# Research-Based Pedagogical Strategies in Thermal Physics: Development and Assessment

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# Introductory Course:

## Iowa State (ISU) General Physics with Calculus

- Second-semester calculus-based physics course (mostly engineering students) at Iowa State University.
- 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).

# Intermediate Course:
## Univ. Washington Sophomore-level Thermal Physics Course

- Physics 224: Part of introductory sequence, but enrolls about 50% physics majors
- Taught by DEM, Winter 2006; heavy use of tutorials and interactive lecture with research-based question sequences
- Students taking both pre- and post-tests: ≈ 30

# Advanced Course:

## ISU Junior-Senior ("Upper-Level") Thermal Physics Course

- Classical macroscopic thermodynamics, and statistical thermodynamics

- Students enrolled [*N* = 33 (*2003-2004*)]

  ≈ 90% were junior or senior physics majors or physics/engineering double majors;

  - all had studied thermodynamics (some at advanced level)

- Taught by DEM; heavy use of tutorials and interactive lecture with research-based question sequences

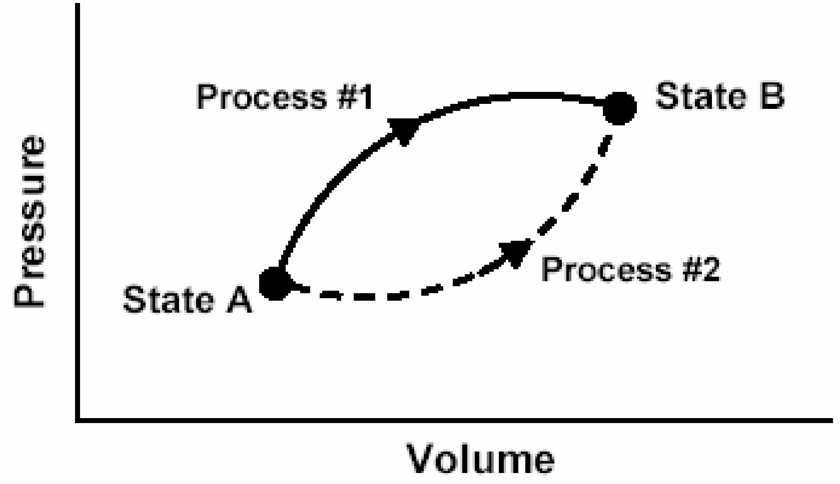
# Diagnostic Questions

- “Two-process” question: requires use of First Law of thermodynamics
- “Spontaneous-process” question: probes understanding of entropy and second law

# Diagnostic Questions

- “Two-process” question: requires use of First Law of thermodynamics

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:

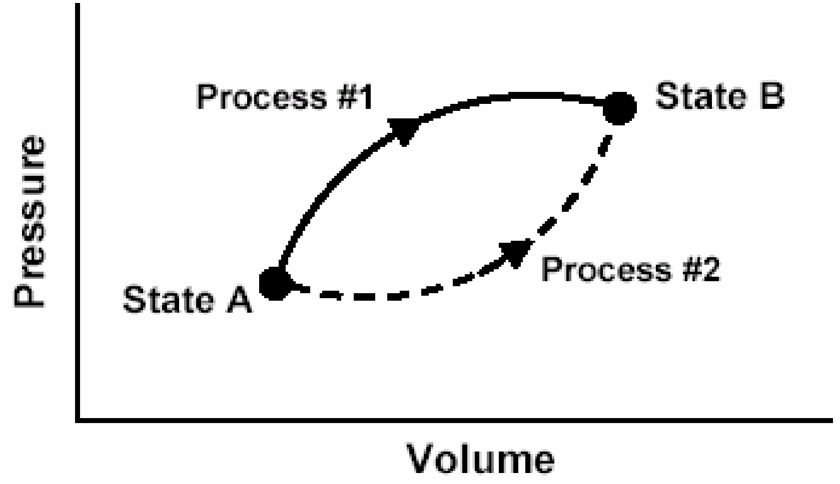



[In these questions, ***W*** represents the work done ***by*** the system during a process; ***Q*** represents the heat ***absorbed*** by the system during a process.]

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

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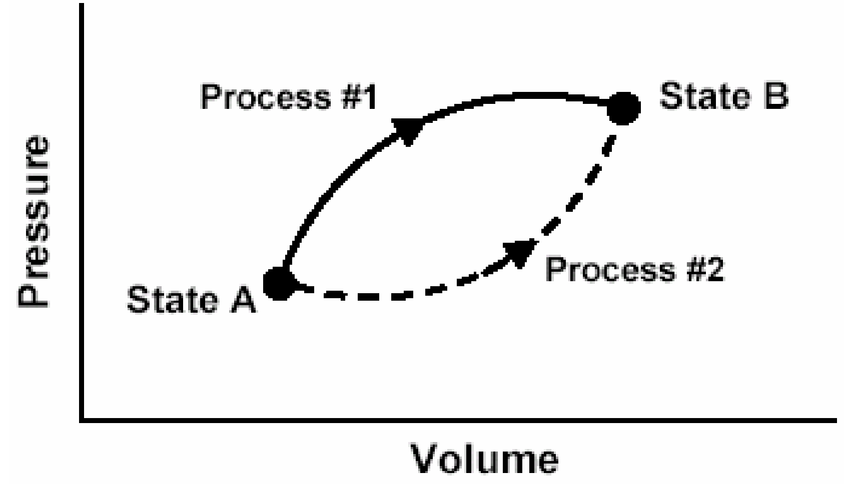
This *P-V* diagram represents a system consisting of a fixed amount of ideal gas that undergoes two ***different*** processes in going from state A to state B:

**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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# Responses to Diagnostic Question #2
## (Heat question)

| | **1999-2001** Introductory Physics (Post-test) Written Sample ($N$=653) | **2002** Introductory Physics (Post-test) Interview Sample ($N$=32) | **2003-4** Thermal Physics (Pretest) ($N$=33) |
|---|---|---|---|
| $Q_1 > Q_2$ | **45%** | **34%** | **33%** |
| *Correct or partially correct explanation* | **11%** | **19%** | **30%** |

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Most upper-level students are initially unable to apply First Law of Thermodynamics

# Responses to Diagnostic Question #2
## (Heat question)

| | | | **2003-4 Thermal Physics** (*N*=33) |
|---|---|---|---|
| $Q_1 > Q_2$ | | | |
| *Correct or partially correct explanation* | | | |

Instruction using tutorials (Univ. Washington + Iowa State), plus interactive lectures

# Heat Question: Posttest Version #1 (Verbal)

1. *[4 points]* A fixed quantity of ideal gas is in an initial state with pressure $P_i$ and volume $V_i$. In Process #1 (a quasistatic, reversible process), the gas pressure stays constant while the volume is increased until it reaches a final volume $V_f$ (and $P_f = P_i$). In a separate Process #2 (also quasistatic and reversible), the gas begins from the same initial state with pressure $P_i$ and volume $V_i$. In this process, the volume increases at a constant rate until it reaches the same $V_f$. However, during Process #2, the pressure first steadily increases until it reaches $2P_i$ midway during the expansion, and then steadily decreases at the same rate until it is back to the initial pressure (so again $P_f = P_i$).

   *[3 pts]* Is the net heat transfer to the gas during Process #2 *greater than*, *less than*, or *equal to* the net heat transfer to the gas during Process #1? Explain your answer.

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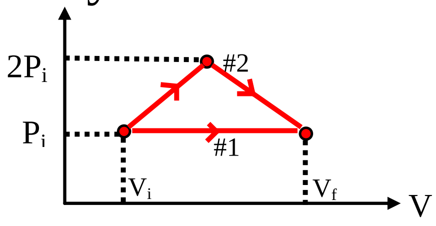


$W_2 > W_1$;   $\Delta U_2 = \Delta U_1$

$\rightarrow Q_2 > Q_1$

# Responses to Diagnostic Question #2
## (Heat question, post-test version #1)

| | | | **2003-4** **Thermal Physics** **(Pretest)** (*N*=33) |
|---|---|---|---|
| $Q_1 > Q_2$ | | | **33%** |
| ***Correct or partially correct explanation*** | | | **30%** |

# Responses to Diagnostic Question #2
## (Heat question, post-test version #1)

| | | | **2003-4 Thermal Physics (Posttest) (*N*=33)** |
|---|---|---|---|
| $Q_1 > Q_2$ | | | ≈ 65% |
| *Correct or partially correct explanation* | | | ≈ 60% |

After use of tutorials and interactive lectures, significant gains are seen with upper-level students.

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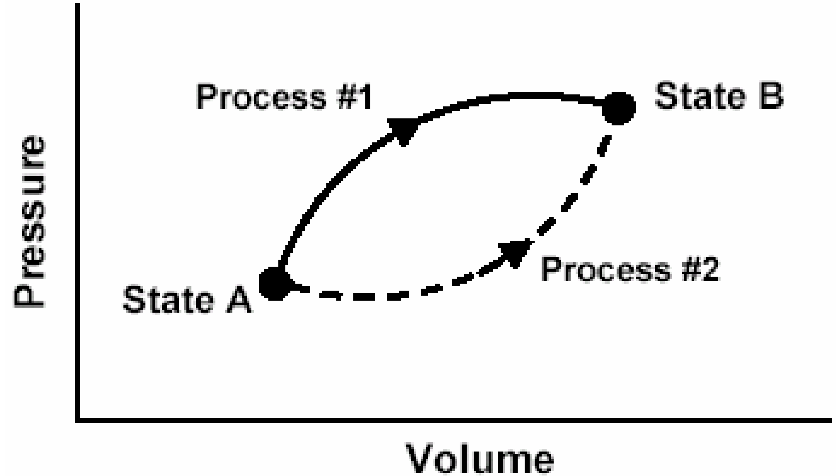


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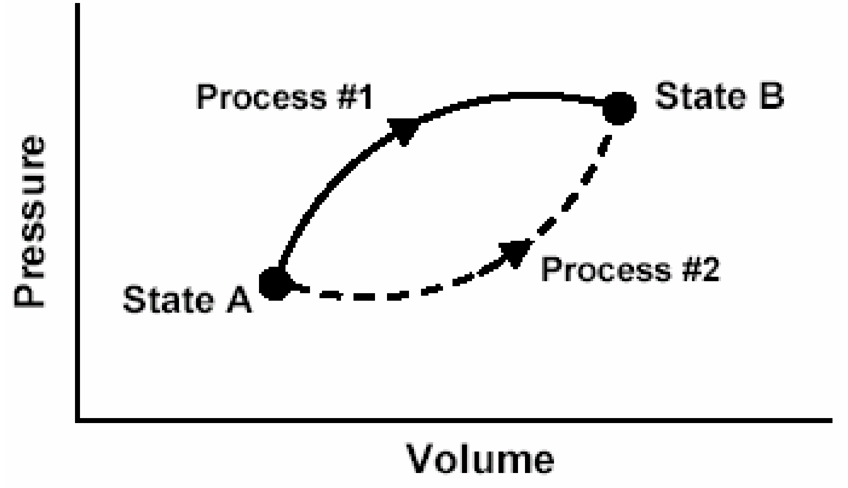


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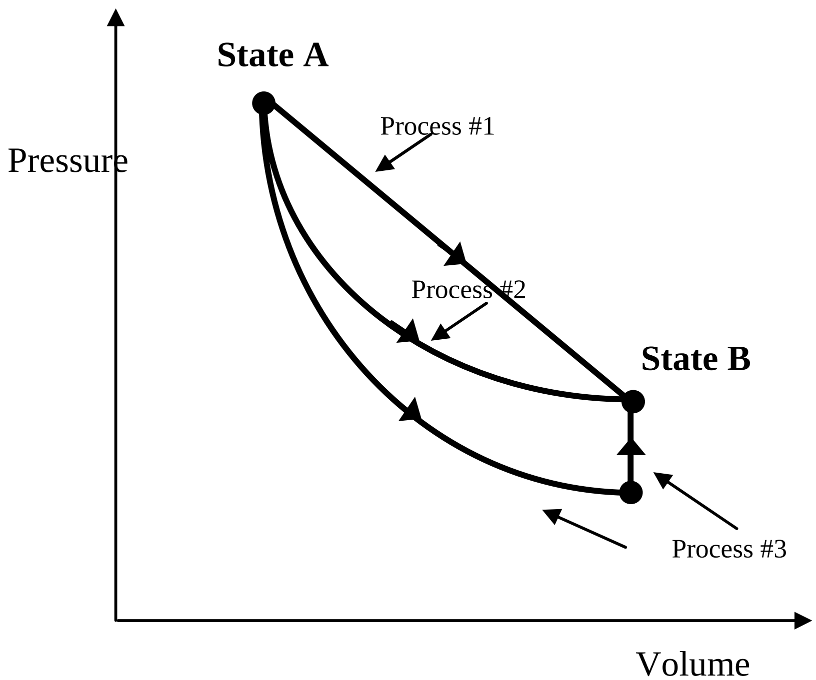
Intermediate students

(*U.W. Phys 224*):

14% correct with correct explanation (pretest)

# Heat Question: Posttest Version #2

6. *[11 points]* This *pV* diagram represents a system consisting of a fixed amount of ideal gas that is initially in state *A* and ends up in State *B*. Process #1 follows the straight-line path from state *A* to state *B*. Process #2 is an isothermal expansion, and Process #3 consists of *two* parts: an adiabatic expansion followed by constant-volume heating of the system. The arrows indicate the direction of each process.



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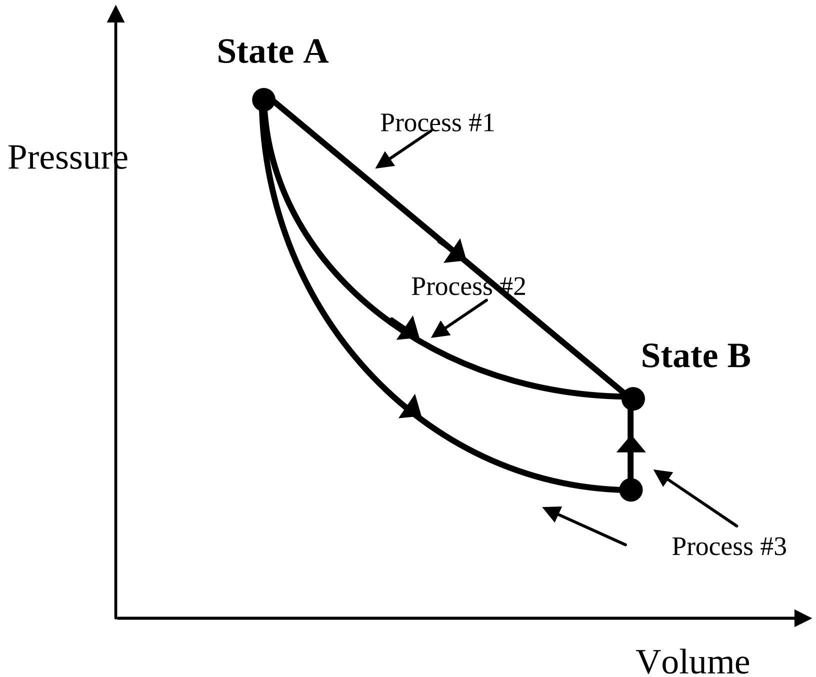


a. Rank $Q_1$, $Q_2$, $Q_3$, the heat transferred to the system in the three processes. (Positive quantity ranks higher than negative quantity.) If two or more are equal, indicate that explicitly. If any of them are equal to zero, indicate that explicitly. Explain your reasoning.

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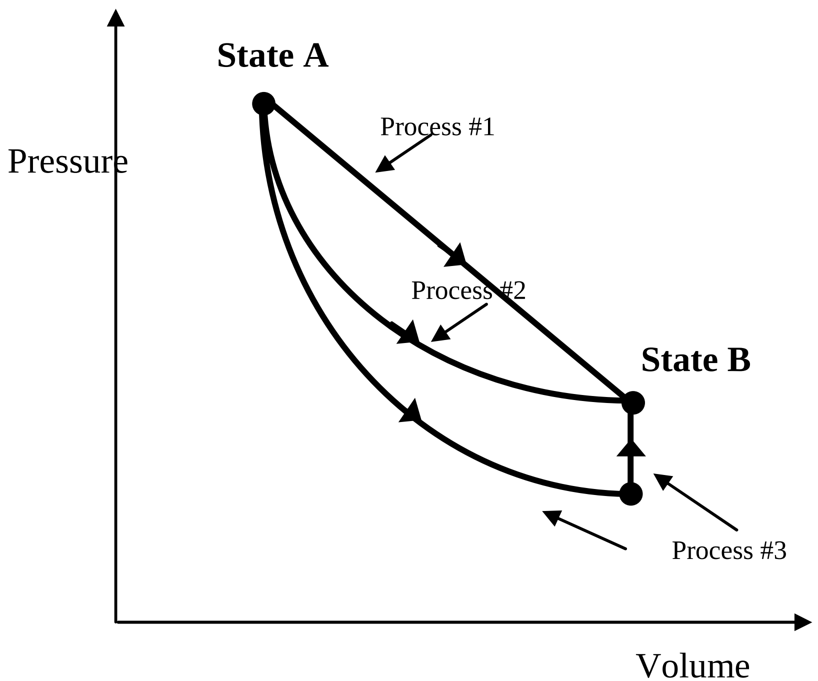


$Q_1 > Q_2 > Q_3$

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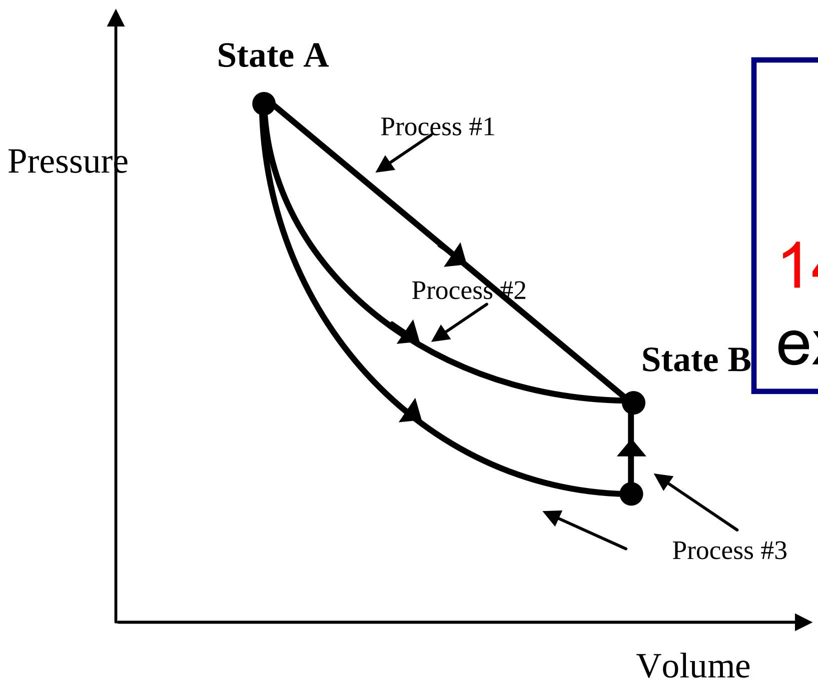


Intermediate students (*U.W. Phys 224*): 14% correct with correct explanation on pretest

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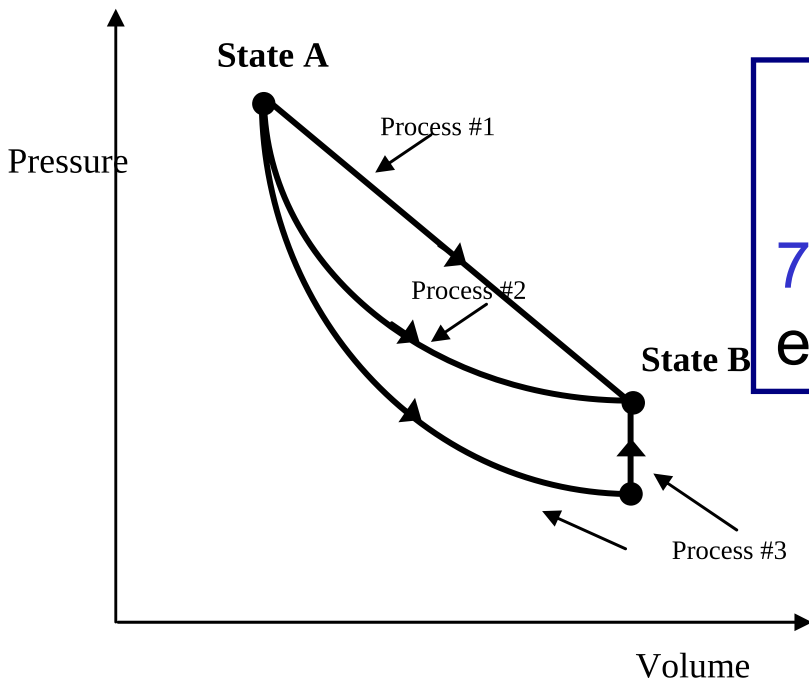


**Intermediate students (*U.W. Phys 224*):**

**71% correct with correct explanation on posttest**

After use of tutorials and interactive lectures

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# Diagnostic Questions

- “Two-process” question: requires use of First Law of thermodynamics

- “Spontaneous-process” question: probes understanding of entropy and second law

# Spontaneous Process Question

For each of the following questions consider a system undergoing a naturally occurring ("spontaneous") process. The system can exchange energy with its surroundings.

A. During this process, does the entropy of the **system** [$S_{system}$] *increase*, *decrease*, or *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

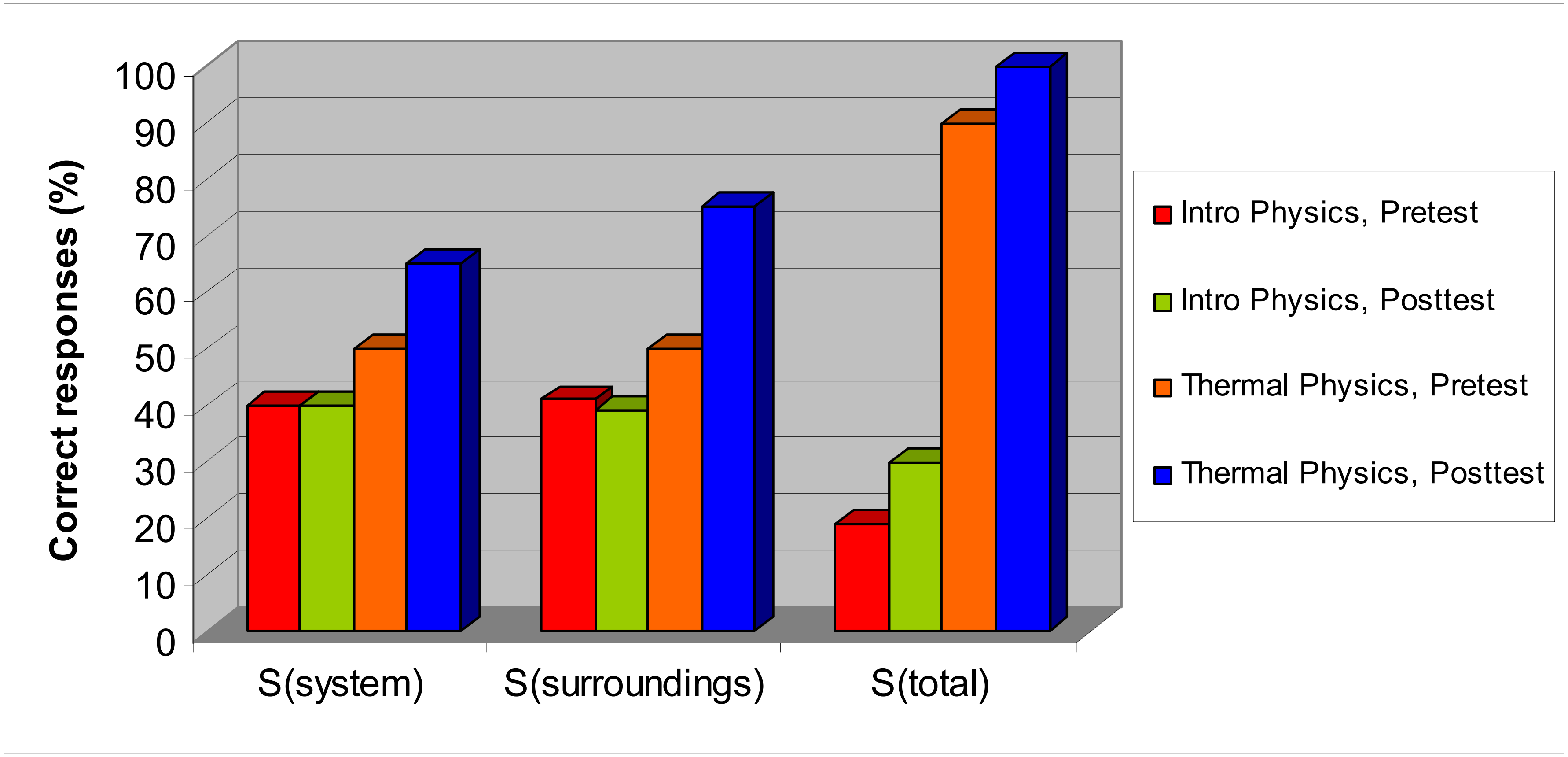
B. During this process, does the entropy of the **surroundings** [$S_{surroundings}$] *increase*, *decrease*, or *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

C. During this process, does the entropy of the system *plus* the entropy of the surroundings [$S_{system} + S_{surroundings}$] *increase*, *decrease*, or *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

# Introductory Physics Students' Thinking on Spontaneous Processes

- Tendency to assume that "system entropy" must *always* increase
- Slow to accept the idea that entropy of system plus surroundings ***increases***

# Responses to Spontaneous-Process Questions




***Thermal Physics Posttest:*** Interactive Engagement, no focused tutorial

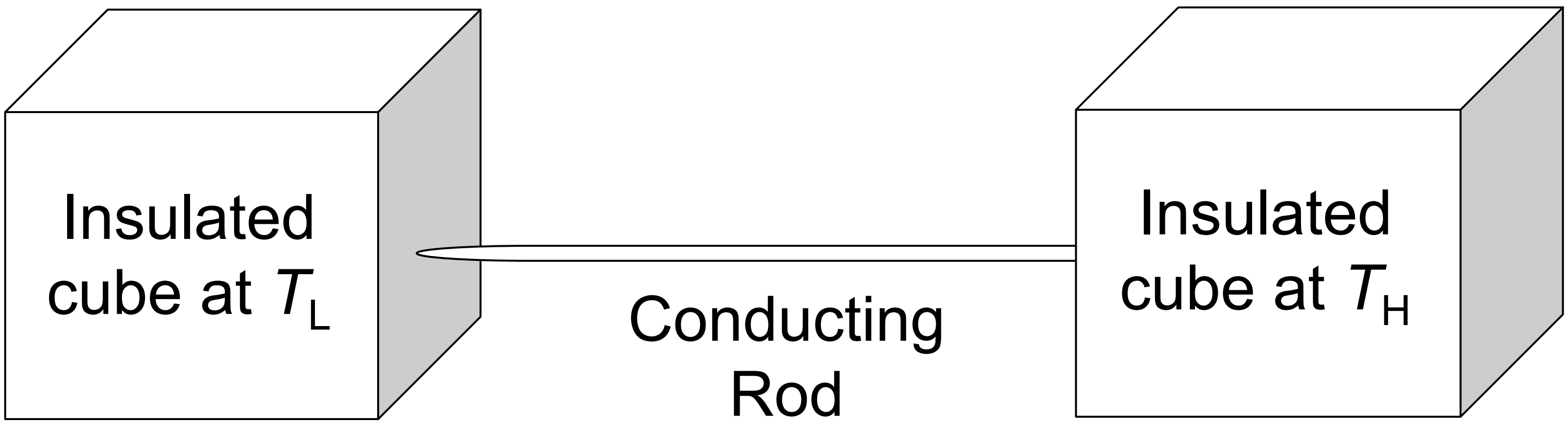
# Thermal Physics Students' Thinking on Spontaneous Processes

- Readily accept that "entropy of system ***plus*** surroundings increases"
  - in contrast to introductory students

- Tendency to assume that "system entropy" must *always* increase
  - similar to thinking of introductory students

# Entropy Tutorial

(draft by W. Christensen and DEM, undergoing class testing)




- Consider slow heat transfer process between two thermal reservoirs (insulated metal cubes connected by thin metal pipe)
    - Does total energy change during process?
    - Does total entropy change during process?

# Entropy Tutorial

(draft by W. Christensen and DEM, undergoing class testing)

- Guide students to find that:

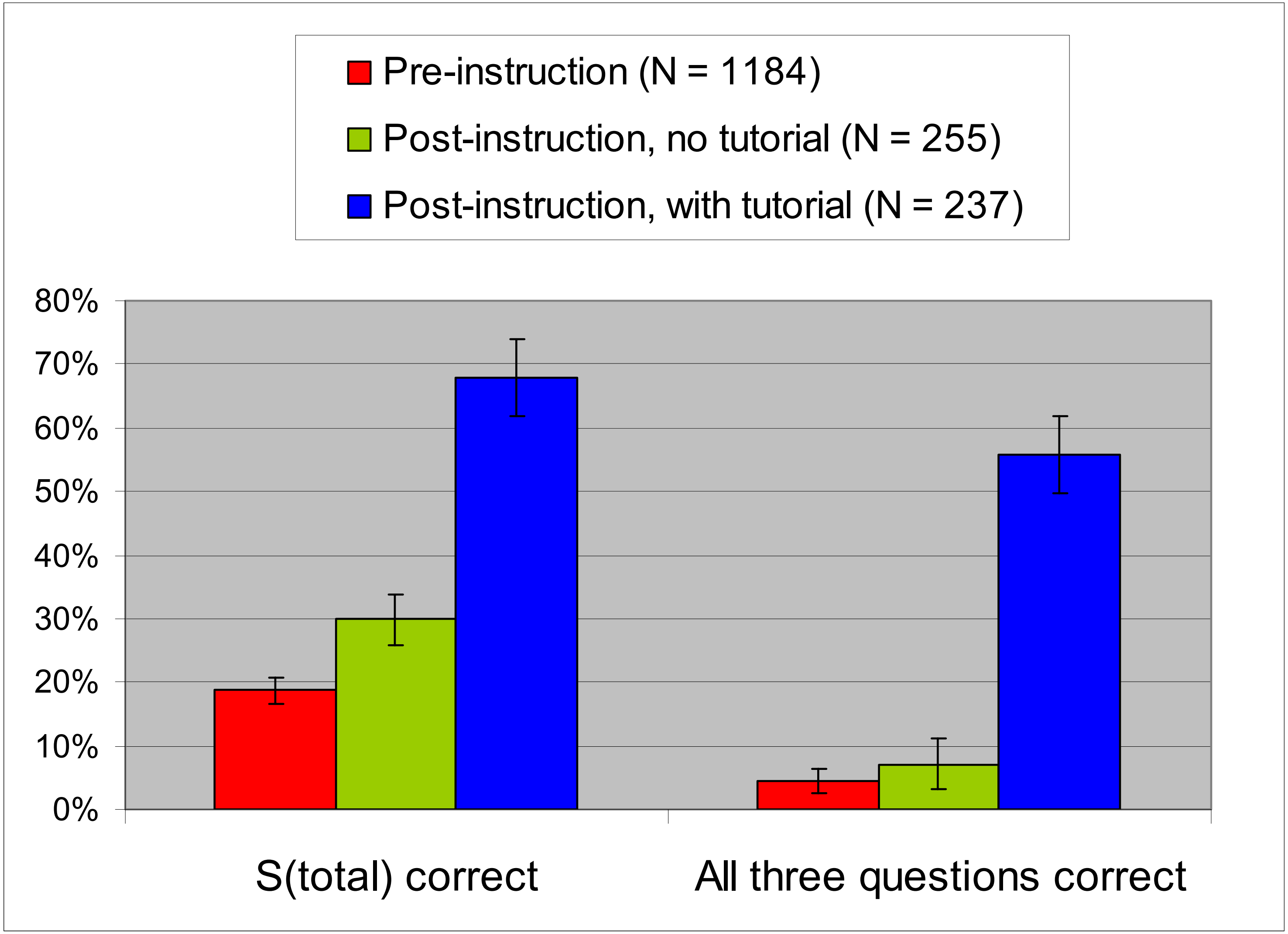
$$\Delta S_{total} = \frac{Q}{T_{cold\ reservoir}} - \frac{Q}{T_{hot\ reservoir}} > 0$$

and that definitions of “system” and “surroundings” are arbitrary

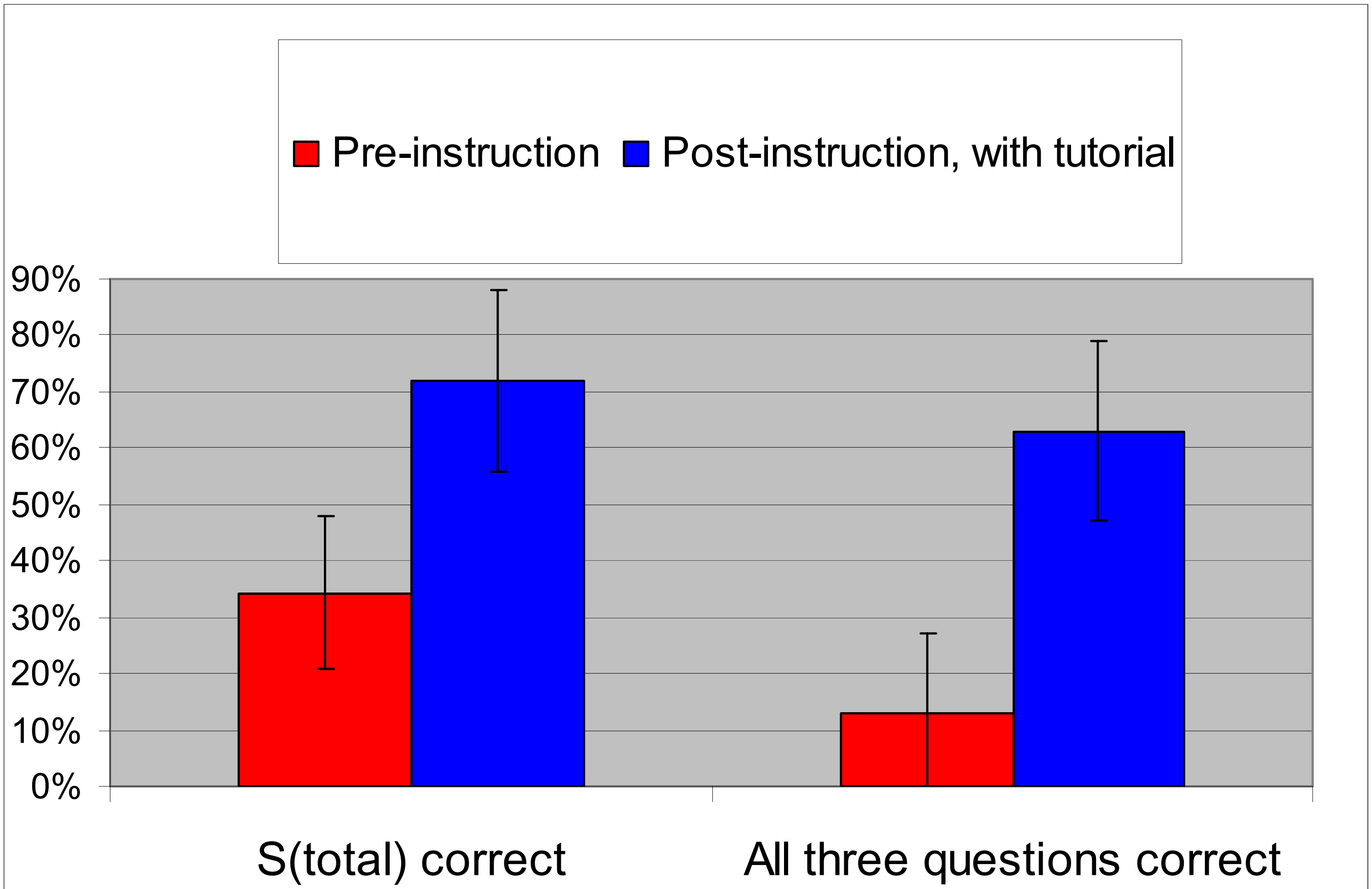
- Examine situation when $\Delta T \rightarrow 0$ to see that $\Delta S \rightarrow 0$ and process approaches “reversible” idealization.

*Preliminary results are promising…*

# Responses to Spontaneous-Process Questions
# **Introductory** Students



# Responses to Spontaneous-Process Questions
## Intermediate Students (*N* = 32, Matched)



# Summary

- Use of research-based materials yielded learning gains in introductory, intermediate, and advanced courses
- Gains in intermediate course relative to *posttests* in introductory course, and to *pretests* in advanced course
- So far, we lack “traditional”-course baseline data in advanced course for comparison