What's Entropy? Student Understanding of Thermodynamics in an Introductory Physics Course*

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Thermodynamics Project

Objective: To investigate students' qualitative understanding of entropy, the second law of thermodynamics, and related topics in introductory calculus-based physics and develop curricular materials based on this research

- In collaboration with John Thompson at the University of Maine and David Meltzer at the University of Washington
- Substantial work in this area has been conducted by Matt Cochran at the University of Washington

Context of Investigation

Second semester calculus-based introductory physics course

- $\approx$ 90% of students have taken high school physics
- $\approx$ 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

"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.

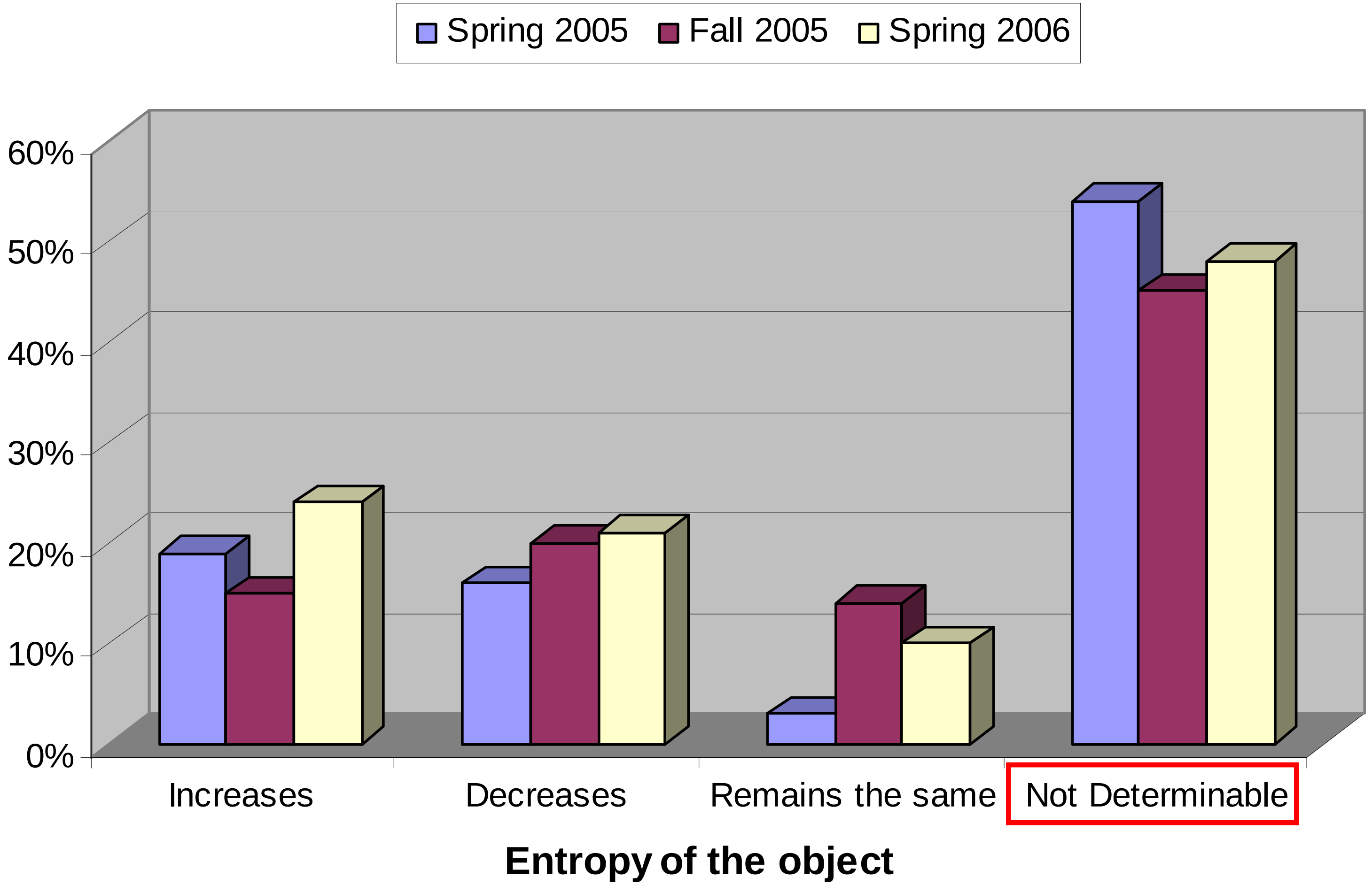
A. During this process, does the entropy of the **object** [S_{object}] *increase*, *decrease*, *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

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.***

Since we don't know the direction of heat transfer, we can't determine whether the object or the air in the room increases or decreases in entropy.

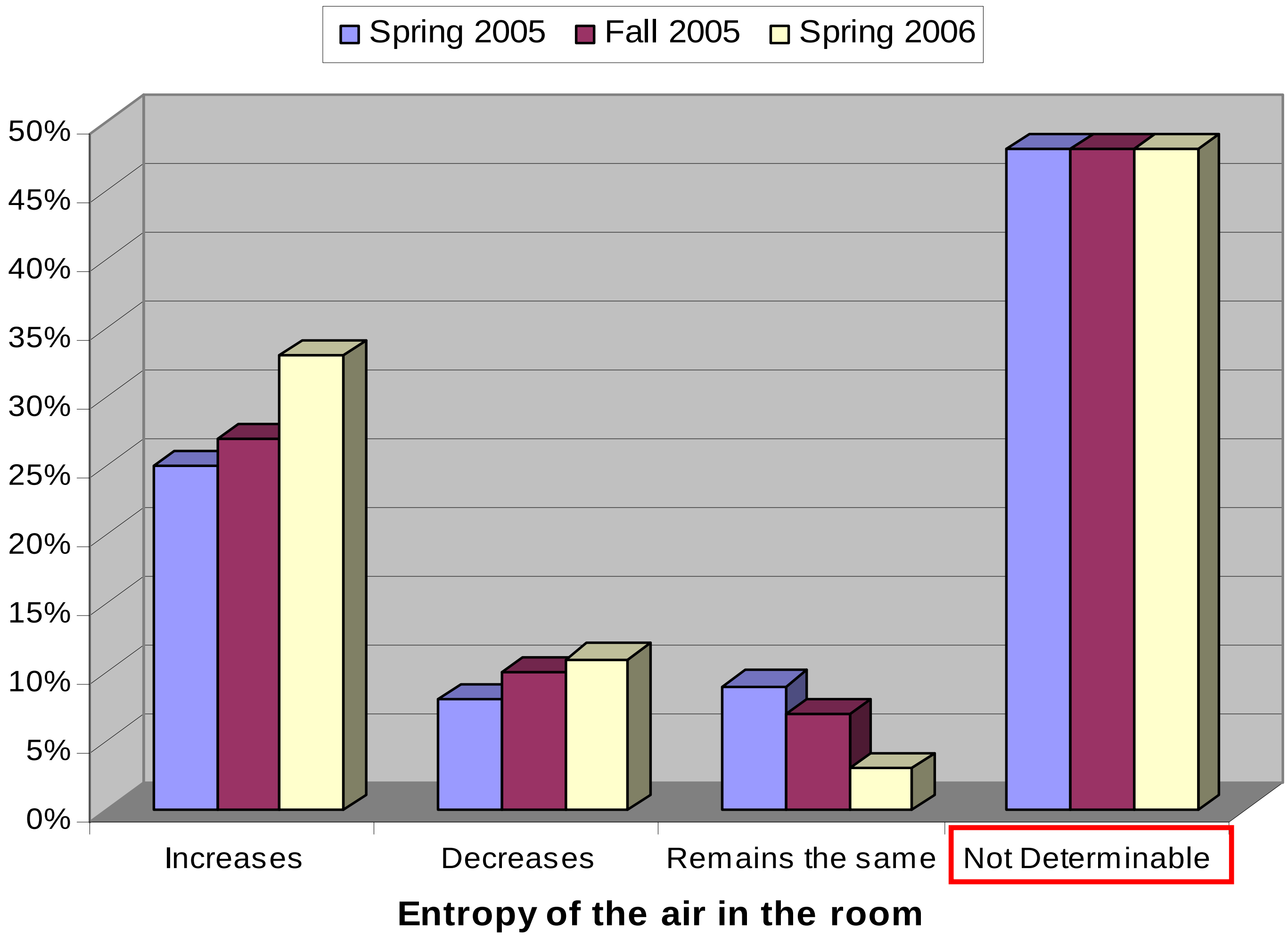
Pre-Instruction Results - Entropy of object

Spring 2005 (*N* = 155), Fall 2005 (*N* = 207), Spring 2006 (*N* = 75)



Pre-Instruction Results – Entropy of air in room

Spring 2005 (*N* = 155), Fall 2005 (*N* = 207), Spring 2006 (*N* = 75)



Student explanations

Total Sample *N* = 437

≈ 50% of students gave a correct response ("not determinable")

≈ 30% gave a correct response with acceptable explanation

Example of acceptable student response:

"[not determinable because] depends on which is the higher temp. to determine increase or decrease"

Student explanations

Total Sample *N* = 437

Tendency to *assume* direction of heat flow for "system"

- Cited as justification for claiming object (or air) entropy increases (or decreases)
- About 60% of all increase/decrease responses were based on this assumption

Concrete Context Question

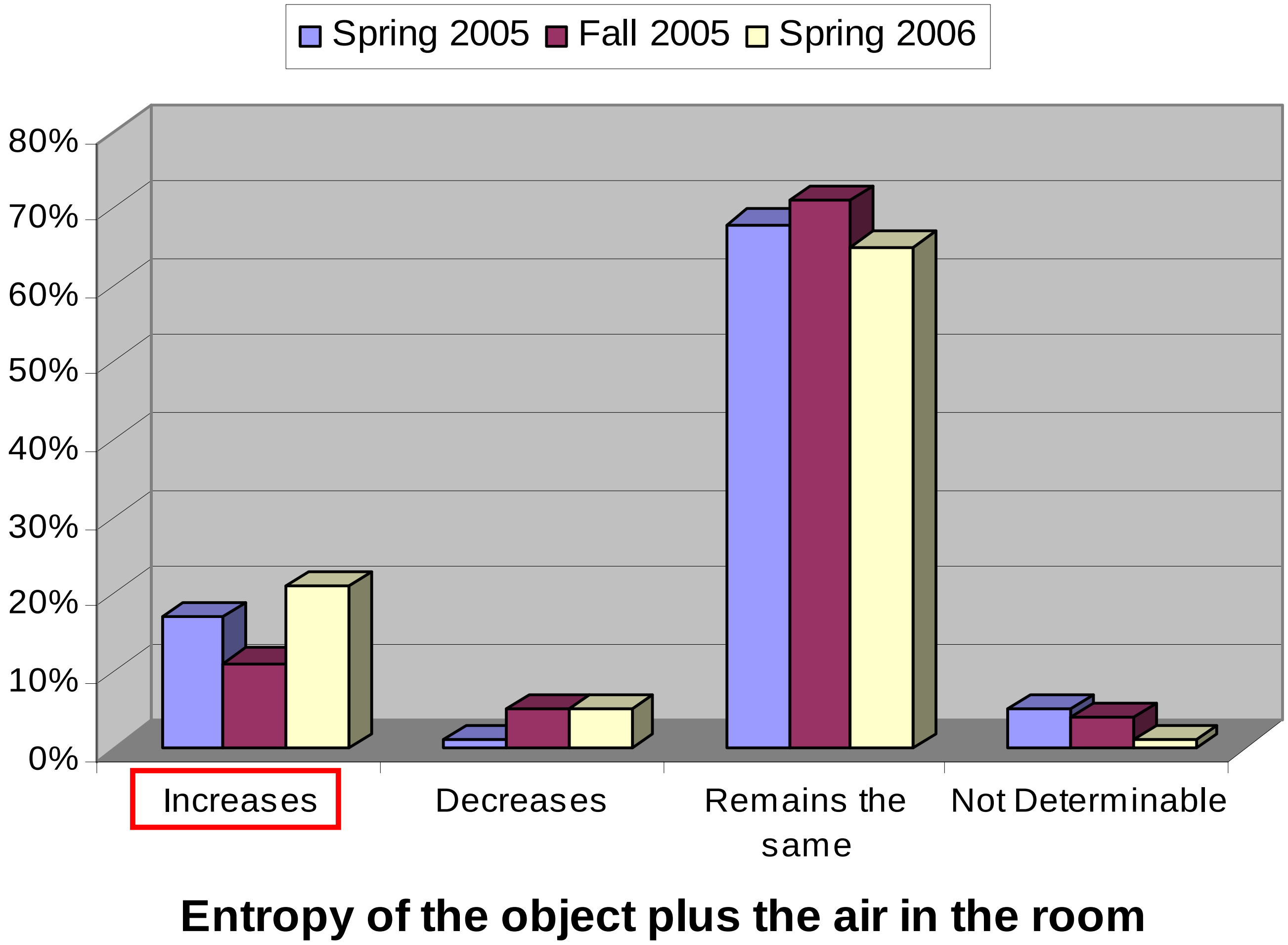
An object is placed in a thermally insulated room that contains air. The object and the air in the room are initially at different temperatures. The object and the air in the room are allowed to exchange energy with each other, but the air in the room does not exchange energy with the rest of the world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

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.***

Pre-Instruction Results – Object + Air

Spring 2005 (*N* = 155), Fall 2005 (*N* = 207), Spring 2006 (*N* = 75)



Object + Air Explanations

Entropy remains the same because…

- energy or entropy is “conserved”
- system is isolated by walls (or it’s a “closed system”)
- total entropy of object and air in room doesn’t change

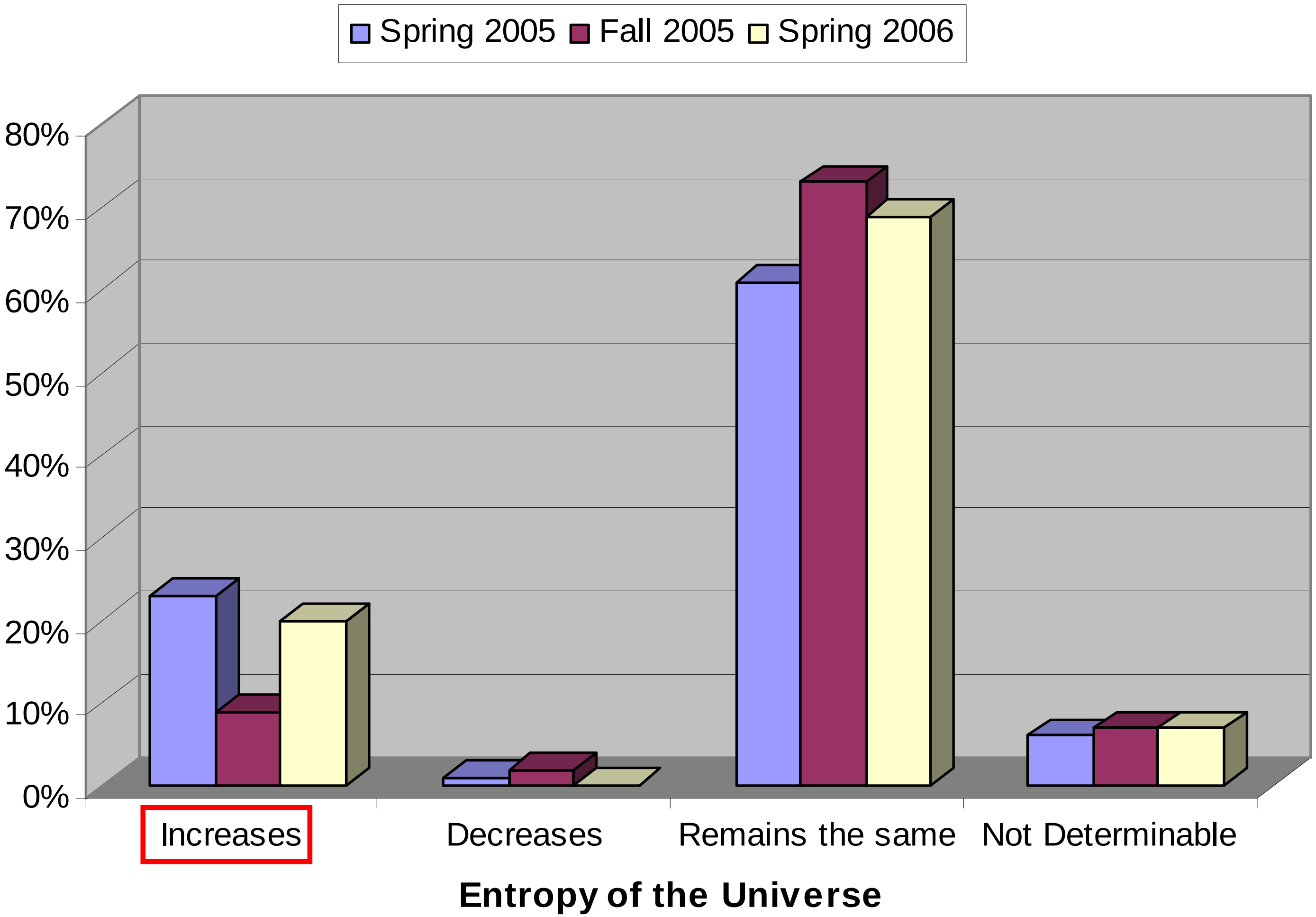
Entropy of Object + Air Conserved

~50% of all 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

Pre-Instruction Results – Universe

Spring 2005 (*N* = 155), Fall 2005 (*N* = 207), Spring 2006 (*N* = 75)



Entropy of the Universe Explanations

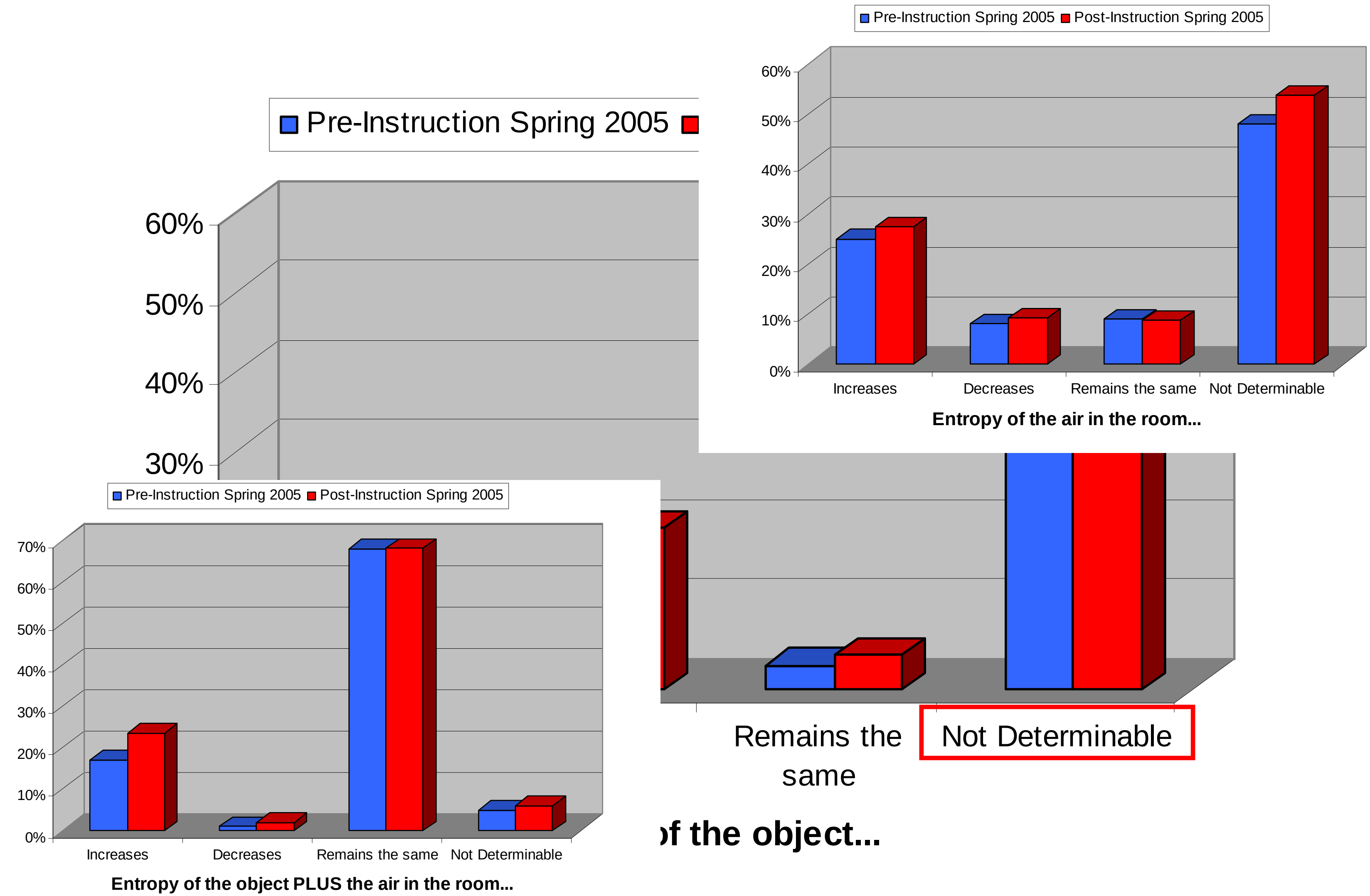
Entropy remains the same because…

- process doesn't affect the universe due to insulation
  – consistent with "universe" being defined as only that which is *outside* the room
- entropy is constant
- universe is too large to change in entropy

Pre- and Post-Instruction Assessment

Spring 2005, attempted modified instruction using a tutorial-style worksheet focusing on the state-function property of entropy

Pre- v. Post-Instruction Data

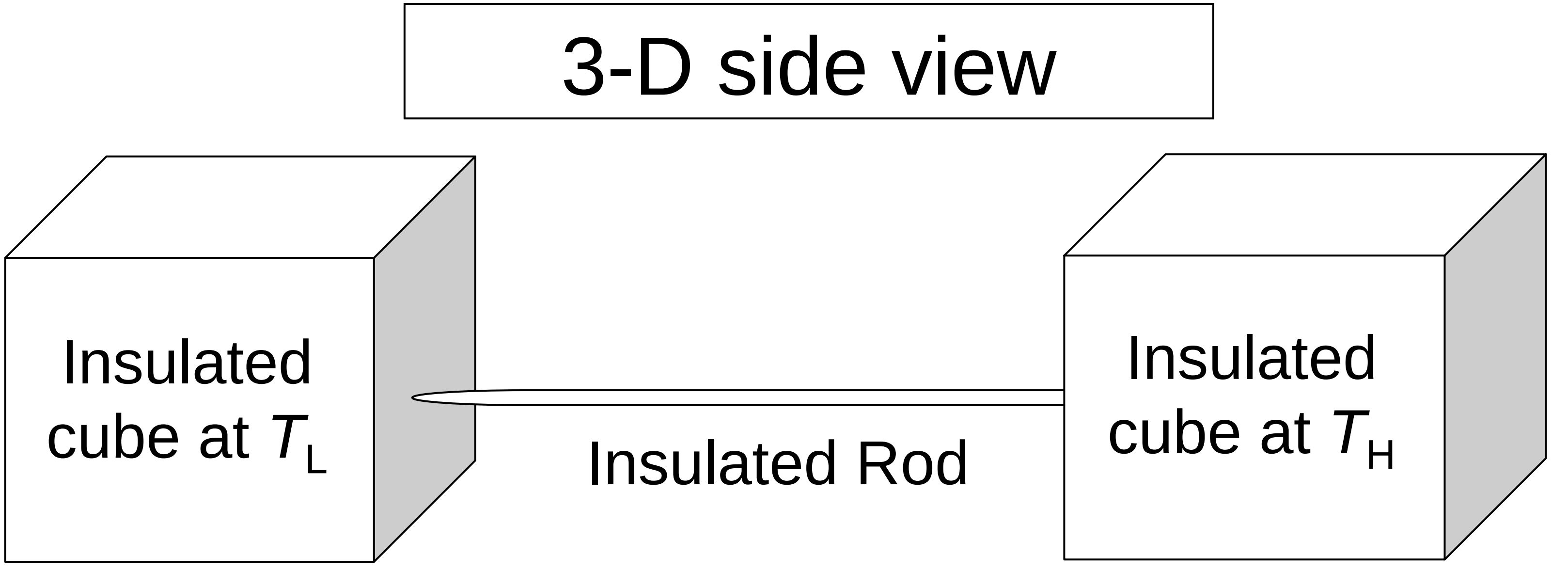


Tutorial Strategy: conceptual goals

Build off of correct student ideas (e.g., heat flow direction)

- For any real process, the entropy of the universe increases (i.e., entropy of the universe is ***not*** conserved).
- Entropy of a particular system can decrease, so long as the surroundings of that system have a larger increase in entropy.
- Universe = system + surroundings; that is, “surroundings” is defined as everything that isn’t the system.
- Reversible processes are idealizations, and don’t exist in the real world; however, for these ideal cases, total entropy remains the same.

Tutorial Design



- Identify Q_H, Q_L, and discuss energy conservation
- Calculate ΔS_H, ΔS_L, compare the magnitudes, and discuss entropy conservation

Conclusions

- Observed persistent pattern of student ideas related to spontaneous processes.
- Initial attempts at tutorial worksheets were ineffective at addressing certain student difficulties.
- New worksheet created from ongoing research currently undergoing classroom testing.

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