Intuitive and Rule-based Reasoning in the Context of Calorimetry

Warren M. Christensen, Ngoc-Loan P. Nguyen, and David E. Meltzer

Department of Physics and Astronomy

Iowa State University

Ames, Iowa

Supported in part by NSF grant #DUE-9981140.

Physics Students' Reasoning in Calorimetry

- Investigation of reasoning regarding calorimetric concepts among students in calculus-based general physics course
- A free-response quiz was administered after lecture instruction to 311 students in an attempt to assess their understanding of calorimetry

Pretest Question #1

Written pretest given after lecture instruction completed

The specific heat of water is ***greater*** than that of copper.

A piece of copper metal is put into an insulated calorimeter which is nearly filled with water. The mass of the copper is the ***same*** as the mass of the water, but the initial temperature of the copper is *lower* than the initial temperature of the water. The calorimeter is left alone for several hours.

During the time it takes for the system to reach equilibrium, will the temperature change (number of degrees Celsius) of the copper be *more than, less than,* or *equal to* the temperature change of the water? Please explain your answer.

Pretest Question #1 Solution

$$Q = mc\,\Delta T$$

$$|Q_{Cu}| = |Q_W| \quad \text{and} \quad m_{Cu} = m_W$$

$$\Rightarrow c_{Cu}\,\Delta T_{Cu} = c_W\,\Delta T_W$$

$$\Delta T_{Cu} = \frac{c_W}{c_{Cu}}\,\Delta T_W$$

$$c_W > c_{Cu} \Rightarrow \Delta T_{Cu} > \Delta T_W$$

***Notation: ΔT ≡ absolute value** of temperature change*

Pretest Question #1 Results

Second-semester calculus-based course (PHYS 222)

N=311

Correct

$\Delta T_{LSH} > \Delta T_{GSH}$	62%
With correct explanation	***55%***

Incorrect

$\Delta T_{LSH} = \Delta T_{GSH}$	22%
$\Delta T_{LSH} < \Delta T_{GSH}$	16%

LSH = lower specific heat
GSH = greater specific heat

(five different versions of question were administered)

Pretest Question #1 Explanations

N=311

Incorrect ($\Delta T_{LSH} = \Delta T_{GSH}$)	**22%**
Temperature changes are equal since energy transfers are equal	9%
Temperature changes are equal since system goes to equilibrium	6%
Other	6%

Example of Incorrect Student Explanation

"Equal, to reach thermal equilibrium the change in heat must be the same, heat can't be lost, they reach a sort of 'middle ground' so copper decreases the same amount of temp that water increases."

"Equal energy transfer" is assumed to imply "equal temperature change"

Pretest Question #1 Explanations

N=311

Incorrect ($\Delta T_{LSH} < \Delta T_{GSH}$)	**16%**
Specific heat directly proportional to temperature change	7%
Other	8%

Example of Incorrect Student Explanation

"The temperature change of copper will be less than that of the ΔT of the water, because the specific heat of water is greater, and the masses are the same."

"Greater specific heat" is assumed to imply "Greater temperature change"

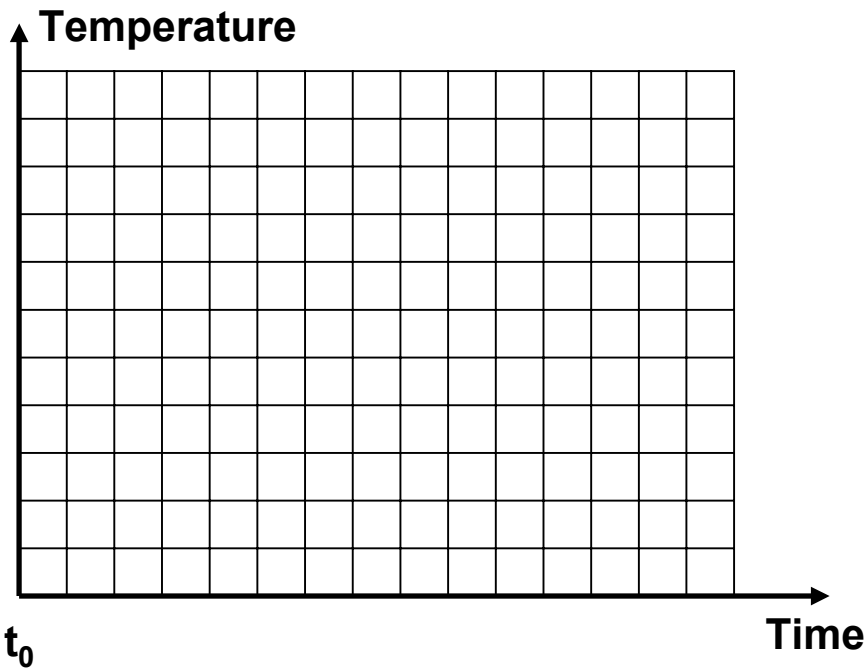
Pretest Question #2

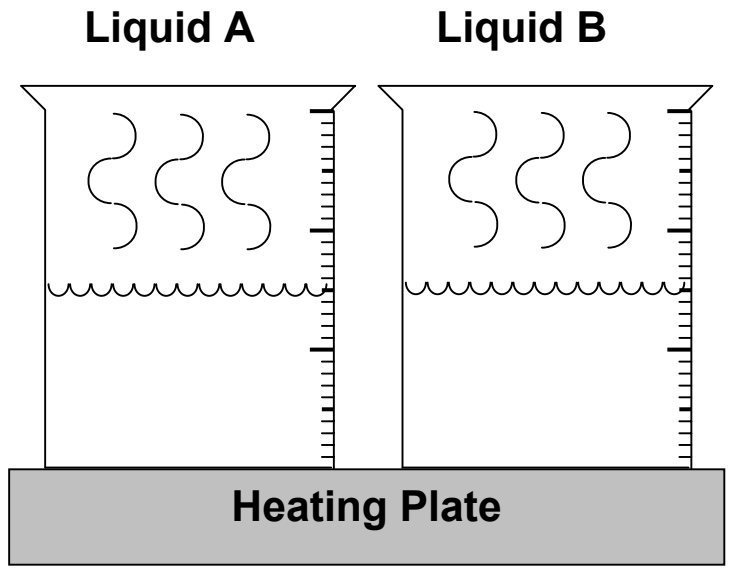
Suppose we have two ***separate*** containers: One container holds Liquid A, and another contains Liquid B. The mass and initial temperature of the two liquids are the same, but the ***specific heat*** of Liquid A is ***two times*** that of Liquid B.

Each container is placed on a heating plate that delivers the ***same rate of heating*** in joules per second to each liquid beginning at initial time $\mathbf{t_0}$.

Pretest Question #2 Graph

$[c_A = 2c_B]$





The specific heat of A is greater than the specific heat of B.

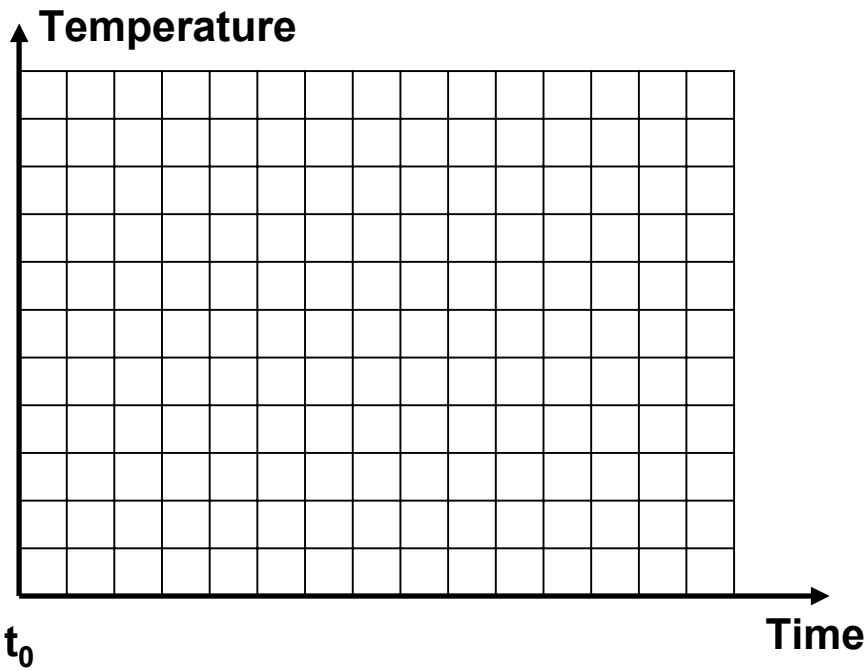
Pretest Question #2 (cont'd)

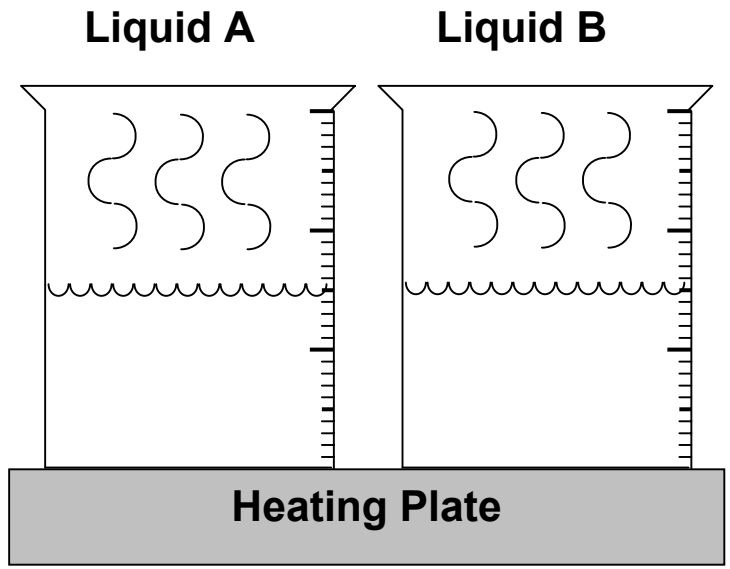
On the grid below, graph the temperature as a function of time for *each* liquid, A and B. Use a separate line for each liquid, even if they overlap. Make sure to clearly label your lines, and use proper graphing techniques.

Please **explain** the reasoning that you used in drawing your graph.

Pretest Question #2 Graph

$[c_A = 2c_B]$

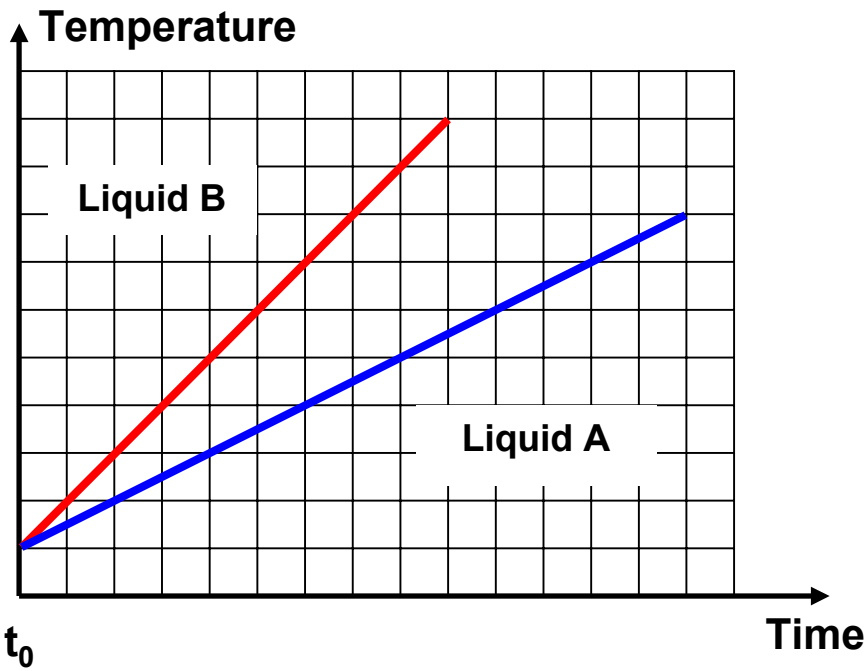


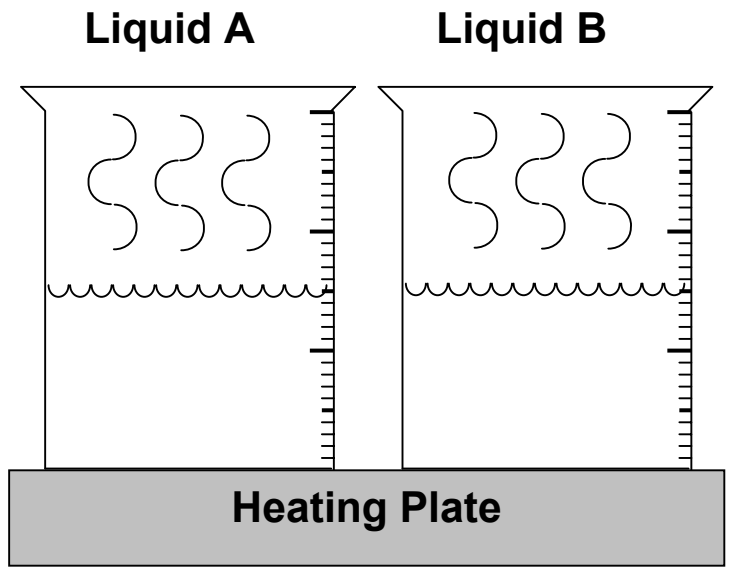


The specific heat of A is greater than the specific heat of B.

Pretest Question #2 Graph

$[c_A = 2c_B]$





The specific heat of A is greater than the specific heat of B.

Pretest Question #2 Results

($N = 311$)

Second-semester calculus-based course (PHYS 222)

Correct *(Slope of B > A)*	70%
with correct explanation	50%
Incorrect	
Slope of B < A	28%
Other	2%

Pretest: Question 1 & 2

(N=311)

	Q #1	Q #2
Incorrect		
($\Delta T_{LSH} = \Delta T_{GSH}$)		
Temperature changes are equal since energy transfers are equal	9%	
Temperature changes are equal since system goes to equilibrium	6%	
Other	6%	
($\Delta T_{LSH} < \Delta T_{GSH}$)		
Specific heat directly proportional to rate of temperature change	7%	
Other	8%	

Pretest: Question 1 & 2

(N=311)

	Q #1	Q #2
Incorrect		
($\Delta T_{LSH} = \Delta T_{GSH}$)		
Temperature changes are equal since energy transfers are equal	9%	**0%**
Temperature changes are equal since system goes to equilibrium	6%	**0%**
Other	6%	**0%**
($\Delta T_{LSH} < \Delta T_{GSH}$)		
Specific heat directly proportional to rate of temperature change	7%	**22%**
Other	8%	**16%**

Where did the $\Delta T_{LSH} = \Delta T_{GSH}$ errors go?

Students who answered (in Q1):

Temperature changes are equal since energy transfers are equal — ***N* = 34**

Switched to:

Correct explanation in Q2	33%
Specific heat directly proportional to rate of temperature change in Q2	44%
Other incorrect explanation in Q2	23%

Where did the $\Delta T_{LSH} = \Delta T_{GSH}$ errors go?

Students who answered (in Q1):

Temperature changes are equal since system goes to equilibrium

***N* = 22**

Where did the $\Delta T_{LSH} = \Delta T_{GSH}$ errors go?

Students who answered (in Q1):

Temperature changes are equal since system goes to equilibrium — ***N* = 22**

Switched to:

Correct explanation in Q2	23%
Specific heat directly proportional to rate of temperature change in Q2	41%
Other incorrect explanation in Q2	32%

Where did $\Delta T_{LSH} < \Delta T_{GSH}$ errors come from?

Students that answered (in Q2):

Specific heat directly proportional to rate of temperature change — ***N* = 81**

Consistent response to Q1:

Specific heat directly proportional to rate of temperature change in Q1	22%

Inconsistent response to Q1:

Correct explanation in Q1	15%
Temperature changes are equal since energy transfers are equal in Q1	19%
Temperature changes are equal since system goes to equilibrium in Q1	11%

Switching Explanations and Rule-Based Reasoning

- Many (≈25%) incorrect explanations to Q1 fell into one of three well-defined categories
- Incorrect explanations frequently had very similar phrasing
- Most students giving incorrect explanations were inconsistent in their responses to Q1 and Q2

➢ This suggests that students are employing context-dependent rule-based reasoning

Follow-up Interviews

Summer and Fall 2003 (Different instructor and class format)

($N = 26$)

- Math errors appeared more frequently than on the free response quizzes (~25%)
- Few conceptual errors observed
  - Due to small sample size and self-selection factors??

Mathematical Errors

- Errors resulting from manipulations of equations (such as $Q = mc\Delta T$)
- Not necessarily indicative of poor conceptual understanding (based on evidence of interview responses)
- Not often seen in answers to free response quizzes
  - Interviews allow us to probe student responses in depth
- Apparently a significant source of student confusion

Conclusion

- Students' reasoning in calorimetry often appears to be based on intuitive context-dependent rules.
- Weak mathematical skills often appear to function as a roadblock to qualitative understanding.