Pedagogical Landscape in Upper-Level Thermal Physics

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Introductory Course (for comparison):

Iowa State (ISU) General Physics with Calculus

- Second-semester calculus-based physics course (mostly engineering students) at Iowa State University.
- Written diagnostic questions administered 1999-2001 (N_{total} = 653) and individual interviews carried out in 2002 (*N* = 32)

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

- 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

Performance on “First-law” Problems

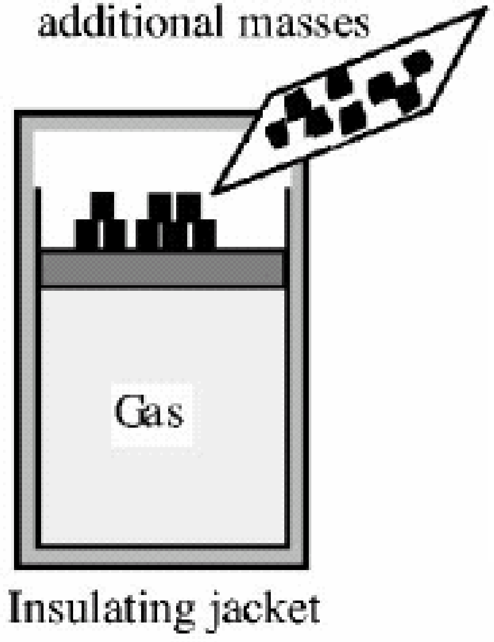
(various tasks to determine relationships among $\Delta E_{internal}$, Q and W during a given process)

- Intermediate students, Pretest: ≈ 15% correct
  - presumably similar to Introductory students
  - strong tendency to assume Q and W are process-independent

- Introductory students (standard instruction),
  Posttest: ≈ 15% correct

- Advanced students, Pretest: ≈ 20-30% correct

[*From Loverude, Kautz, and Heron (2002)*]

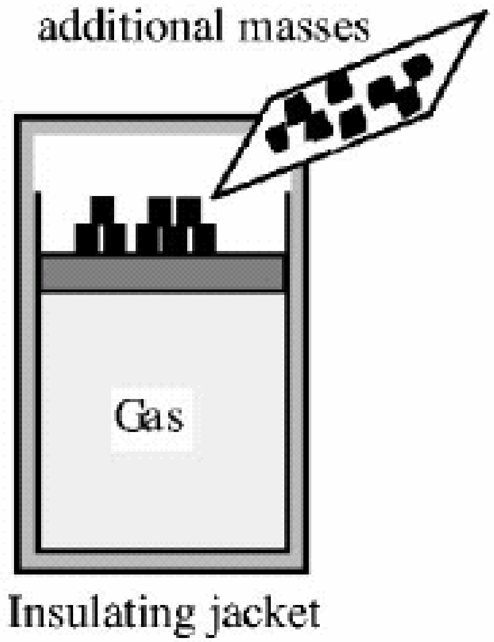


An ideal gas is contained in a cylinder with a tightly fitting piston. Several small masses are on the piston. (See diagram above.)

(Neglect friction between the piston and the cylinder walls.)

The cylinder is placed in an insulating jacket. A large number of masses are added to the piston.

Tell whether the pressure, temperature, and volume of the gas will increase, decrease, or remain the same. Explain.



Correct response regarding temperature (2003 student):

"*Work is done on the gas, but no heat transferred out, so* *<u>T increases</u>*."

Thermal Physics (Pre-instruction)

Correct responses regarding temperature:

2003: 20% (*N* = 14)

2004: 20% (*N* = 19)

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- Advanced students, Pretest: ≈ 20-30% correct
- Intermediate and Advanced students (interactive-engagement instruction), Posttest: ≈ 50-70% correct

Difficulties with Fundamental Concepts are Persistent in the Upper-Level Courses

With intensive instructional effort:

- performance on first-law related problems improved from ≈ 30% correct to 50-70% correct;
- Performance on questions involving cyclic processes improved from ≈ 10% correct to ≈ 35% *consistently* correct in the intermediate course

A Special Difficulty: Free Expansion

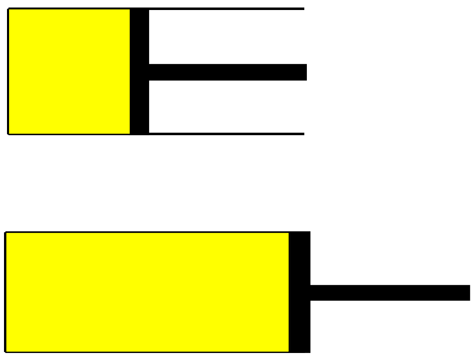
[University of Maine question]

A system consisting of one mole of a monatomic *ideal gas* goes through three different processes as shown below. The initial values of volume (V_o), pressure (P_o), and temperature (T_o) are the same for each process. Also note that the final volume (V_f) is the same for each process, and that Processes #1 and #2 occur very slowly.

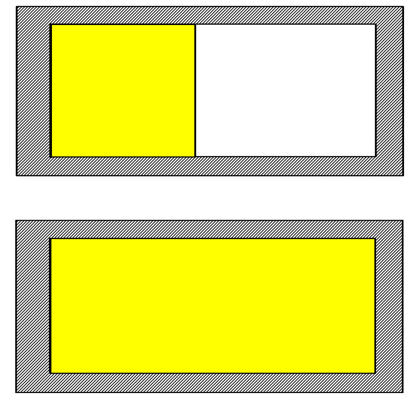
#1: *Isothermal Expansion*

Initial State:

Final State:



#3: *Free Expansion into a Vacuum*



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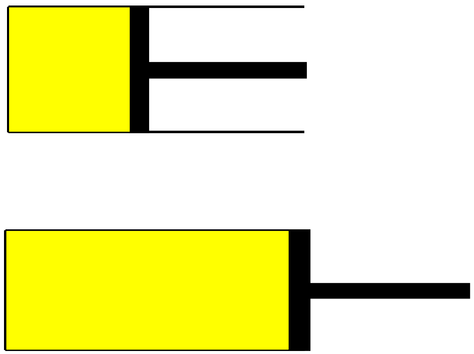

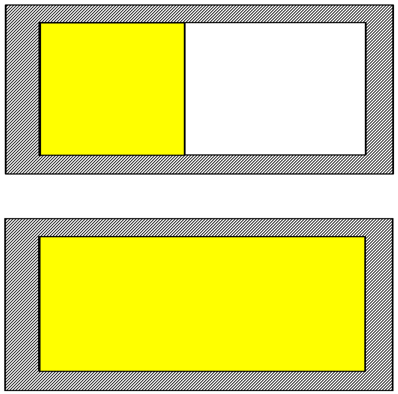

Students were asked to rank magnitudes of Q, W, $\Delta E_{internal}$, and ΔS for #1 and #3

(initial and final states are the same for both)

A Special Difficulty: Free Expansion

- Discussed extensively in class in context of entropy's state-function property
  - group work using worksheets
  - homework assignment
- Poor performance on 2004 final-exam question in advanced course (< 50% correct)
  - frequent errors: belief that temperature or internal energy must change, work is done, etc.
  - difficulties with first-law concepts prevented students from realizing that T does not change

Consistent with U. Maine results

Entropy and Second-Law Questions

- Heat-engine questions
- “Spontaneous-process” question

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Heat-engine Questions

- Most advanced students are initially able to recognize that "perfect heat engines" (i.e., 100% conversion of heat into work) violate second law;
- Most are initially *unable* to recognize that engines with greater than ideal ("Carnot") efficiency also violate second law (consistent with result of Cochran and Heron, 2006);
- After (special) instruction, most students recognize impossibility of super-efficient engines, but still have difficulties understanding cyclic-process requirement of $\Delta S = 0$; many also still confused about $\Delta E_{\mathrm{internal}} = 0$.

Entropy and Second-Law Questions

- Heat-engine questions
- “Spontaneous-process” question

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.

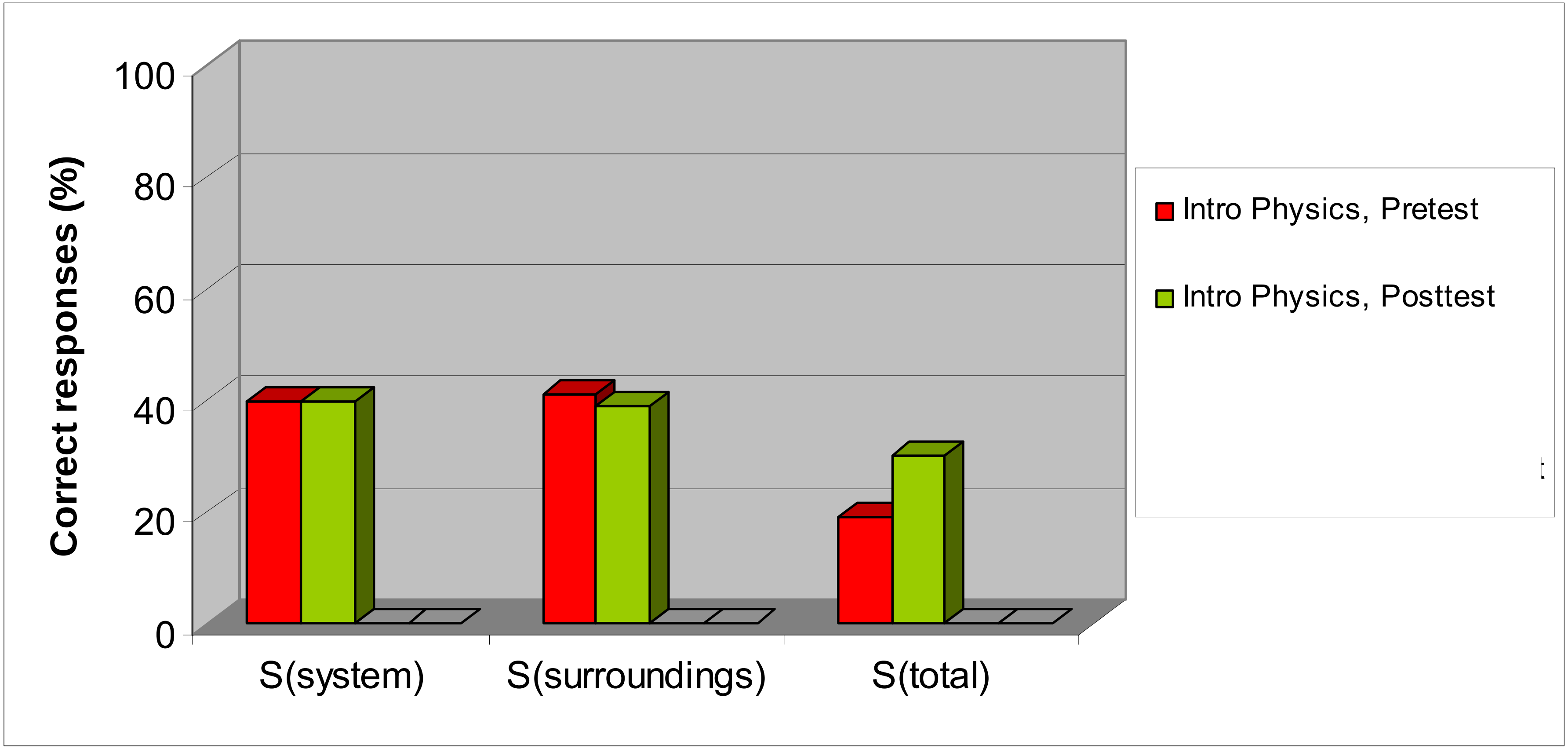
A. During this process, does the entropy of the **system** [S_{system}] *increase*, *decrease*, or *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

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.***

Responses to Spontaneous-Process Questions

Introductory Students (*N* = 1184 pre, 255 post)



Less than 40% correct on each question

Introductory Physics Students' Thinking on Spontaneous Processes

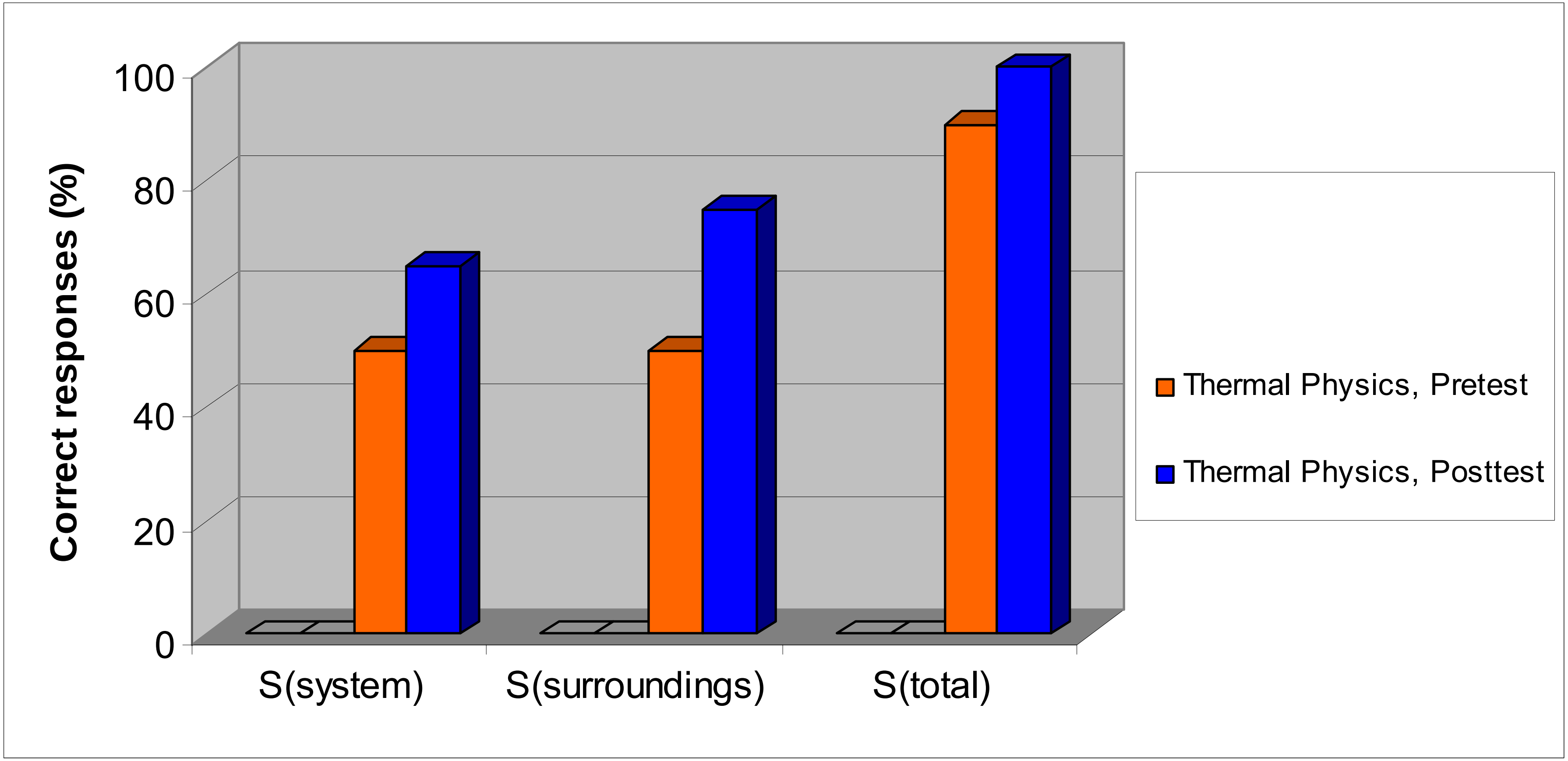
- Tendency to assume that "system entropy" must *always* increase

- Slow to accept the idea that entropy of system plus surroundings ***increases***

  - *Most students give incorrect answers to all three questions*

Responses to Spontaneous-Process Questions

Advanced Students (N = 12)



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

Summary

- Use of research-based materials yielded learning gains in introductory, intermediate, and advanced courses

- Difficulties with fundamental concepts persist for many students despite special instruction