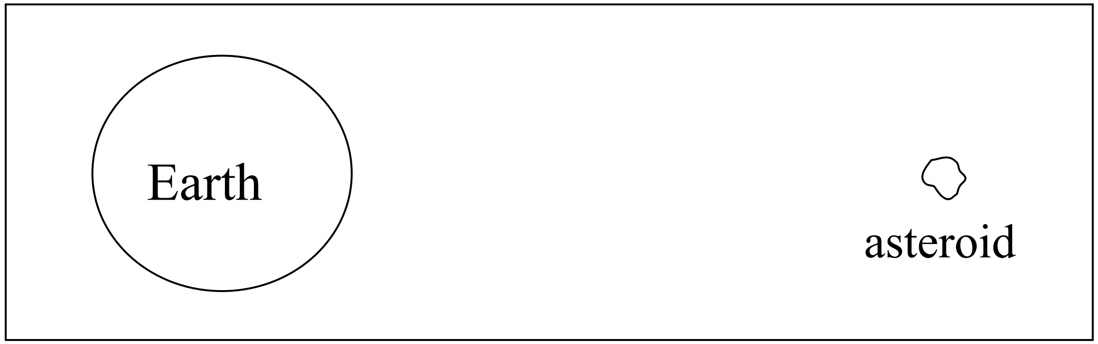

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[Presented during first week of class to all students taking calculus-based introductory physics at ISU during Fall 1999.]

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*

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
- No net additional instructional time on gravitation
- Conceptual questions added to final exam with instructor’s approval

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Physics 221

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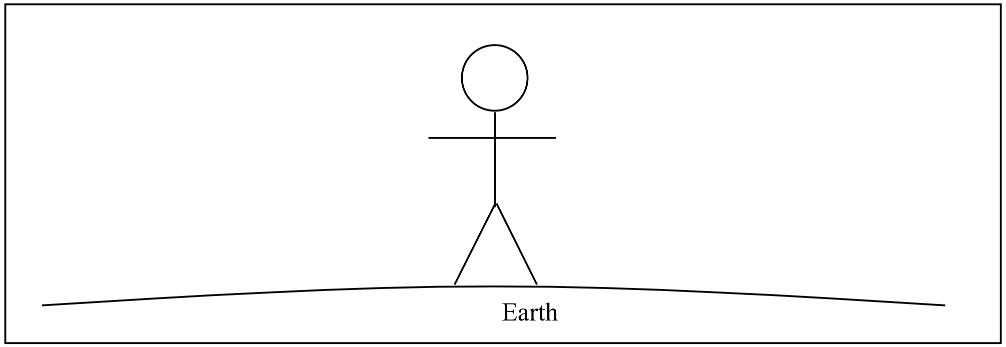

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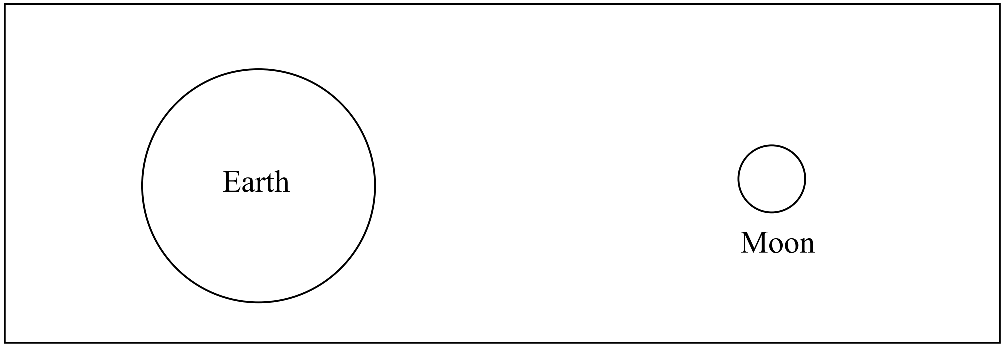

c) Now, in the same picture (above), draw an arrow which represents the force exerted ***by*** the Moon ***on*** the Earth. Label this arrow **(c)**. Remember to draw the arrow with the correct length and direction as compared to the arrow you drew in **(b)**.

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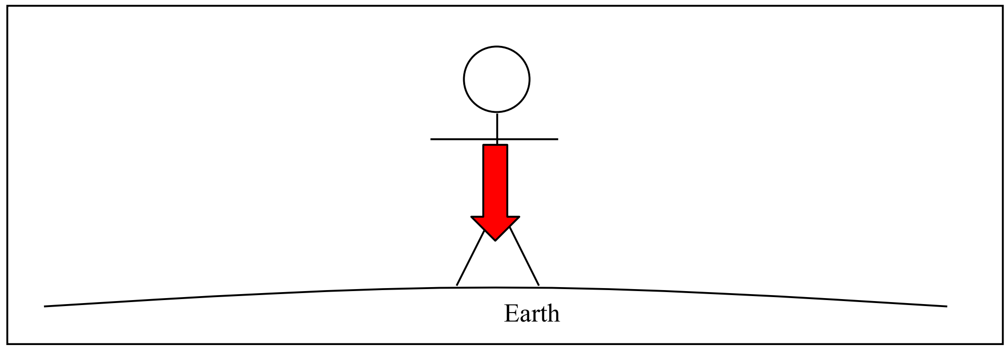

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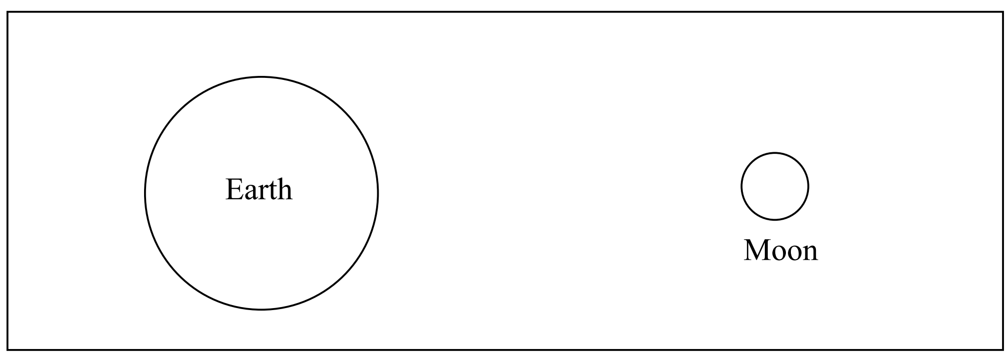

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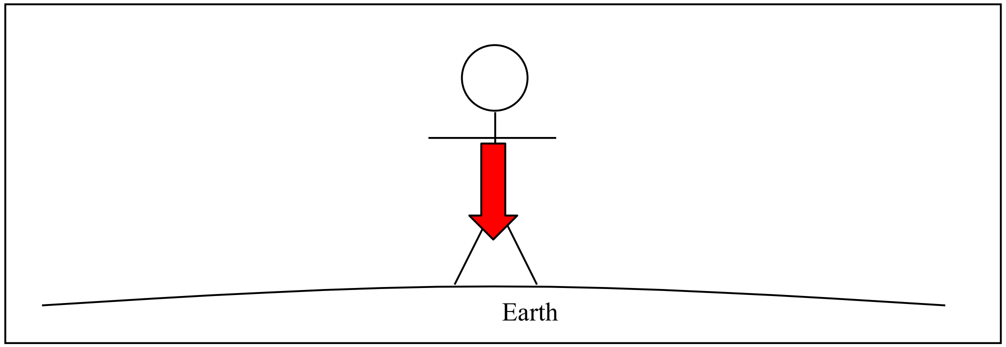

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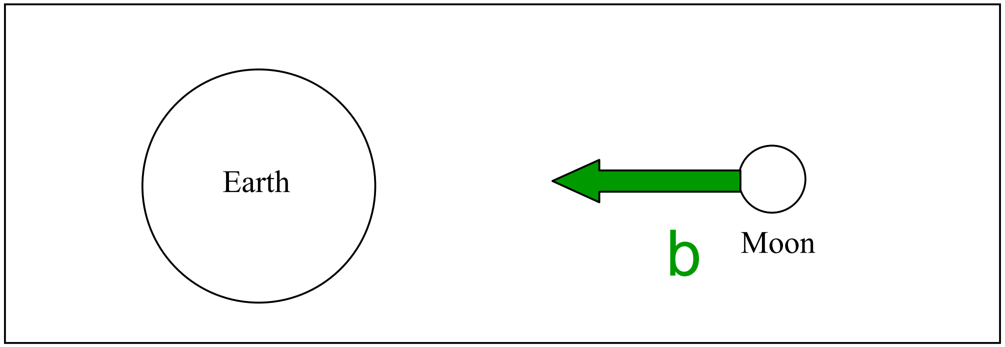

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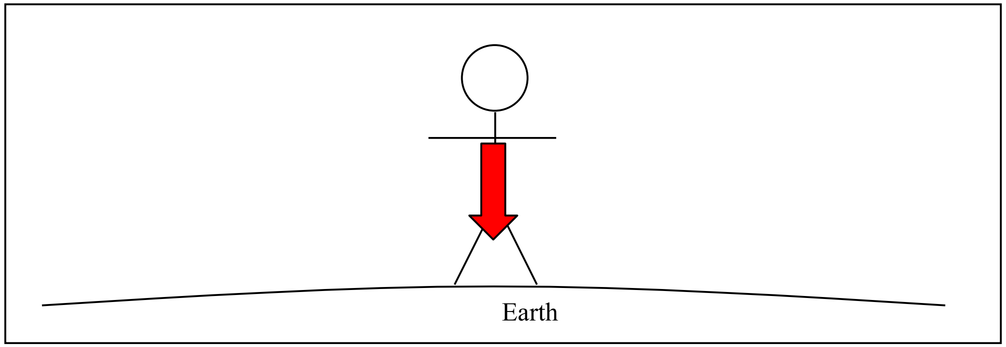

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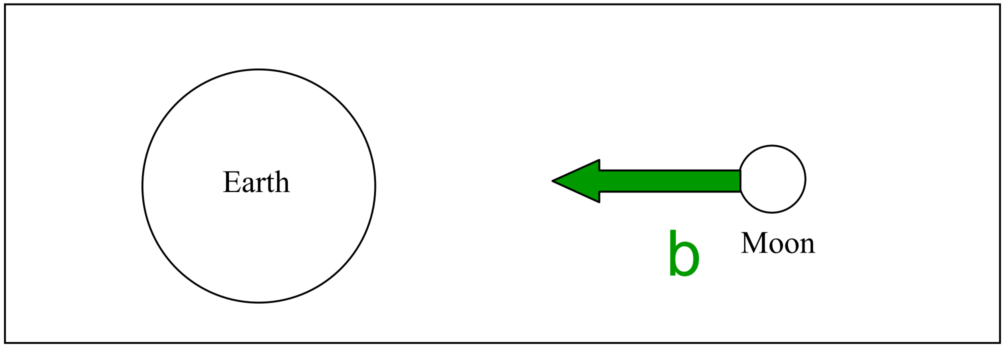

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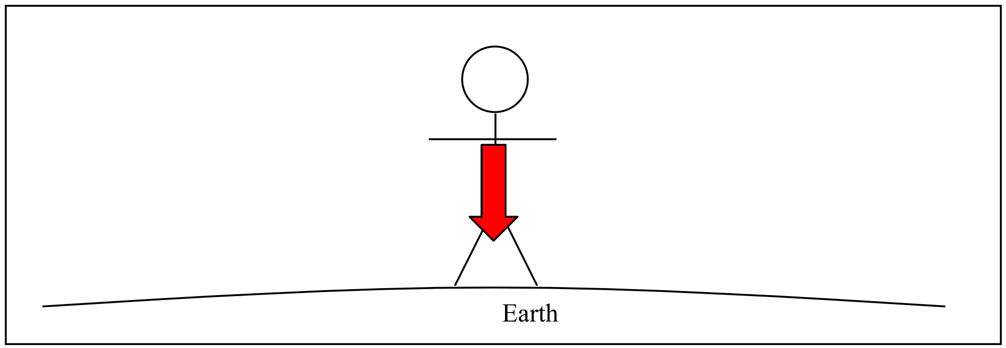

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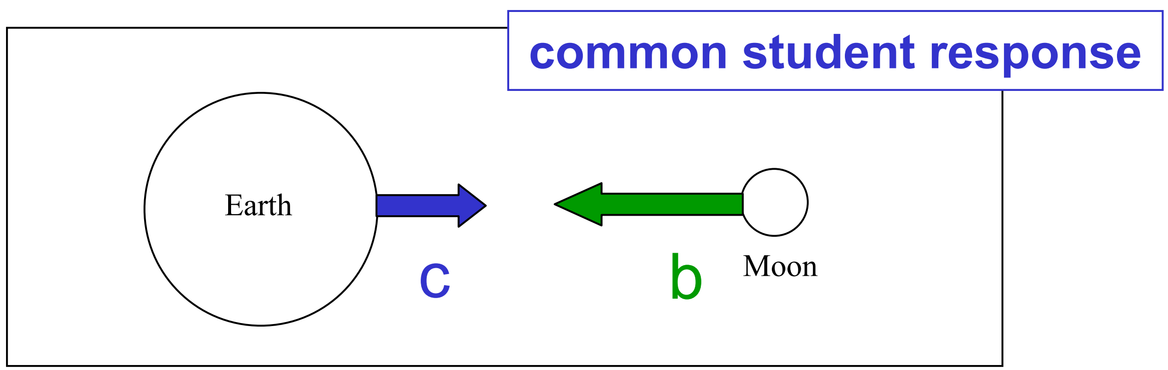

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f) Consider the magnitude of the gravitational force in (c). Write down an algebraic expression for the strength of the force. (Again, refer to Newton's Universal Law of Gravitation at the top of the previous page.) Use M_e for the mass of the Earth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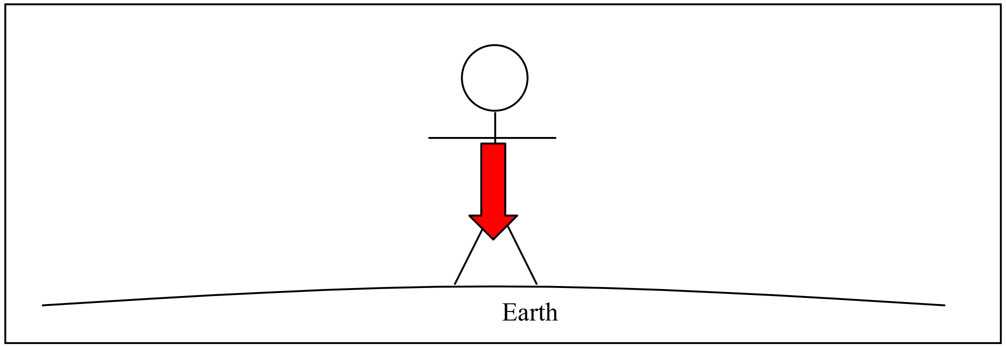

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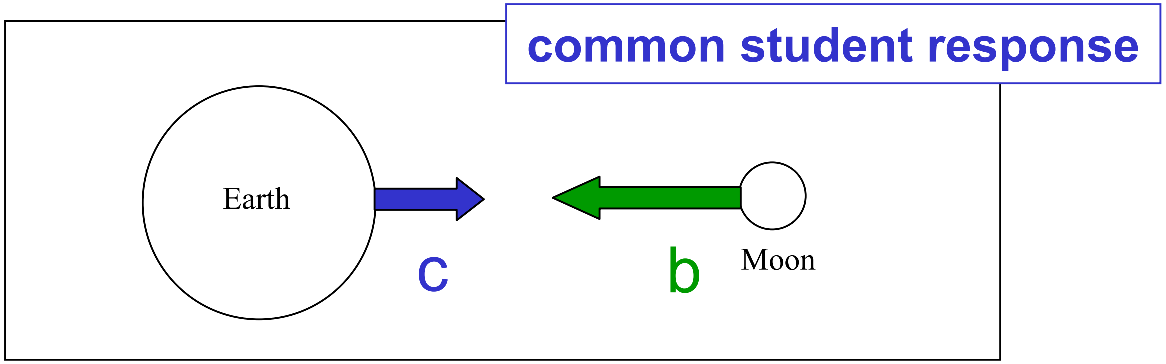

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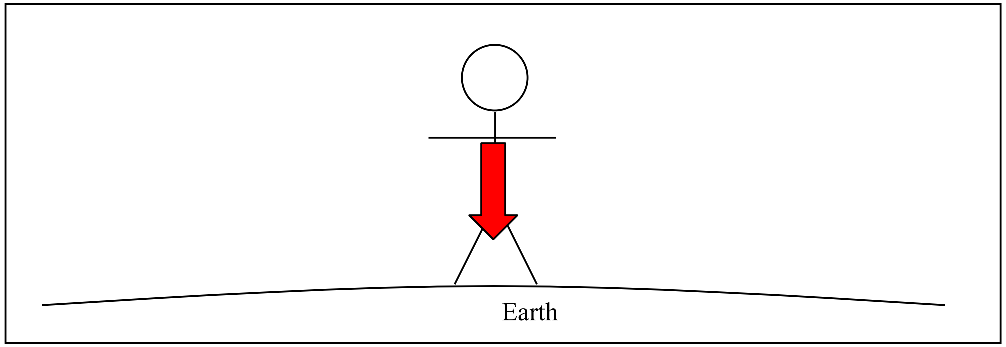

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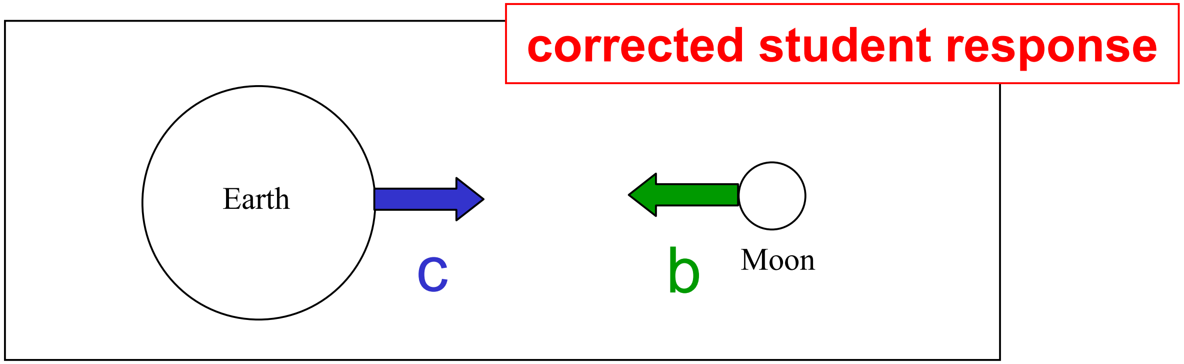

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Post-test Question (Newton's third law)

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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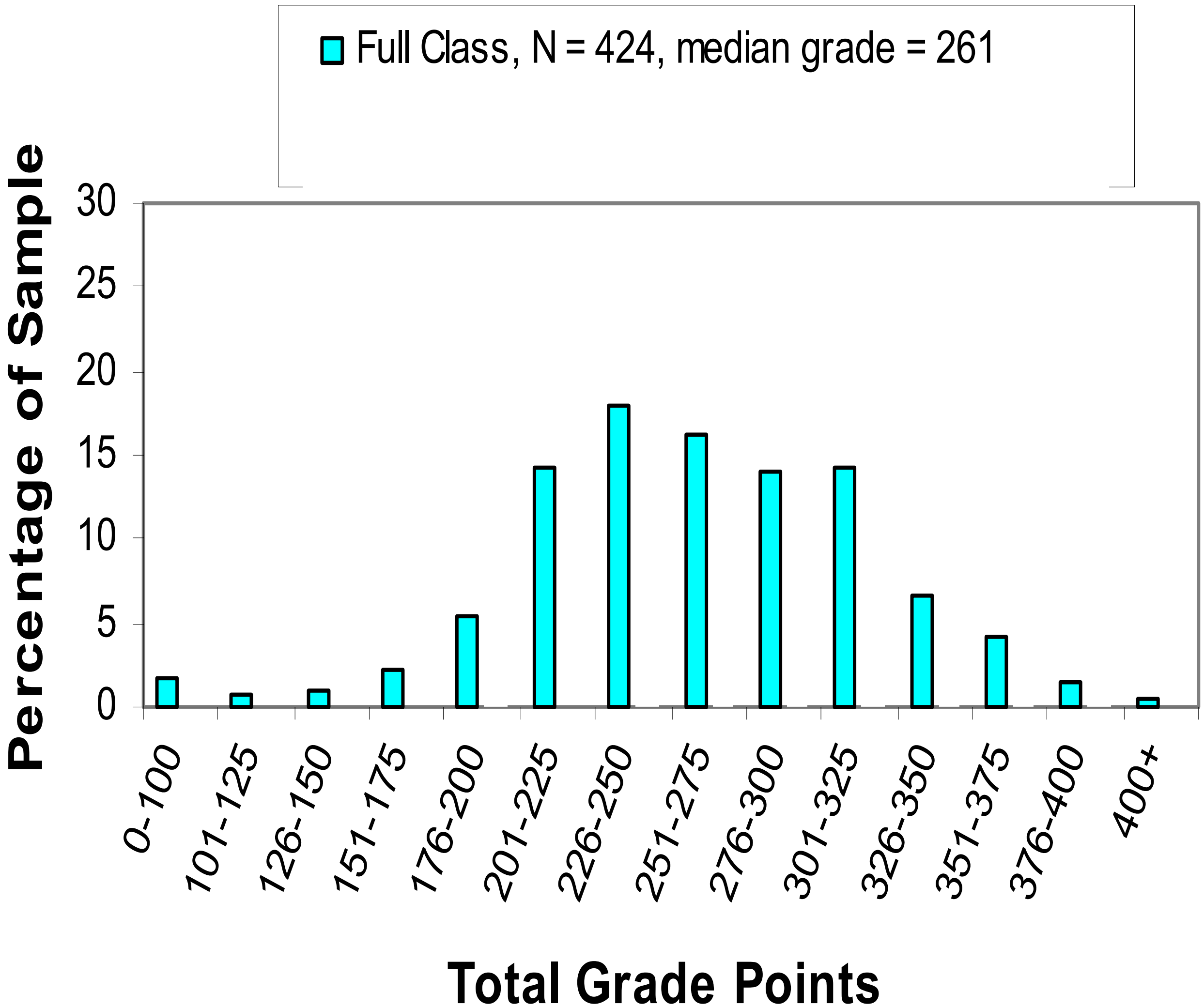
Research Basis for Curriculum Development

(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 $\geq$ 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*

Grade Distributions: Interview Sample vs. Full Class



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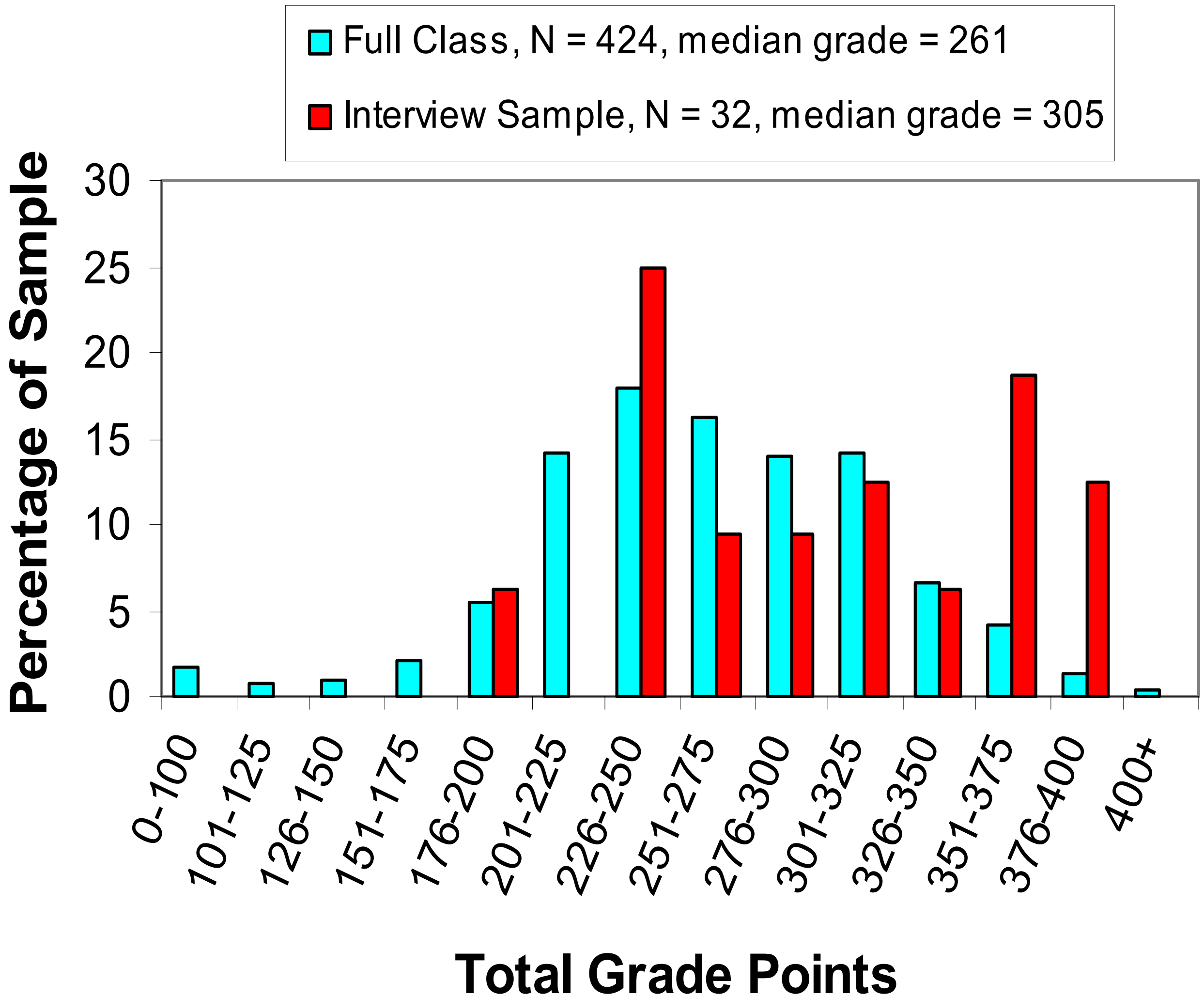

***Interview Sample*:**

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 transferred during a cyclic process are zero.
5. Inability to apply the first law of thermodynamics.

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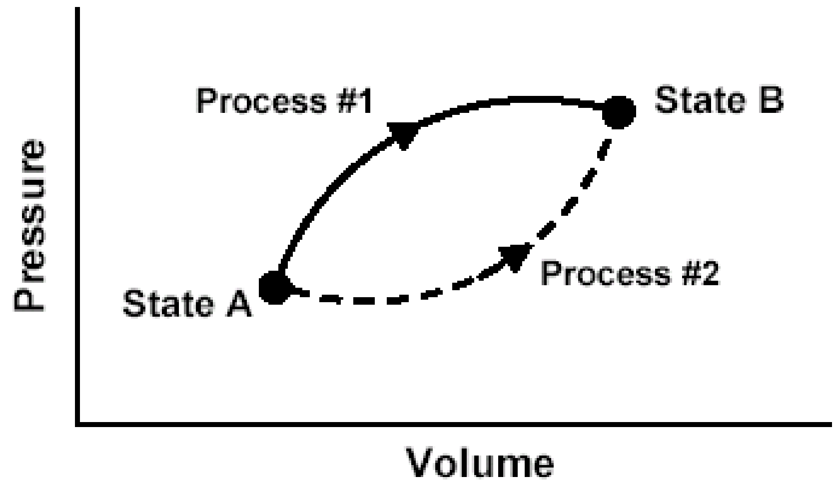
Understanding of Concept of State Function in the Context of Energy

- 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.]

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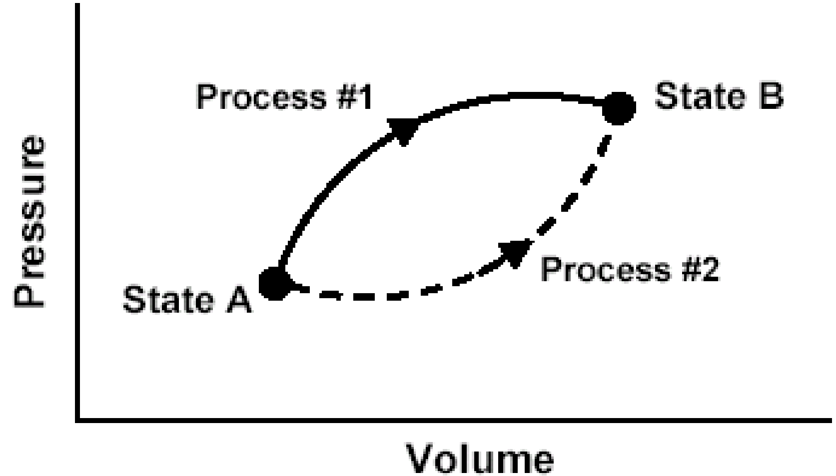

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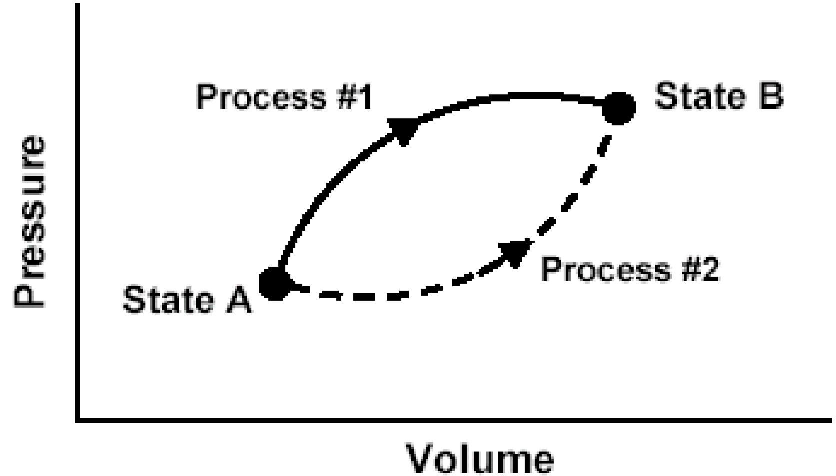

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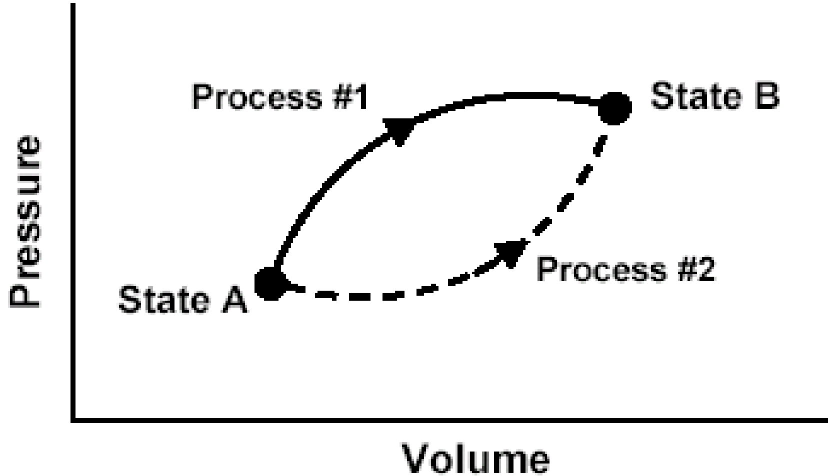

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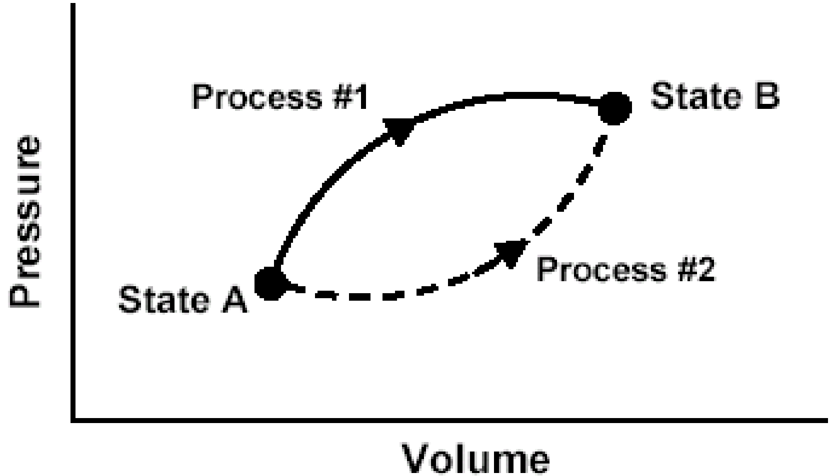

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Students seem to have adequate grasp of state-function concept in *this* context

- Consistently high percentage (70-90%) of correct responses on written question with good explanations.

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

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Predominant Themes of Students' Reasoning

1. Understanding of concept of state function in the context of energy.
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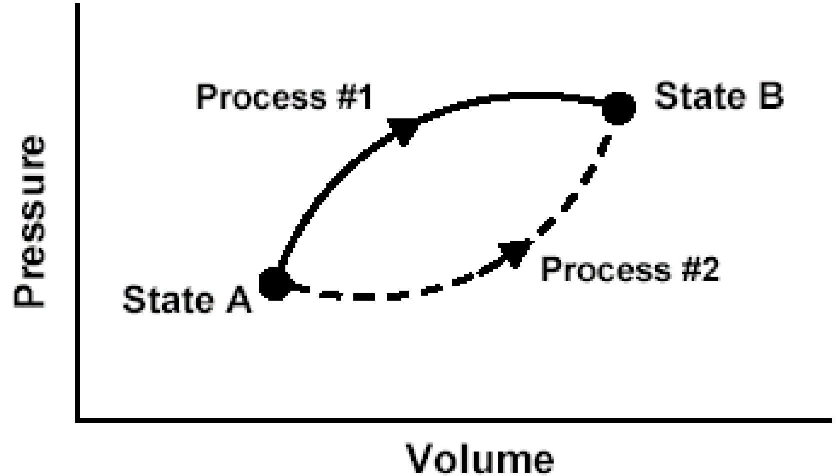

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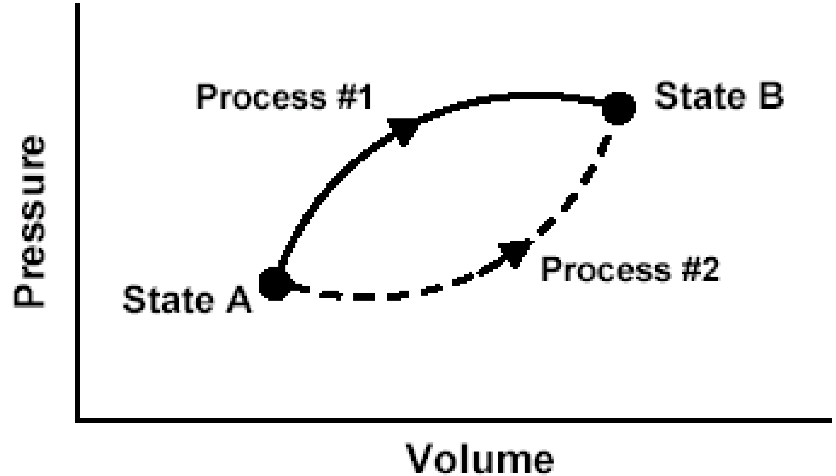

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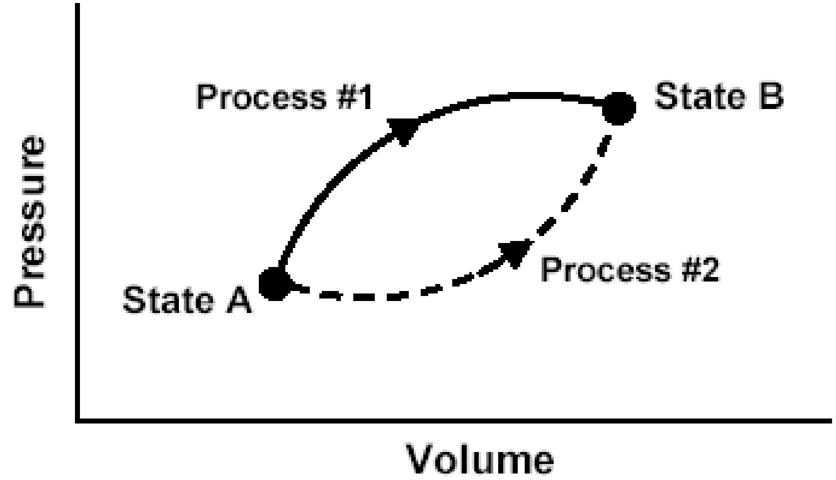

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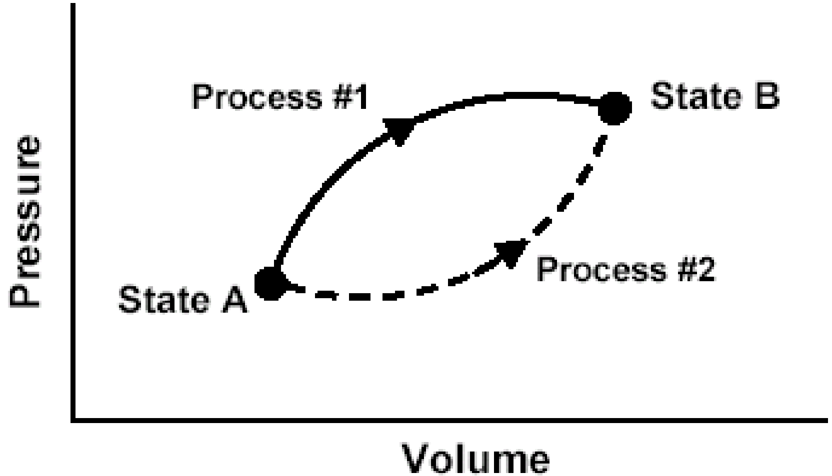

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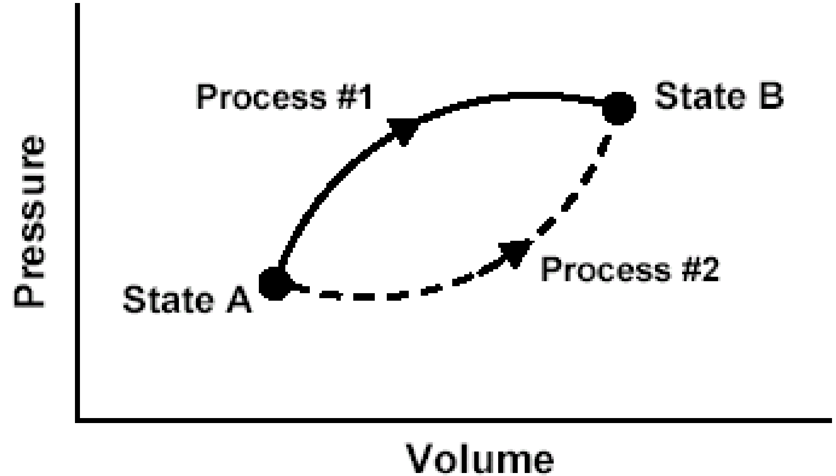

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(Work question)

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$W_1 > W_2$				
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$W_1 = W_2$	**25%**	**26%**	**35%**	**22%**
Because work is independent of path	*	14%	23%	22%
Other reason, or none	*	12%	13%	0%

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

- "*Work is a state function*."
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Confusion with mechanical work done by conservative forces?

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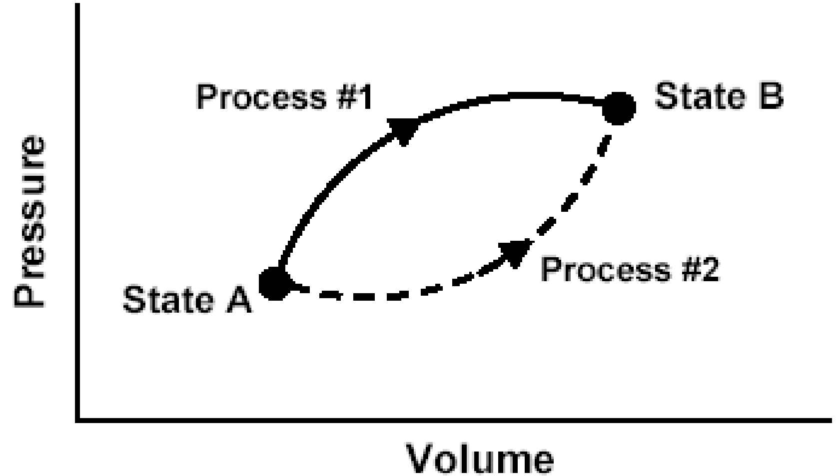

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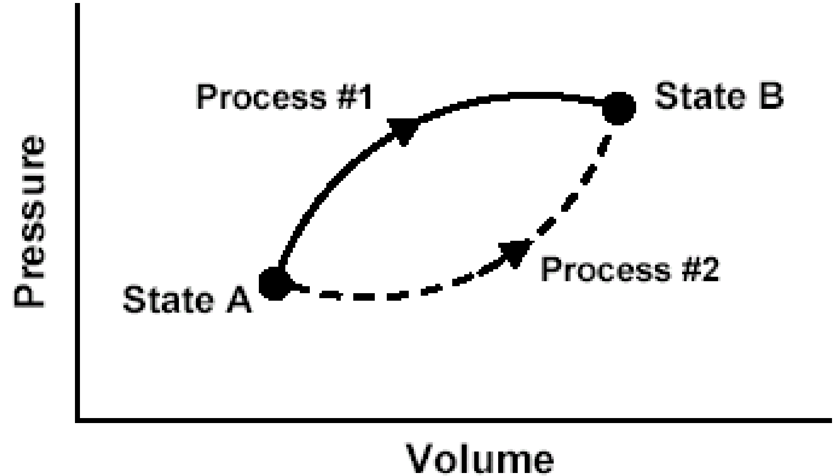

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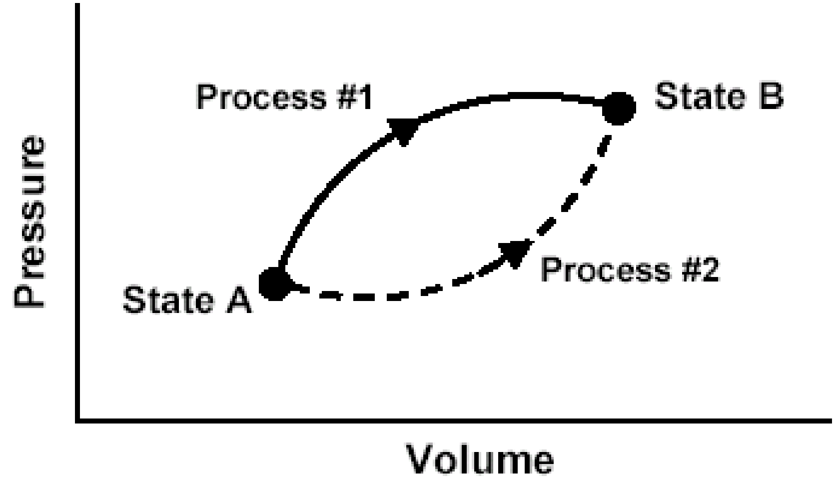
Change in internal energy is the same for Process #1 and Process #2.



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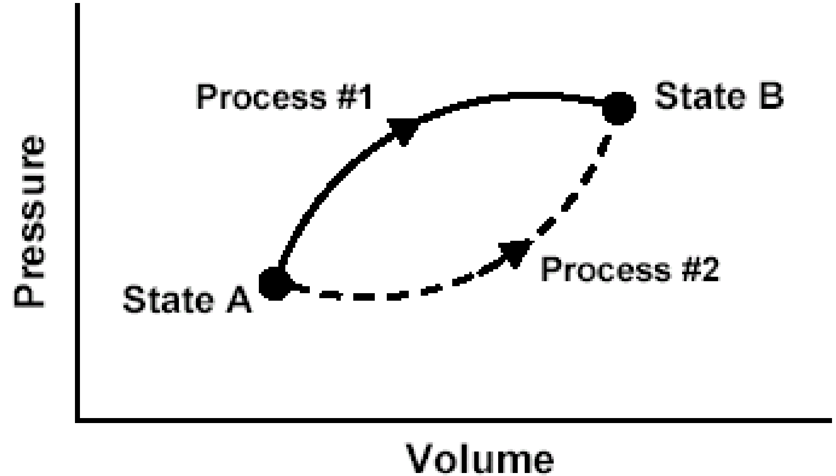

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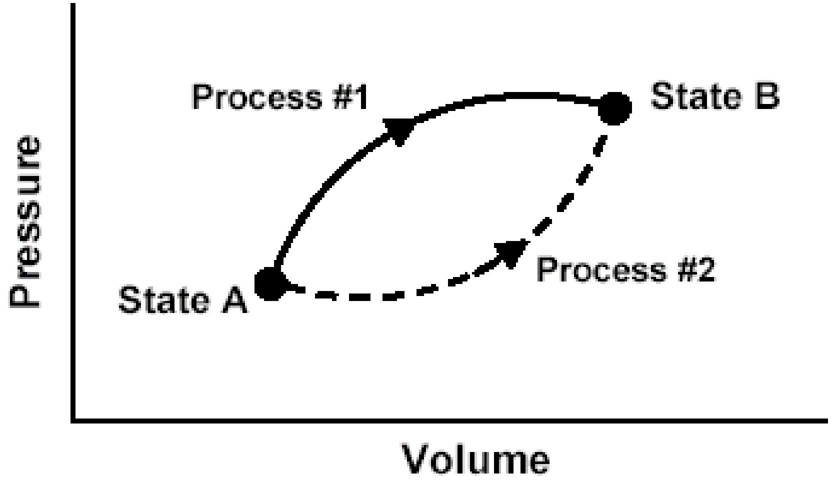

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Responses to Diagnostic Question #2
(Heat question)

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$Q_1 > Q_2$				
$Q_1 = Q_2$				
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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)
$Q_1 = Q_2$	**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*."

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Research Basis for Curriculum Development

(NSF CCLI Project with T. Greenbowe)

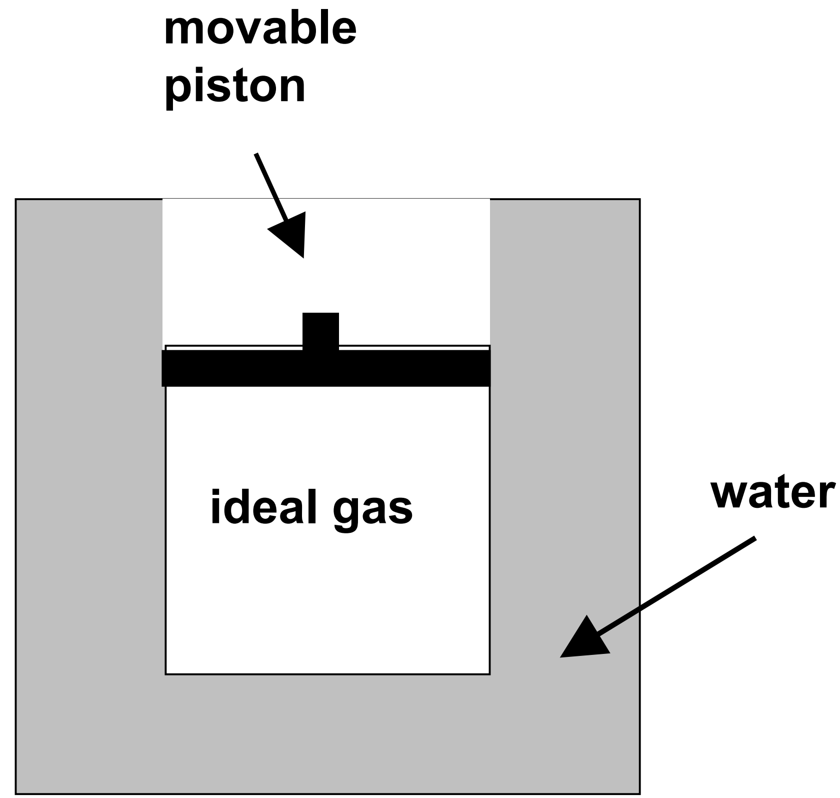
- Investigation of second-semester calculus-based physics course (mostly engineering students).
- Written diagnostic questions administered last week of class in 1999, 2000, and 2001 (N_{total} = 653).
- Detailed interviews (avg. duration $\geq$ one hour) carried out with 32 volunteers during 2002 (total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

Interview Questions

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

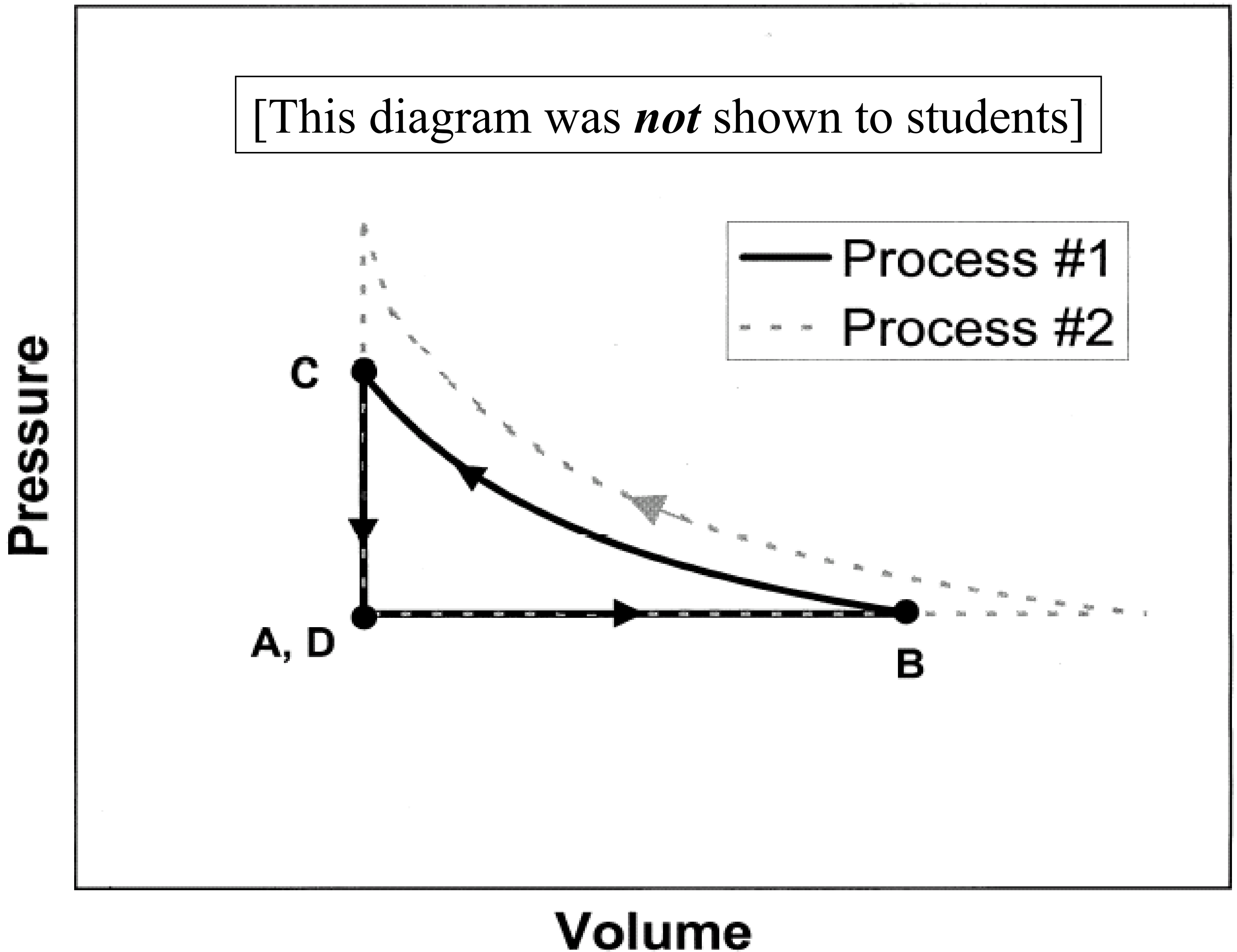
The cylinder is surrounded by a large container of water with high walls as shown. We are going to describe two separate processes, Process #1 and Process #2.

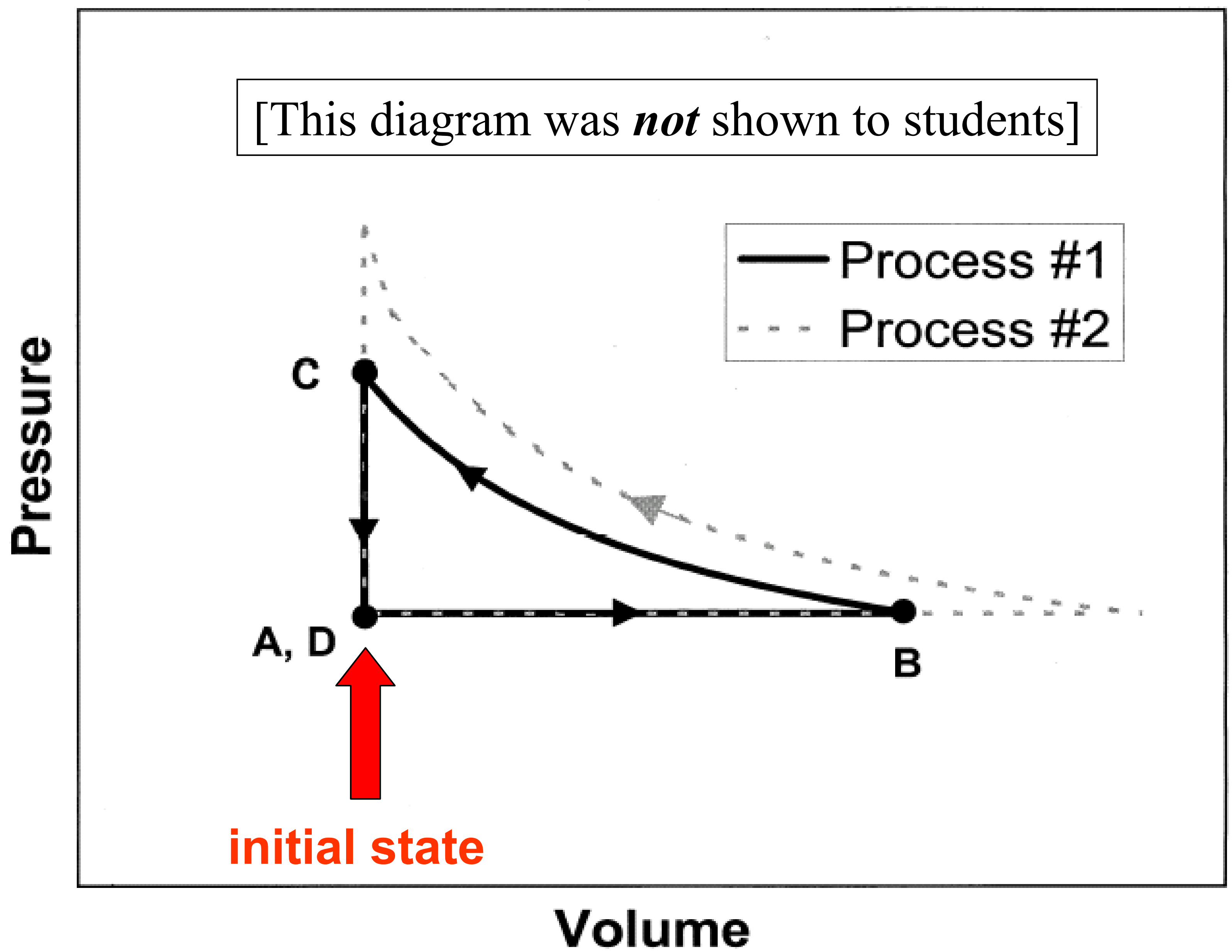
At initial time *A*, the gas, cylinder, and water have all been sitting in a room for a long period of time, and all of them are at room temperature



Time *A*

Entire system at room temperature.


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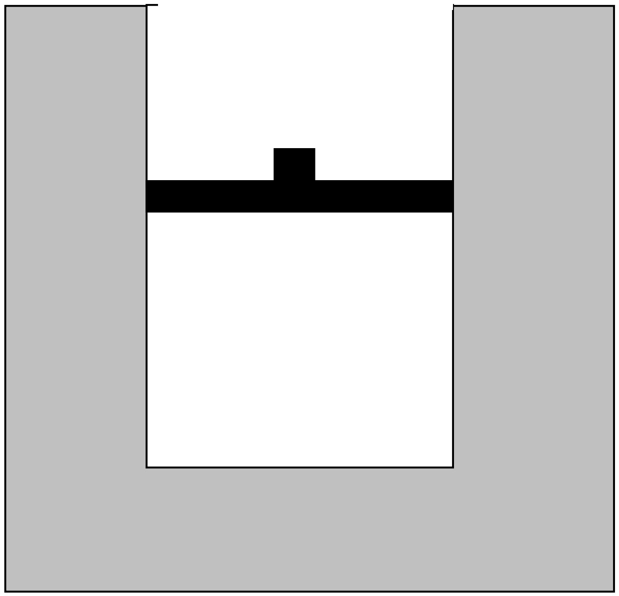
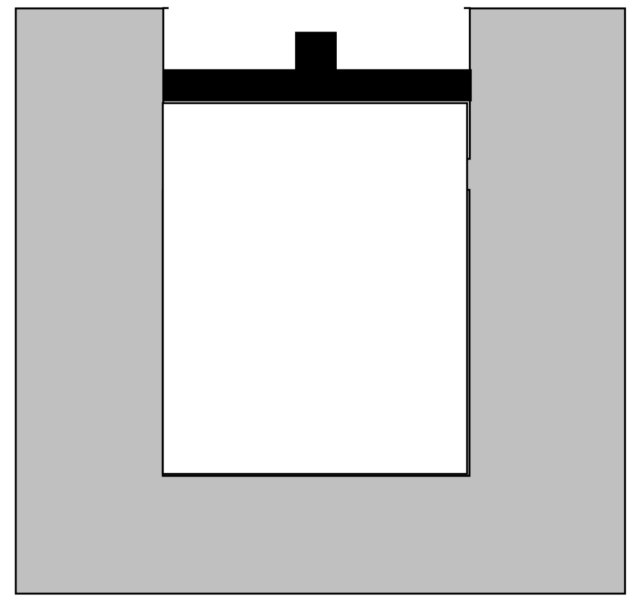
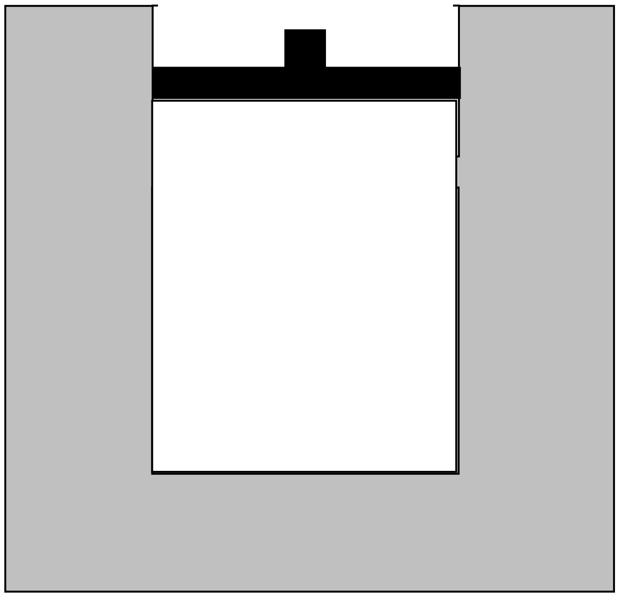
Process #1
Process #2
C
A, D
B
initial state
Pressure
Volume

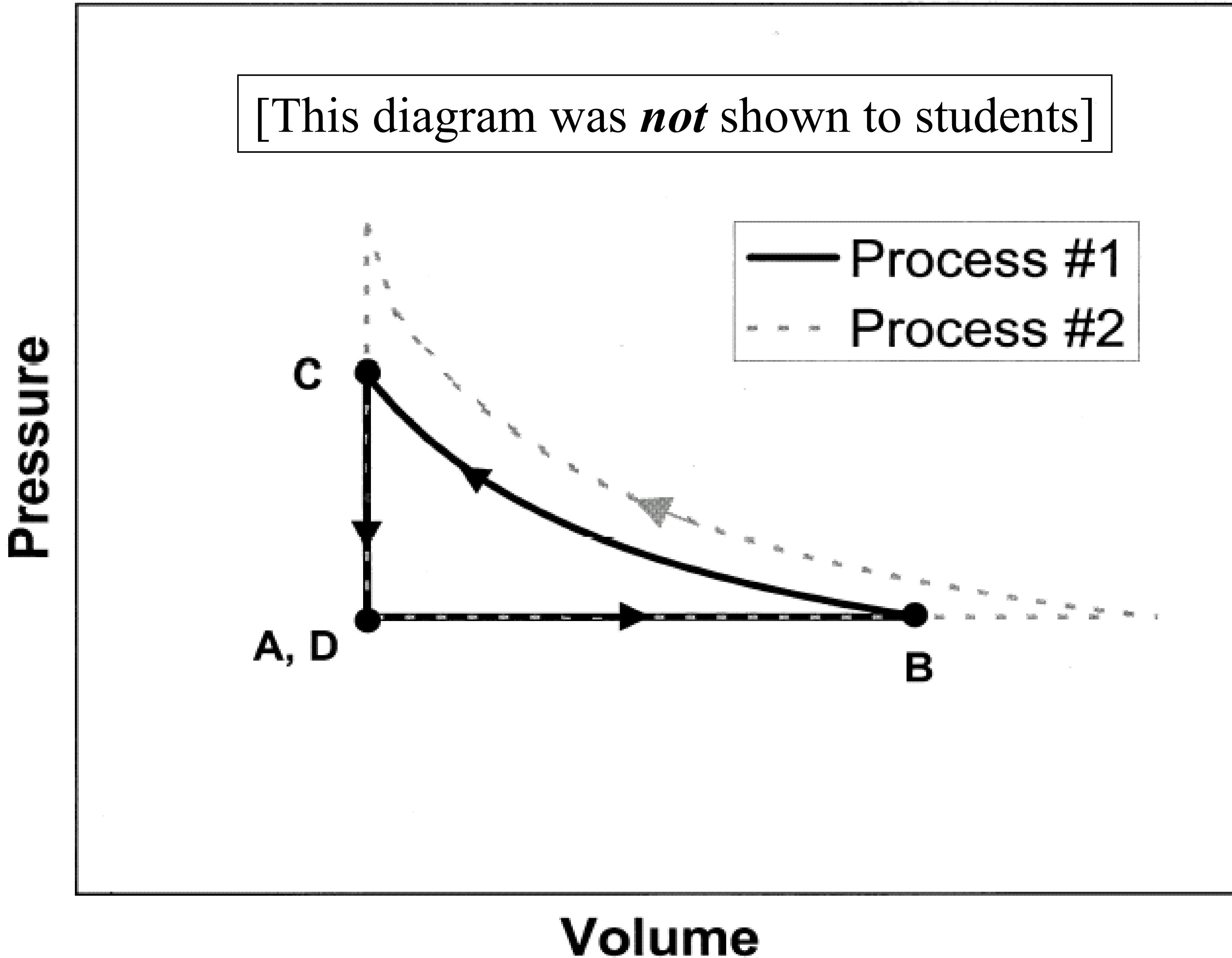
Beginning at time *A*, the water container is gradually heated, and the piston *very slowly* moves upward.





At time ***B*** the heating of the water stops, and the piston stops moving

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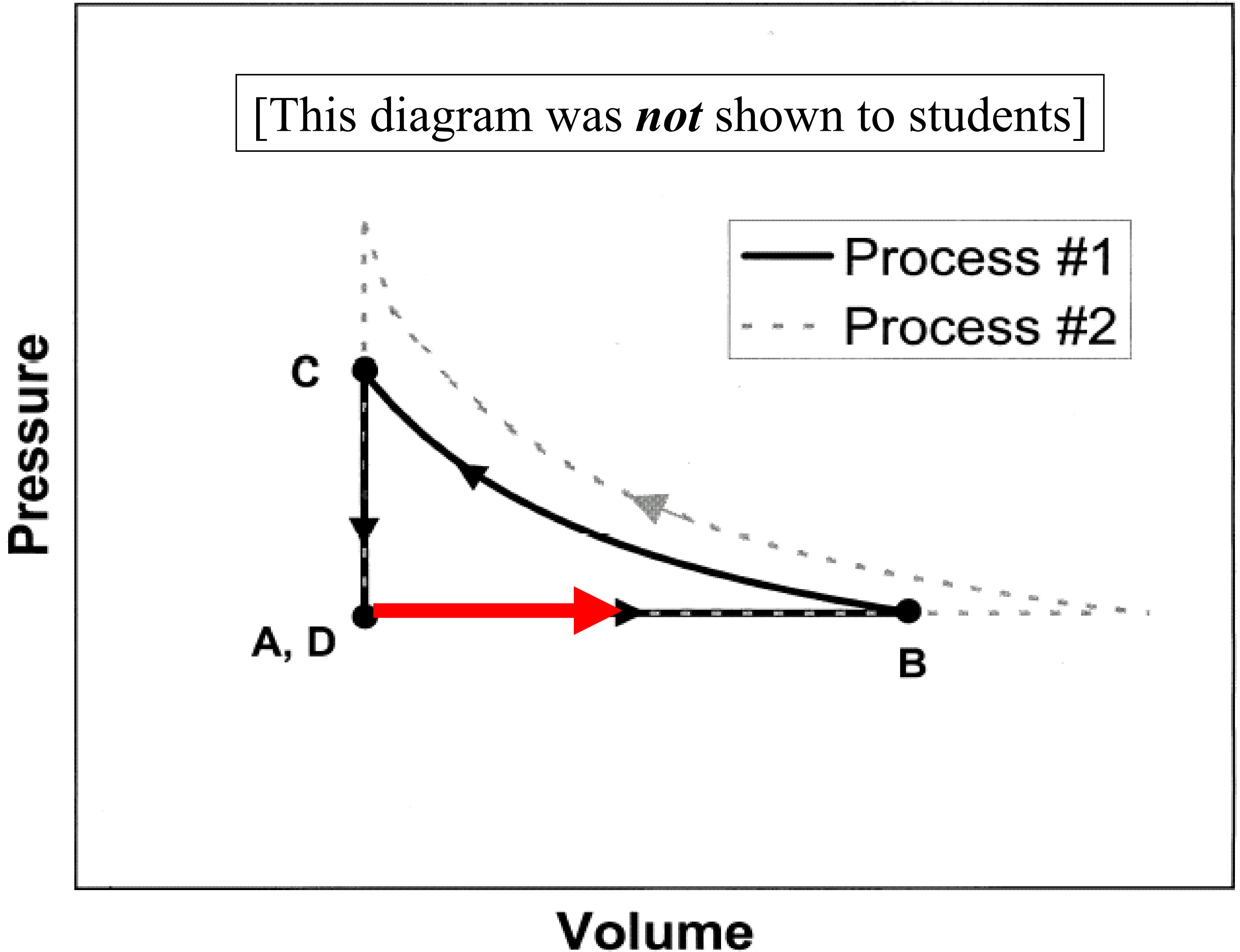
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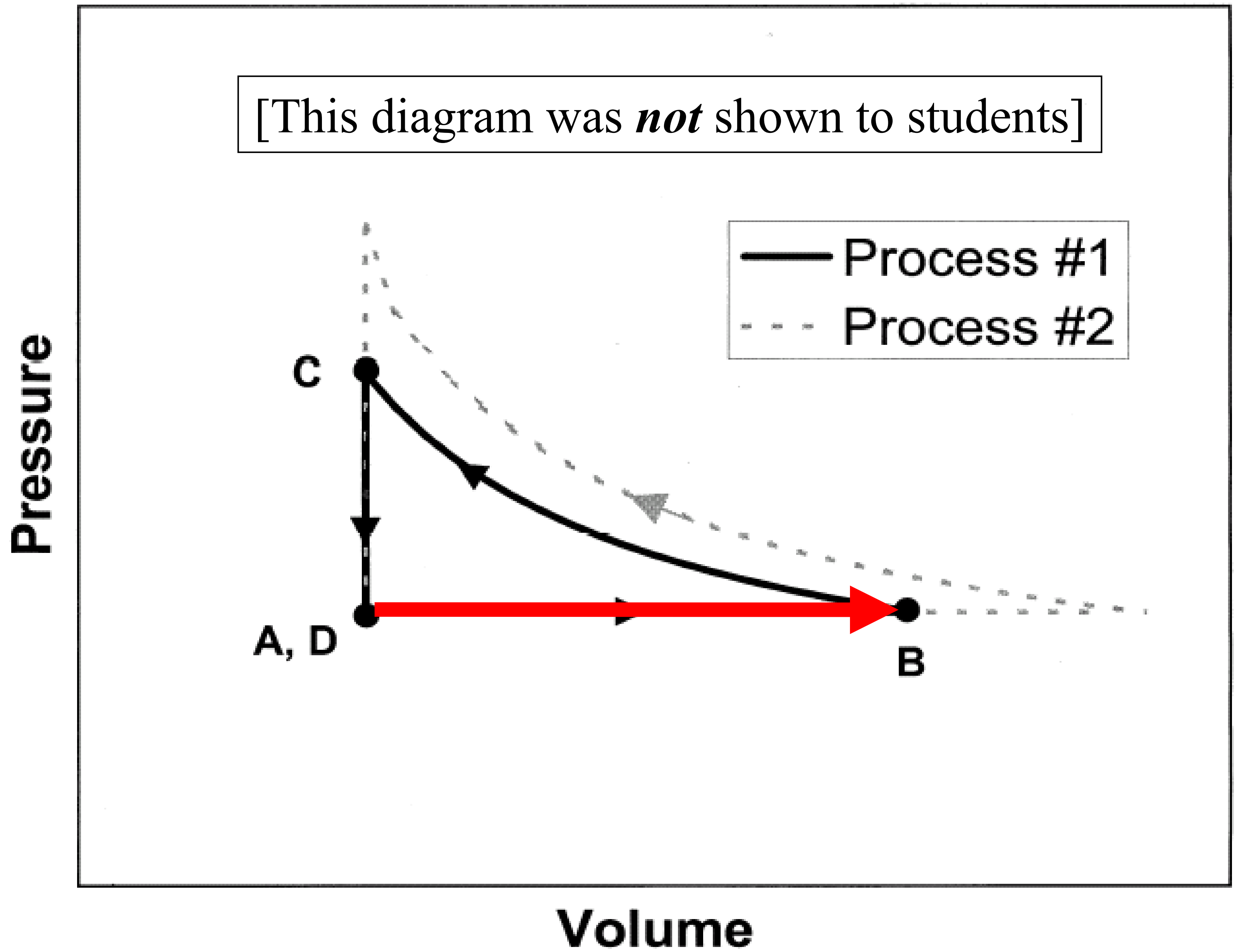

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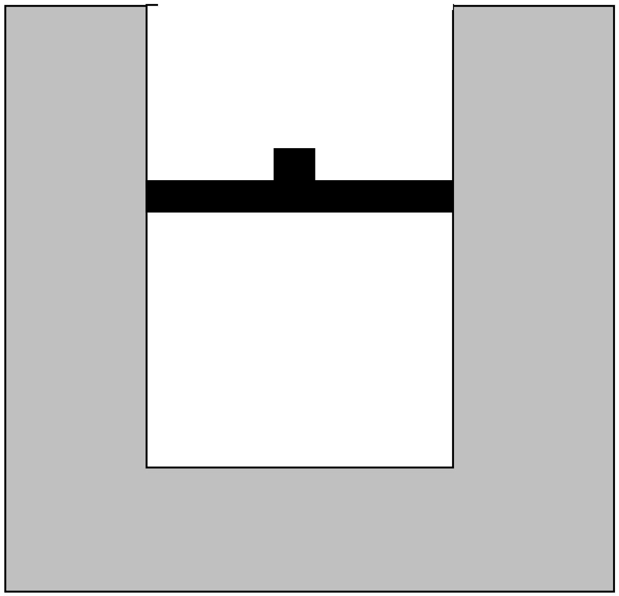

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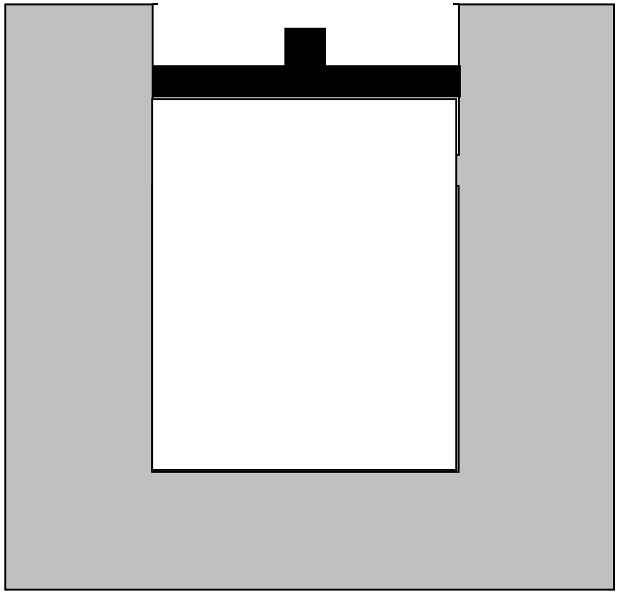

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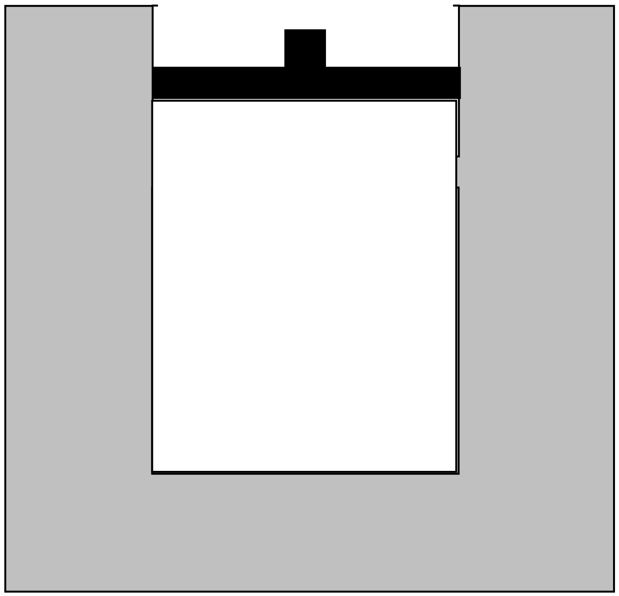

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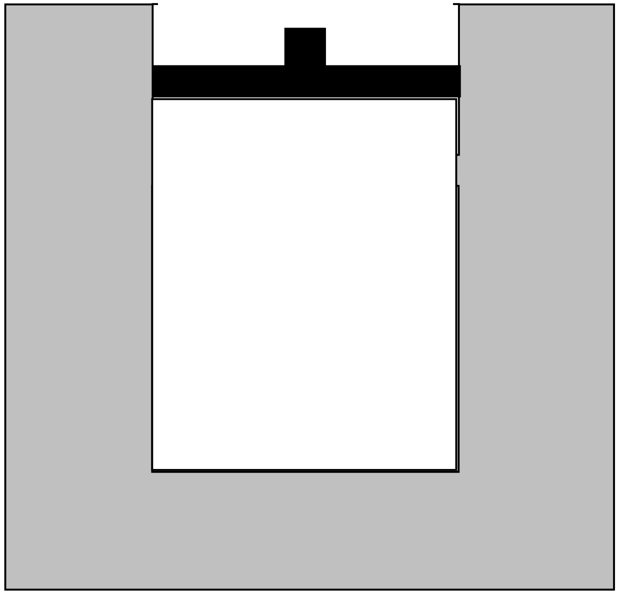

Question #1: During the process that occurs from time *A* to time *B*, which of the following is true: (a) positive work is done *on* the gas *by* the environment, **(b) positive work is done *by* the gas *on* the environment,** (c) no *net* work is done on or by the gas.

Results on Question #1

(a) positive work done *on* gas *by* environment:
31%

(b) positive work done *by* gas *on* environment *[correct]:*
69%

Results on Question #1

(a) positive work done *on* gas *by* environment:
31%

(b) positive work done *by* gas *on* environment *[correct]:*
69%

Sample explanations for (a) answer:

Results on Question #1

(a) positive work done *on* gas *by* environment:
31%

(b) positive work done *by* gas *on* environment *[correct]:*
69%

Sample explanations for (a) answer:

"The water transferred heat to the gas and expanded it, so work was being done to the gas to expand it."

"The environment did work on the gas, since it made the gas expand and the piston moved up . . . water was heating up, doing work on the gas, making it expand."

Results on Question #1

(a) positive work done *on* gas *by* environment:
31%

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69%

Sample explanations for (a) answer:

"The water transferred heat to the gas and expanded it, so work was being done to the gas to expand it."

"The environment did work on the gas, since it made the gas expand and the piston moved up . . . water was heating up, doing work on the gas, making it expand."

Many students employ the term "work" to describe a heating process.

Results on Question #1

(a) positive work done *on* gas *by* environment:
31%

(b) positive work done *by* gas *on* environment *[correct]:*
69%

Sample explanations for (a) answer:

"The water transferred heat to the gas and expanded it, so work was being done to the gas to expand it."

"The environment did work on the gas, since it made the gas expand and the piston moved up . . . water was heating up, doing work on the gas, making it expand."

Nearly one third of the interview sample believe that environment does positive work **on** *gas during expansion.*

Results on Question #1

(a) positive work done *on* gas *by* environment:
31%

(b) positive work done *by* gas *on* environment *[correct]:*
69%

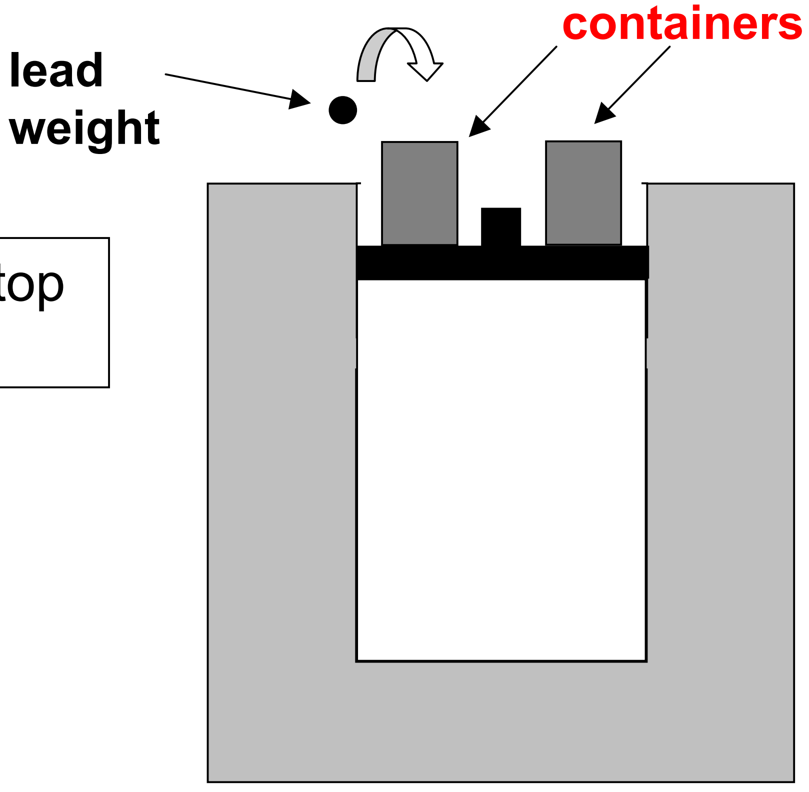
Sample explanations for (a) answer:

"The water transferred heat to the gas and expanded it, so work was being done to the gas to expand it."

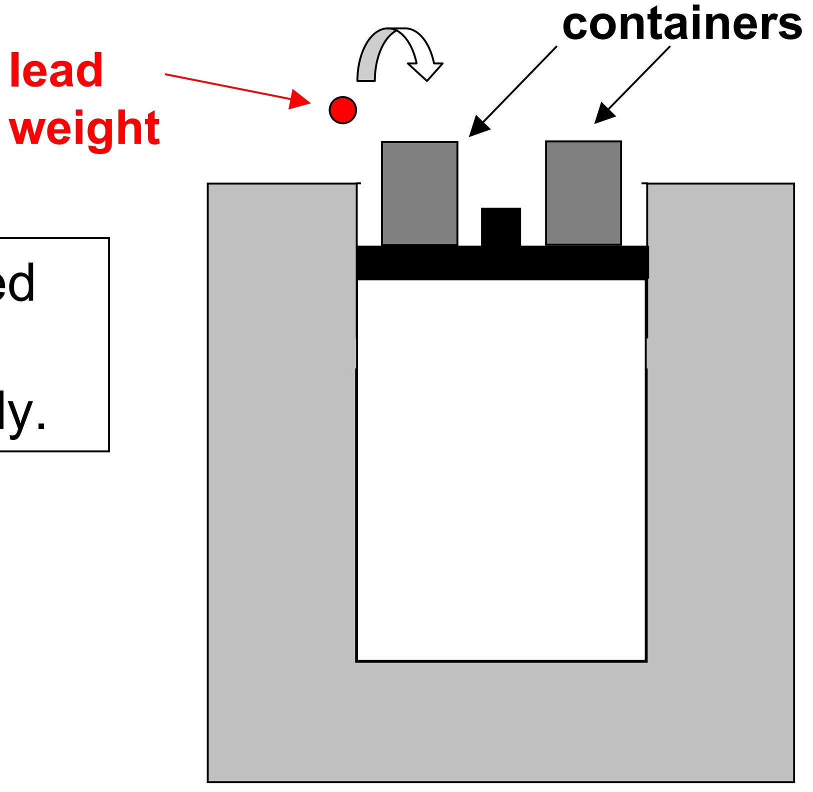
"The environment did work on the gas, since it made the gas expand and the piston moved up . . . water was heating up, doing work on the gas, making it expand."

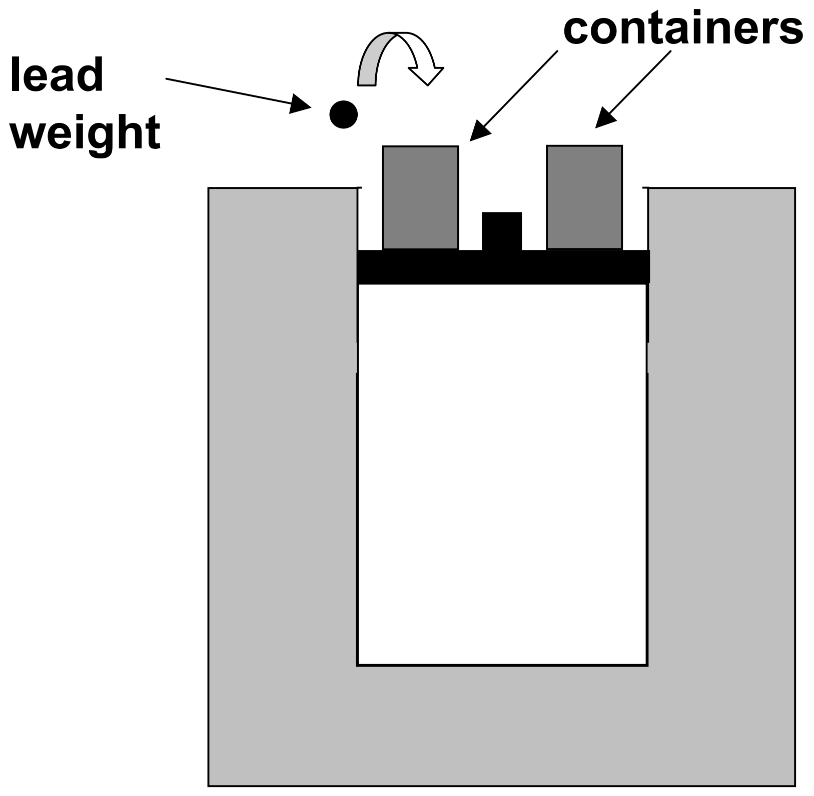
Additional questions showed that half the sample did not realize that some energy was transferred away from gas due to expansion.

Now, empty containers are placed on top of the piston as shown.

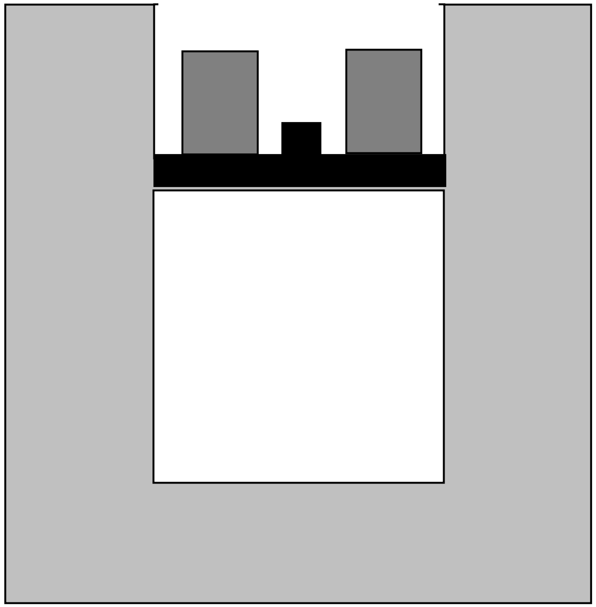


Small lead weights are gradually placed in the containers, one by one, and the piston is observed to move down slowly.

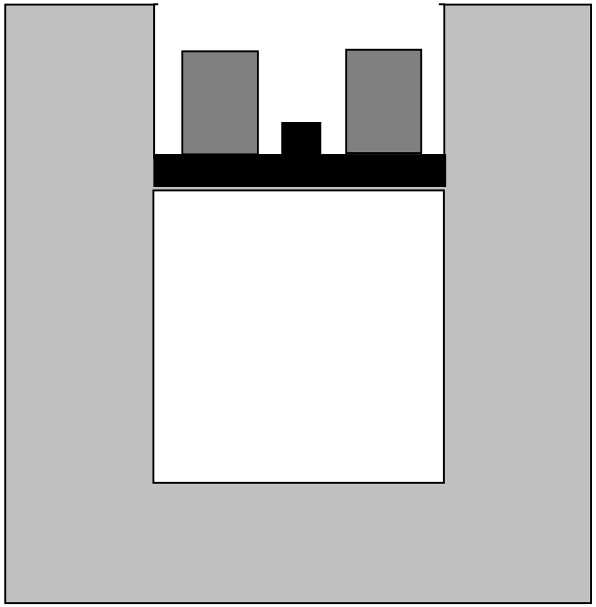




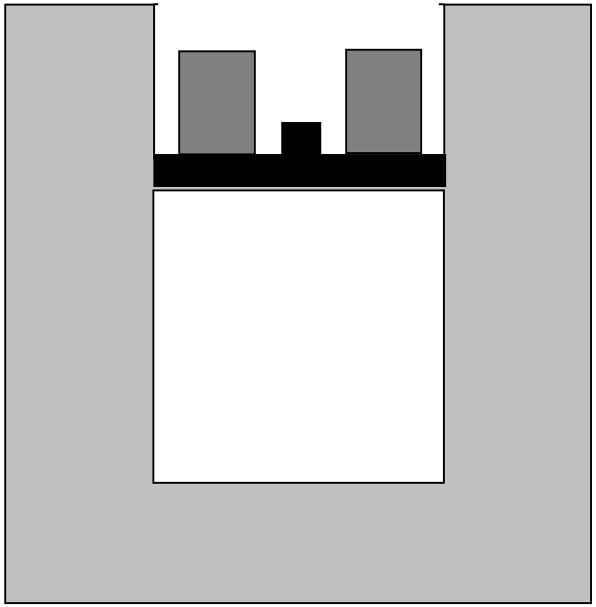
lead
weight
containers



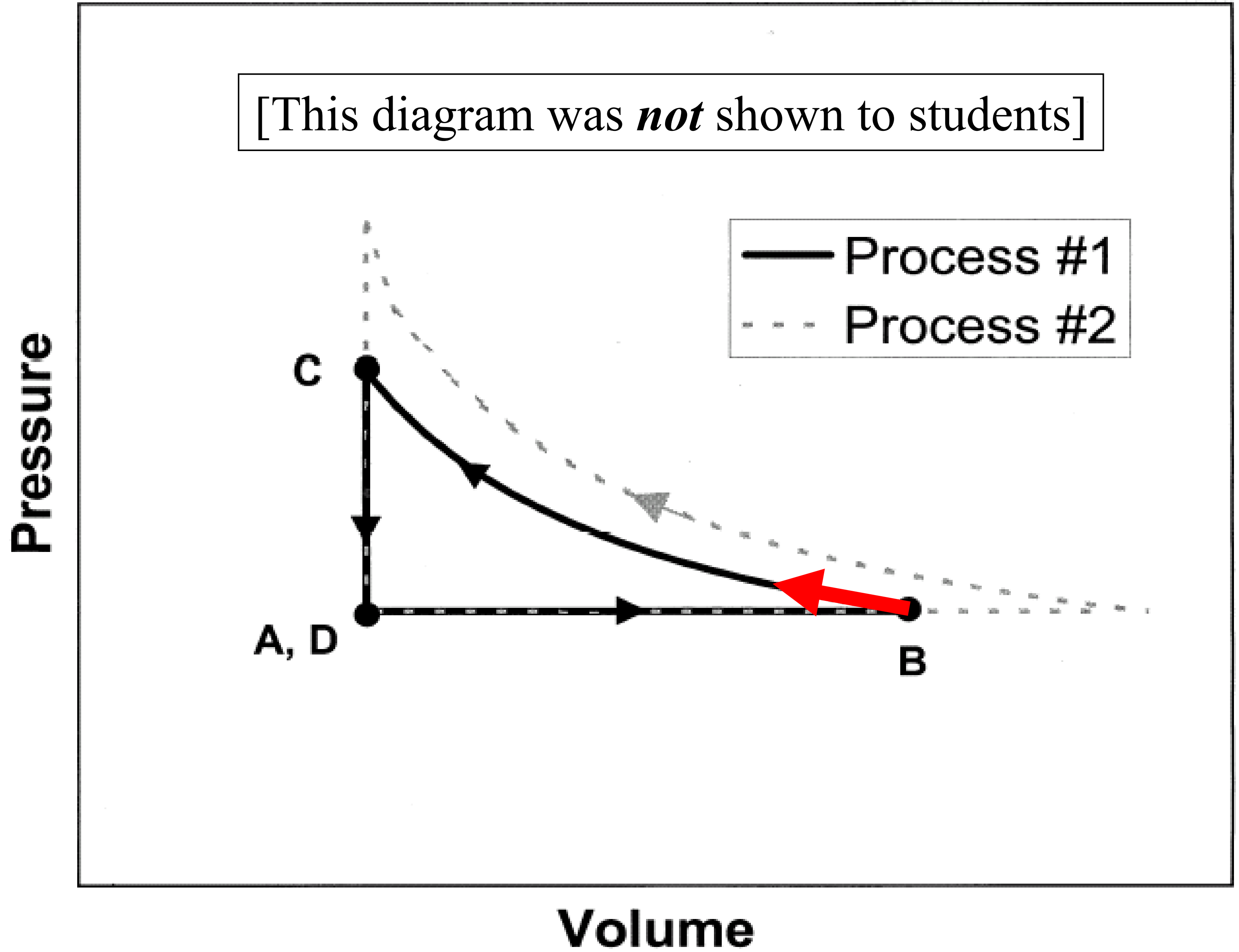
While this happens the temperature of the water is nearly unchanged, and the gas temperature remains practically *constant*.

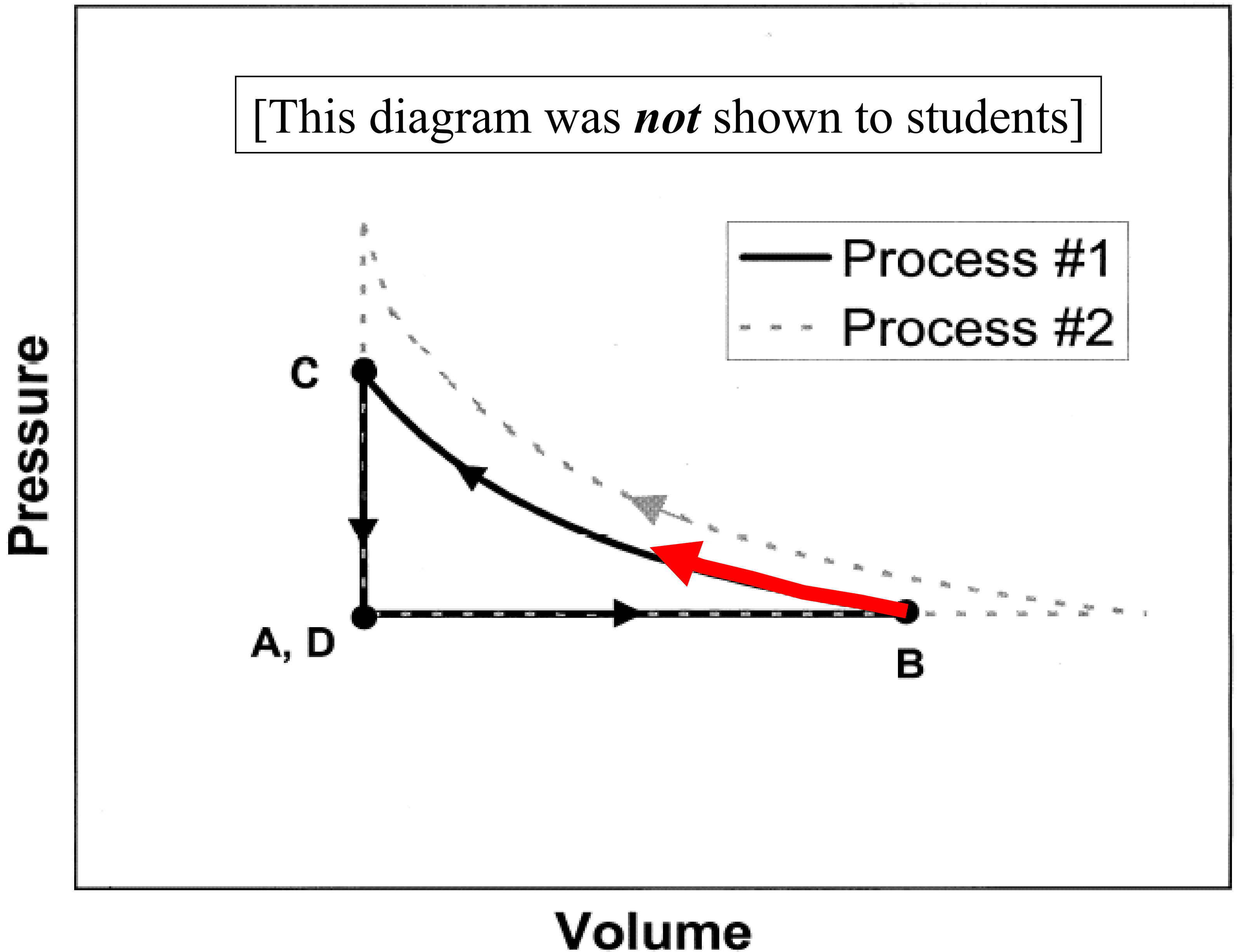


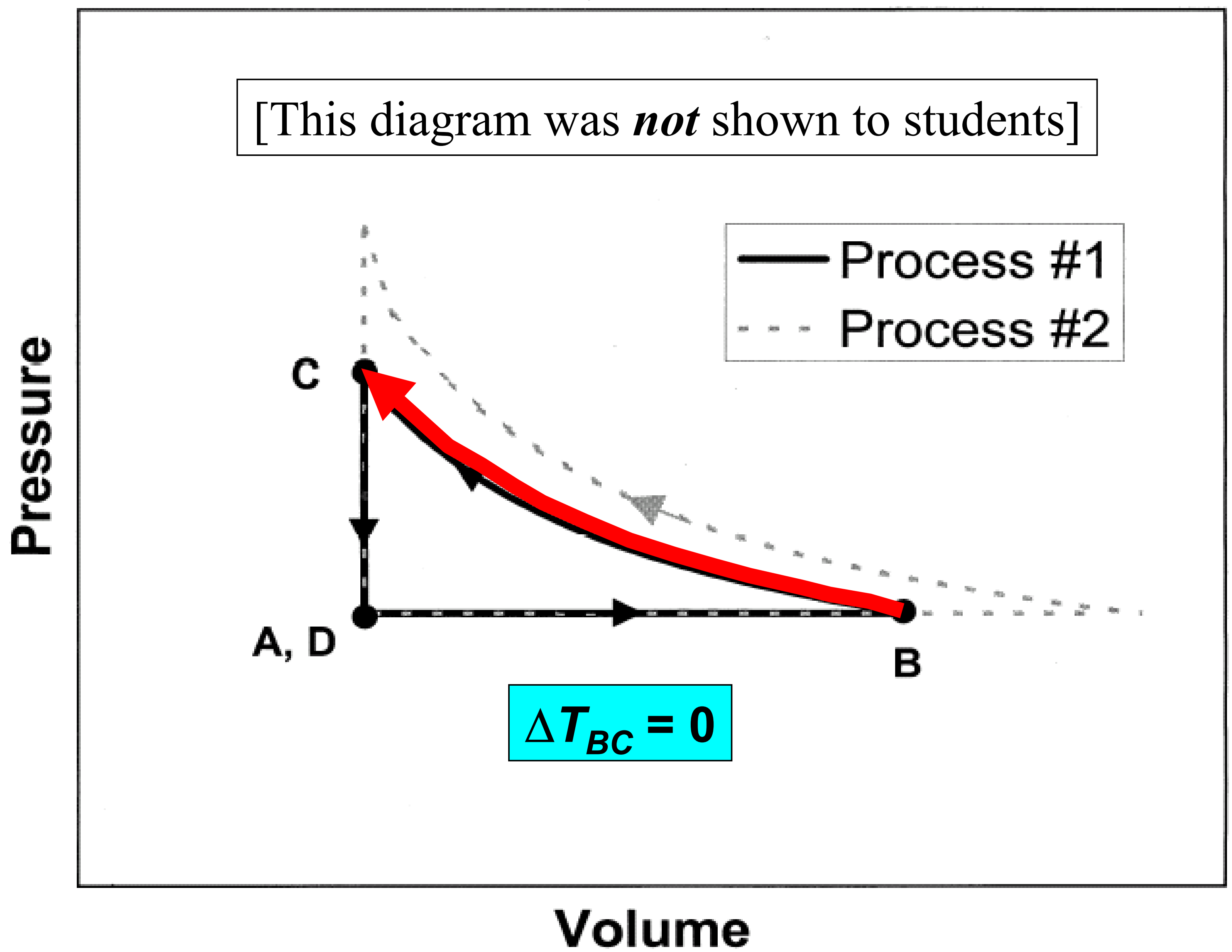
At time ***C*** we stop adding lead weights to the container and the piston stops moving. The piston is now at exactly the same position it was at time ***A*** .



[This diagram was ***not*** shown to students]

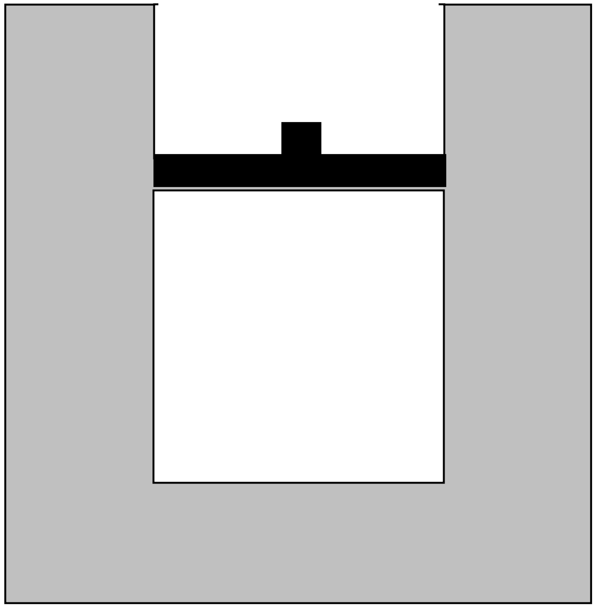



[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
Pressure
Volume

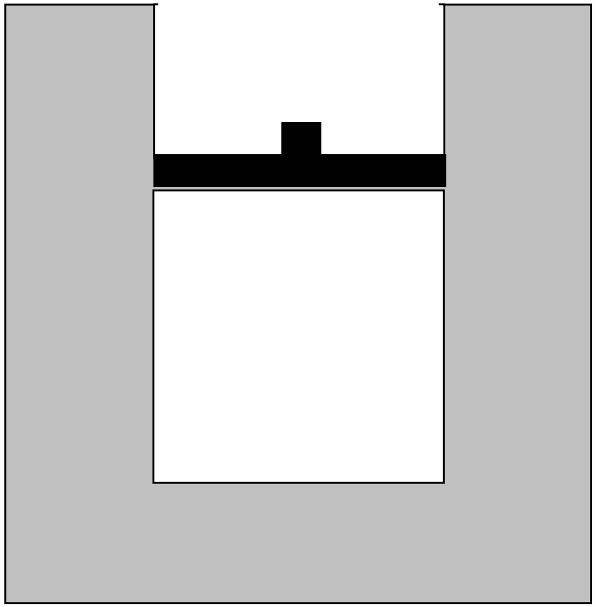


[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
$\Delta T_{BC} = 0$
Pressure
Volume

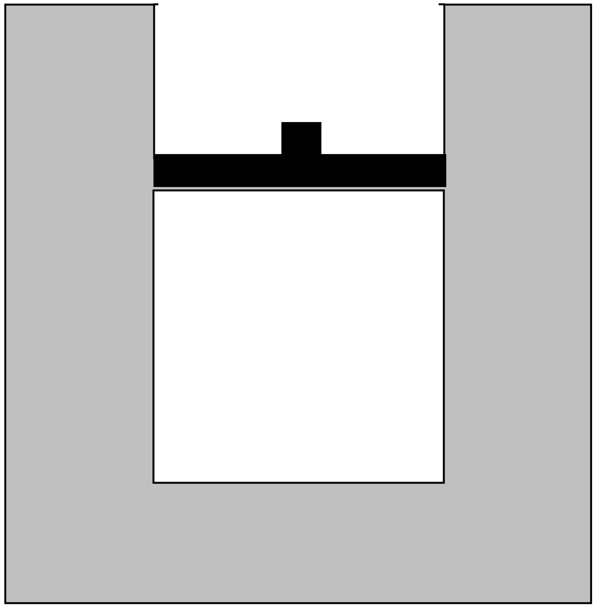
Now, the piston is locked into place so it *cannot move*, and the weights are removed from the piston.



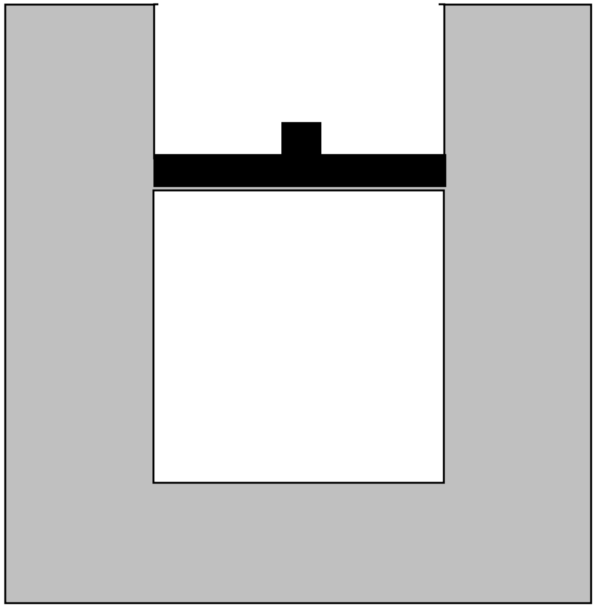
The system is left to sit in the room for many hours.

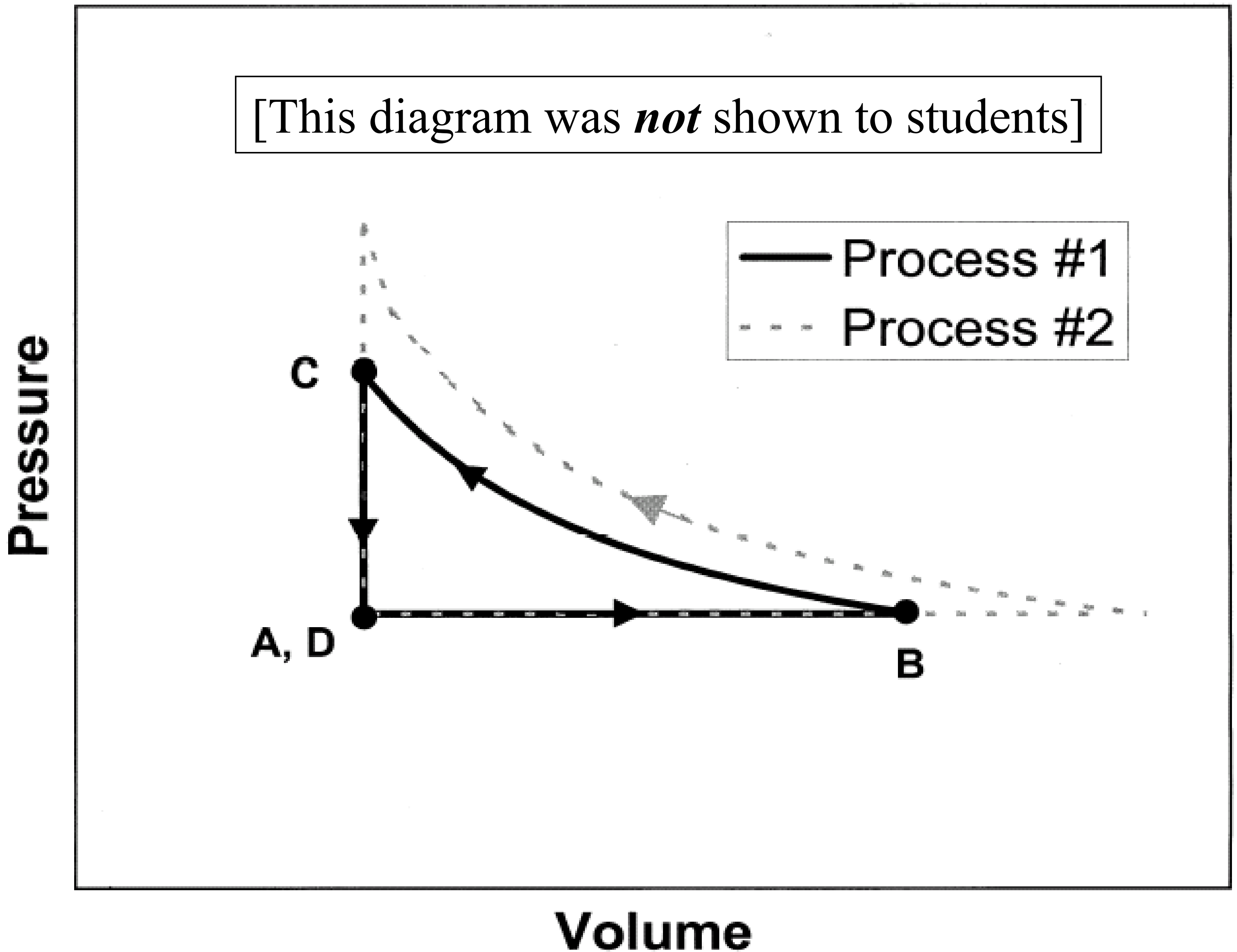


Eventually the entire system cools back down to the same room temperature it had at time ***A***.



After cooling is complete, it is time ***D.***

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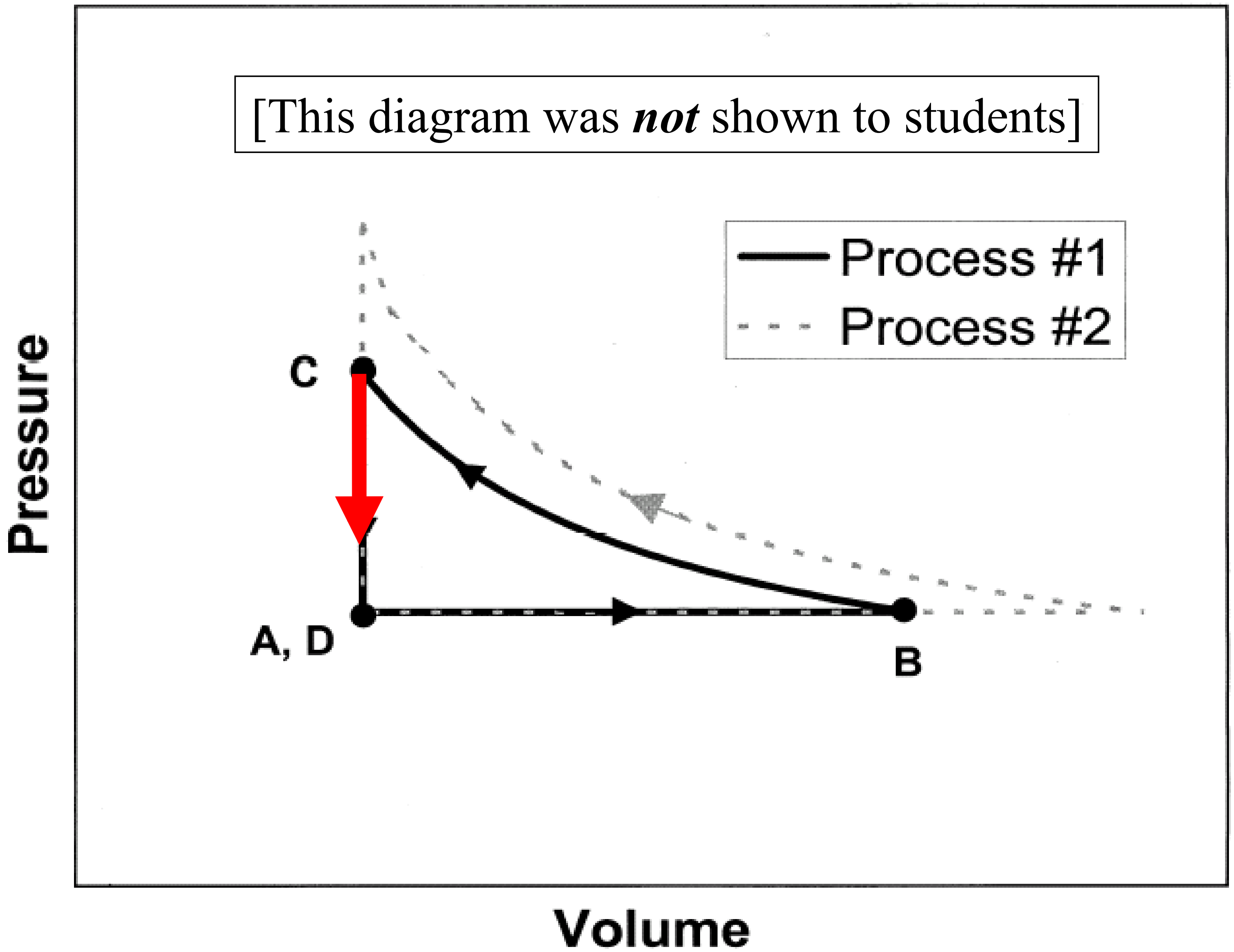
Process #1
Process #2
C
A, D
B
Pressure
Volume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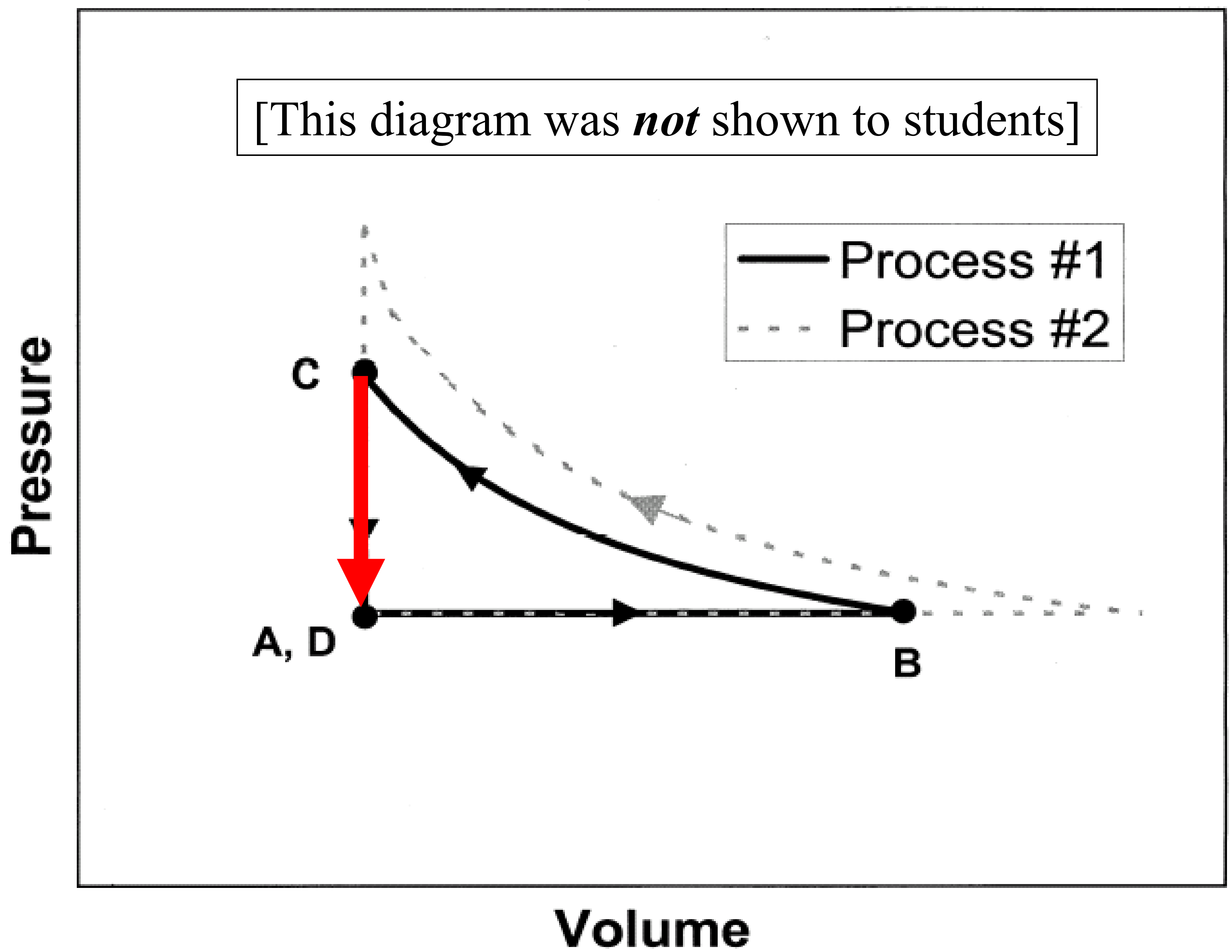
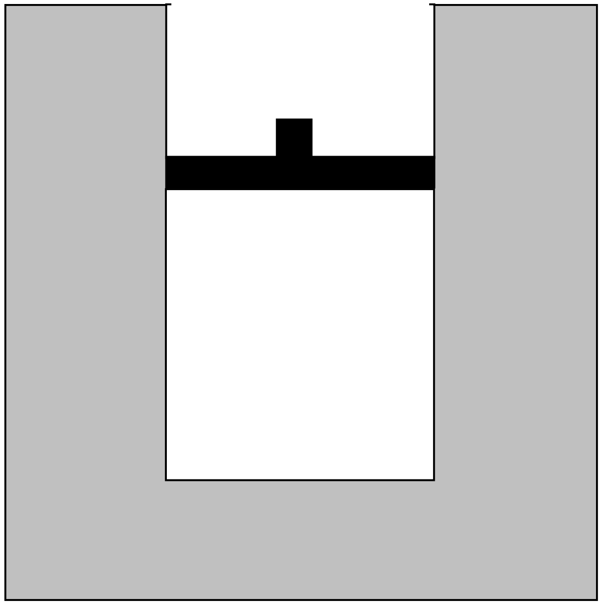
Process #1
Process #2
C
A, D
B
Pressure
Volume

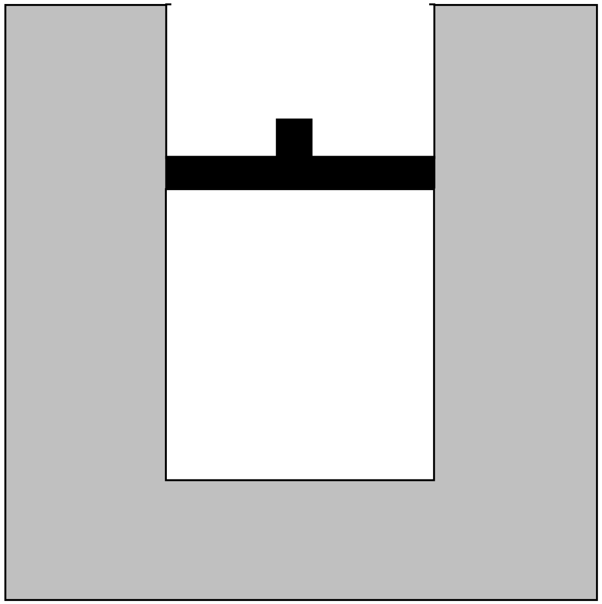

[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
Pressure
Volume



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?



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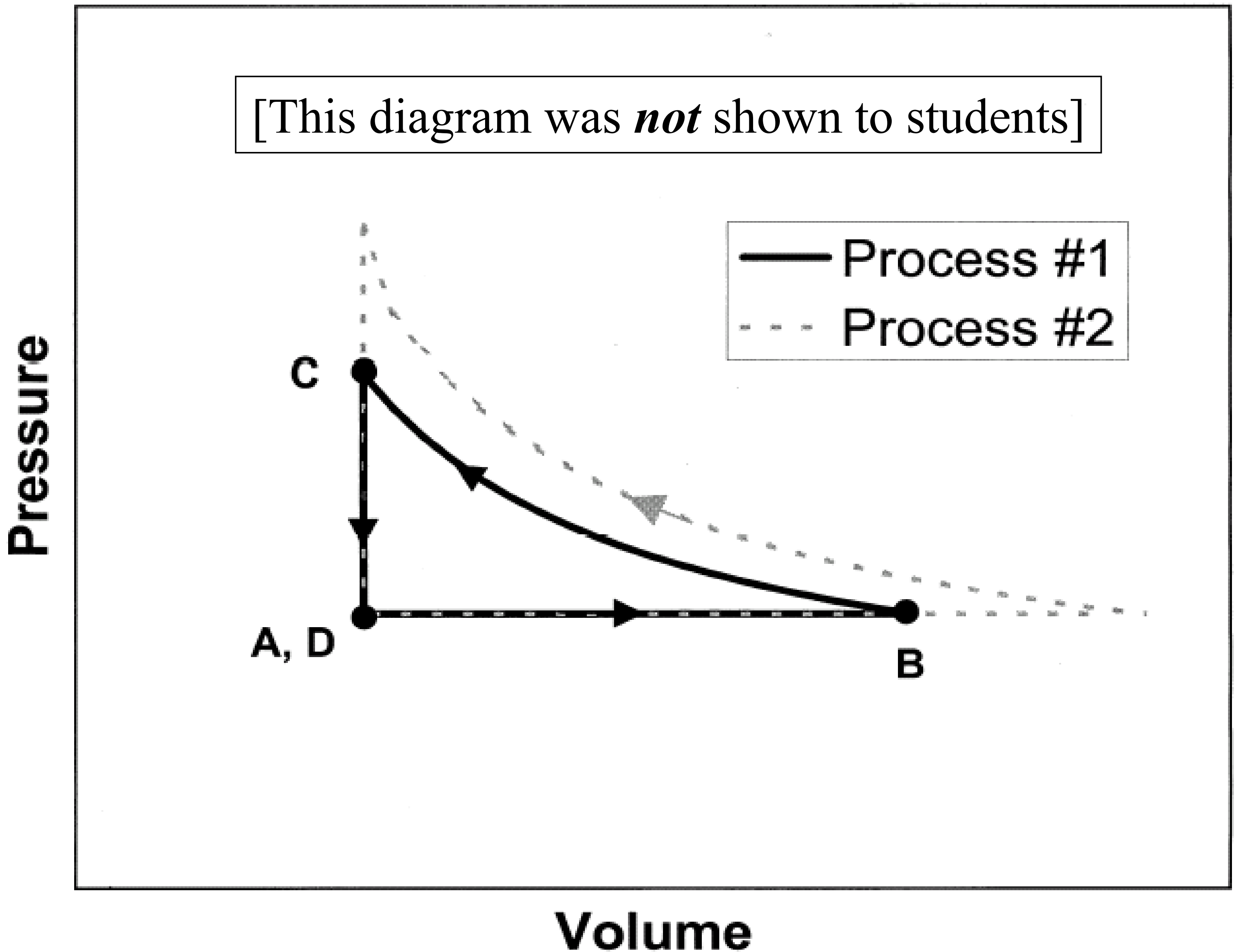
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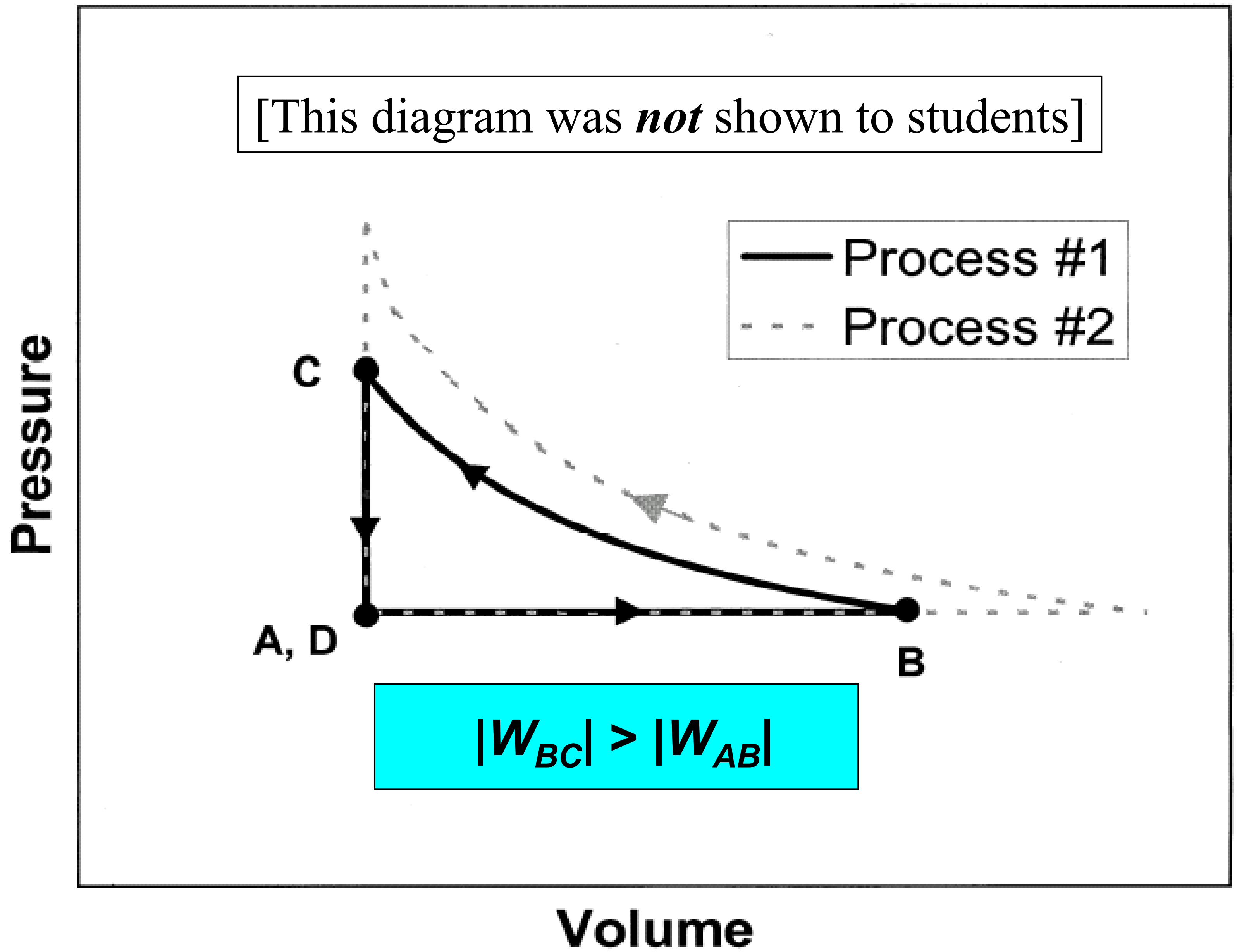
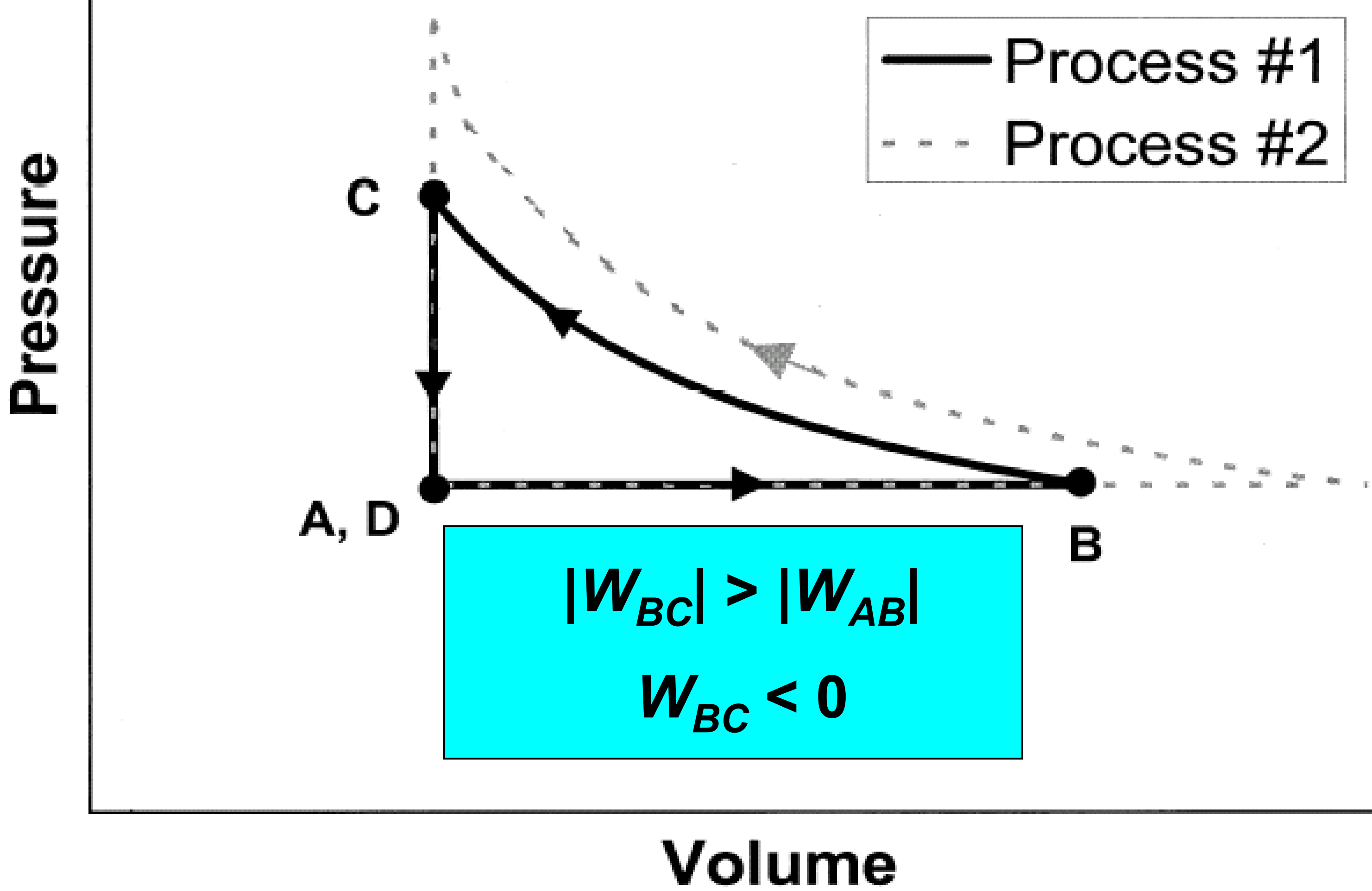
Process #2
C
A, D
B
Pressure
Volume


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

[This diagram was ***not*** shown to students]



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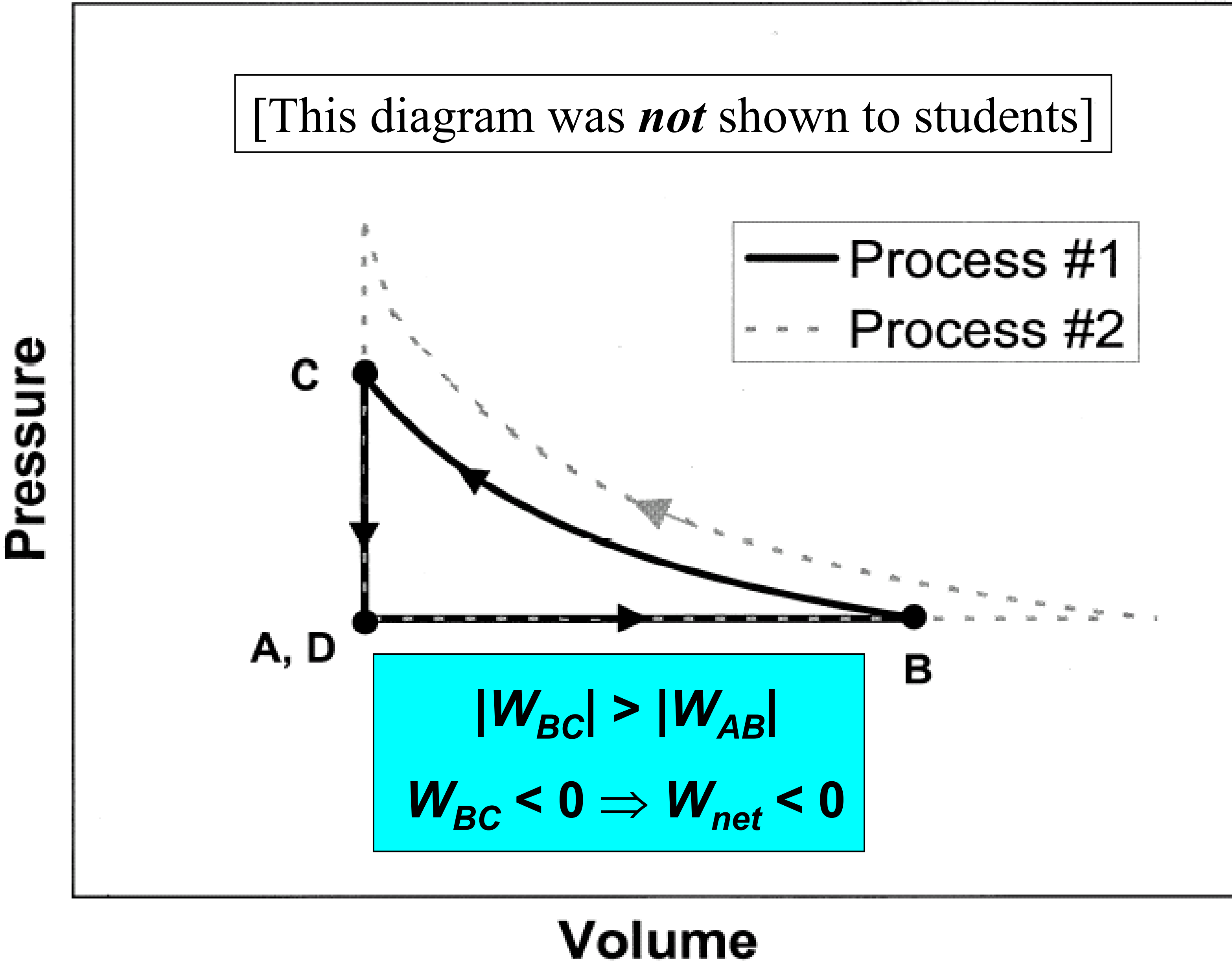
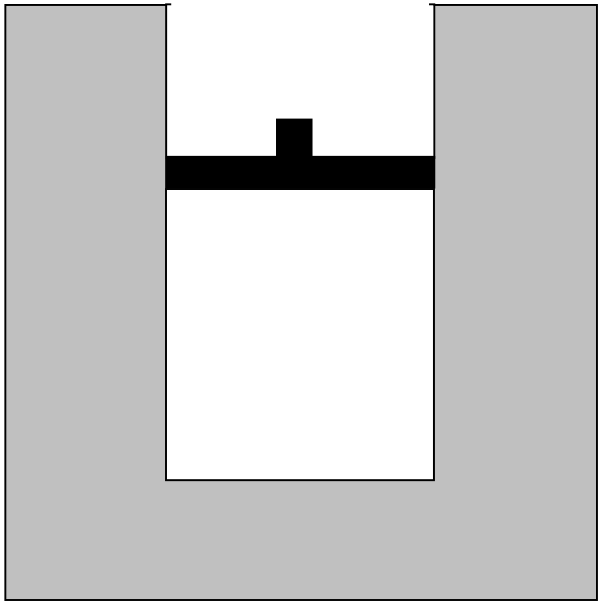


$$|W_{BC}| > |W_{AB}|$$

$$W_{BC} < 0 \Rightarrow W_{net} < 0$$



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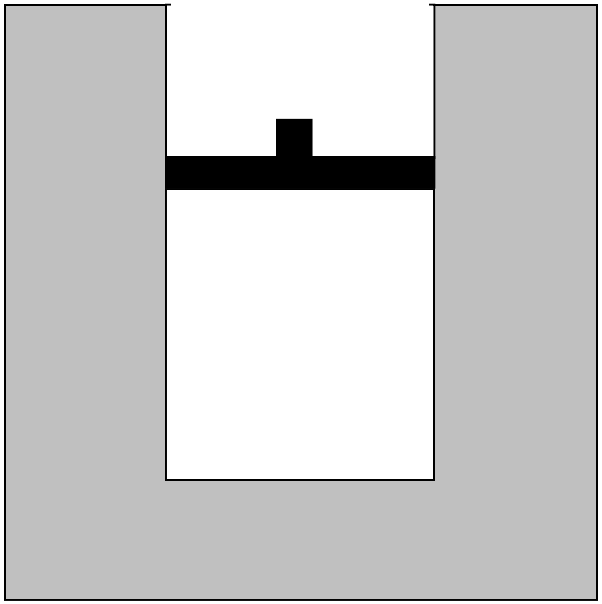

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(i) Is the net work done *by* the gas on the environment during that process (a) greater than zero, (b) equal to zero, or **(c) less than zero?**

(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%

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%

Nearly two thirds of the interview sample believed that net work done was equal to zero.

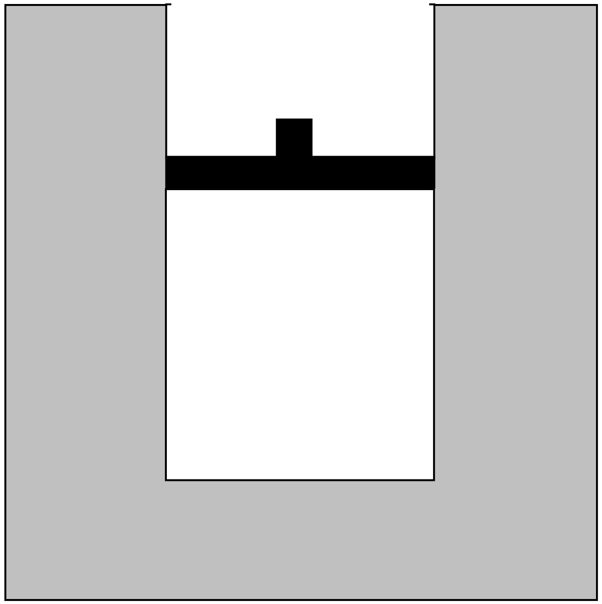
Explanations offered for $W_{net} = 0$

"[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*."

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*."



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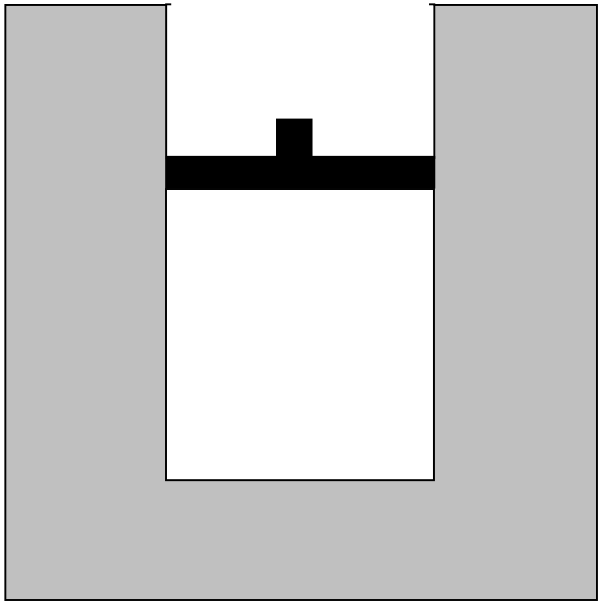

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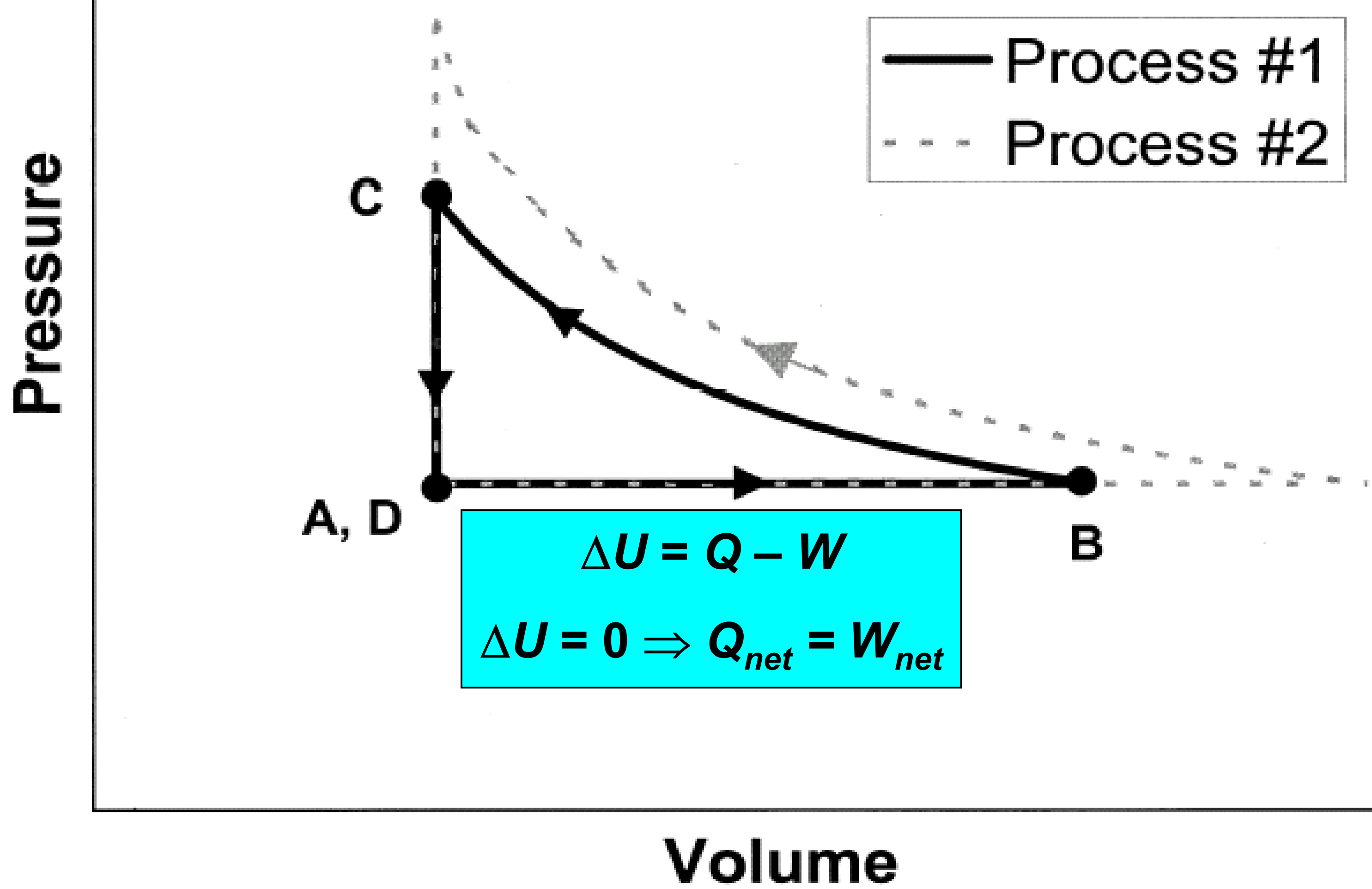
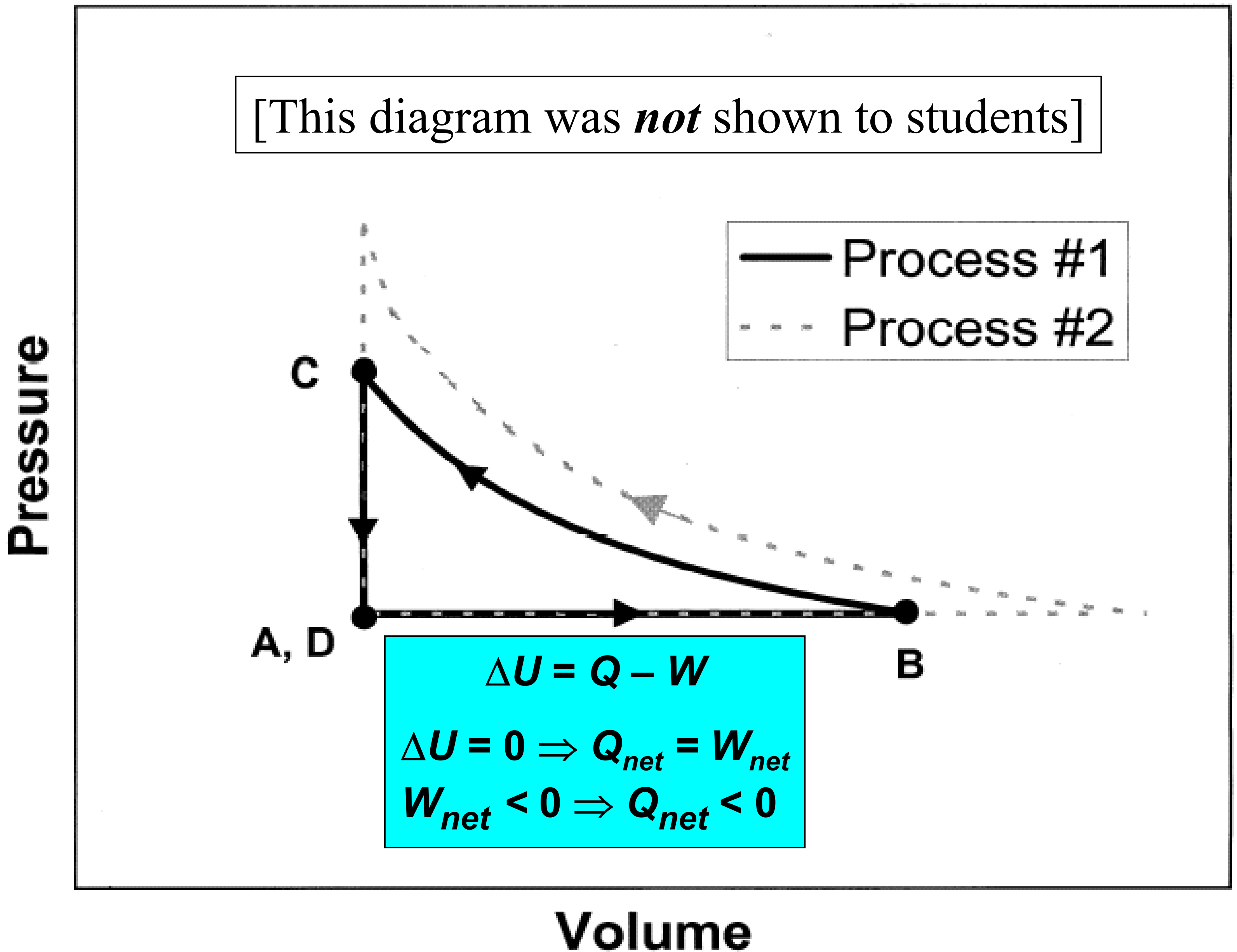
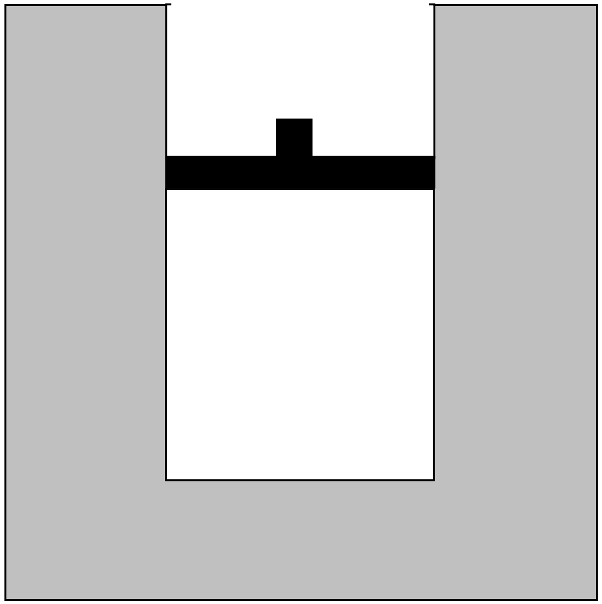
[This diagram was ***not*** shown to students]




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



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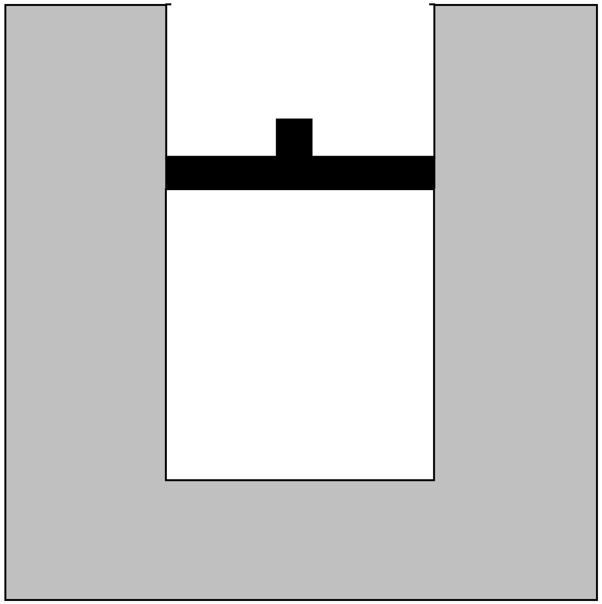

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Results on Interview Question #6 (ii)

N = 32

Results on Interview Question #6 (ii)

$N = 32$

(c) $Q_{net} < 0$ **16%** ***[correct]***

with correct explanation: 13%

with incorrect explanation: 3%

Results on Interview Question #6 (ii)

$N = 32$

(a) $Q_{net} > 0$ **9%**

(c) $Q_{net} < 0$ **16%** ***[correct]***

with correct explanation: 13%

with incorrect explanation: 3%

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%***

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%**		

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.*”

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 transferred during a cyclic process are zero.
5. Inability to apply the first law of thermodynamics.

Students' Difficulties with the First Law of Thermodynamics

- Fewer than 20% of all students were able to use the first law of thermodynamics to give correct answers with adequate explanations on written diagnostic questions.
- About 80% of students in interview sample manifested similar difficulties with the first law.

Primary Findings

*Even **after** instruction, many students (40-80%):*

- believe that heat and/or work are state functions independent of process

- believe that net work done and net heat absorbed by a system undergoing a cyclic process must be zero

- are unable to apply the First Law of Thermodynamics in problem solving

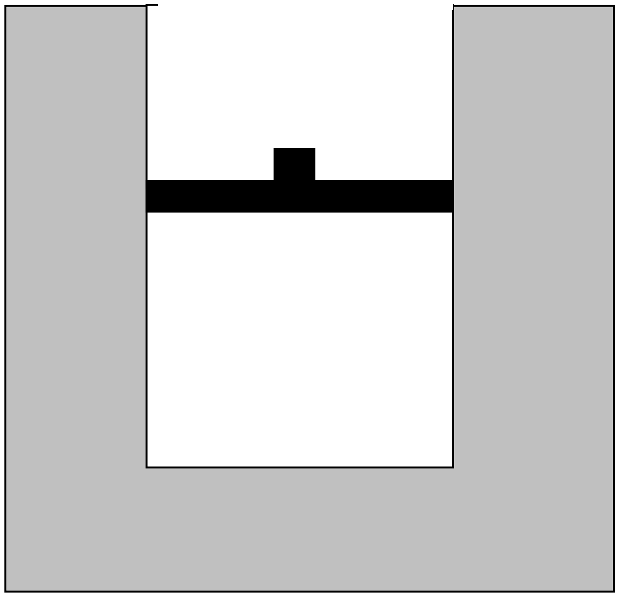
Implementation of Instructional Model

"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

Cyclic Process Worksheet

(adapted from interview questions)

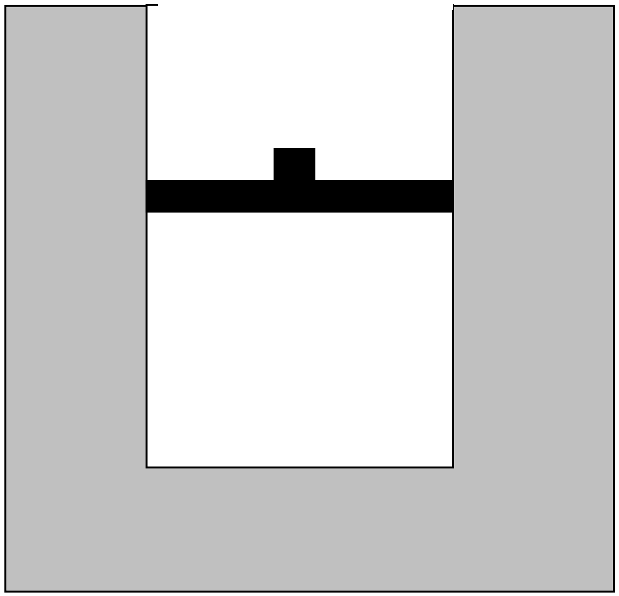


Worksheet Strategy

- First, allow students to read description of entire process and answer questions regarding work and heat.

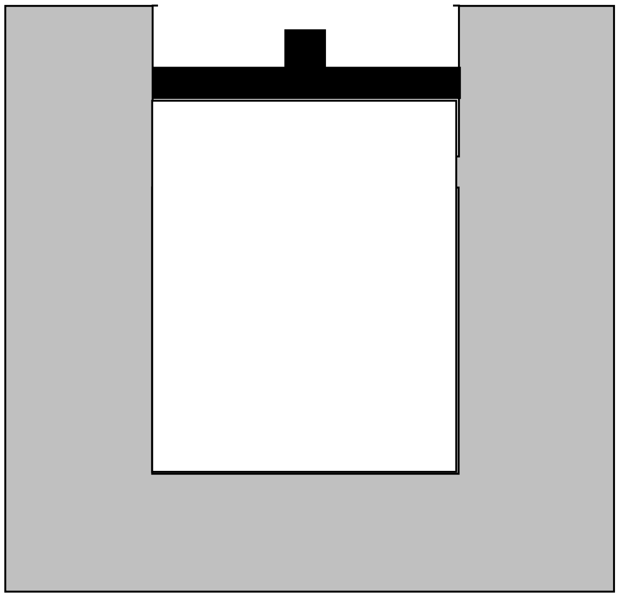
System heated

Time *A*

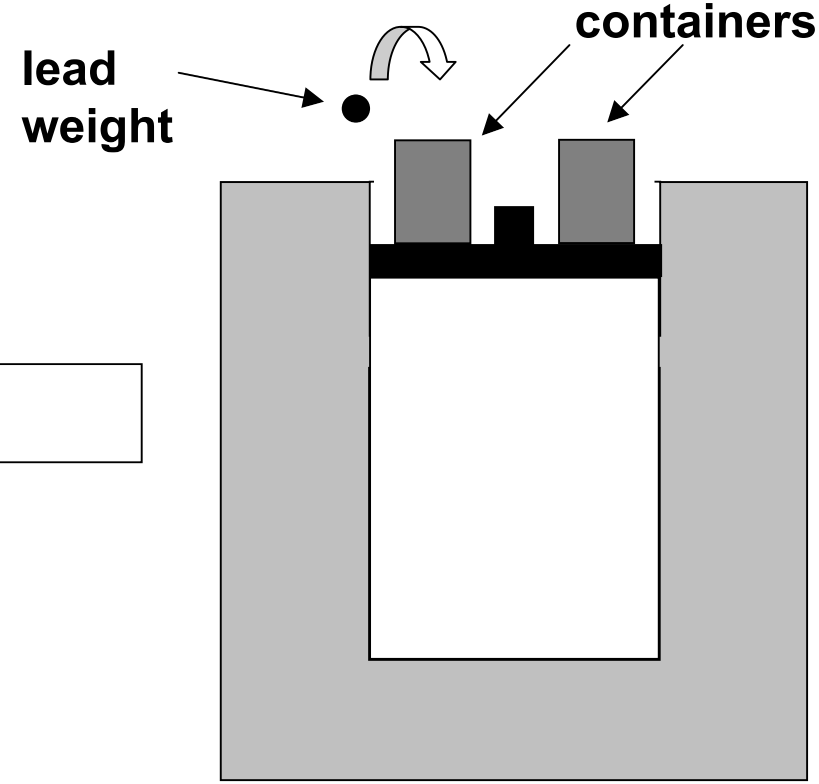


Time *B*

System heated, piston goes up.



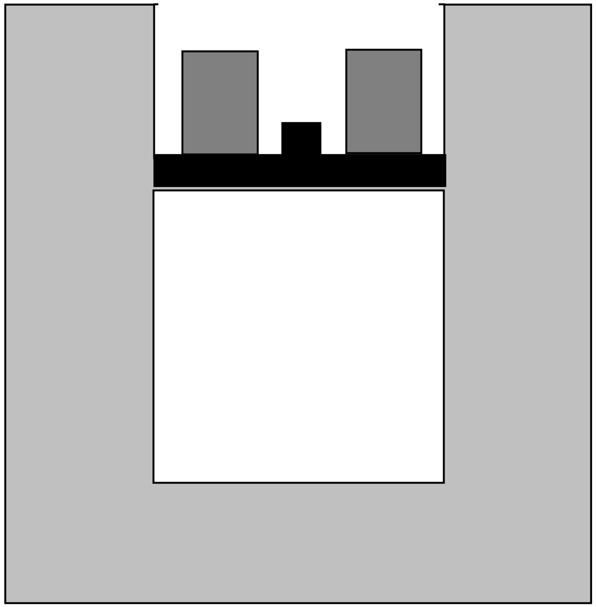
Time *B*



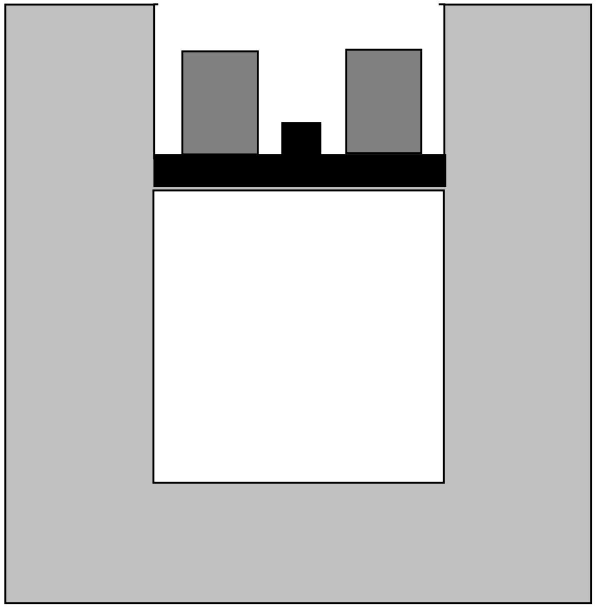
Weights added

Time *C*

Weights added, piston goes down.



Time *C*



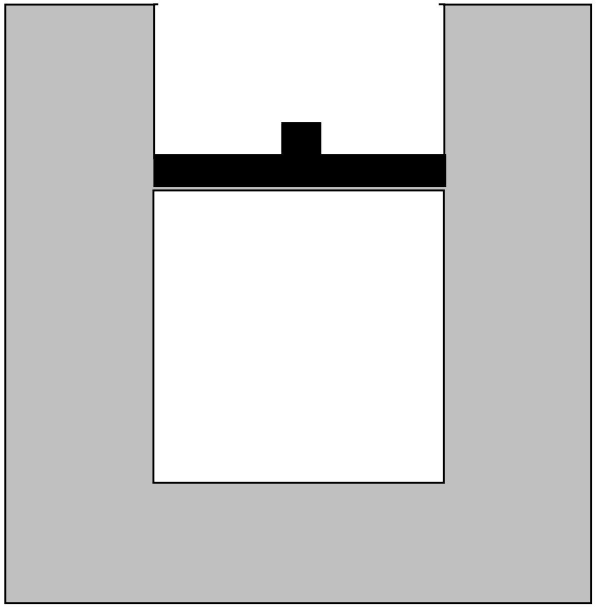
Weights added, piston goes down.

[Temperature remains constant]

Time *C*

Temperature *C*

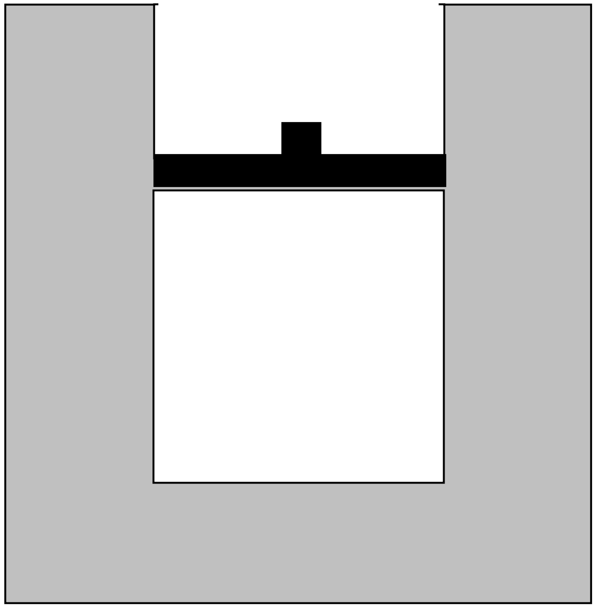
Piston locked

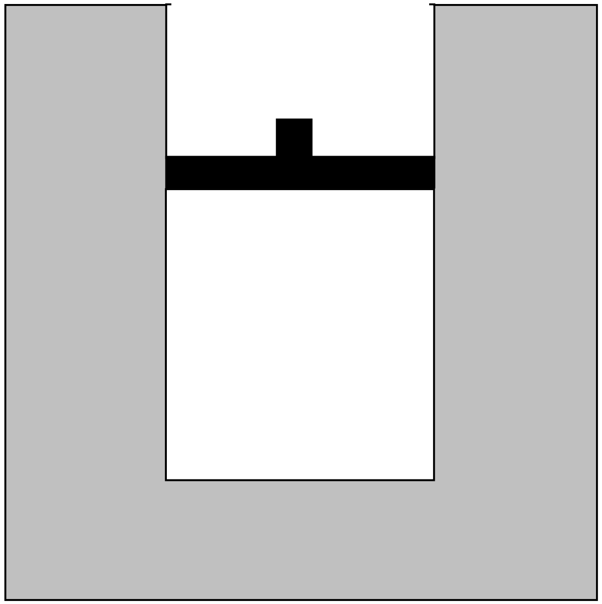


Time *D*

Temperature *D*

Piston locked, temperature goes down.





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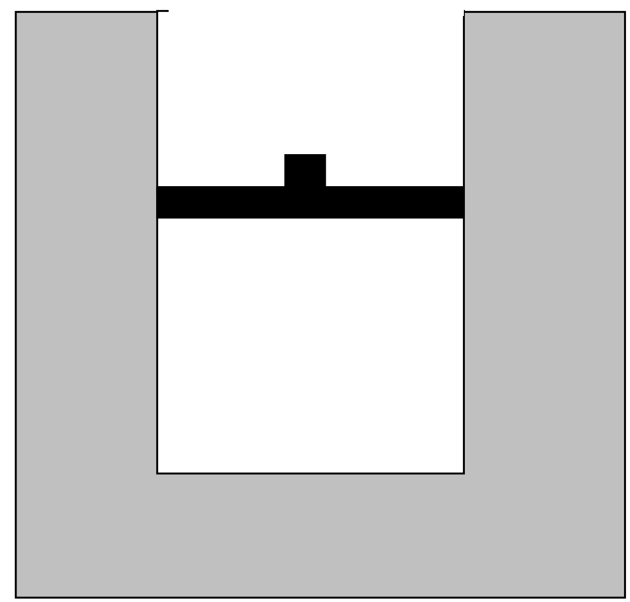
(i) Is the net work done *by* the gas on the environment during that process (a) greater than zero, (b) equal to zero, or (c) less than zero?

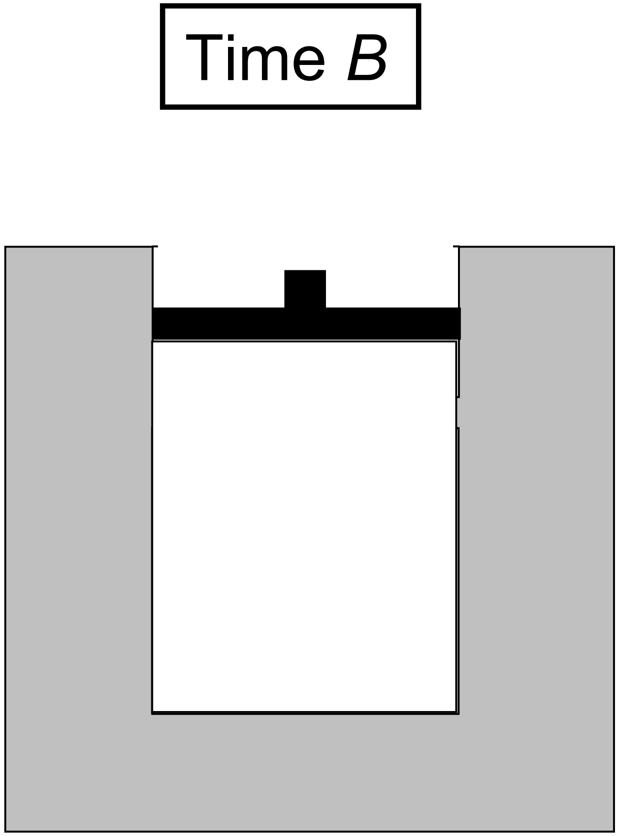
(ii) Is the total heat transfer to the gas during that process (a) greater than zero, (b) equal to zero, or (c) less than zero?

Worksheet Strategy

- First, allow students to read description of entire process and answer questions regarding work and heat.
- Then, prompt students for step-by-step responses.

Time *A*

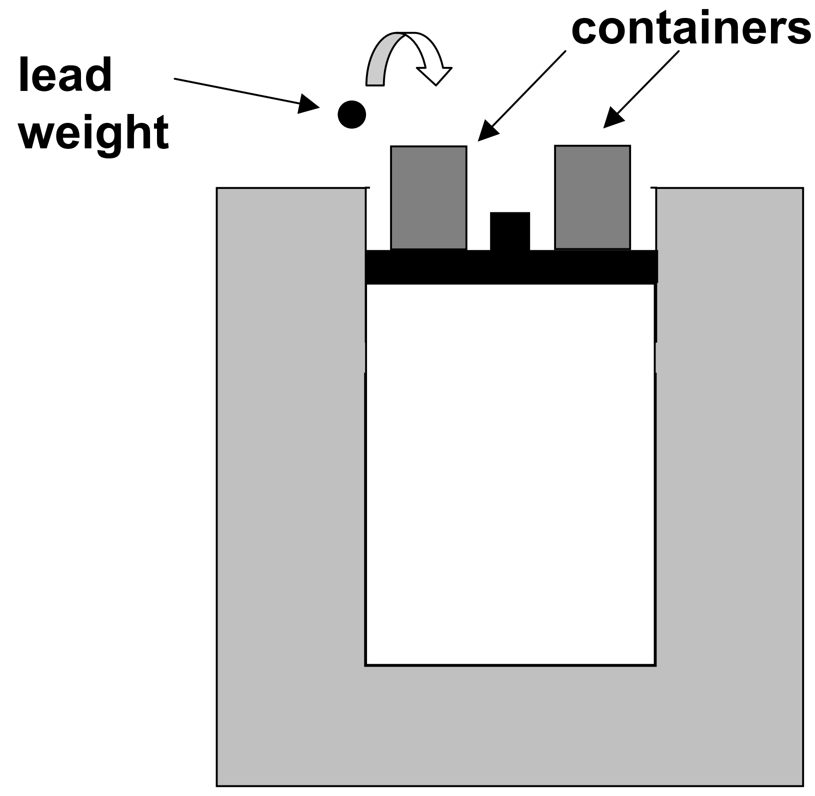



Time B

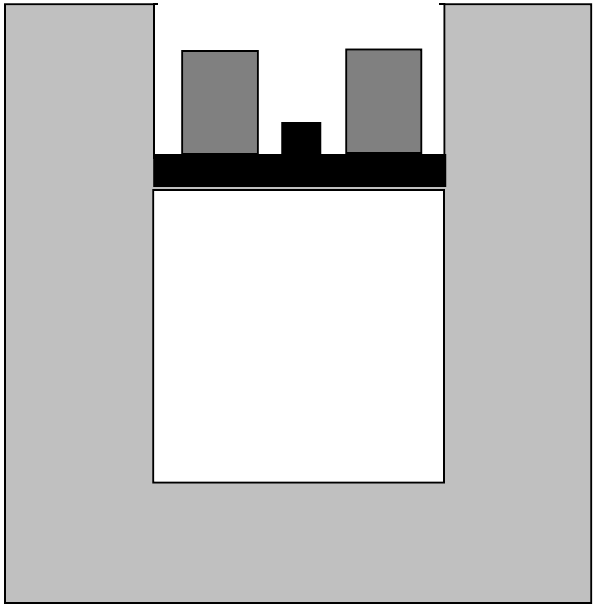
1) For the process A → B, is the work done by the system (W_{AB}) *positive*, *negative*, or *zero*?

Explain your answer.

Time *B*



Time C

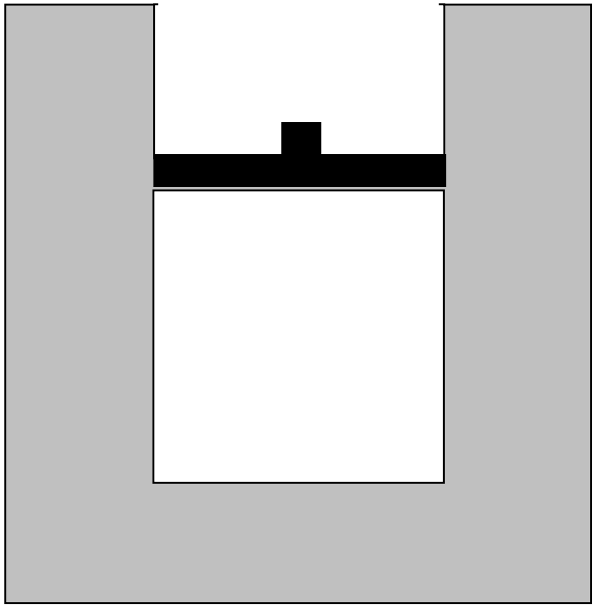


1) For the process A → B, is the work done by the system (W_{AB}) *positive*, *negative*, or *zero*?

2) For the process B → C, is the work done by the system (W_{BC}) *positive*, *negative*, or *zero*?

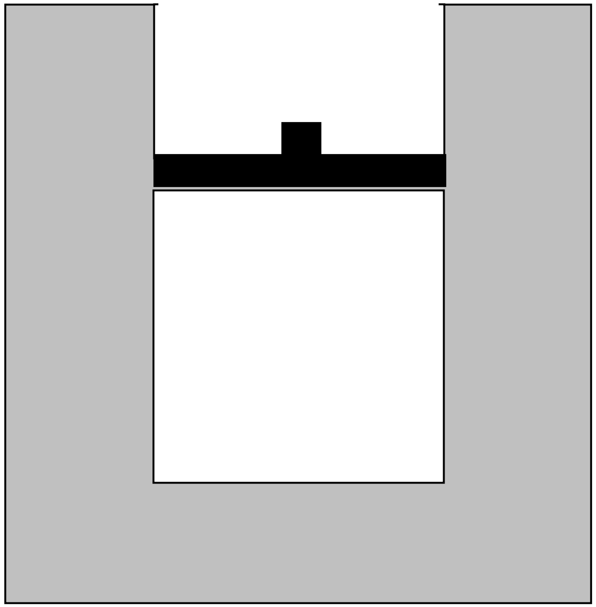
Time *C*

Temperature *C*



Time *D*

Temperature *D*



1) For the process A → B, is the work done by the system (W_{AB}) *positive*, *negative*, or *zero*?

2) For the process B → C, is the work done by the system (W_{BC}) *positive*, *negative*, or *zero*?

3) For the process C → D, is the work done by the system (W_{CD}) *positive*, *negative*, or *zero*?

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3) For the process C → D, is the work done by the system (W_{CD}) *positive*, *negative*, or *zero*?

4) Rank the *absolute values* $|W_{AB}|$, $|W_{BC}|$, and $|W_{CD}|$ from largest to smallest; if two or more are equal, use the "=" sign:

largest ______________________________ *smallest*

Explain your reasoning.

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largest $|\boldsymbol{W}_{\mathbf{BC}}| > |\boldsymbol{W}_{\mathbf{AB}}| > |\boldsymbol{W}_{\mathbf{CD}}| = \mathbf{0}$ *smallest*

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- First, allow students to read description of entire process and answer questions regarding work and heat.
- Then, prompt students for step-by-step responses.
- Finally, compare results of the two chains of reasoning.

Consider the net work done by the system during the complete process A → D, where

$$W_{net} = W_{AB} + W_{BC} + W_{CD}$$

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i) Is this quantity *greater than zero*, *equal to zero*, or *less than zero*?

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i) Is this quantity *greater than zero*, *equal to zero*, or *less than zero*?

ii) Is your answer consistent with the answer you gave for #6 (i)? Explain.

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ii) Is your answer consistent with the answer you gave for #6 (i)? 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

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

Current Work: Advanced-Level Thermal Physics Course

Funded by Physics Division of NSF

- Investigate student learning of statistical thermodynamics
- Probe evolution of students' thinking from introductory through advanced-level course
- Develop research-based curricular materials

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Summary

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

Active Learning in Large Physics Classes

- **De-emphasis of lecturing**; Instead, ask students to respond to many questions.
- Use of classroom communication systems to obtain **instantaneous feedback** from entire class.
- Cooperative **group work** using carefully structured free-response worksheets

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

“Fully Interactive” Physics Lecture

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

- 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

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

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Kandiah Manivannan
Department of Physics, Astronomy, and Materials Science, Southwest Missouri State University, 901 South National Avenue, Springfield, Missouri 65804

(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.
[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-

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

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

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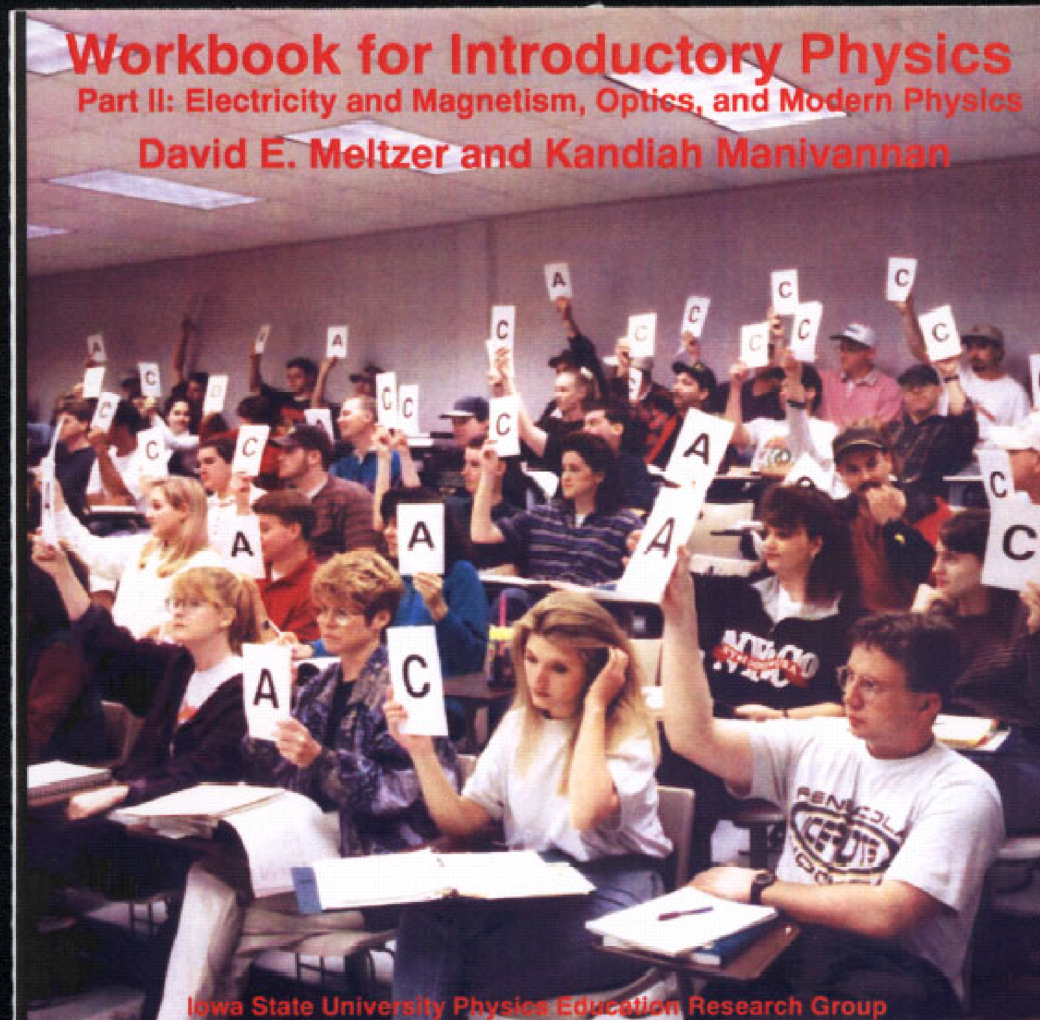
Supported by NSF under “Assessment of Student Achievement” program



dem@iastate.edu

AUTHORS:

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kam319f@smsu.edu

Curricular Material for Large Classes

"Workbook for Introductory Physics"

- Multiple-choice "Flash-Card" Questions
  - Conceptual questions for whole-class interaction
- Worksheets for Student Group Work
  - Sequenced sets of questions requiring written explanations
- Lecture Notes
  - Expository text for reference
- Quizzes and Exams
  - some with worked-out solutions

Chapter 1 Electrical Forces

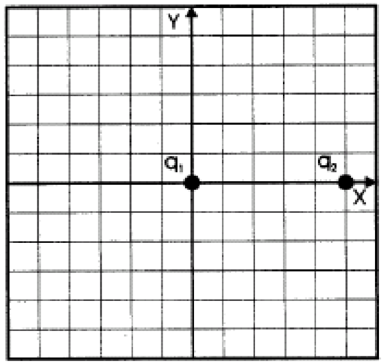
“Flash-Card” Questions

In-Class Questions

Prerequisite Concepts:

- **Positive and negative charges; Coulomb's law: $F = kq_1q_2/r^2$**
- **Protons (+) and electrons (–)**
- **Superposition principle: $F_{net}=F_1+F_2 + . . . + F_n$**
- **Vector addition: $F_{netx}=F_{1x} + F_{2x} + . . . F_{nx}$**
- **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
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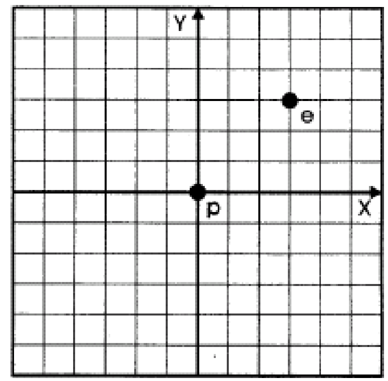
"Flash-Card" Questions

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. 

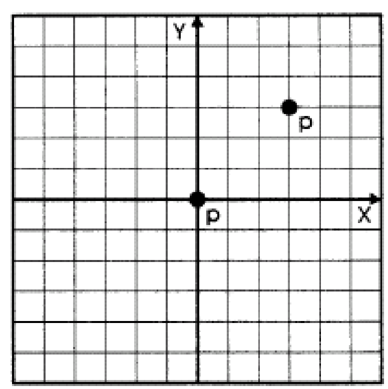
C. 

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?



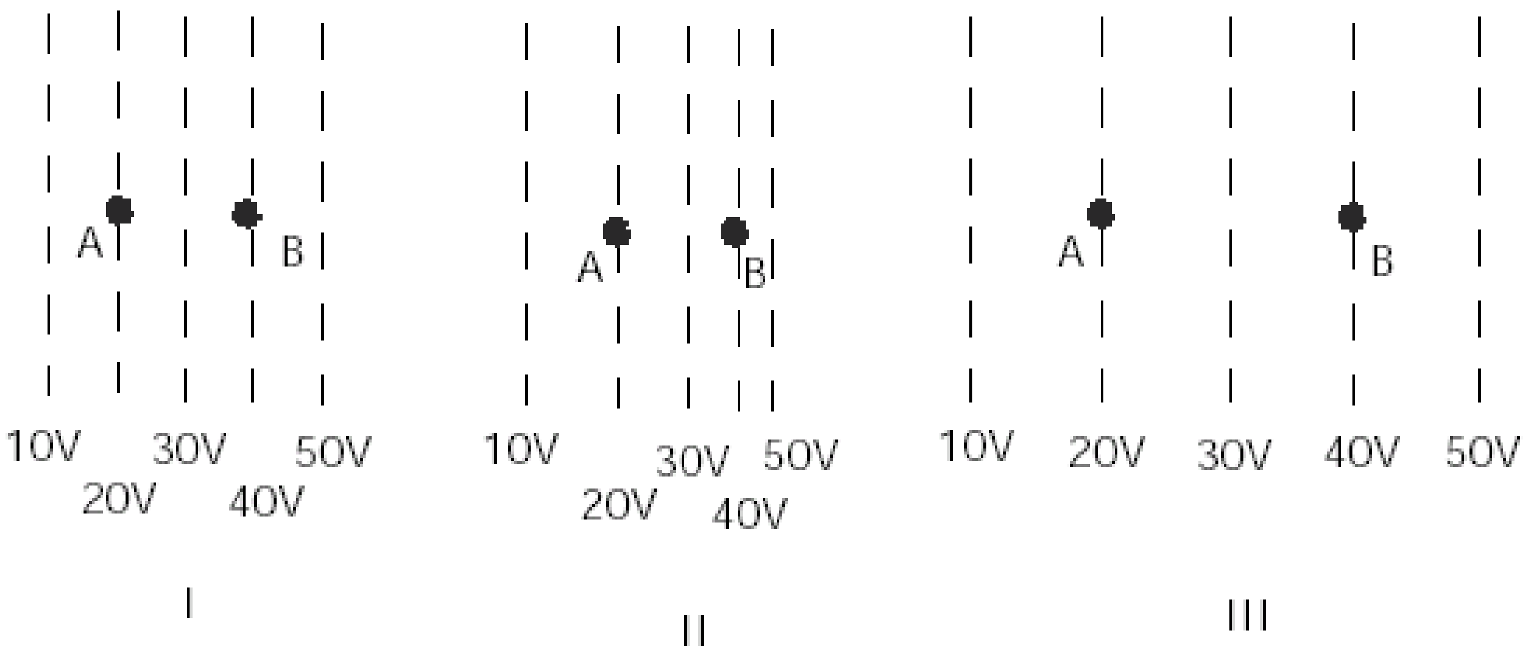
A. 0°
B. 45°
C. 90°
D. 135°
E. 225°
F. 270°

Assessment Data

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

Sample	*N*
National sample (algebra-based)	402
National sample (calculus-based)	1496

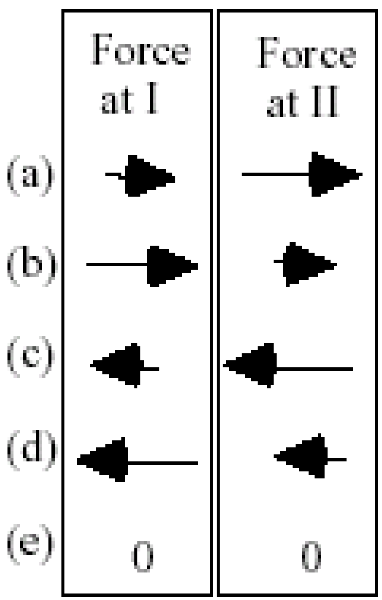
In the figures below, the dotted lines show the equipotential lines of electric fields. (A charge moving along a line of equal potential would have a constant electric potential energy.) A charged object is moved directly from point A to point B. The charge on the object is +1 μC.

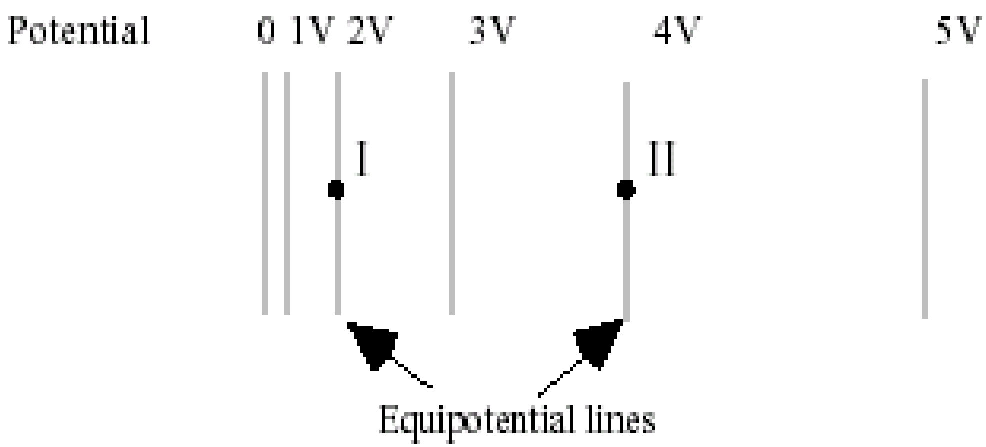


1. How does the magnitude of the electric field at B compare for these three cases?
   (a) I > III > II
   (b) I > II > III
   (c) III > I > II
   (d) II > I > III
   (e) I = II = III

D. Maloney, T. O'Kuma, C. Hieggelke, and A. Van Heuvelen, PERS of Am. J. Phys. ***69****, S12 (2001).*

2. A positively-charged proton is first placed at rest at position I and then later at position II in a region whose electric potential (voltage) is described by the equipotential lines. Which set of arrows on the left below best describes the relative magnitudes and directions of the electric force exerted on the proton when at position I or II?





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Sample	*N*	Mean pre-test score	Mean post-test score	<g>
National sample (algebra-based)	402	**27%**	**43%**	**0.22**
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ISU 1998	70	**30%**		
ISU 1999	87	**26%**		
ISU 2000	66	**29%**		

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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 221: F97 & F98 **Subset of three questions**	*372*	59%

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Physics 112: F98, F99, F00 **Subset of three questions**	*241*	

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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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- “Interactive-engagement” instruction using research-based curricula can improve student learning.
- Ongoing development and testing of instructional materials lays the basis for new directions in research, holds promise for sustained improvements in learning.

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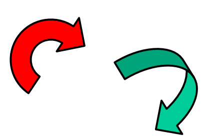

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