Student understanding of entropy and the second law of thermodynamics in an introductory physics course *

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Thermodynamics Project

- Objectives: (a) To investigate students' qualitative understanding of entropy, the second law of thermodynamics, and related topics in a second-semester calculus-based physics course*; (b) To develop research-based curricular materials
- In collaboration with John Thompson at the University of Maine on investigations in an upper-level undergraduate thermal physics course

**Previous work on related topics: M. Cochran (2002)*

Pretest - Fall 2004

Second semester calculus-based introductory physics course

≈ 90% of students have taken high school physics

≈ 90% have completed college chemistry course where entropy is discussed

- A series of written questions was administered before instruction to assess students' reasoning regarding entropy and the second law of thermodynamics
  - Question 3: Change in entropy during a spontaneous process

Spontaneous Process Question

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

Spontaneous Process Question

3. 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 Entropy Question

2004 Introductory Physics

Pretest Results

(*N*=289)

	Increase	Decrease	Remain the same	Not determinable
S_{system}	29%	19%	10%	39%
$S_{surroundings}$	24%	18%	11%	43%
S_{total}	15%	2%	71%	8%

Pretest Results

[$N = 289$]

- 71% of students said that the total entropy (*system* + *surroundings*) would remain the same
- 31% of student responses were consistent with some sort of "conservation" principle
  - e.g., A. Increases, B. Decreases, and so C. Stays the same

Pretest Results

[$N = 289$]

- 15% of students indicated that the total entropy (*system* + *surroundings*) would increase

BUT…

- Only 4% gave a correct response for all three parts

Final Exam Question

[$N = 539$]

A question similar to the pretest was administered on the final exam.

Final Exam Question

[$N = 539$]

A subsystem A is in thermal contact with its environment B, which together comprise an isolated system. Consider the following situations:

I. Entropy of system increases by 5 J/K; entropy of the environment decreases by 5 J/K.

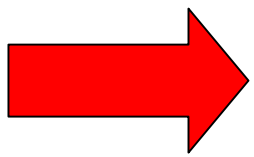
II. Entropy of system increases by 5 J/K; entropy of the environment decreases by 3 J/K.

III. Entropy of system increases by 3 J/K; entropy of the environment decreases by 5 J/K.

IV. Entropy of system decreases by 3 J/K; entropy of the environment increases by 5 J/K.

Which of the above four situations can actually occur in the real world?

A. I only
B. II only
C. III only
D. II and III only
E. II and IV only



A. 54%
B. 5%
C. 7%
D. 4%
E. 30%

Pre- and Post-Instruction Comparison

- The results of the final-exam question are most directly comparable to the responses on part C of the pretest:

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.***

S_{TOT} stays the same	
Pretest	Final Exam
71%	54%

S_{TOT} increases	
Pretest	Final Exam
15%	**30%**

Correct answer

Interview Data

[Fall 2004: $N = 8$; Spring 2005: $N = 8$]

- Hour-long interviews with student volunteers
  - conducted after instruction on all relevant material was completed
- Students asked to respond to several questions regarding entropy and the second law

Interview Results

- Nearly half asserted that total entropy could either increase ***or*** remain the same during spontaneous process

➡ Response options altered for Spring 2005 to allow for “increase or remain the same” response

Final Exam Question - Spring 2005

A subsystem *A* is in thermal contact with its environment *B* and they together comprise an isolated system that is undergoing an irreversible process. Consider the following situations:

I. Entropy of system increases by 5 J/K; entropy of the environment decreases by 5 J/K.

II. Entropy of system increases by 5 J/K; entropy of the environment decreases by 3 J/K.

III. Entropy of system increases by 3 J/K; entropy of the environment decreases by 5 J/K.

IV. Entropy of system decreases by 3 J/K; entropy of the environment increases by 5 J/K.

Which of the above four situations can actually occur ?

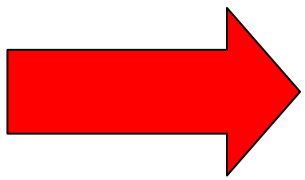
A. I only

B. II only

C. III only

D. II and IV only

E. I, II, and IV only



A. 36%

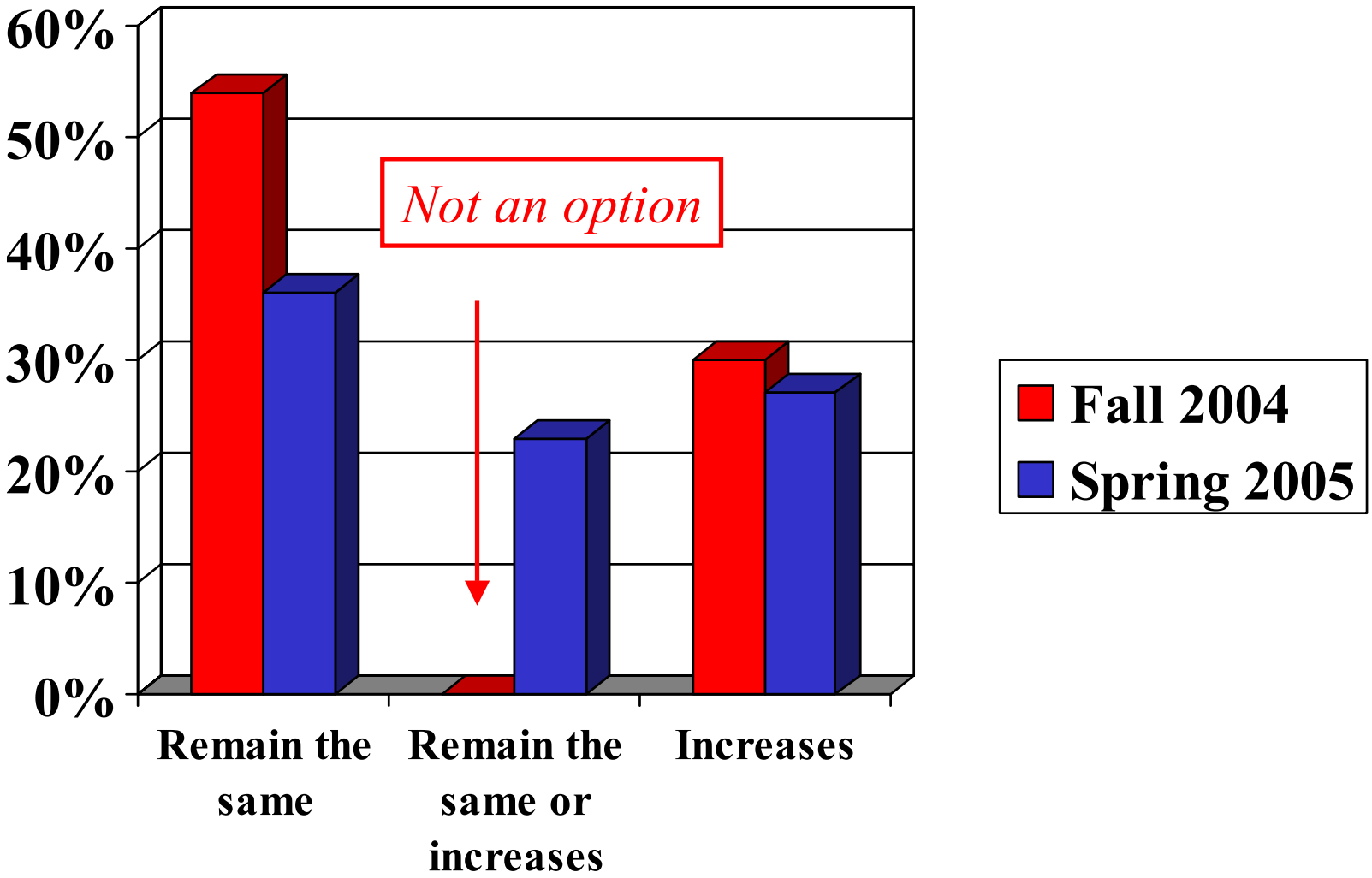
B. 12%

C. 2%

D. 27%

E. 23%

Posttest responses



Conclusions

- Students appear to have an idea that the total entropy during a natural process remains unchanged ("conserved"?)
- Student confusion concerning the relationships among S_{system}, $S_{surroundings}$, and S_{total} during a naturally occurring process seems resistant to instruction