# Investigating student understanding of entropy and second law of thermodynamics*

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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)*

# Context of Investigation

*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
  - 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.

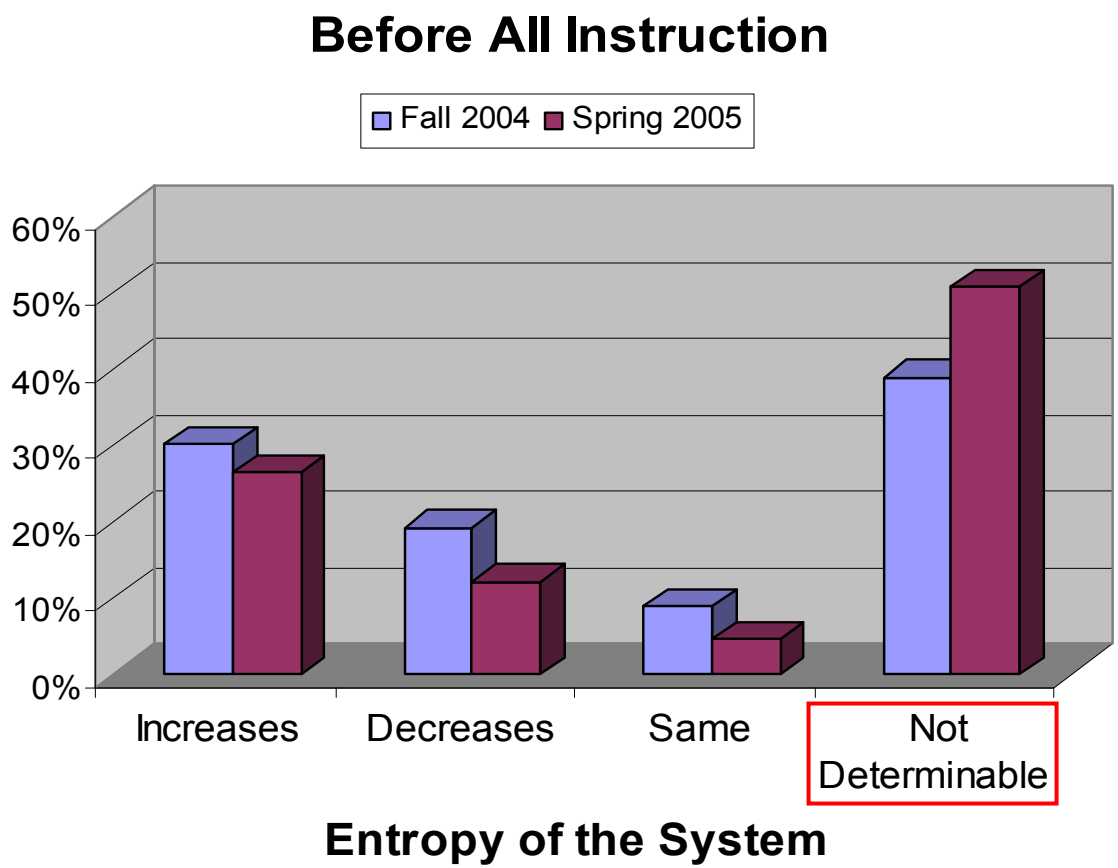
A. During this process, does the entropy of the **system** [$S_{system}$] *increase*, *decrease*, or *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

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

Fall 2004 ($N = 406$) & Spring 2005 ($N = 132$)



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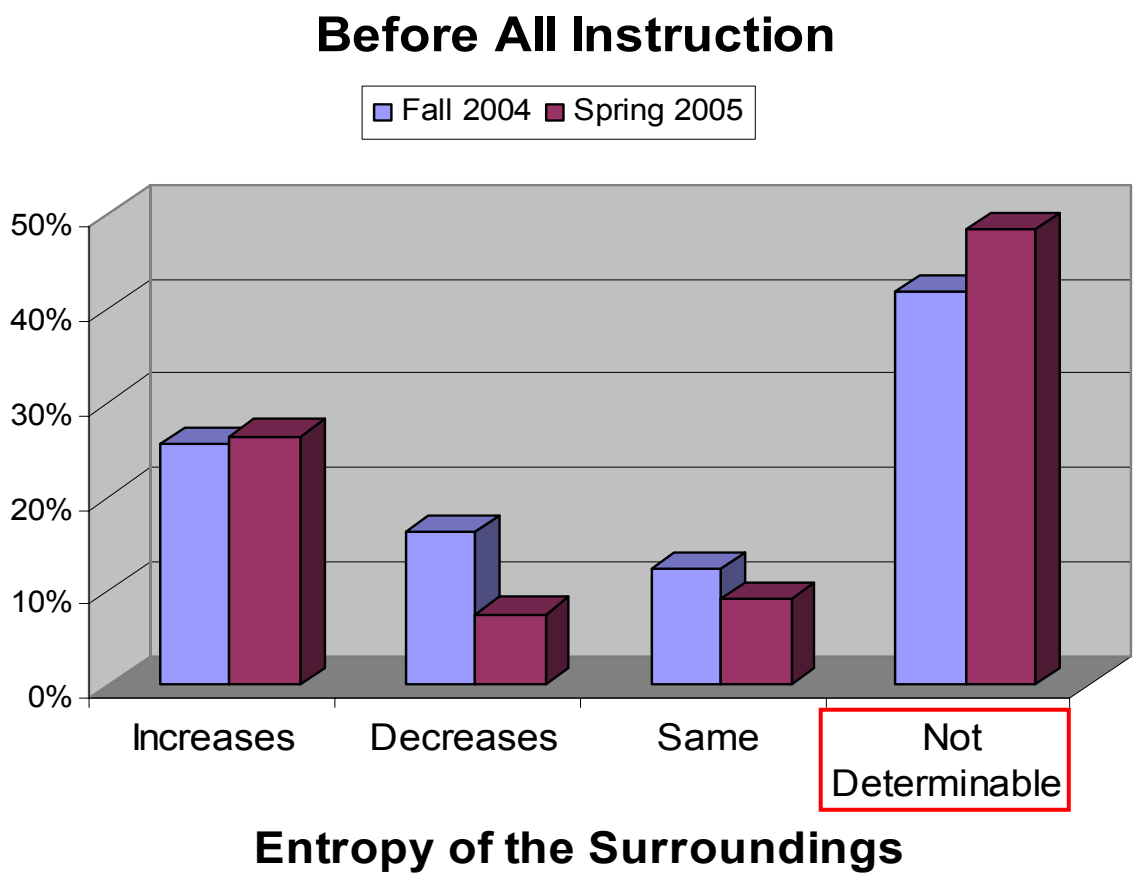

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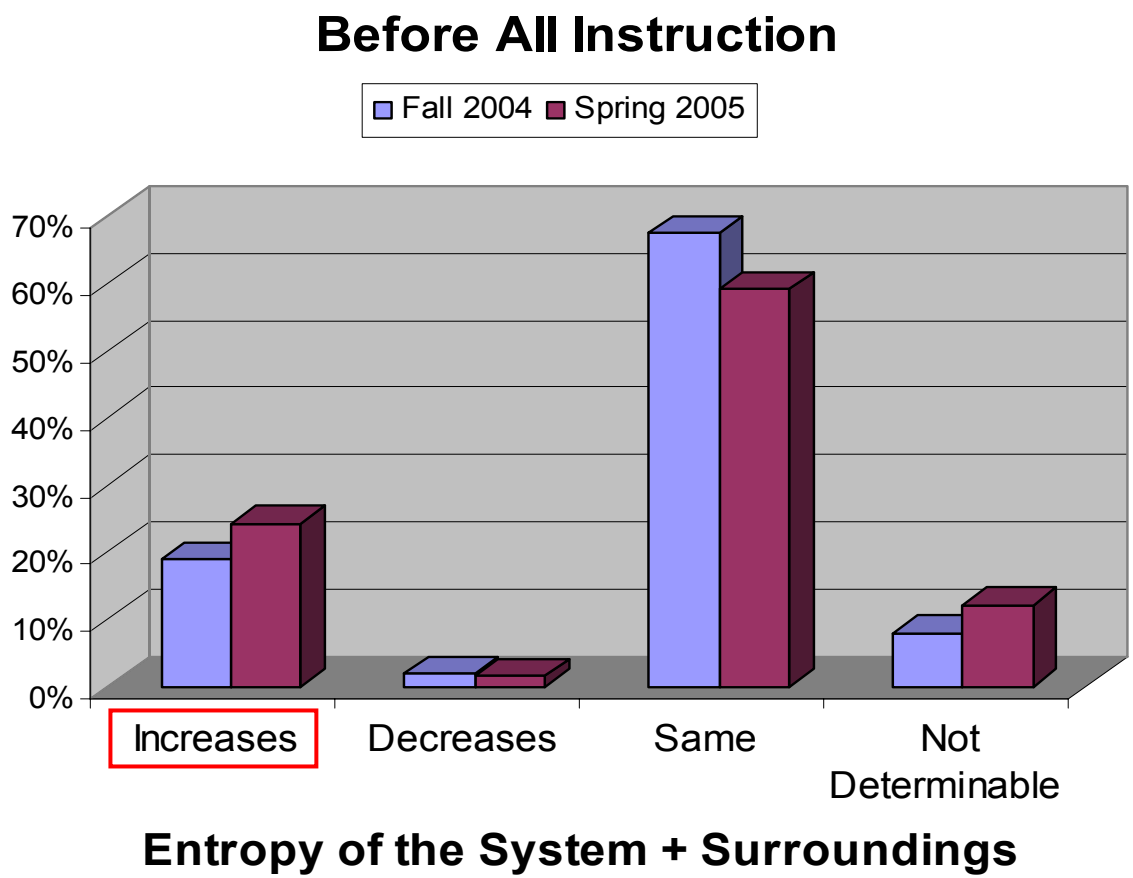


# Pre-Instruction Results

Fall 2004 & Spring 2005 ($N = 538$)

- 48% of student responses were consistent with some sort of "conservation" principle, for example:
  - A. increases [*decreases*], B. decreases [*increases*], and so C. stays the same
  - A. not determinable, B. not determinable, but C. stays the same because entropy [*energy, matter, etc.*] is conserved
- Only 4% gave a correct response for all three parts

# Post-Instruction Question

## Final Exam, Fall 2004 ($N = 539$)

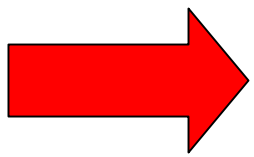
A subsystem $A$ is in thermal contact with its environment $B$, which together comprise an isolated system. Consider the following situations:

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

***$S_{TOT}$ remains the same***



***$S_{TOT}$ increases* (Correct)**

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 |
| **67%** | **54%** |

| $S_{TOT}$ increases | |
|---|---|
| Pretest | Final Exam |
| **19%** | **30%** |

***Correct answer***

# Interview Data

Fall 2004 & Spring 2005 ($N = 16$)

- 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

➡ Multiple-choice options altered for Spring 2005 to allow for "increase or remain the same" response

# Post-Instruction Question

## Spring 2005 ($N = 386$)

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 ?

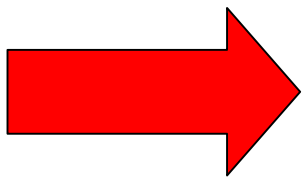
A. I only

B. II only

C. III only

D. II and IV only

E. I, II, and IV only



***$S_{TOT}$ increases* (Correct)**

***$S_{TOT}$ remains the same or increases***

A. 36%

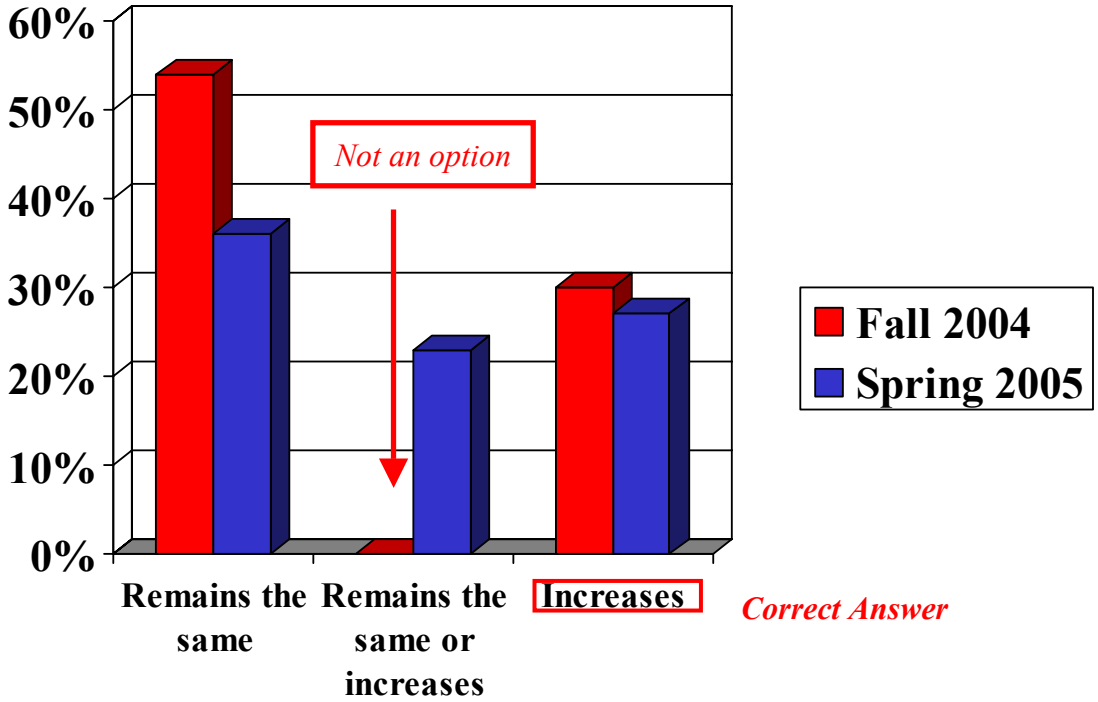
B. 12%

C. 2%

D. 27%

E. 23%

# Post-Instruction responses for $S_{TOT}$




Allowing for entropy to either remain the same or increase appears to more accurately reflect student thinking

# Is the Question too General?

## 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.***

# Entropy Question in Context

## Spring 2005

3. An object is placed in a thermally insulated room that contains air. The object and the air in the room are initially at different temperatures. The object and the air in the room are allowed to exchange energy with each other, but the air in the room does not exchange energy with the rest of the world or with the insulating walls.

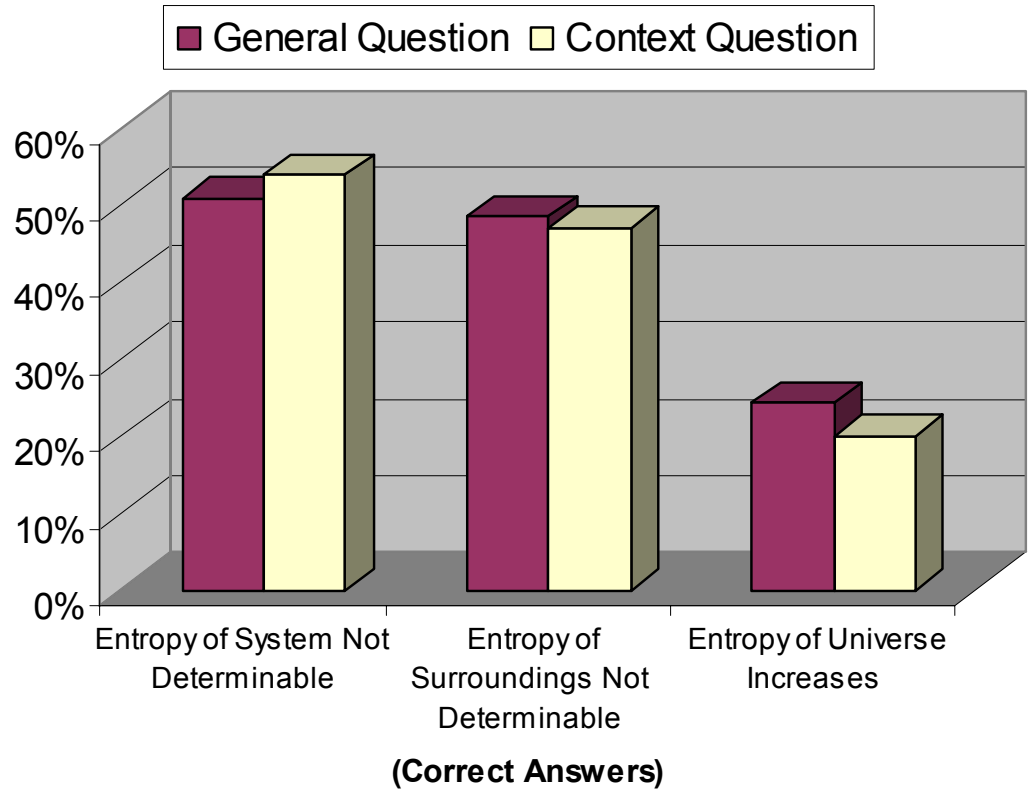
A. During this process, does the entropy of the **object** [$S_{object}$] *increase*, *decrease*, *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

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

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

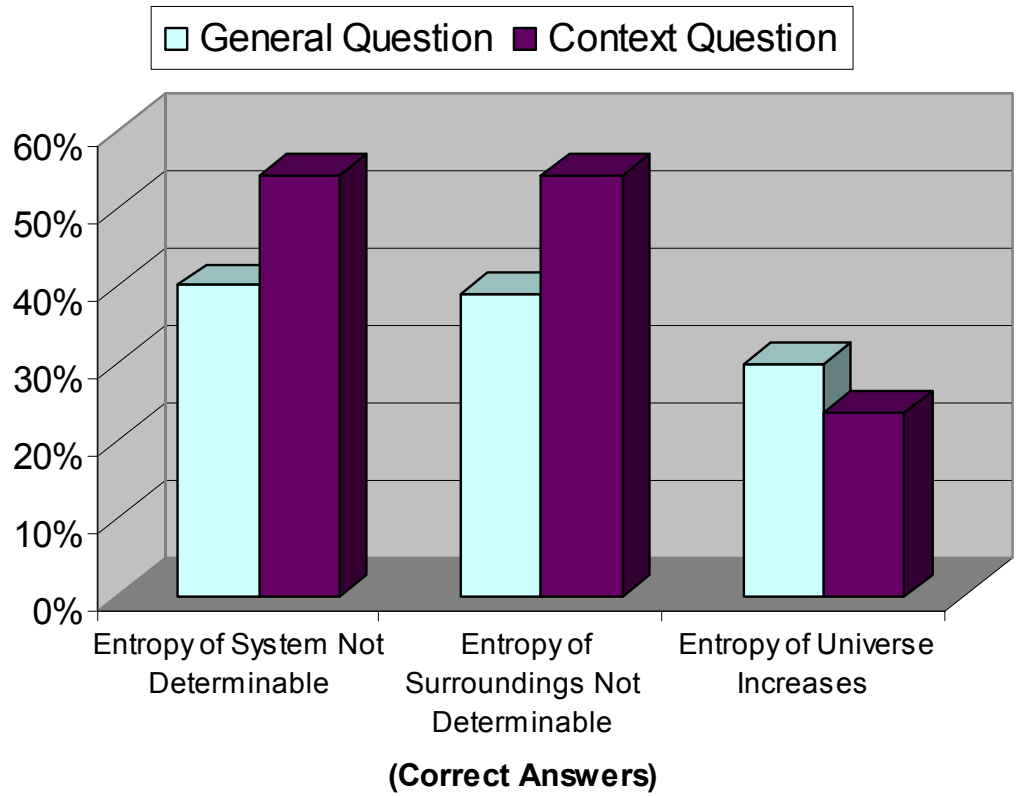
D. During this process, does the entropy of the **universe** [$S_{universe}$] *increase*, *decrease*, *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

# General vs. Context (Pre-Instruction)




• Students' correct responses initially show consistency in and out of context

# General vs. Context (Post-Instruction)




- Student responses initially show consistency in and out of context
- After instruction students seem willing to apply different rules for a problem in context

# General and Context Comparison

Placing the question in context:

- does not yield a higher proportion of correct answers concerning entropy of the universe, pre- or post-instruction
- *does* yield a higher proportion of correct answers concerning entropy of the system and surroundings, post-instruction only

# 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
- Questions within a concrete context appear to yield some improved student responses, but difficulties remain