A Window on Student Thinking in the Context of Calorimetry

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Supported in part by U.S. National Science Foundation
Grant Nos. DUE 9981140, PHY 0406724, PHY 0604703, and DUE 0817282

Abstract

We report on students' thinking in the context of calorimetry in an introductory calculus-based physics course. Student responses to a variety of questions in diverse contexts (see Figs. 1-4) demonstrated overall good performance (> 60% correct responses), although only about half of all students were able to provide correct answers with satisfactory explanations. Student response patterns varied significantly depending on the context of the question and often seemed to rely on algorithmic or "rule-based" reasoning. Interviews with students suggested that difficulty with algebraic manipulations was a significant contributor to incorrect responses. Strikingly, both unhelpful algorithmic reasoning and unnecessary algebraic manipulations were characteristic of students having *good* conceptual understanding, as well as students lacking such understanding.

Target Concepts and Student Responses

I. *When two objects are in an insulated container, the magnitude of heat transfer from one object is equal to the magnitude of heat transfer to the other object.*

Responses from over 1000 students across three semesters indicate that 12-25% of students believed that the magnitude of heat transfer to the colder substance was *not* equal to the magnitude of heat transfer away from the hotter substance (see Table I).

Target Concepts and Student Responses

ii. The specific heat is the amount of energy per unit mass required to change the temperature of some object.

a. About half of all students gave correct responses with correct explanations.

b. Between 0-25% of students ignored effects of differing specific heats, with prevalence strongly dependent on question context

c. Approximately 15-30% of students incorrectly associated larger specific heat with greater temperature changes under equal heating conditions

[see Tables I-III]

Patterns of Student Thinking

- Student explanations for both incorrect *and* correct written responses tended to be straightforward assertions, with no supporting arguments, of purported "rules" such as "larger specific heat implies a larger [or, smaller] temperature change."
- In one-on-one interviews students usually approached the problems through algebraic manipulations (correct or incorrect), even though responses to *written* questions showed very little evidence of such manipulations.

General Observations

- During interviews students seemed to take “extra care” to provide algebraic manipulations to support their responses, even though such manipulations caused more difficulties than they solved—even for students who had good conceptual understanding in the first place.
- Students with both weak *and strong* conceptual understanding attempted to argue inefficiently by combining purported “rules” with algebraic manipulations, even when they also demonstrated an ability to deploy simple conceptual arguments that could easily have solved the problems.

Implications for Instruction

Even in a relatively simple context such as calorimetry—or perhaps *particularly* in such a context—students tend to “reason” unproductively through intuitive rules and algebraic manipulations. They can not achieve deeper understanding unless and until they are persuaded to replace such ostensible shortcuts with more thoughtful and reasoned approaches.

Figure 1. Object in Liquid, free response question. (Four different versions of this question were used.)

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 higher 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.

Table I. Comparison of three versions of Object in Liquid question: free response, text multiple-choice, and symbol multiple-choice. The free-response version was given after lecture instruction only, while the multiple-choice versions were given after all instruction was complete.

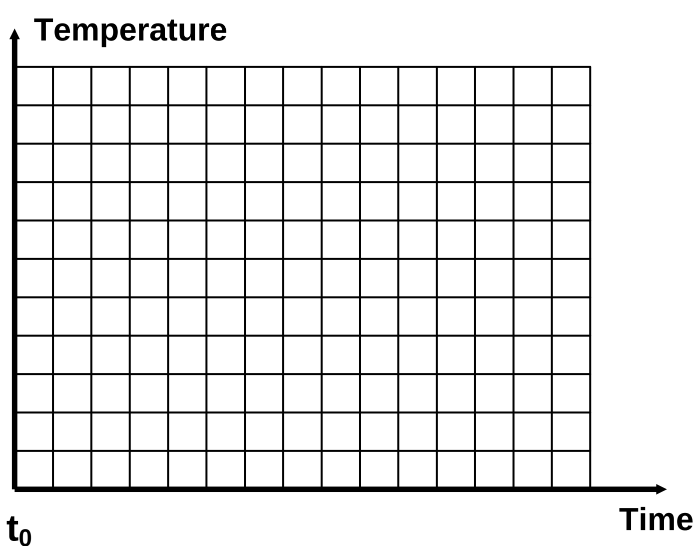
	Object in Liquid, Free Response (3 samples)	Object in Liquid Text MC (2 samples)	Object in Liquid Symbol MC (2 samples)
	$N = 1036$	$N = 760$	$N = 731$
*Greater c ⇨ Smaller ΔT	63 ± 4%	66%	70%
Equal ΔT	22 ± 7%	13%	8%
Greater c ⇨ Greater ΔT	15 ± 2%	22%	23%
Heat transfers are not equal	--	21%	16%
*Heat transfers are equal	--	79%	85%

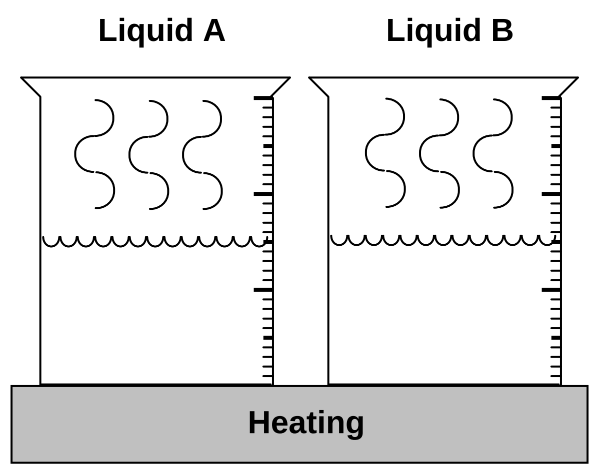
*Correct response

Figure 2. Two-Liquids, free response question. Three different versions of this question were used in which the ratios of specific heats of Liquids A and B were specified as being either 2, 3, or 4.

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 $\mathbf{t_0}$.

a) 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.





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

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

Table II. Two-Liquids question, free response, after lecture instruction. Correct "Greater c ⇨ Smaller ΔT" responses associate greater specific heat with *smaller* slope on the temperature vs. time graph.

	Spring 2003	Fall 2005
	$N = 361$	$N = 427$
*Greater c ⇨ Smaller ΔT	70%	73%
Correct with Correct Explanation	*50%*	*65%*
Equal ΔT	0%	0%
Greater c ⇨ Greater ΔT	28%	26%

*Correct response

Figure 3. Two-Liquids, multiple-choice version.

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 *four 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 t_0.

On the grids below are four graphs that represent the temperature-versus-time plots for liquid *A* and liquid *B*, with liquid A represented by a solid line and liquid *B* by a dashed line. Indicate the graph whose temperatures are plotted most accurately for liquid *A* versus liquid *B*.

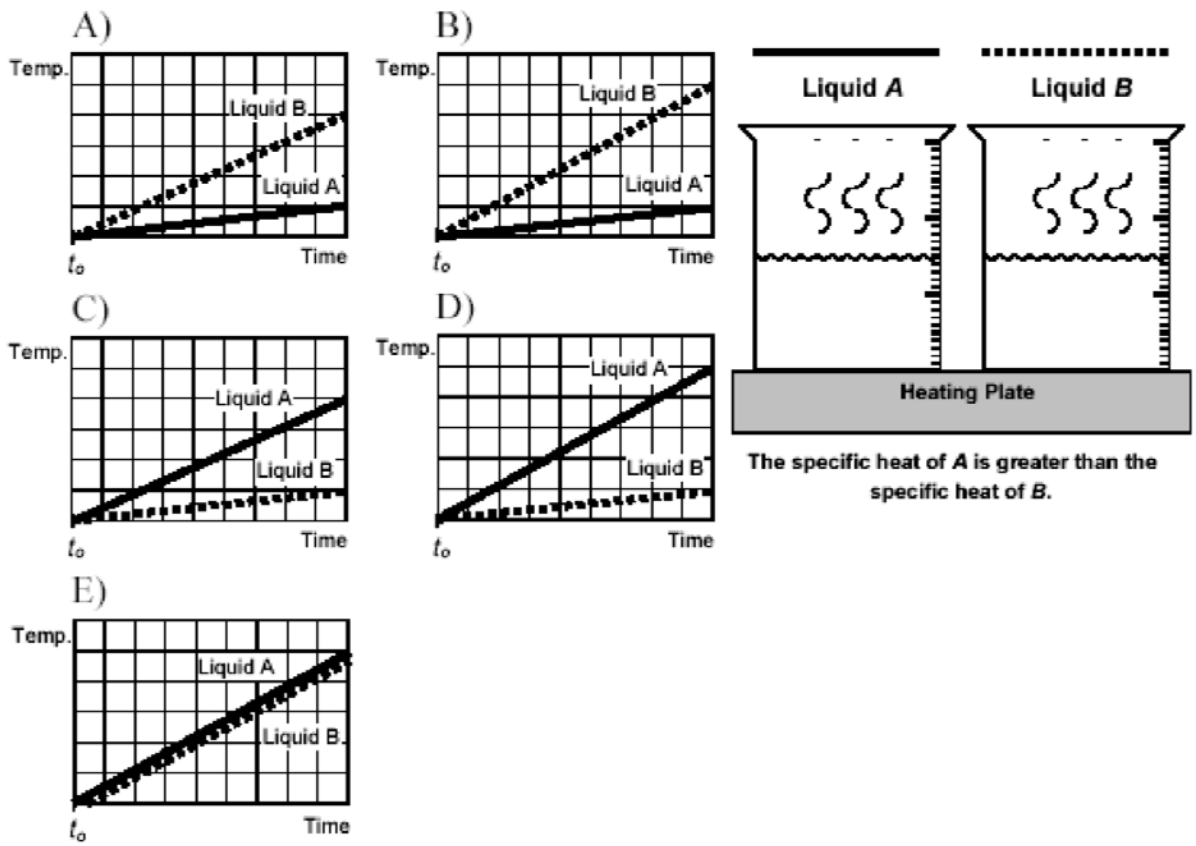


Figure 4a. Object in Liquid, multiple-choice "text-based" version

An object is immersed in a liquid within a sealed and insulated container. The mass of the object is the same as the mass of the liquid. The initial temperature of the object is lower than the initial temperature of the liquid, but the specific heat of the object is ***greater*** than that of the liquid. The calorimeter is left alone for several hours until it reaches equilibrium. Which of the following is true? *Note: Here, "temperature change" means "number of degrees Kelvin increased* **or** *decreased."*

A. The energy transfer to the object is *not* equal to the energy transfer away from the liquid, and the temperature change of the object is greater than the temperature change of the liquid.

B. The energy transfer to the object is *not* equal to the energy transfer away from the liquid, and the temperature change of the object is less than the temperature change of the liquid.

C. The energy transfer to the object is equal to the energy transfer away from the liquid, and the temperature change of the object is greater than the temperature change of the liquid.

D. The energy transfer to the object is equal to the energy transfer away from the liquid, and the temperature change of the object is equal to the temperature change of the liquid.

E. The energy transfer to the object is equal to the energy transfer away from the liquid, and the temperature change of the object is less than the temperature change of the liquid.

Figure 4b. Object in Liquid, multiple-choice "equation-based" version

Object A has mass m_A, specific heat c_A, and the initial temperature $T_{initial\ A}$. Liquid B has mass m_B, specific heat c_B, and initial temperature $T_{initial\ B}$. Object A is immersed in Liquid B within a sealed and insulated container (i.e., a calorimeter). We are given the following information:

$$m_A = m_B$$
$$c_A > c_B$$

$T_{initial\ A} < T_{initial\ B}$ but after a long time, $T_{final\ A} = T_{final\ B}$

Which of the following is true? [Q is heat transfer; $\Delta T \equiv T_{final} - T_{initial}$]

A. $Q_{to\ A} \neq Q_{away\ from\ B}$; $|\Delta T_A| > |\Delta T_B|$

B. $Q_{to\ A} \neq Q_{away\ from\ B}$; $|\Delta T_A| < |\Delta T_B|$

C. $Q_{to\ A} = Q_{away\ from\ B}$; $|\Delta T_A| > |\Delta T_B|$

D. $Q_{to\ A} = Q_{away\ from\ B}$; $|\Delta T_A| = |\Delta T_B|$

E. $Q_{to\ A} = Q_{away\ from\ B}$; $|\Delta T_A| < |\Delta T_B|$

Table III. After all instruction, Two-Liquids, free response vs. Two-Liquids, multiple choice. "Greater c ⇨ Smaller ΔT" corresponds to responses A or B on the multiple-choice version; "Equal ΔT" corresponds to response E, and "Greater c ⇨ Greater ΔT" corresponds to responses C or D.

	Two-Liquids, free response Summer 2002	Two-Liquids, multiple choice Spring 2004
	$N = 32$	$N = 447$
*Greater c ⇨ Smaller ΔT	69%	73%
Correct with correct explanation	*59%*	--
Equal ΔT	0%	1%
Greater c ⇨ Greater ΔT	22%	26%

*Correct response