# Student Conceptions of Entropy in an Introductory Physics Course

Warren Christensen
Iowa State University

April 12, 2007

# Outline

- Discipline-based Education Research
- Theoretical Background
- Entropy in Spontaneous Processes
  - General context question
  - Concrete context question
  - Tutorial development and implementation
- Conclusions

# Traditional Education Reform

- Traditional Educational Reform
  - I noticed something in my class.
  - I made an adjustment to address the problem.
  - The students seem to like it.
- Traditional measures of success
  - Instructor perception of student understanding
  - Students' class evaluations

➢ *Alternate Model:* Evaluate reform by assessing student learning through multiple and varied measures of student understanding.

# Discipline-based Education Research

Discipline-based Education Research (DBER) attempts to treat science and math learning as rigorously as scientists treat investigations in their respective professional fields.

# Treating physics education as a physics research (PR) problem

- PR: Careful, controlled experiments on specific features of a system.
  - **PER: Our system is a group of students in a particular class.**
- PR: A system has particular properties and a measuring device is used to measure those particular properties.
  - **PER: We're trying to measure knowledge and our measuring device is a set of physics problems.**
- PR: Research is often grounded in a mathematically descriptive theory that provides predictive power.
  - **PER: We utilize theoretical frameworks of knowledge structure to help guide our investigations.**

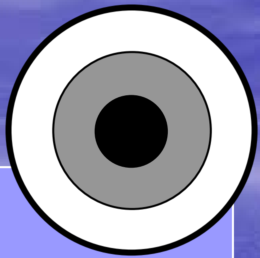
# Constructivist Approach*

- All individuals must construct their own concepts, and the knowledge they already have (or think they have) significantly affects what they can learn.
- The student mind is not a blank slate on which new information can be written without regard to what is already there.
- If the instructor does not make a conscious effort to guide the student in incorporating new information correctly, the message inscribed may not be the one the instructor intended.

* Taken from McDermott's Millikan Lecture, *AJP* (1991)

# A Model for Students' Knowledge Structure

[Redish, *AJP* (1994), *Teaching Physics* (2003)]



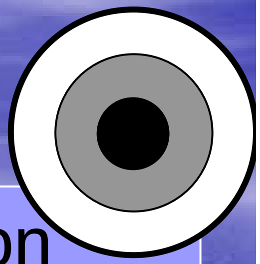
*Archery Target: three concentric rings*

- Central black bull's-eye: what students know well
  - *tightly linked network of well-understood concepts*
- Middle gray ring: students' partial and imperfect knowledge [Vygotsky: "Zone of Proximal Development"]
  - *knowledge in development: some concepts and links strong, others weak*
- Outer white region: what students don't know at all
  - *disconnected fragments of poorly understood concepts, terms and equations*

# Methods for Probing Knowledge

- One-on-one Problem Solving Interviews
  - Deepest probe of student understanding
  - Time consuming, small sample size, and self-selection issues
- Free-response questions
  - Allows for explanation of answers, but no dialogue
  - Fairly quick and very informative
- Multiple-choice questions
  - Difficult to understand why students are giving a particular answer
  - Fastest by far, and big sample sizes

# Response Characteristics Corresponding to Knowledge Structure

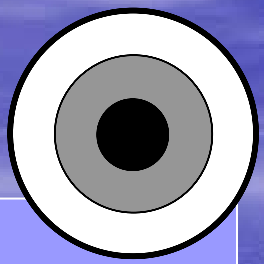


- When questions are posed related to **black**-region knowledge, students answer rapidly, confidently, and correctly – independent of context
- Questions related to **gray** region yield correct answers in some contexts and not in others; explanations may be incomplete or partially flawed
- Questions related to **white** region yield mostly noise: highly context-dependent, inconsistent, and unreliable responses, deeply flawed or totally incorrect explanations

# Developing "good" questions

- Measuring content knowledge in the gray region (and borders of the gray region) requires care
- Questions should be concise and focused, with minimal technical language
- Questions should be posed in multiple contexts and representations
- Continuous review and revision of questions is necessary, via interviews and multiple measurements

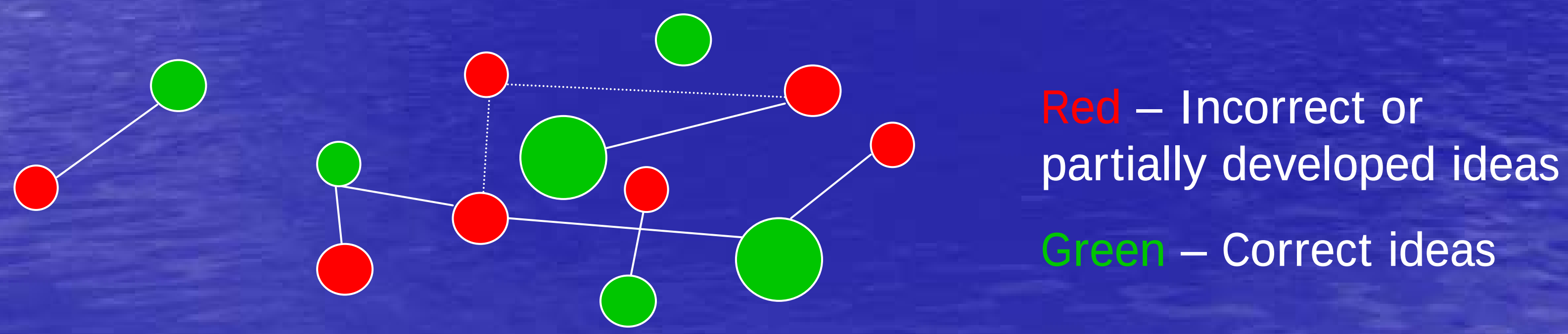
# Teaching Effectiveness, Region by Region



- In central **black** region, difficult to make significant relative gains: instead, polish and refine a well-established body of knowledge
- Learning gains in **white** region minor, infrequent, and poorly retained: lack anchor to regions containing well-understood ideas
- Teaching most effective when targeted at **gray**: a few key concepts and links can catalyze substantial leaps in student understanding

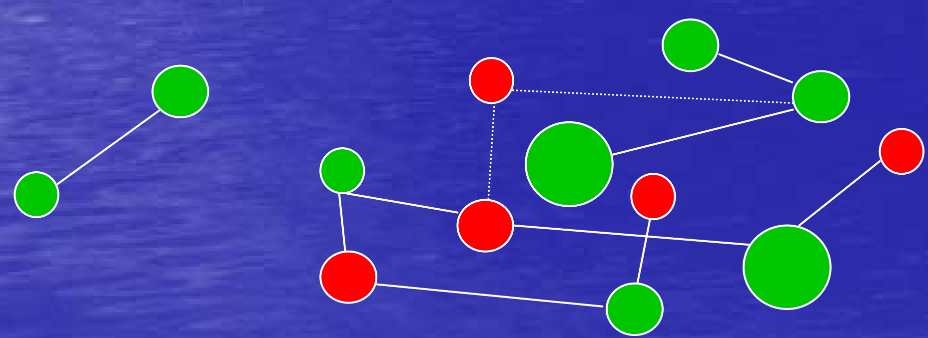
# Using a Constructivist Model to Inform Instruction

- Students are not blank slates on which you can simply "write" correct knowledge and reasoning.
- We must guide students to modify incorrect or incomplete existing knowledge and build on their correct understanding.



# Using a Constructivist Model to Inform Instruction

- Students are not blank slates on which you can simply "write" correct knowledge and reasoning.
- We must guide students to modify incorrect or incomplete existing knowledge and build on their correct understanding.

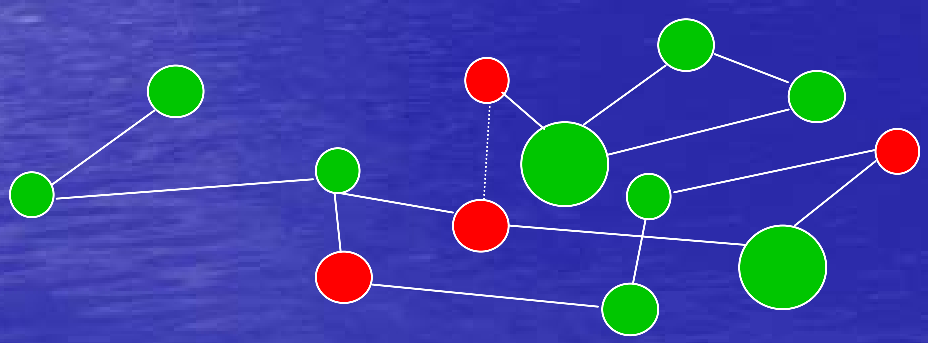


Red – Incorrect or partially developed ideas

Green – Correct ideas

# Using a Constructivist Model to Inform Instruction

- Students are not blank slates on which you can simply "write" correct knowledge and reasoning.
- We must guide students to modify incorrect or incomplete existing knowledge and build on their correct understanding.

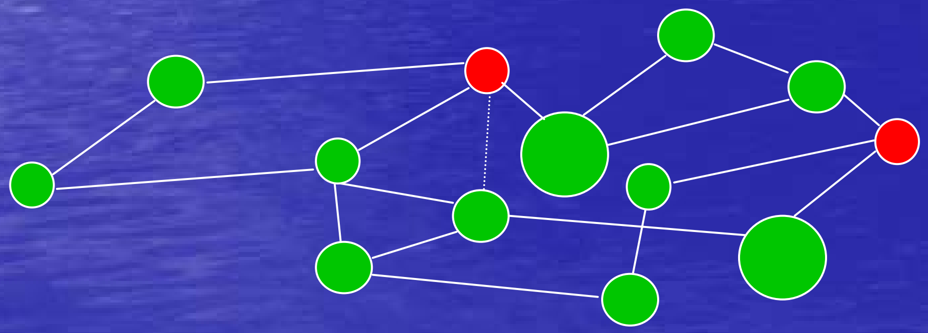


Red – Incorrect or partially developed ideas

Green – Correct ideas

# Using a Constructivist Model to Inform Instruction

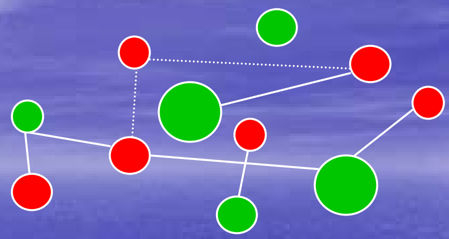
- Students are not blank slates on which you can simply "write" correct knowledge and reasoning.
- We must guide students to modify incorrect or incomplete existing knowledge and build on their correct understanding.



Red – Incorrect or partially developed ideas

Green – Correct ideas

# Using a Constructivist Model to Inform Instruction



- Cognitive Conflict
  - Elicit student ideas about a particular topic
  - Present potentially conflicting situation and guide students to confront their previous ideas
  - Require students to resolve any inconsistent ideas
- Multiple Representations
  - Use various contexts and representations to develop more robust understanding
- Guided Inquiry
  - Include student "discovery" as part of instruction

# Let's do some PER, shall we?

- Set the constraints for what we want to study
  - Student understanding of entropy in a second semester calculus-based physics course at a large research-intensive university in the Midwest.
- Identify the concepts we want to investigate
  - The entropy of the universe (which is comprised of any system and all of its surroundings) must increase during any naturally occurring process.
- Previous research: Cochran and Heron (2006)

  Focus on application of entropy to cyclic processes

# "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.***

# Sample of Correct Explanation

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

"*I'd say it's not determinable, there is no information about the system. I'd like to know at the very least a temperature, [or] energy exchange... all it says is that it can exchange energy but that doesn't mean that it is. There'd be a heat transfer, like Q...*"

---

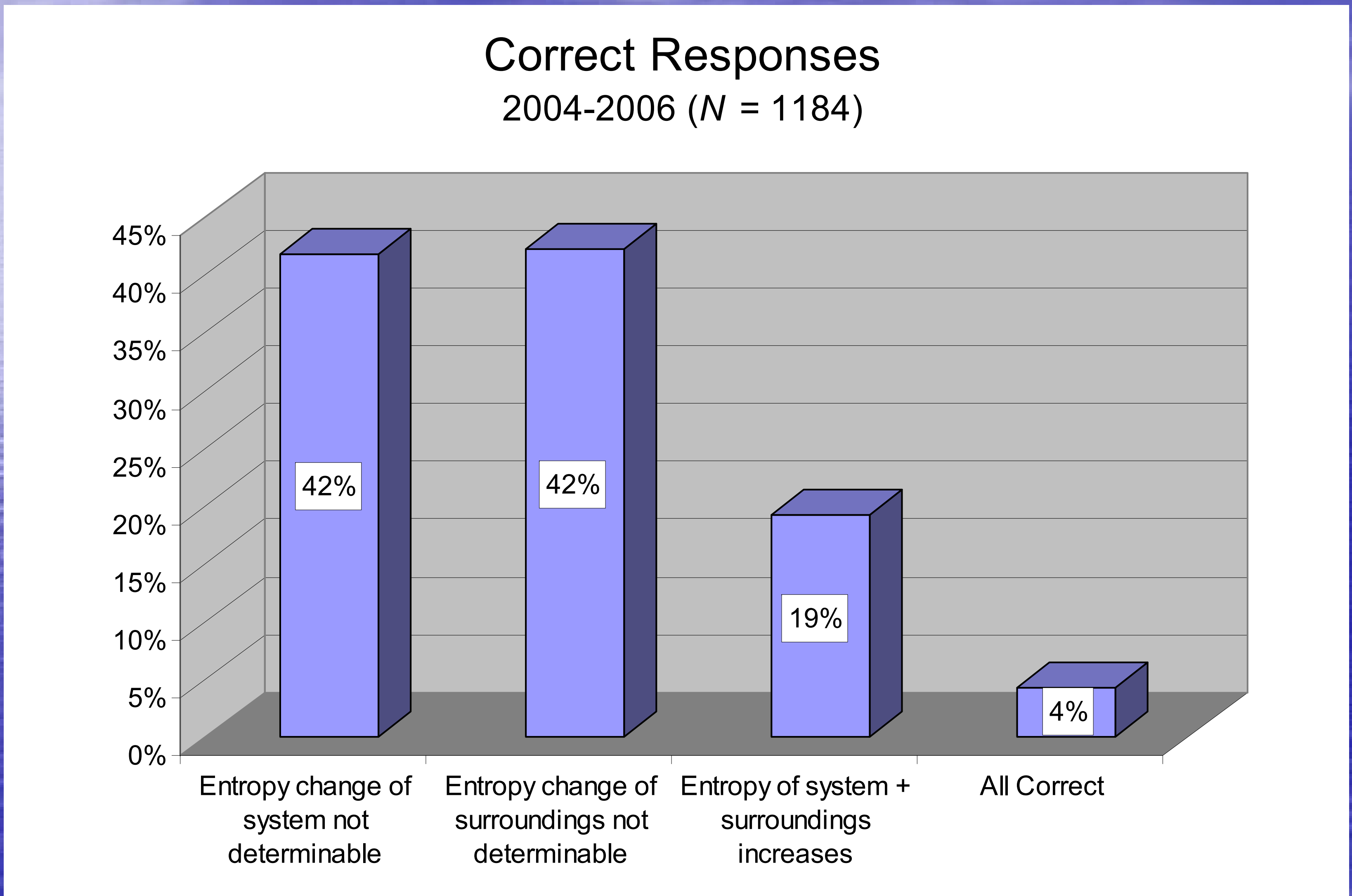
Part B response similar to Part A

# Sample of Correct Explanation

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.***

*"If it's an irreversible process entropy always goes up."*

# General Context - Before All Instruction

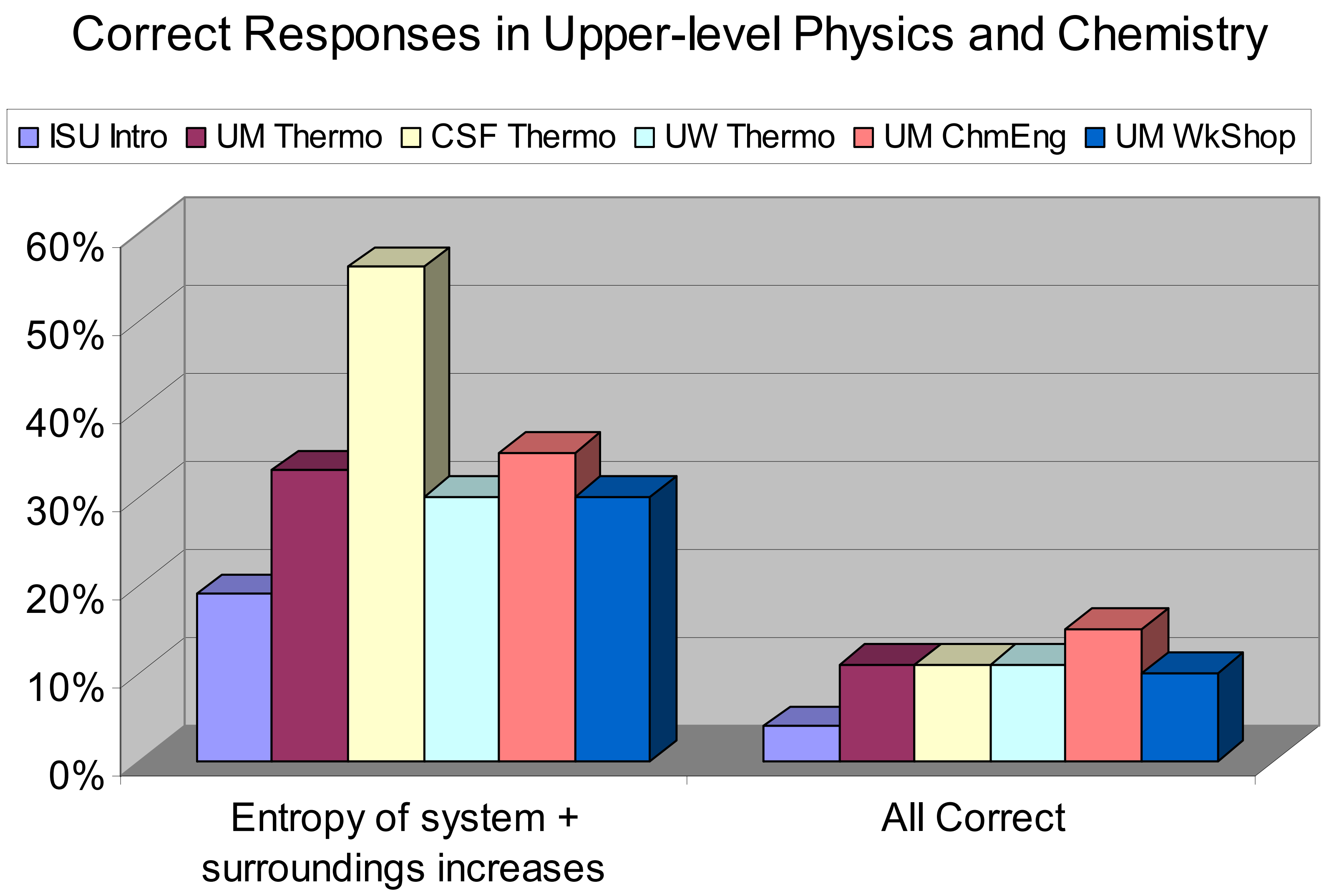


# Off-site testing with Collaborating institutions

- U Maine
  - Upper-level Thermo ($N$ = 9)
  - Physical Chemistry ($N$ = 8)
  - Chemical Engineering ($N$ = 20)
  - In-service Chemistry Teachers ($N$ = 10)

- Cal State Fullerton, Upper-level Thermo ($N$ = 9)
- U Washington, Sophomore-level Thermo ($N$ = 32)

# Pre-Instruction Testing



# “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.

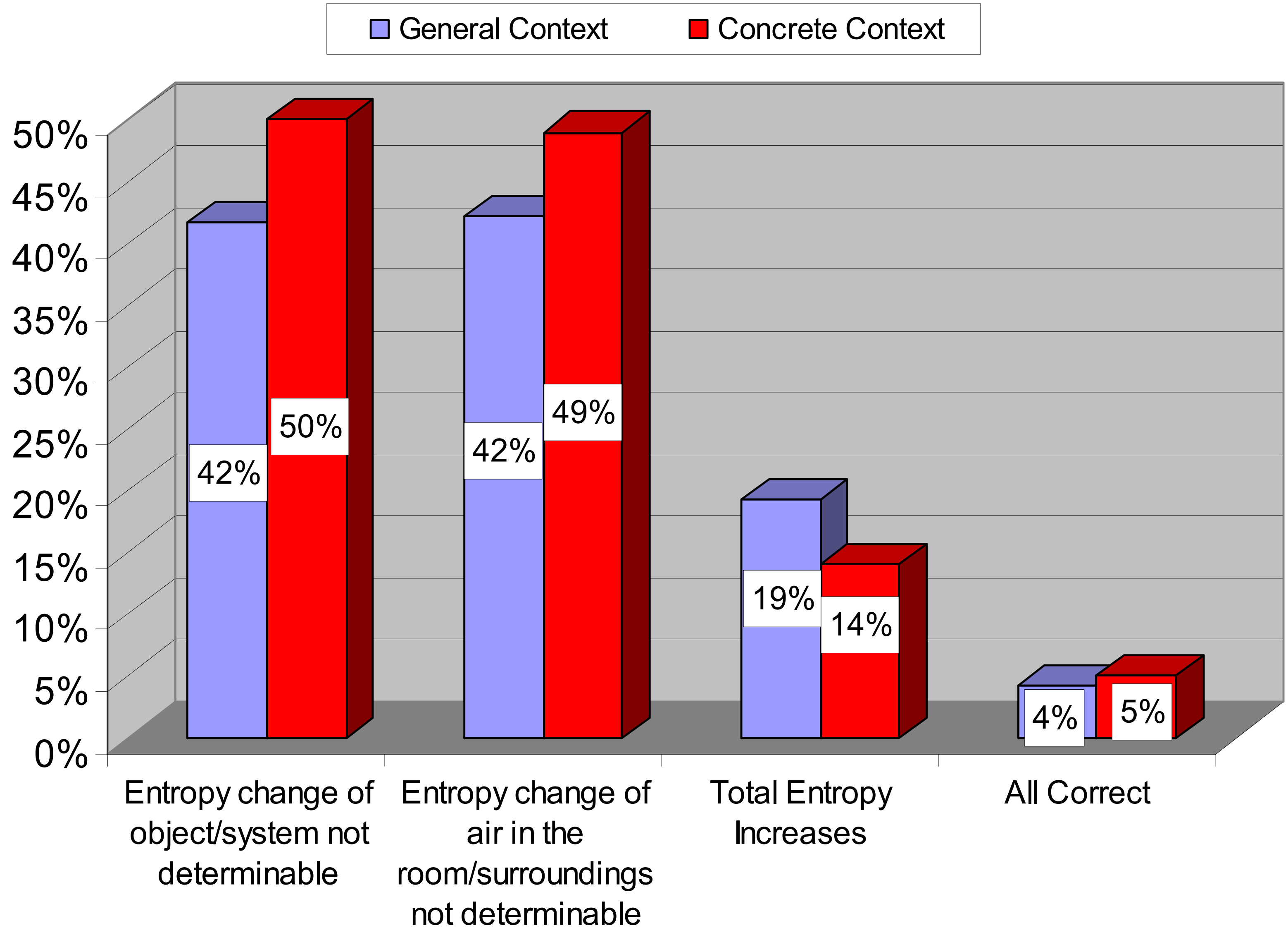
A. During this process, does the entropy of the **object** [$S_{object}$] *increase*, *decrease*, *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

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, Correct Responses

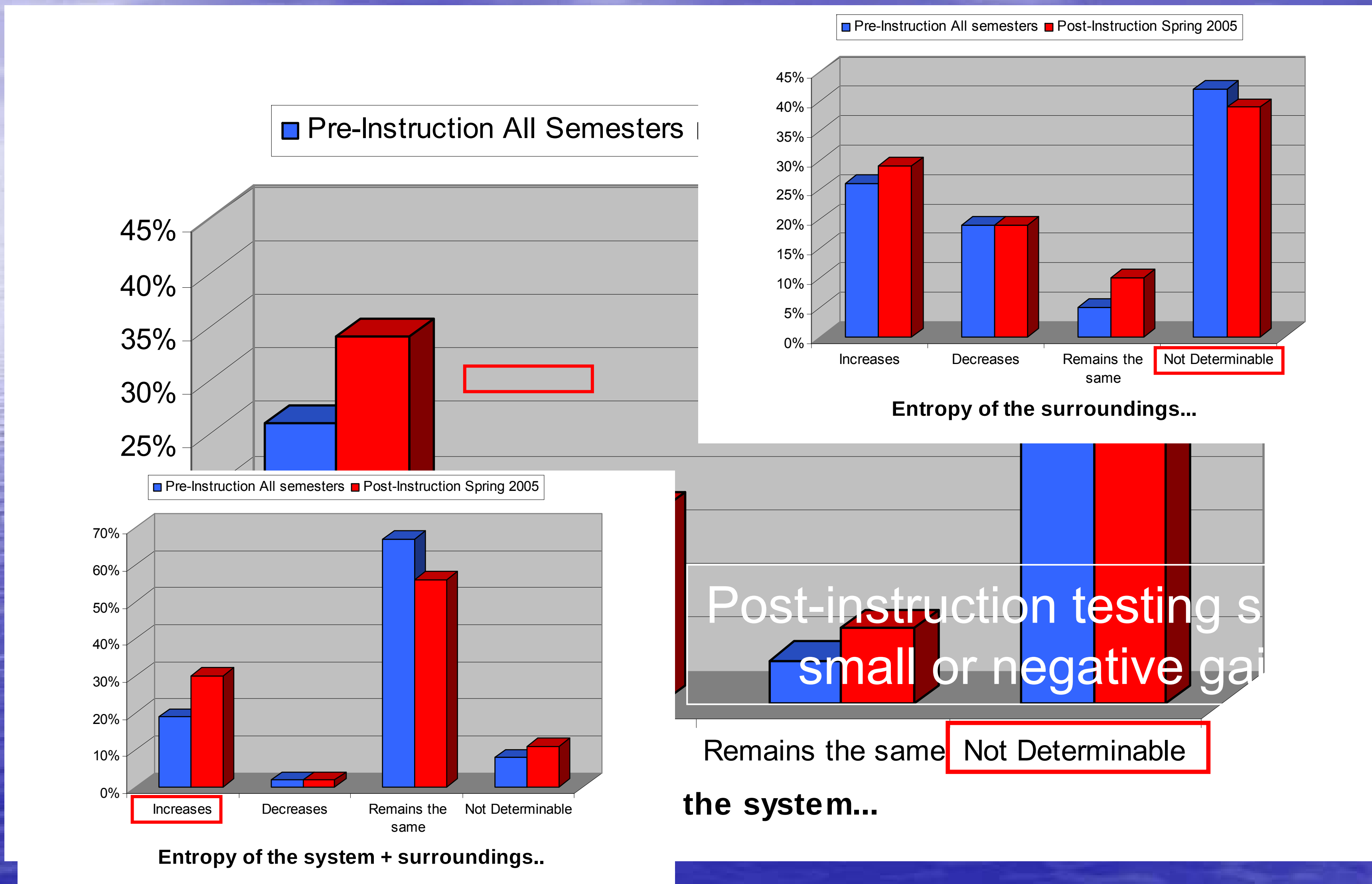
2004-2006 ($N$ = 1184), 2005-2006 ($N$ = 609)



# Post-Instruction Testing - Spring 2005 ($N$ = 255)

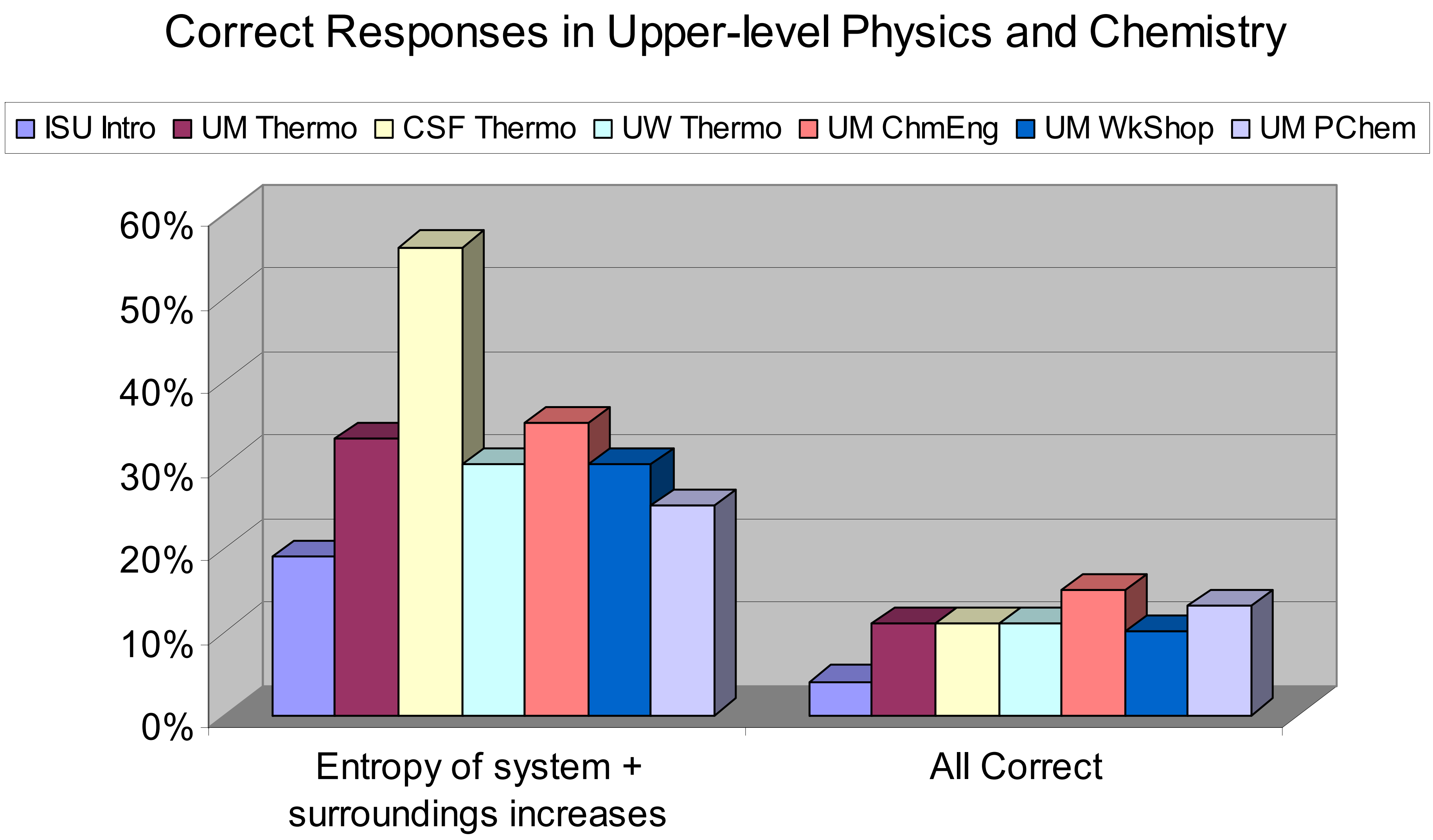
- Experienced and knowledgeable instructor
- Instruction
  - Two 50-minute lectures on entropy
  - One 50-minute recitation: Tutorial that focused on state-function property of entropy
  - Homework consisted of both quantitative and qualitative questions
- Post-instruction testing took place after all lecture and testing on entropy and thermodynamics was complete

# Pre- v. Post-Instruction Data




Post-instruction testing s ed
small or negative gai

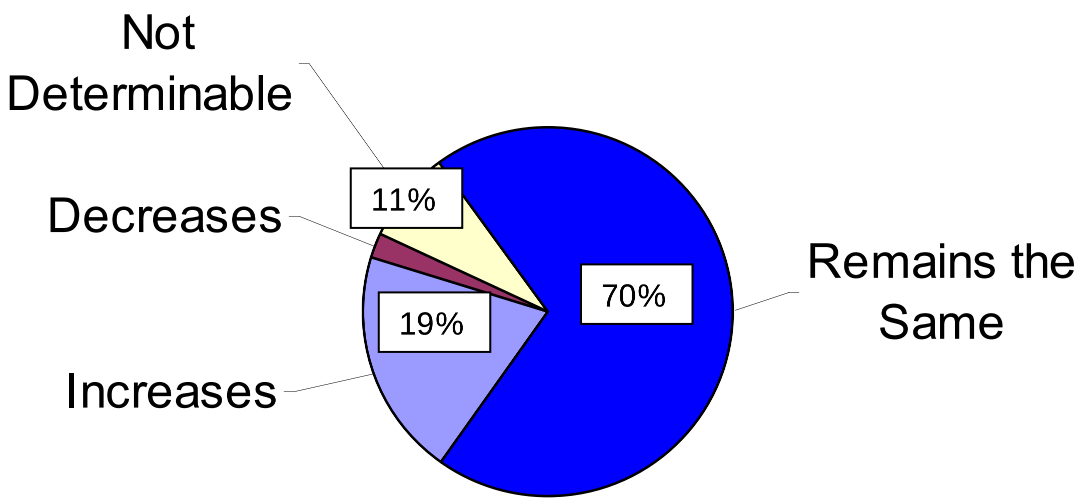
# Qualitative comparison of Physical Chemistry course after All Instruction



# What ideas do students have?

## Entropy of system + surroundings…

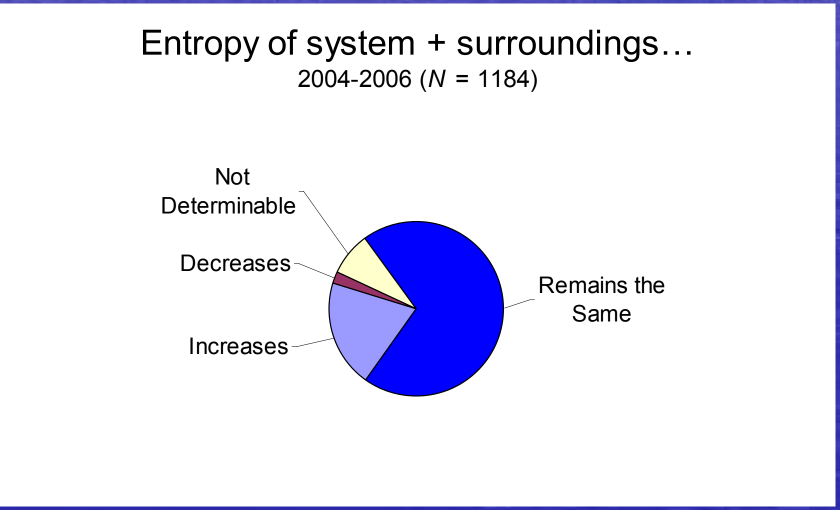
2004-2006 ($N$ = 1184)




Nearly three-quarters of all students responded that the "total entropy" ("system plus surroundings" or "object plus air") remains the same.

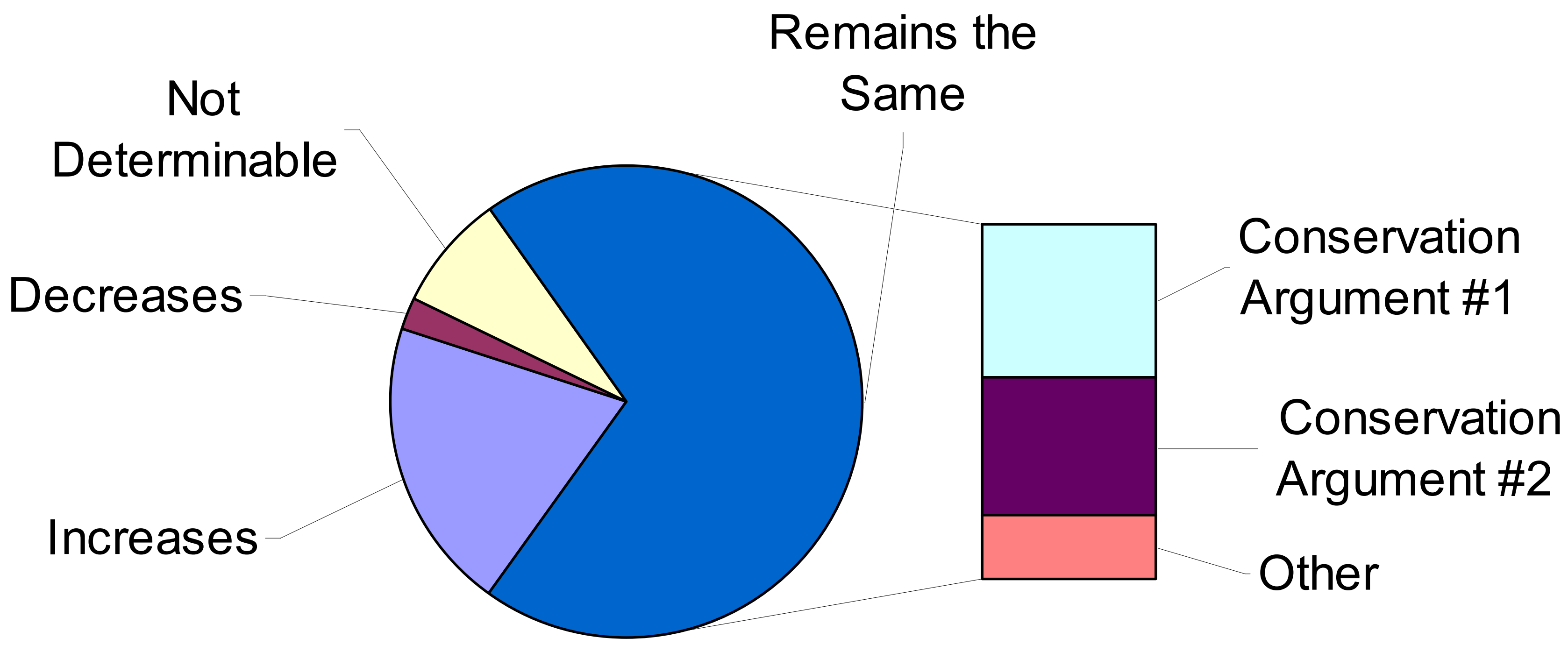
# “Total” Entropy Responses

- We can further categorize these responses according to the ways in which the other two parts were answered



# Entropy of system + surroundings…

2004-2006 ($N$ = 1184)




90% of these responses fall into one of two specific conservation arguments

# Conservation Arguments

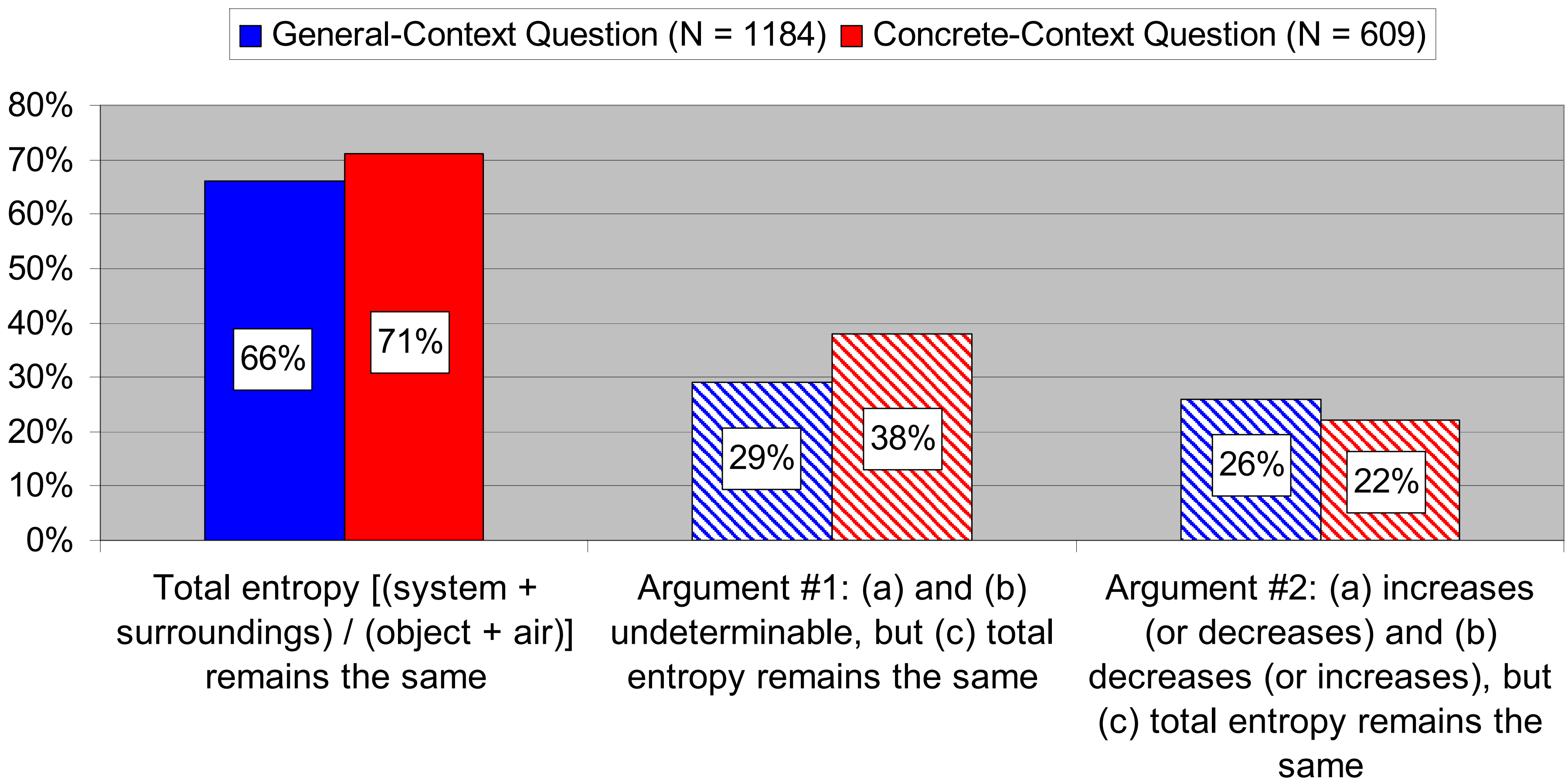
- **Conservation Argument #1**

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

- **Conservation Argument #2**

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

# Pre-Instruction Responses Consistent with Entropy "Conservation"



# Sample of Incorrect Explanation

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.***

"*Remain the same... any change in entropy in the system would result in a negative change of entropy for the surroundings, because energy could not be created or lost just exchanged.*"

# Entropy Tutorial Design

- The frameworks in which we understand student learning informs our instruction

  For instance, previous work shows substantial difficulties in developing first law concepts*

- Our model guides us to build off of correct student ideas (e.g., heat flow direction and relative magnitude), rather than build off of poorly established notions of the first law

*Loverude, *et al*, AJP (2002), Meltzer, AJP (2004)

# Entropy Tutorial Design


- Consider slow heat transfer process between two thermal reservoirs (insulated metal cubes connected by thin metal pipe)
  - ➢Does total energy change during process?
  - ➢Does total entropy change during process?

# Entropy Tutorial Design

- Guide students to find that:

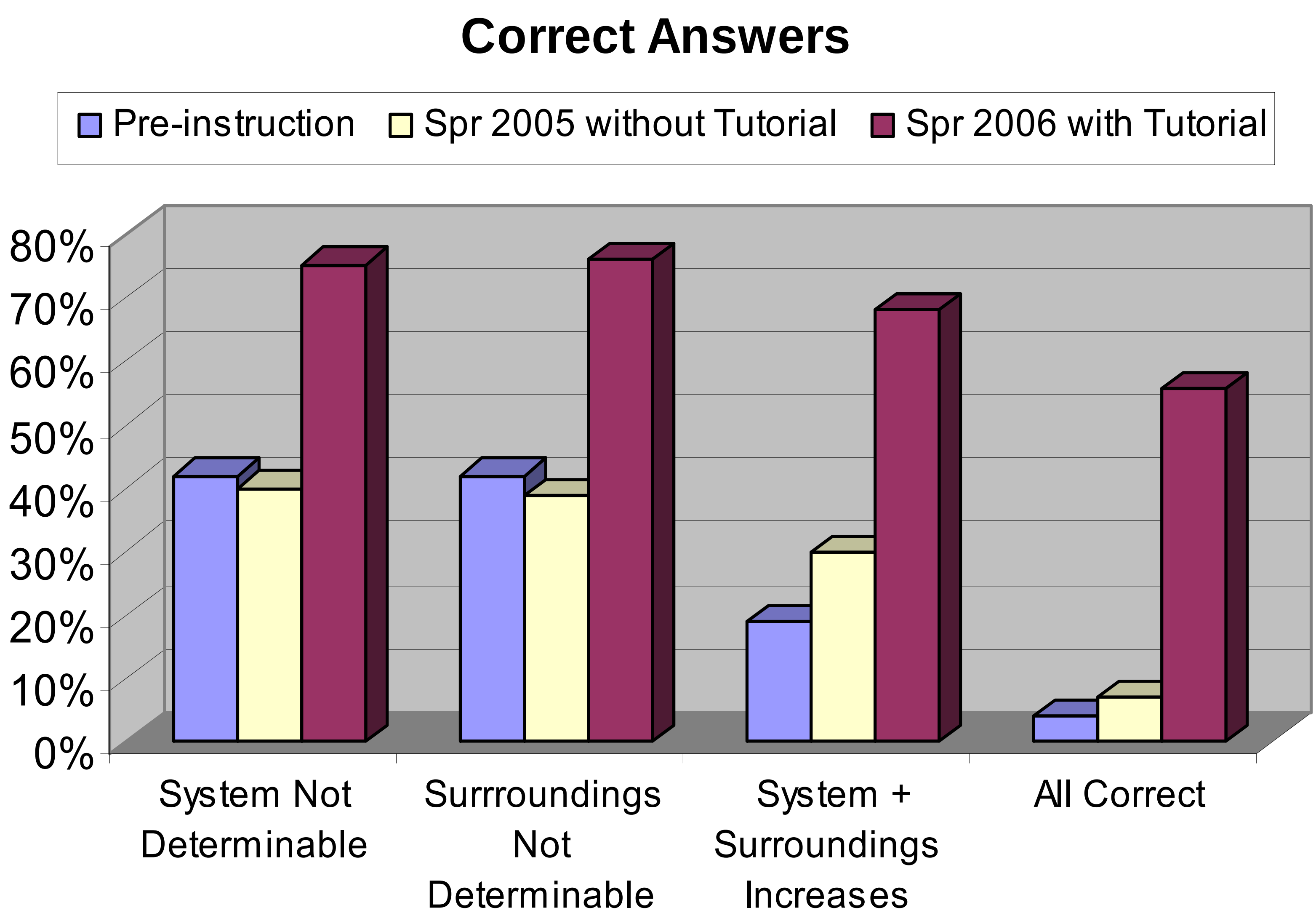
$$\Delta S_{total} = \frac{Q}{T_{low\ T\ reservoir}} - \frac{Q}{T_{high\ T\ reservoir}} > 0$$

- definitions of “system” and “surroundings” are arbitrary
- Examine situation when $\Delta T \rightarrow 0$ to see that $\Delta S \rightarrow 0$ and process approaches “reversible” idealization.

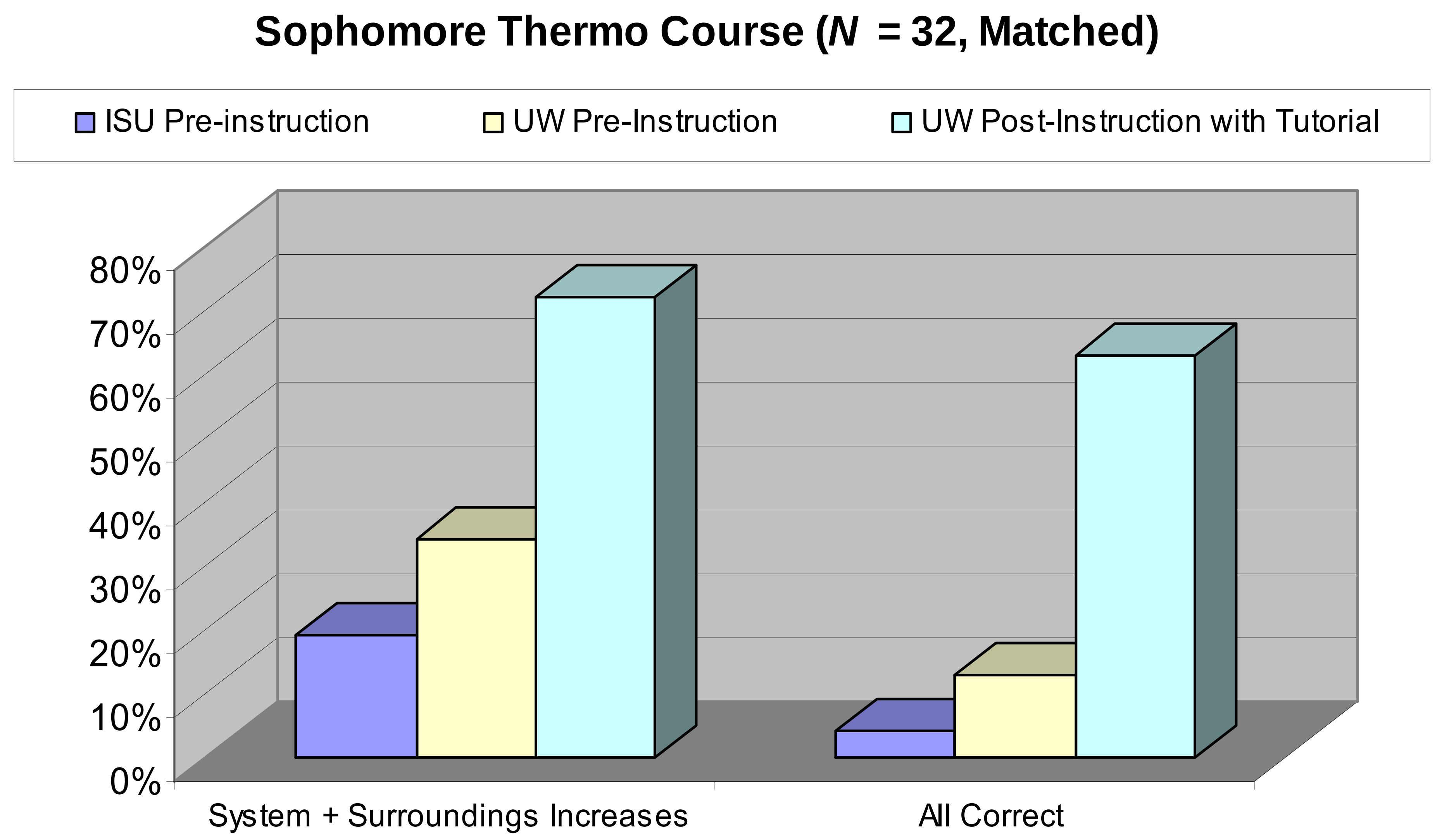
# Post-Instruction Testing - Spring 2006 (*N* = 231)

- Same course instructor as Spring 2005
- Instruction
  - Two 50-minute lectures on entropy
  - One 50-minute recitation with entropy tutorial
  - Homework consisted of both quantitative and qualitative questions
- Post-instruction testing took place after all lecture and testing on entropy was complete

# Post-instruction with Tutorial



# Off-site Implementation



# Future Work

- Additional testing runs needed before we can draw significant conclusions about the effectiveness of this instruction
- To improve curricular materials, we must further investigate student ideas about state function properties of entropy and other concepts

# Conclusions

- Discipline-based research goes beyond traditional education reform by deeply probing students' understanding of science concepts during ongoing instruction.
- Our research and research-based instruction is carried out within a framework with which we model student learning and thinking.
- Creating effective and efficient research-based curricula that improve learning is a lengthy process; there are no shortcuts.