“Is entropy conserved?” Student understanding of entropy and the second law of thermodynamics*

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*Supported in part by NSF grants #DUE-9981140 and #PHY-0406724.

Context of Investigation

- Part of a broad study of student learning of thermodynamics in a second-semester calculus-based physics course at Iowa State University
- In collaboration with John Thompson at the University of Maine and David Meltzer at the University of Washington

Pre-instruction Testing

- Initial testing took place before all instruction on entropy and the second law of thermodynamics

“General-Context” 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.***

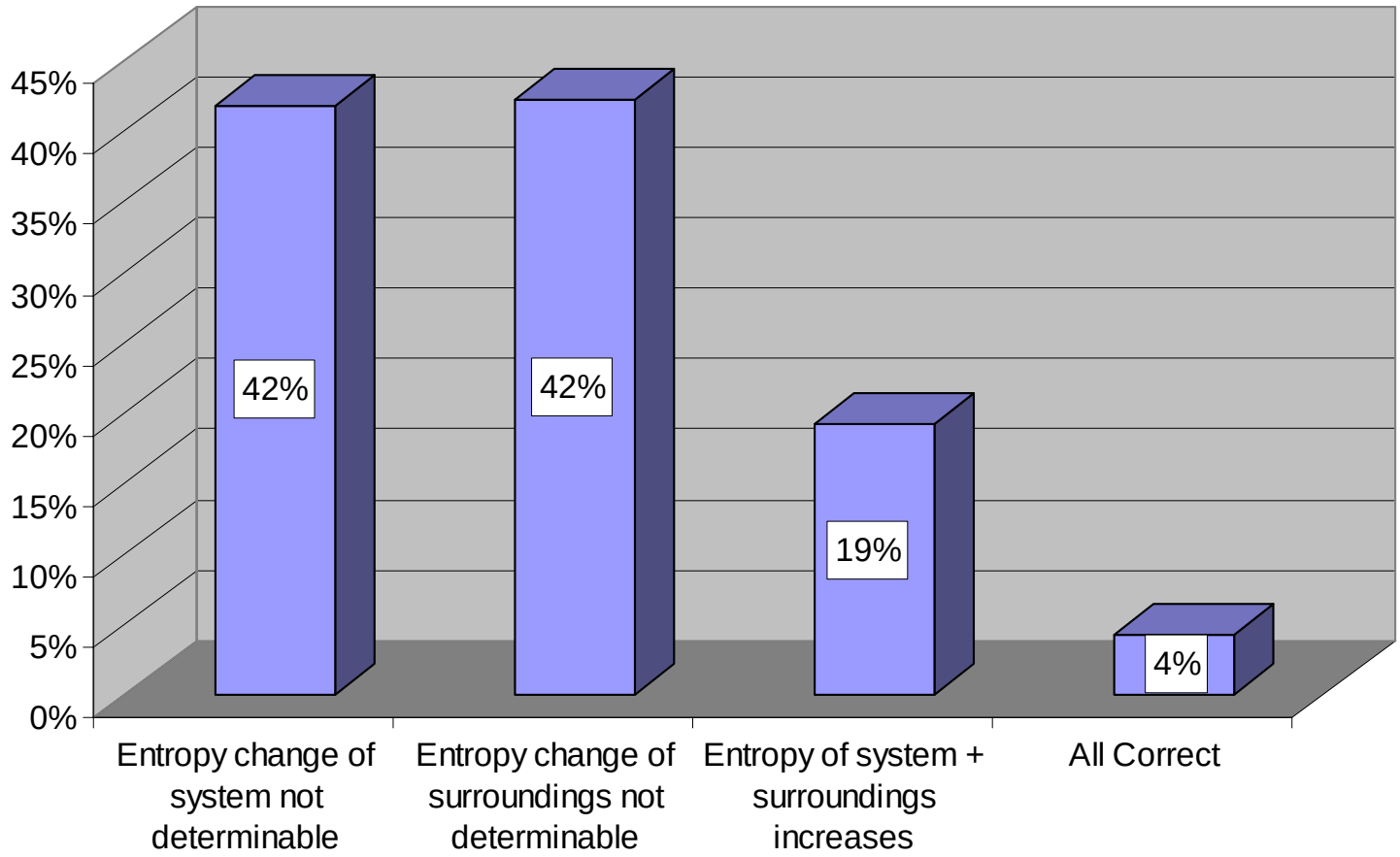
B. During this process, does the entropy of the **surroundings** [$S_{surroundings}$] *increase*, *decrease*, or *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

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.***

Pre-instruction Data

Correct Responses

Fall 2004, Spring 2005, Fall 2005, Spring 2006 (*N* = 1184)



“Concrete-Context” Question

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.***

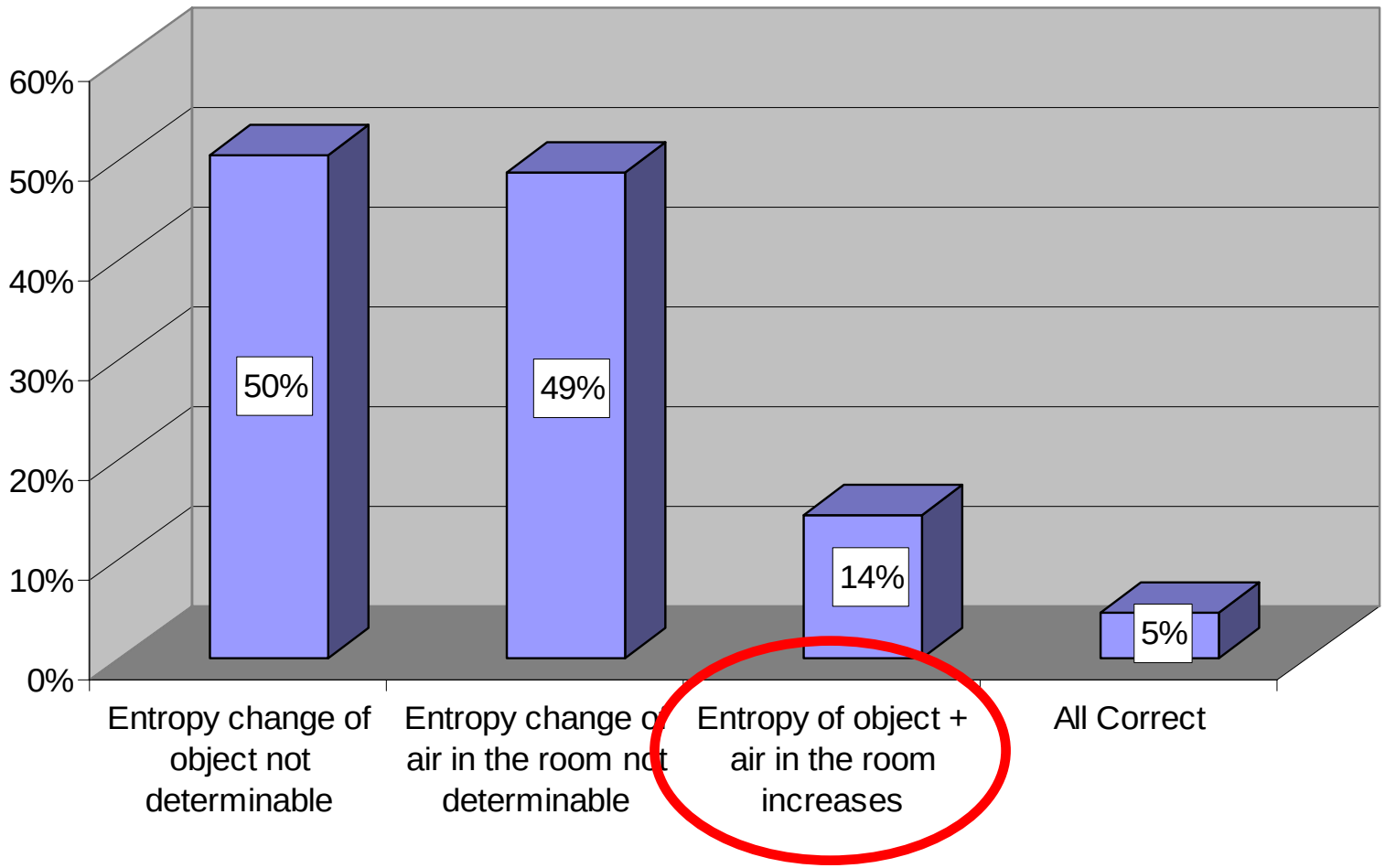
B. During this process, does the entropy of the **air in the room** [S_{air}] *increase*, *decrease*, *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

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.***

Pre-instruction Data

Correct Responses

Spring 2005, Fall 2005, Spring 2006 (*N* = 609)



“Total entropy” responses

- Nearly three-quarters of all students responded that the “total entropy” (“system plus surroundings” or “object plus air”) remains the same.
- We can further categorize these responses according to the ways in which the other two parts were answered
- 90% of these responses fall into one of two specific conservation arguments:

Conservation Arguments

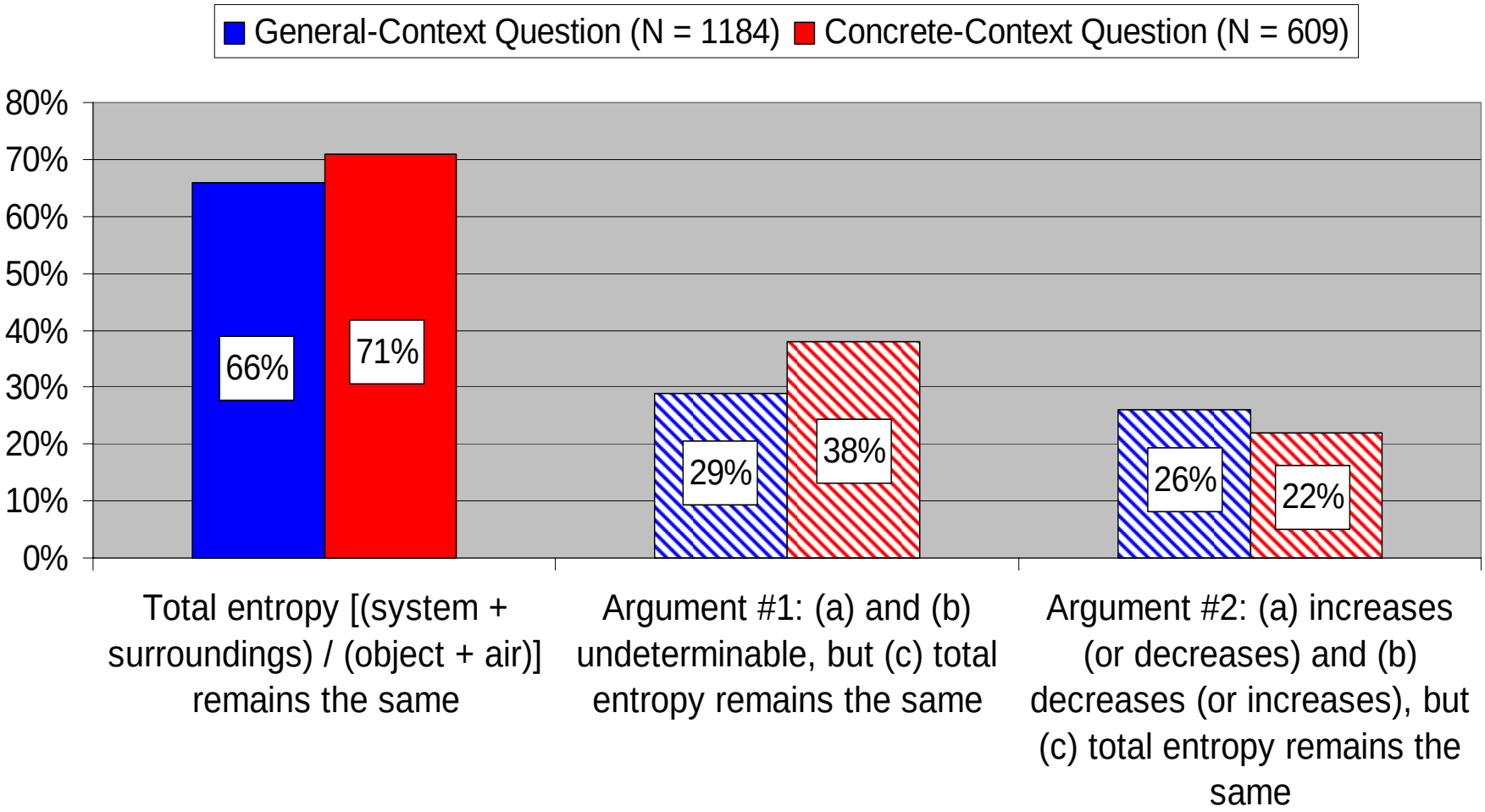
Conservation Argument #1

S_{System} not determinable,
$S_{Surroundings}$ not determinable, and
$S_{System} + S_{Surroundings}$ stays the same

Conservation Argument #2

S_{System} increases [*decreases*],
$S_{Surroundings}$ decreases [*increases*], and
$S_{System} + S_{Surroundings}$ stays the same

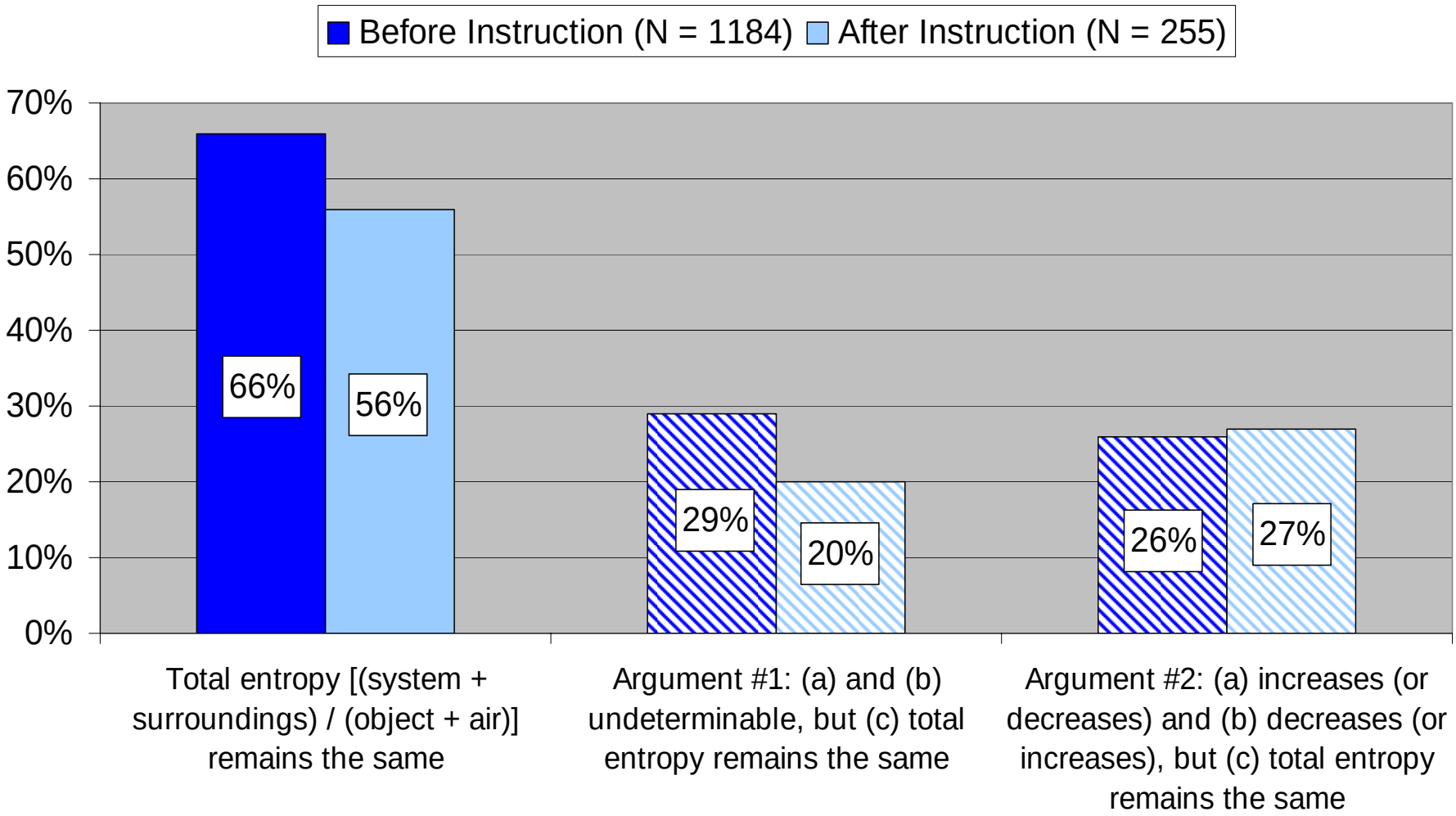
Pre-Instruction Responses Consistent with Entropy "Conservation"



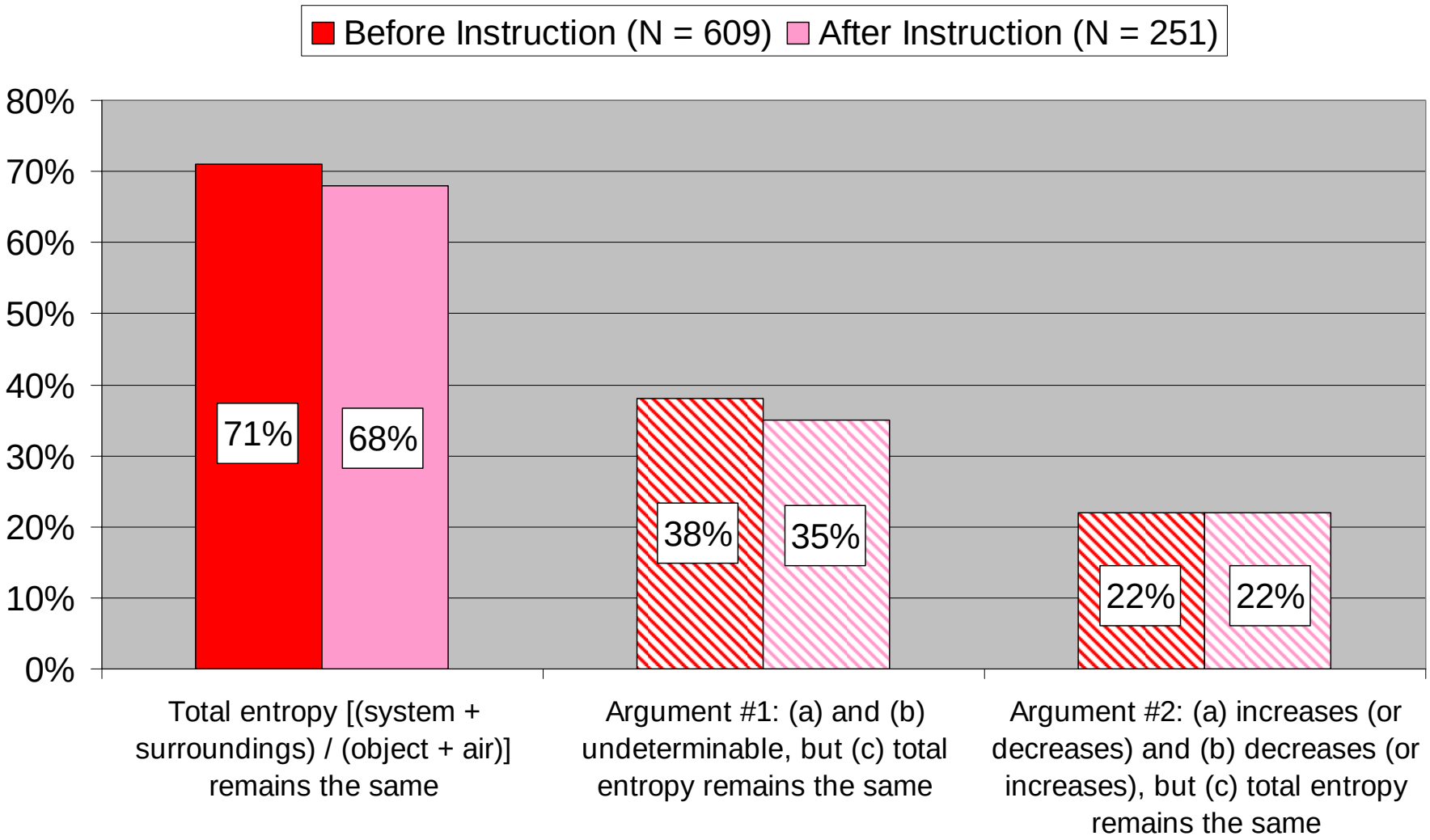
Pre- vs. Post-instruction

- Post-instruction testing occurred after all instruction on thermodynamics was complete

General-Context Question Pre-Instruction vs. Post-Instruction



Concrete-Context Question, Pre-Insruction vs. Post-Instruction



Conclusions

Both before and after instruction…

In both a general and a concrete context:

- Students have significant difficulty applying fundamental concepts of entropy
- More than half of all students utilized inappropriate conservation arguments in the context of entropy