The Value and the Challenge of Interdisciplinary Research in STEM Education

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Supported in part by NSF Grants DUE-9981140, PHY-0406724, PHY-0604703, and DUE-0817282

Collaborators

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Funding

- NSF Division of Undergraduate Education
- NSF Division of Physics

Outline

- The Pedagogical Need for Interdisciplinary STEM Research
- The Challenge of Learning Each Other's Languages
- The Potential Value and Impact of Interdisciplinary Research

[with examples drawn from collaborative project on learning of thermodynamics in physics and chemistry]

Students Are Exposed to the Same or Similar Concepts in Multiple, Diverse Contexts

- Numerous concepts appear repeatedly in different courses in various STEM fields
- Almost always, the context, notation, particular emphasis, and interpretation of the concepts differs significantly in the different fields
- It is generally left up to the students to attempt to integrate the different viewpoints, since STEM faculty usually focus on their own area

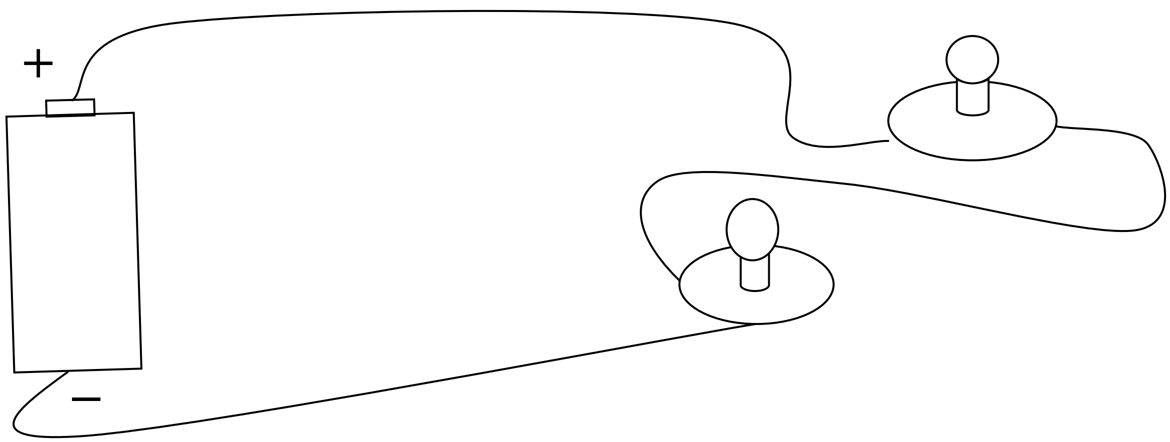
Interdisciplinary Researchers Must Become Familiar with Each Other's' Language

- The particular instructional focus of the different fields must be identified and addressed
- Diagnostic instruments must be translated in notation, diagrammatic conventions, and context

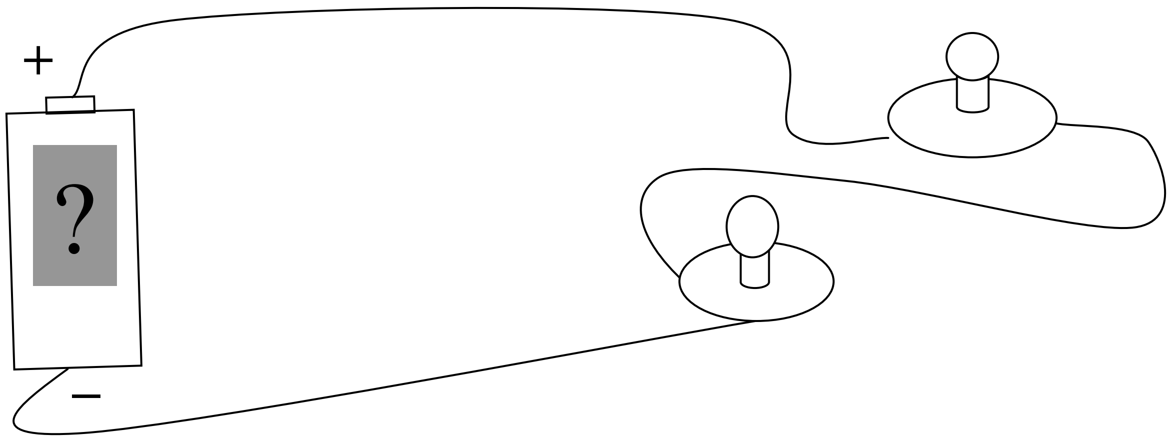
Key Conceptual Issues Differ Among STEM Fields

- Even when dealing with the same or similar physical contexts, conceptual emphasis generally has different focus
- Issues that may be crucial for one field may be insignificant for others

Example: Electric Circuits (batteries and bulbs)

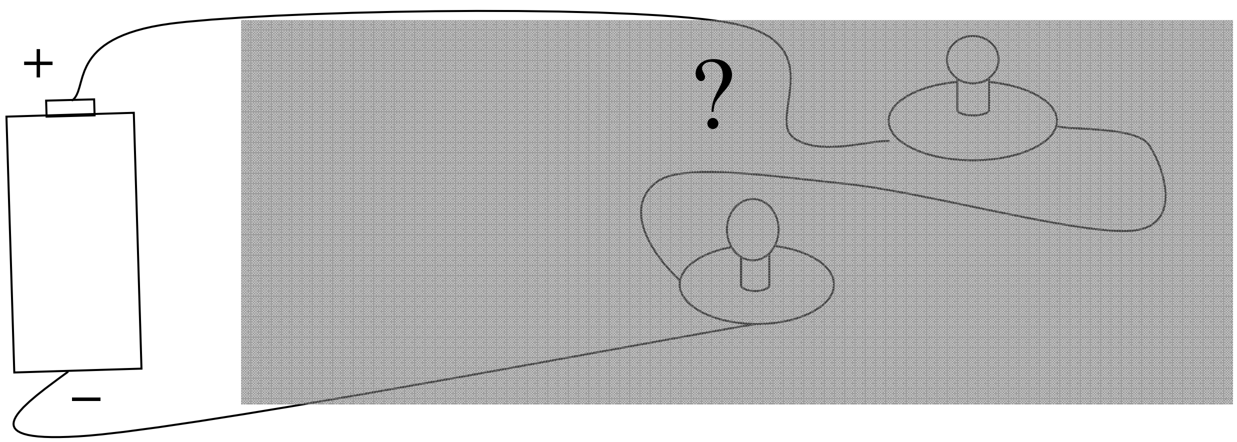


Physics view: Battery is of interest solely for creating potential difference



Focus is entirely on interactions occurring *outside* the battery

Chemistry view: Circuit is of interest solely for expediting flow of charge



Focus is entirely on electrochemical reactions *inside* the battery

Interpretation of Specific Terms May Vary Substantially Among STEM Fields

- Terms such as “model,” “multiple representations,” etc., often have different connotations in different fields
- Researchers must ensure they understand each other’s interpretation

Example: Multiple Representations

- In physics, one often emphasizes **verbal**, **mathematical/symbolic**, **graphical**, and **pictorial/diagrammatic** representations
- In chemistry, emphasis is often on **macroscopic**, **microscopic** [particulate], and **symbolic** [chemical equations] representations

Application:
Investigation of Learning in Physics and Chemistry with Diverse Representations

- Probe student understanding of standard representations

- Compare student reasoning with different forms of representation

“Multiple-Representation” Quiz

- Same or similar question asked in more than one form of representation
- Comparison of responses yields information on students’ reasoning patterns with diverse representations

Coulomb's Law Quiz in Multiple Representations

IF YOU WANT A QUESTION GRADED OUT OF THREE POINTS (–1 [MINUS ONE] FOR WRONG ANSWER!!) WRITE "3" IN SPACE PROVIDED ON EACH QUESTION.

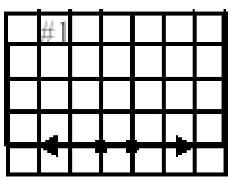
1. When two identical, isolated charges are separated by two centimeters, the magnitude of the force exerted by each charge on the other is eight newtons. If the charges are moved to a separation of eight centimeters, what will be the magnitude of that force now?

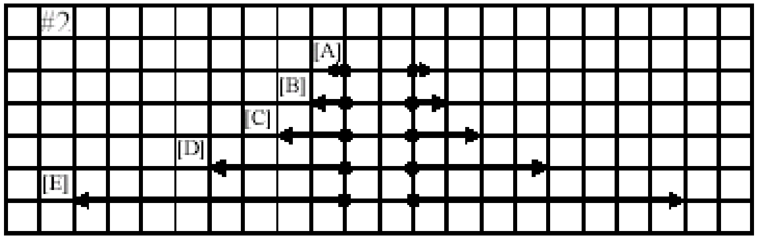
A. one-half of a newton
B. two newtons
C. eight newtons
D. thirty-two newtons
E. one hundred twenty-eight newtons

Grade out of three? Write "3" here: ______

V [verbal]

2. Figure #1 shows two identical, isolated charges separated by a certain distance. The arrows indicate the forces exerted by each charge on the other. The same charges are shown in Figure #2. Which diagram in Figure #2 would be correct?





A.
B.
C.
D.
E.

Grade out of three? Write "3" here: ______

D [diagrammatic]

3. Isolated charges q_1 and q_2 are separated by distance r, and each exerts force F on the other. $q_1^{initial} = q_1^{final}$ and $q_2^{initial} = q_2^{final}$; $r^{initial} = 10m$; $r^{final} = 2m$. $F^{initial} = 25N$; $F^{final} = ?$

A. 1 N
B. 5 N
C. 25 N
D. 125 N
E. 625 N

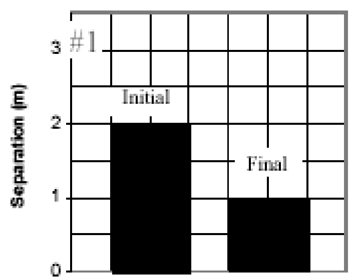
Grade out of three? Write "3" here: ______

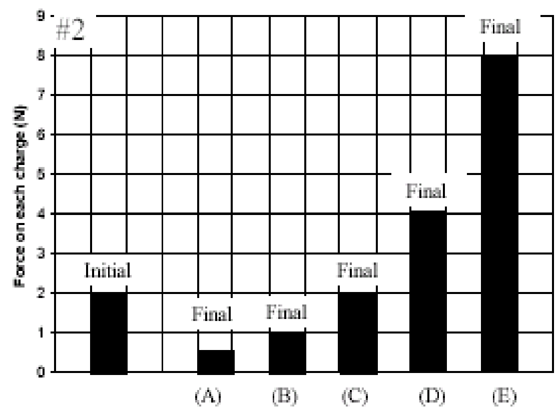
M [mathematical/symbolic]

4. Graph #1 refers to the initial and final separation between two identical, isolated charges. Graph #2 refers to the initial and final forces exerted by each charge on the other. Which bar is correct?

Grade out of three? Write "3" here: ______

A.
B.
C.
D.
E.





G [graphical]

DC Circuits Quiz

1. In a parallel circuit, a three-ohm resistor and a six-ohm resistor are connected to a battery. In a series circuit, a four-ohm and an eight-ohm resistor are connected to a battery that has the ***same*** voltage as the battery in the parallel circuit. What will be the ratio of the current through the six-ohm resistor to the current through the four-ohm resistor? Current through six-ohm resistor divided by current through four-ohm resistor is:

   A. greater than one

   B. equal to one

   C. less than one

   D. equal to negative one

   E. cannot determine without knowing the battery voltage

   Grade out of 3? Write "3" here: _____

V

2. Parallel circuit: $R_A = 6\ \Omega;\ R_B = 9\ \Omega.$
   Series circuit: $R_C = 7\ \Omega;\ R_D = 3\ \Omega.$
   $\Delta V_{bat}(series) = \Delta V_{bat}(parallel)$

M

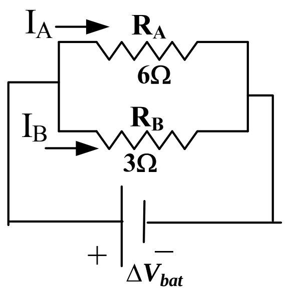
A. $\frac{I_B}{I_C} > 1$ B. $\frac{I_B}{I_C} = 1$ C. $\frac{I_B}{I_C} < 1$ D. $\frac{I_B}{I_C} = -1$ E. need ΔV_{bat}

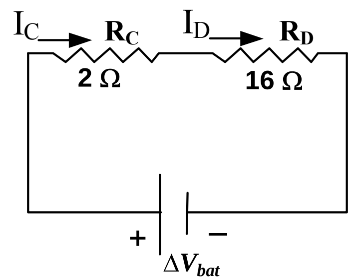
Grade out of 3? Write "3" here: _____

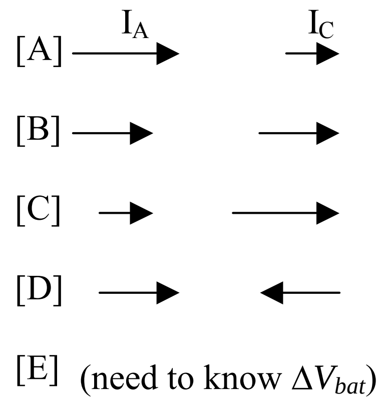
D

3. The arrows represent the magnitude and direction of the current through resistors A and C. Choose the correct diagram.

A.
B.
C.
D.
E. need to know ΔV_{bat}





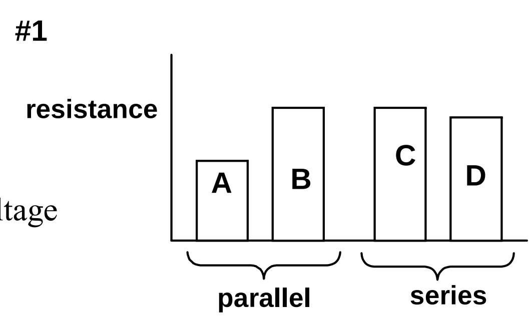


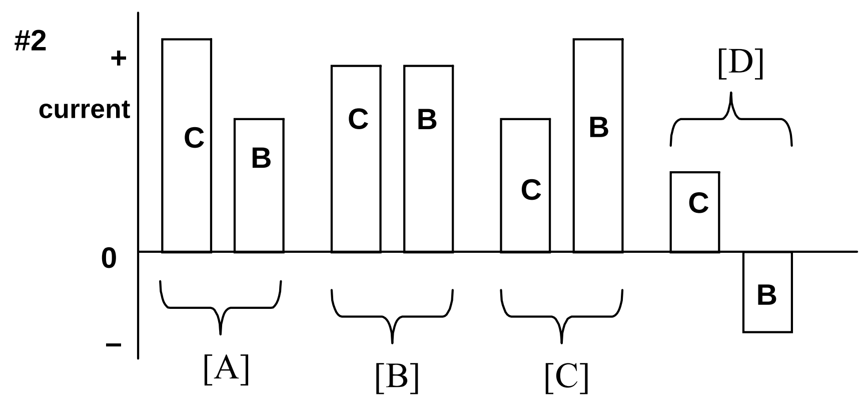
Grade out of 3? Write "3" here: _____

G

4. Graph #1 represents the relative resistances of resistors A, B, C, and D. Resistors A and B are connected in a parallel circuit. Resistors C and D are connected in a series circuit. The battery voltage in both circuits is the same. Graph #2 represents the currents in resistors C and B respectively. Which pair is correct?

A.
B.
C.
D.
E. need to know voltage





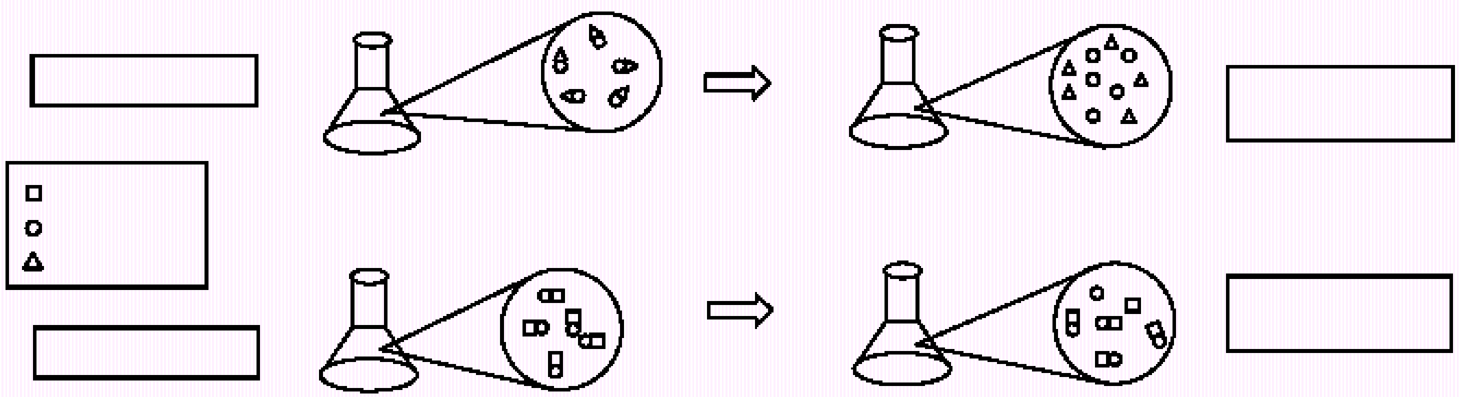
1. Hydrogen chloride gas is bubbled into water, resulting in a one-tenth molar hydrochloric acid solution. In that solution, after dissociation, all of the chlorine atoms become chloride ions, and all of the hydrogen atoms become hydronium ions. In a separate container, HA acid is added to water creating an initial concentration of one-tenth molar HA-acid solution. In that solution (at equilibrium), twenty percent of the H atoms becomes hydronium ions, and twenty percent of the A atoms become A^- ions.

(a) Find the pH of the hydrochloric acid solution and explain your reasoning.

(b) Find the pH of the HA-acid solution and explain your reasoning

[Chemistry Multi-representation Quiz]

2. (a) Given these two samples below, find the pH of each solution



(b) Explain the reasoning you used to come to this conclusion.

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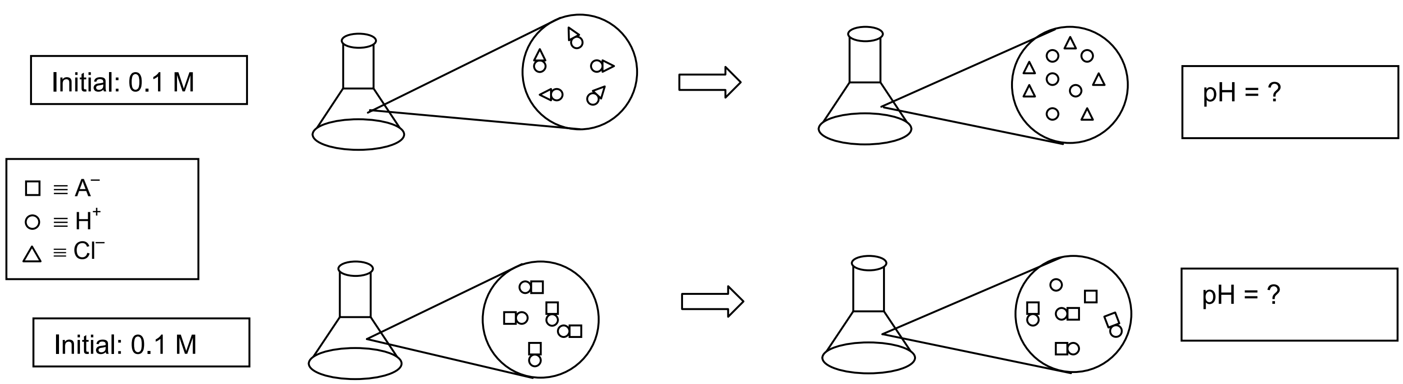


(b) Explain the reasoning you used to come to this conclusion.

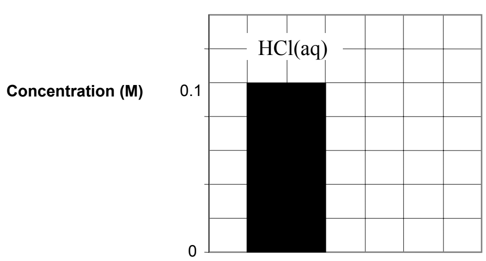
3. (a) Given these two solutions below, find the pH of each solution.

$HA(s) + H_2O(l) \Leftrightarrow H_3O^+(aq) + A^-(aq)$ ionization = 20% initial concentration = 0.1 M pH = ?	$HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$ ionization = 100% initial concentration = 0.1 M pH = ?

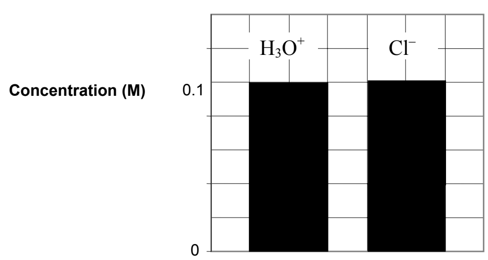
(b) Explain your reasoning.

4. (a) Given the solutions below, find the pH of each solution.

Before dissociation

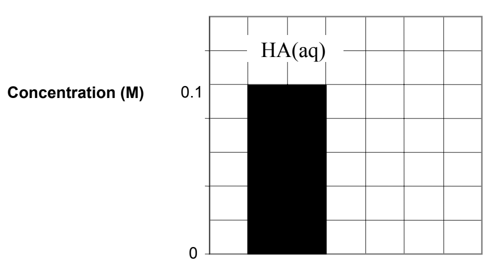


After dissociation

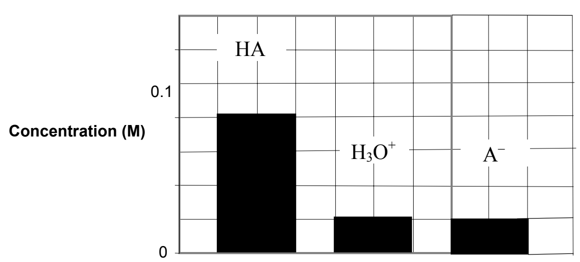


pH = ?

Before dissociation



At equilibrium



pH = ?

(b) Explain your reasoning.

How do these issues play out in collaborative research?

Example: Iowa State Thermodynamics Project

Investigate learning difficulties in thermodynamics in both chemistry and physics courses

- First focus on students' ***initial*** exposure to thermodynamics (i.e., in chemistry courses), then follow up with their ***next*** exposure (in physics courses).
- Investigate learning of same or similar topics in two different contexts (often using different forms of representation).
- Devise methods to directly address these learning difficulties.
- Test materials with students in both courses; use insights gained in one field to inform instruction in the other.

Students' Evolving Concepts of Thermodynamics

- Most students study thermodynamics in chemistry courses before they see it in physics
  - E.g., at Iowa State U.: ≈ 90% of engineering students
- Ideas acquired in chemistry may impact learning in physics
- Certain specific misconceptions are widespread among chemistry students

Physics and Chemistry Instructors Working "At Cross Purposes" in Introductory Courses

- Physicists want to emphasize energy as a general, unifying concept, focusing on heating, working, and radiating as diverse energy transfer mechanisms.

- Chemists emphasize analysis and understanding of common chemical reactions, focusing on specific quantities and particular conditions most likely to be encountered in the lab
  - (e.g., enthalpy changes in constant-pressure reactions).

Initial Hurdle: Different approaches to thermodynamics in physics and chemistry

- ***For physicists:***
  - Primary (?) unifying concept is transformation of ***internal energy E*** of a system through heating and doing work;
  - Second Law analysis focuses on ***entropy*** concept, and analysis of cyclical processes.

- ***For chemists:***
  - Primary (?) unifying concept is ***enthalpy H [H = E + PV]*** (ΔH = heat absorbed in ***constant-pressure*** process)
  - Second law analysis focuses on ***free energy*** (e.g., Gibbs free energy $G = H – TS$)

Conceptual Minefields Created in Chemistry

- The state function enthalpy [H] comes to be identified in students' minds with *heat in general,* which is *not* a state function.

  [$H = E + PV$; ΔH = heat absorbed in ***constant-pressure*** process]

- Contributions to ΔE due to work usually neglected; gas phase reactions de-emphasized

- The distinction between H and internal energy E is explicitly downplayed (due to small proportional difference)

- Sign convention different from that most often used in physics: $\Delta E = Q + W$ (vs. $\Delta E = Q - W$)

How might this affect physics instruction?

- For many physics students, initial ideas about thermodynamics are formed during ***chemistry*** courses.

- In chemistry courses, a particular state function (enthalpy) comes to be identified -- in students' minds -- with ***heat in general***, which is ***not*** a state function.

Initial Objectives:

Students' understanding of "*state functions*" and First Law of Thermodynamics

*Diagnostic Strategy: Examine two **different** processes leading from state "A" to state "B":*

Sample Populations

Introductory courses for science majors

- **First-semester Chemistry**
  - 2000: $N = 532$
- **Second-semester Physics**
  - 1999: $N = 186$
  - 2000: $N = 188$
  - 2001: $N = 279$
  - 2002: $N = 32$ [Interview sample]

Thermodynamics in Physics Context: Introductory Students vs. Advanced Students

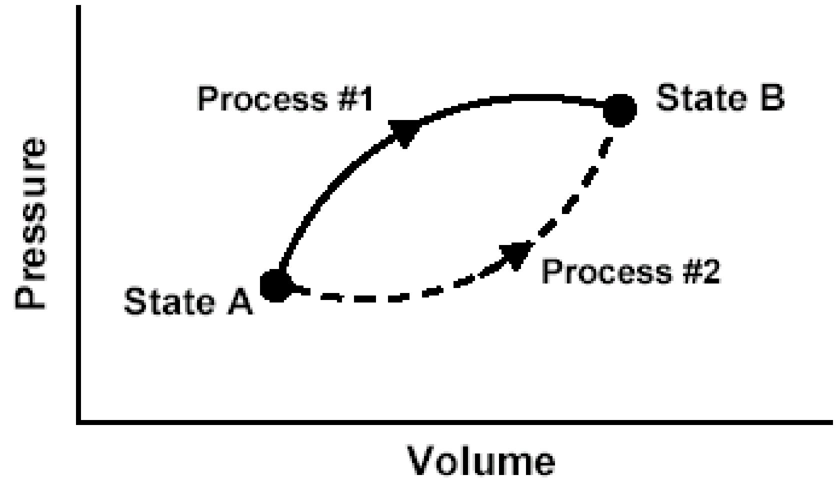
- **Introductory course:** second-semester general physics course with calculus at Iowa State, primarily engineering majors

- **Advanced course:** junior/senior-level Thermal Physics course at Iowa State, almost all physics majors or physics/engineering double majors

Performance Comparison: Introductory Students vs. Advanced Students

- Diagnostic questions given to students in introductory calculus-based course *after* instruction was complete:
  - 1999-2001: 653 students responded to written questions
  - 2002: 32 self-selected, high-performing students participated in one-on-one interviews
- Written pre-test questions given to Thermal Physics students on first day of class

This *P-V* diagram represents a system consisting of a fixed amount of ideal gas that undergoes two ***different*** processes in going from state A to state B:



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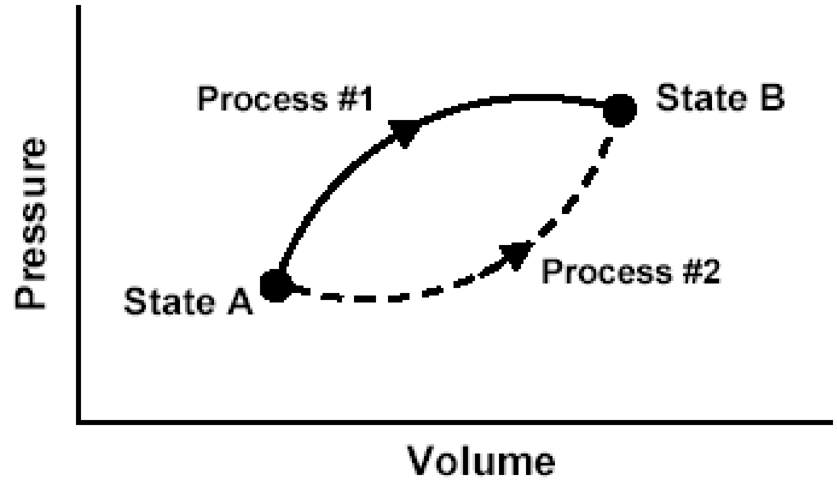

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1. Is *W* for Process #1 ***greater than, less than***, or ***equal to*** that for Process #2? Explain.

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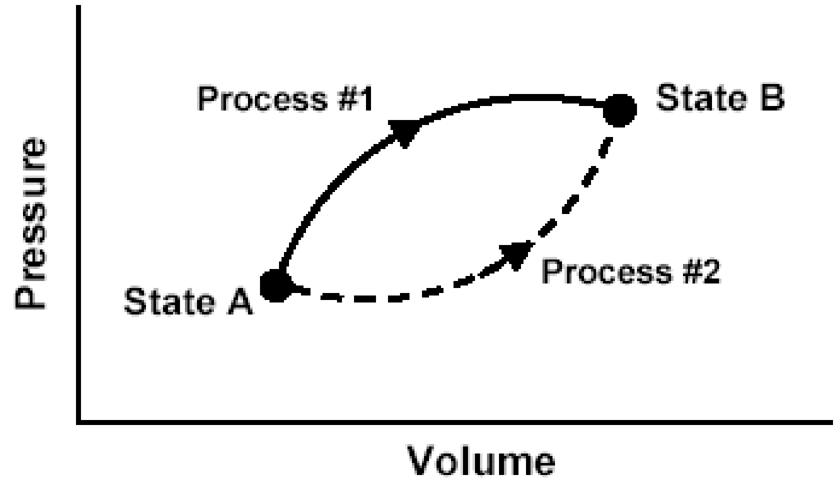

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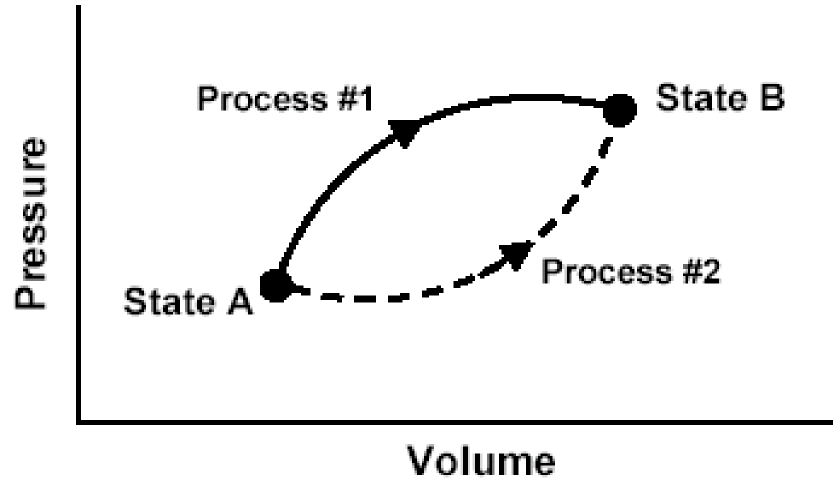
$$W = \int_{V_A}^{V_B} P\,dV$$



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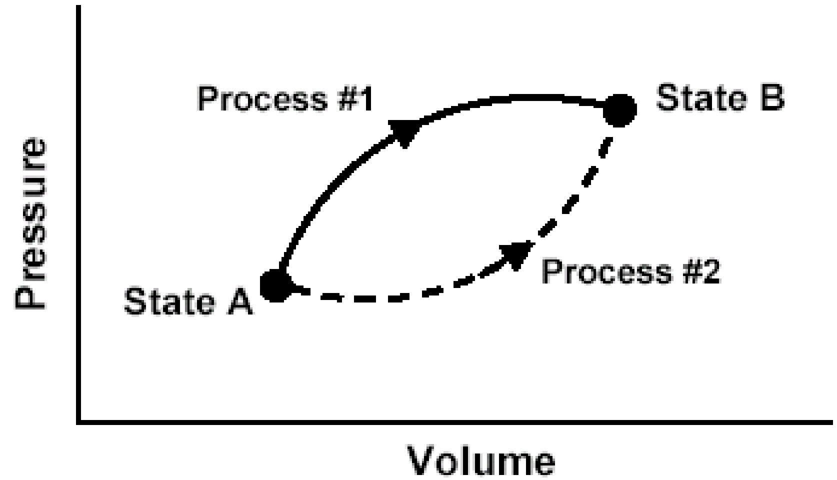

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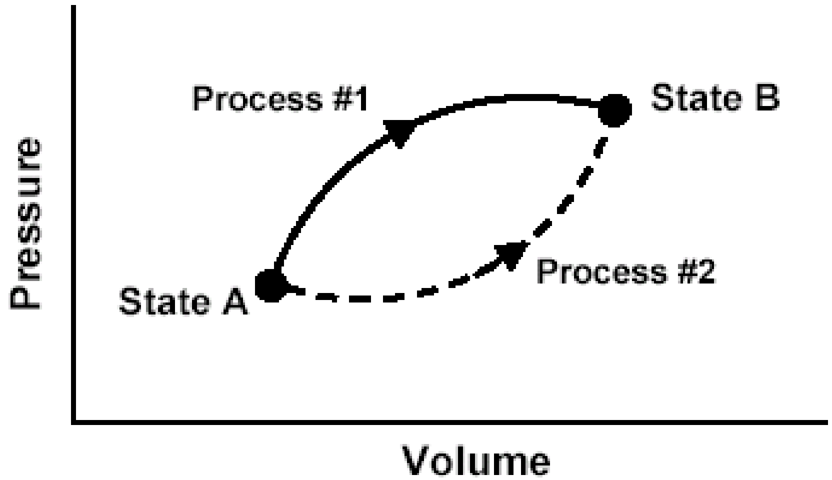

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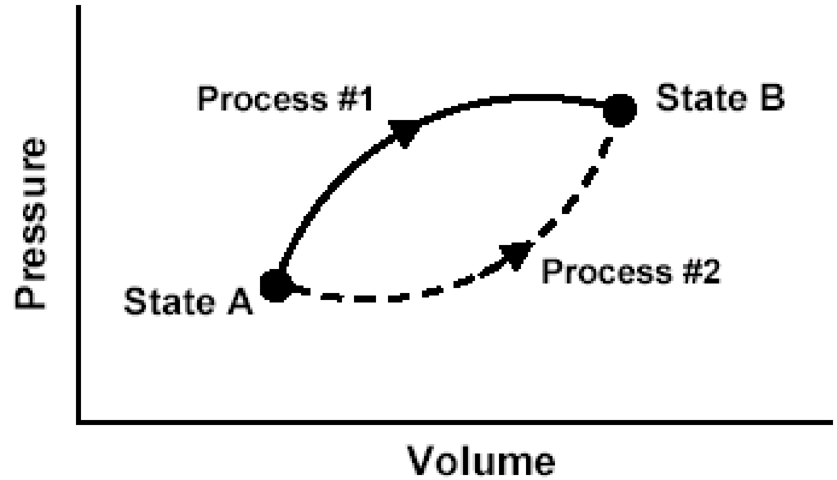

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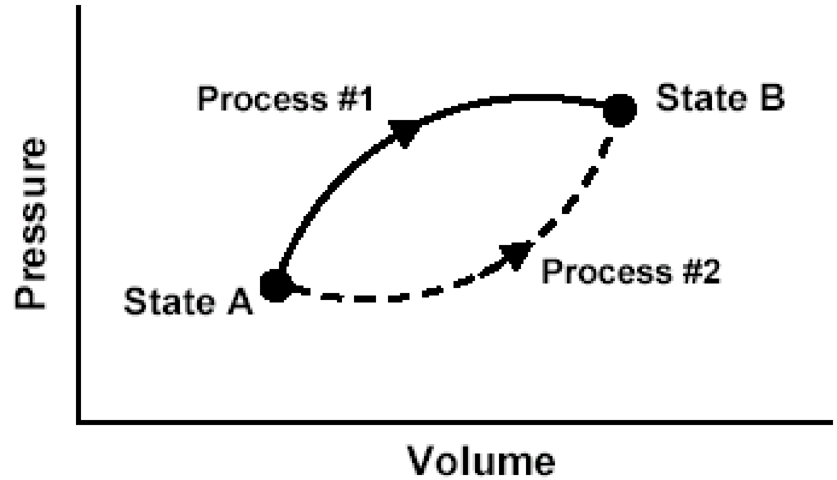

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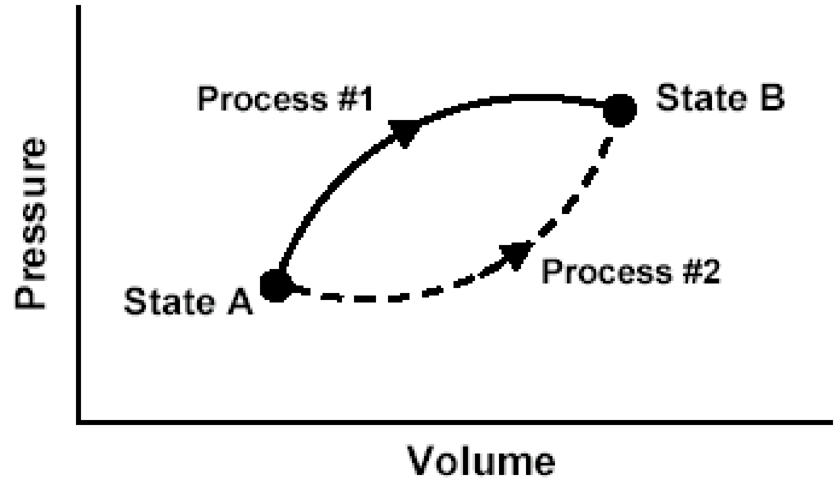
This *P-V* diagram represents a system consisting of a fixed amount of ideal gas that undergoes two ***different*** processes in going from state A to state B:

Change in internal energy is the same for Process #1 and Process #2.



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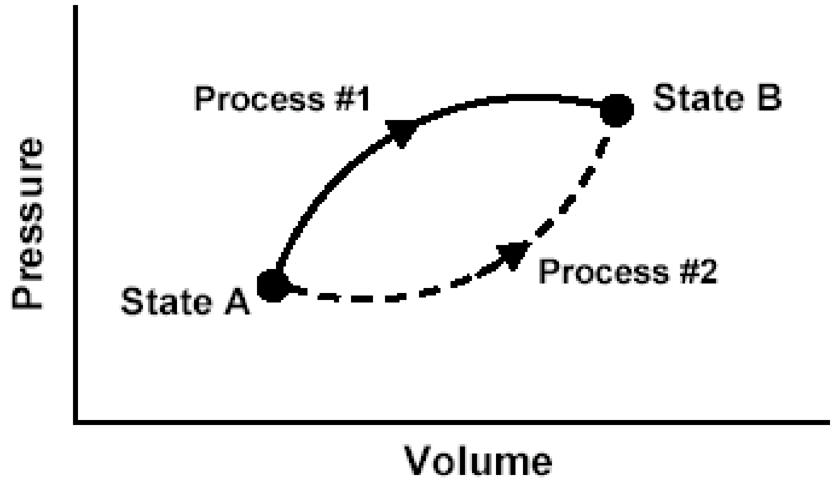
This *P-V* diagram represents a system consisting of a fixed amount of ideal gas that undergoes two ***different*** processes in going from state A to state B:

The system does more work in Process #1, so it must absorb more heat to reach same final value of internal energy:
$Q_1 > Q_2$



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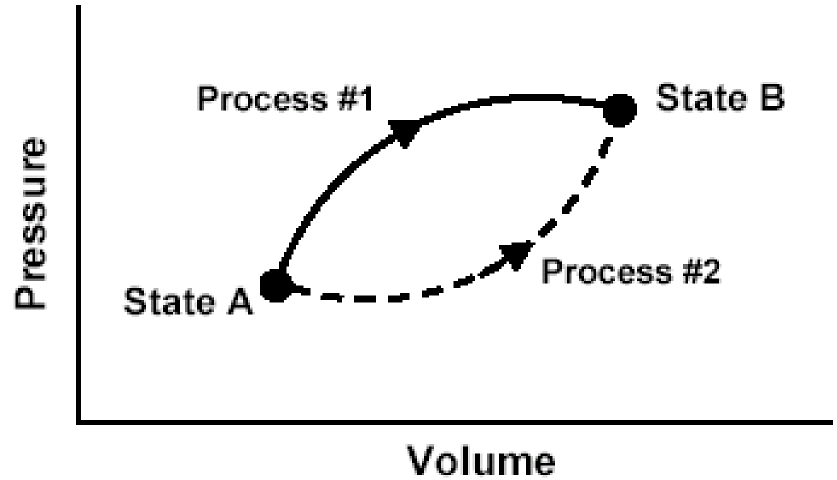
Algebraic Method:

$$\Delta E_1 = \Delta E_2$$

$$Q_1 - W_1 = Q_2 - W_2$$

$$W_1 - W_2 = Q_1 - Q_2$$

$$W_1 > W_2 \Rightarrow Q_1 > Q_2$$



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Responses to Diagnostic Question #2
(Heat question)

	1999-2001 Introductory Physics (Post-test) Written Sample (*N*=653)	**2002** Introductory Physics (Post-test) Interview Sample (*N*=32)	**2003-4** Thermal Physics (Pretest) (*N*=33)
$Q_1 > Q_2$			
$Q_1 = Q_2$			
$Q_1 < Q_2$			

Responses to Diagnostic Question #2

(Heat question)

$Q_1 = Q_2$			

[most common incorrect answer]

Responses to Diagnostic Question #2
(Heat question)

	1999-2001 **Introductory Physics** **(Post-test)** **Written Sample** **(*N*=653)**		
$Q_1 = Q_2$	**38%**		

[most common incorrect answer]

Responses to Diagnostic Question #2
(Heat question)

	1999-2001 Introductory Physics (Post-test) Written Sample (*N*=653)	2002 Introductory Physics (Post-test) Interview Sample (*N*=32)	
$Q_1 = Q_2$	38%	47%	

[most common incorrect answer]

Responses to Diagnostic Question #2
(Heat question)

	1999-2001 **Introductory Physics** **(Post-test)** **Written Sample** **(*N*=653)**	**2002** **Introductory Physics** **(Post-test)** **Interview Sample** **(*N*=32)**	**2003-4** **Thermal Physics** **(Pretest)** **(*N*=33)**
$Q_1 = Q_2$	**38%**	**47%**	**30%**

[most common incorrect answer]

Explanations Given to Justify $Q_1 = Q_2$

- "*Equal. They both start at the same place and end at the same place*."
- *"I believe that heat transfer is like energy in the fact that it is a state function and doesn't matter the path since they end at the same point."*
- **Many introductory *and* advanced physics students stated or implied that heat transfer is independent of process.**

Responses to Diagnostic Question #2
(Heat question)

$Q_1 > Q_2$			
[Correct answer]			

Responses to Diagnostic Question #2
(Heat question)

	1999-2001 **Introductory Physics** **(Post-test)** **Written Sample** **(*N*=653)**		
$Q_1 > Q_2$	**45%**		

Responses to Diagnostic Question #2
(Heat question)

	1999-2001 **Introductory Physics** **(Post-test)** **Written Sample** **(*N*=653)**	**2002** **Introductory Physics** **(Post-test)** **Interview Sample** **(*N*=32)**	
$Q_1 > Q_2$	**45%**	**34%**	

Responses to Diagnostic Question #2

(Heat question)

	1999-2001 **Introductory Physics** **(Post-test)** **Written Sample** **(*N*=653)**	**2002** **Introductory Physics** **(Post-test)** **Interview Sample** **(*N*=32)**	**2003-4** **Thermal Physics** **(Pretest)** **(*N*=33)**
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Responses to Diagnostic Question #2

(Heat question)

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$Q_1 > Q_2$	**45%**	**34%**	**33%**
Correct or partially correct explanation			

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(Heat question)

	1999-2001 Introductory Physics (Post-test) Written Sample (*N*=653)	**2002** Introductory Physics (Post-test) Interview Sample (*N*=32)	**2003-4** Thermal Physics (Pretest) (*N*=33)
$Q_1 > Q_2$	**45%**	**34%**	**33%**
Correct or partially correct explanation	**11%**	**19%**	**30%**

Responses to Diagnostic Question #2
(Heat question)

	1999-2001 Introductory Physics (Post-test) Written Sample (N=653)	**2002** Introductory Physics (Post-test) Interview Sample (N=32)	**2003-4** Thermal Physics (Pretest) (N=33)
$Q_1 > Q_2$	**45%**	**34%**	**33%**
Correct or partially correct explanation	**11%**	**19%**	**30%**

Fewer than 20% of students in introductory course are successful in answering first-law question

Responses to Diagnostic Question #2

(Heat question)

	1999-2001 **Introductory Physics** (Post-test) **Written Sample** **(*N*=653)**	**2002** **Introductory Physics** (Post-test) **Interview Sample** **(*N*=32)**	**2005** **Physical Chemistry** (Post-test) **(*N*=8)**
$Q_1 > Q_2$	45%	34%	15%
Correct or partially correct explanation	**11%**	**19%**	**15%**

Post-test performance of Physical Chemistry students at University of Maine comparable to introductory course; consistent with Towns and Grant (1997)

Thermodynamics in the Context of First-Year Chemistry

- *P-V* diagrams not generally used in introductory chemistry so must translate diagnostic into appropriate context

- Initial trials indicated that even use of standard symbolic notation such as "ΔX" (= "change in X") required explicit explanation

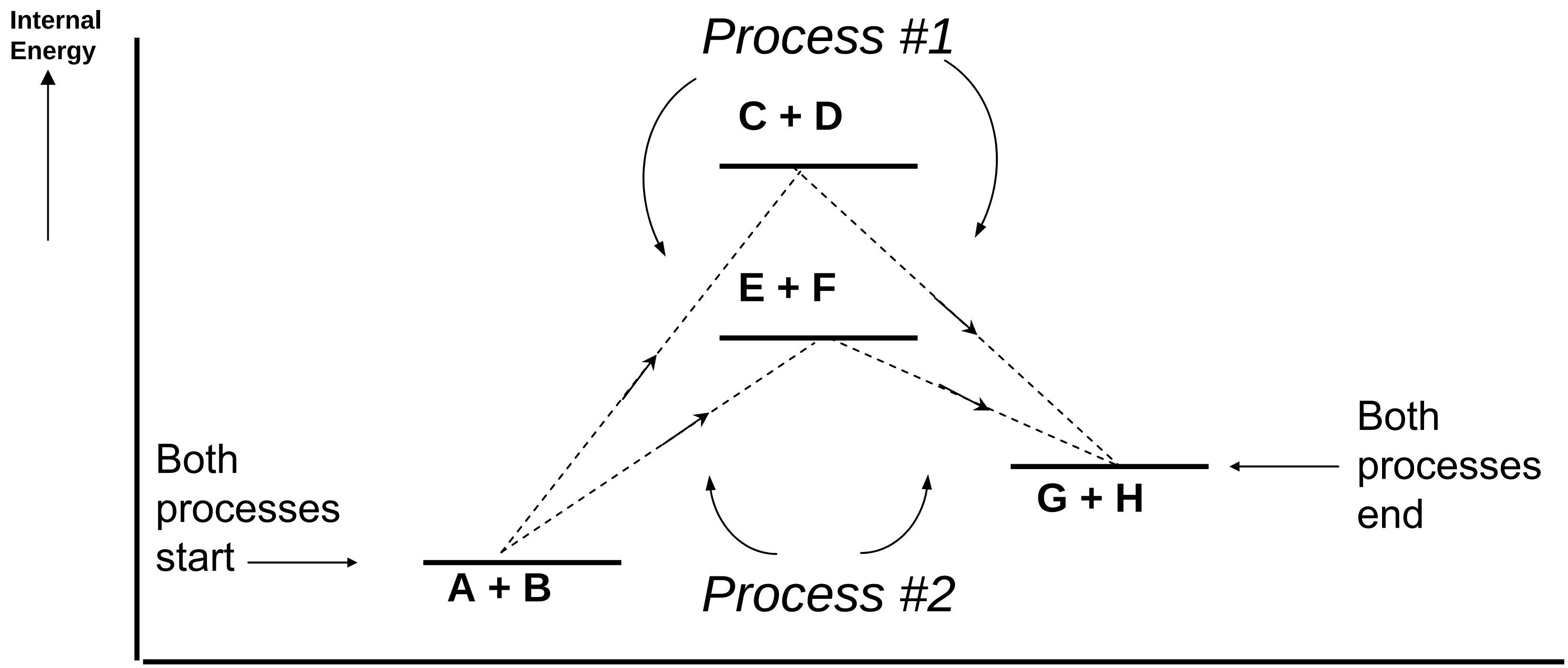


Diagram for Chemistry diagnostic

Name ______________________________ **Chem 177 Section** ____________

TA ________________________

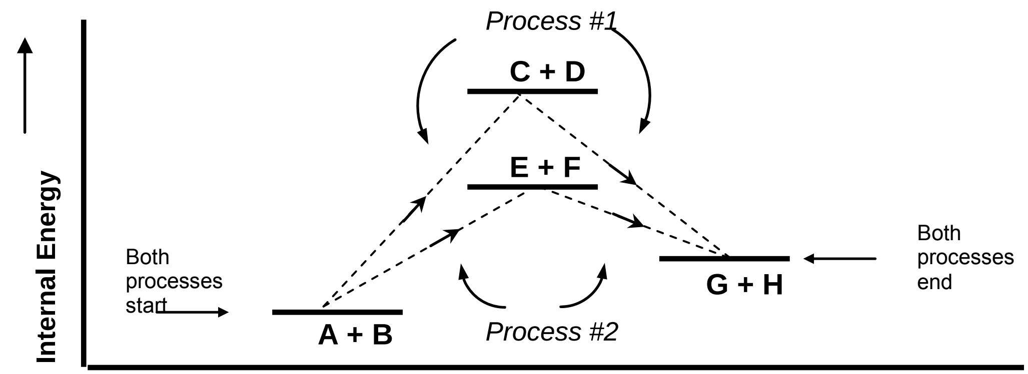
Consider the following two processes, #1 and #2:

Process #1:

$$\begin{array}{ll} & A + B \rightarrow C + D \\ & \underline{C + D \rightarrow G + H} \\ \textit{Net}: & A + B \rightarrow G + H \end{array}$$

Process #2:

$$\begin{array}{ll} & A + B \rightarrow E + F \\ & \underline{E + F \rightarrow G + H} \\ \textit{Net}: & A + B \rightarrow G + H \end{array}$$



The reactants (**A** and **B**) and the products (**G** and **H**) are ***identical*** in both cases and are in ***identical states***. [**A** + **B**] is the initial state for ***both*** processes #1 and #2, while [**G** + **H**] is the final state for both processes. **However**, the ***intermediate*** reactions are different.

Here we will assume that **the total heat absorbed by the system during Process #1 is larger than the total heat absorbed by the system during Process #2.** *Note that these are **not** constant-pressure processes, **nor** are they constant-volume processes; in other words, **both** the pressure **and** the volume may vary during each process.*

➡ *Note: The **"net change"** in a quantity "ΔM" means how much "M" changes from the beginning (initial state) to the end (final state) of a process:*

$$\boxed{\Delta M = M_{final} - M_{initial}}$$

1) *[one point]* Is the ***net change*** in temperature of the system ΔT during Process #1 *greater than, less than*, or *equal to* the ΔT during Process #2?

***equal to**, because both processes share the same initial and final states*

Name ________________________________ **Chem 177 Section** ______________

TA _________________________

Consider the following two processes, #1 and #2:

Process #1:

A + B $\rightarrow$ C + D

C + D $\rightarrow$ G + H

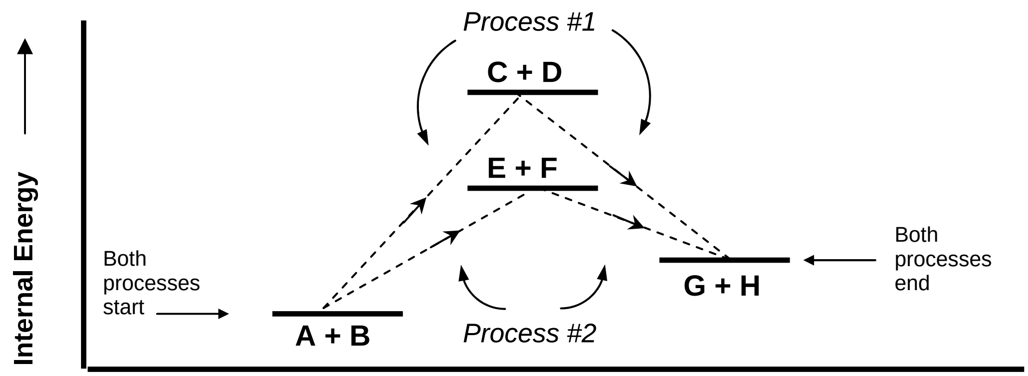
Net: A + B $\rightarrow$ G + H

Process #2:

A + B $\rightarrow$ E + F

E + F $\rightarrow$ G + H

Net: A + B $\rightarrow$ G + H



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   equal to*, because both processes share the same initial and final states*

2) *[one point]* Is the ***net change*** in internal energy of the system ΔE during Process #1 *greater than*, *less than*, or *equal to* the ΔE during Process #2? Explain your answer.

   equal to*, because both processes share the same initial and final states. The fact that the ΔE's are equal can also be read directly off of the diagram*

3) *[two points]* Is the work done ***on the system*** during Process #1 *greater than*, *less than*, or *equal to* the work done ***on the system*** during Process #2? Explain.

   less than. *$\Delta E = q + w$ and $\Delta E_1 = \Delta E_2$, so $(q + w)_1 = (q + w)_2$. Since $q_1 > q_2$, we have $w_1 < w_2$*

4) *[one point]* Is the ***net change*** in enthalpy of the system ΔH during Process #1 *greater than*, *less than*, or *equal to* the ΔH during Process #2? Explain your answer.

   equal to*, because both processes share the same initial and final states*

Results of Chemistry Diagnostic:

Is the net change in [(a) temperature ΔT; (b) internal energy ΔE] of the system during Process #1 ***greater than, less than,*** *or* ***<u>equal to</u>*** *that for Process #2?*

ΔT **during Process #1 is:**

greater than: …….*48%*

less than:…………..*3%*

equal to:…………..*47%*

ΔT **for Process #2.**

ΔE **during Process #1 is:**

greater than: …….*30%*

less than:…………..*2%*

equal to:…………..*66%*

ΔE **for Process #2.**

Students answering correctly that *<u>both</u>* ΔT *and* ΔE are equal: *33%*

Results from Chemistry Diagnostic

[*Given in general chemistry course for science majors, Fall 2000, N =532]*

- 66% of students recognized that change in internal energy was same for both processes. (But this merely represented correct interpretation of diagram itself.)

- 47% of students recognized that change in temperature must be the same for both processes, since initial and final states are identical. (But this merely represented correct interpretation of “state.”)

- Only 11% gave correct answer to first-law question regarding work.

Results from Chemistry Diagnostic

[*Given in general chemistry course for science majors, Fall 2000, N =532*]

- 66% of students recognized that change in internal energy was same for both processes. (But this merely represented correct interpretation of diagram itself.)
- 47% of students recognized that change in temperature must be the same for both processes, since initial and final states are identical. (But this merely represented correct interpretation of “state.”)
- **Only 11% gave correct answer to first-law question regarding work.**

Students' Ideas in Chemistry Context Have Different Focus than in Physics Context

- 11% gave correct or partially correct answer to work question ($W_1 < W_2$) based on first law of thermodynamics.

- Only 16% stated $W_1 = W_2$ (about half stating because "initial and final states are same").
  - *In the physics sample, this was the* ***most popular*** *justification for incorrect answers*

- 62% stated $W_1 > W_2$ (almost half stating because "internal energy is greater).

Summary of Results on First Law

- No more than $\approx$15% of students are able to make effective use of first law of thermodynamics after introductory chemistry *or* introductory physics course.

- Although similar errors regarding thermodynamics appear in thinking of both chemistry and physics students, possible linking of incorrect thinking needs further study.

Example: Student Learning of Calorimetry Concepts in Chemistry and Physics

1. Learning of calorimetry concepts in physics context

2. Learning of thermochemical concepts in the context of calorimetry

Temperature change of material being heated

Amount of heating

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

Mass of material being heated

Specific heat of material being heated

Key Equation for Calorimetry Problems in both Physics and Chemistry Context

Calorimetry Question in Physics Context

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.

Solution in Mathematical Form

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

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

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

Solution in Mathematical Form

$$Q = mc\Delta T$$

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

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

Notation: ΔT ≡ absolute value *of temperature change*

Solution in Mathematical Form

$$Q = mc\Delta T$$

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

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

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

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

Notation: ΔT ≡ absolute value *of temperature change*

Free-Response Question Results

Second-semester calculus-based course

	N=311
Correct	
$\Delta T_{LSH} > \Delta T_{GSH}$	62%
With correct explanation	***55%***

LSH = lower specific heat
GSH = greater specific heat

Free-Response Question Results

Second-semester calculus-based course

		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

Example of Incorrect Student Explanation to Justify $\Delta T_{LSH} = \Delta T_{GSH}$

"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"

Example of Incorrect Student Explanation to Justify $\Delta T_{LSH} < \Delta T_{GSH}$

"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"

Learning of Thermochemical Concepts in Context of Calorimetry

T. J. Greenbowe and D. E. Meltzer, Int. J. Sci. Educ. *25, 779 (2003)*

- Investigated students' misunderstanding of role of bond breaking and forming in determining heats of reaction
  - *belief that heat flows <u>from</u> one reactant <u>to</u> the other*

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- Uncovered students' misinterpretation of role of mass in relationship $Q = mc\Delta T$
  - *tendency to associate* "m" *with reactants only, instead of with total mass undergoing temperature change*

INT. J. SCI. EDUC., 2003, VOL. 25, NO. 1, 1–22

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Student learning of thermochemical concepts in the context of solution calorimetry

Thomas J. Greenbowe, Department of Chemistry, Iowa State University of Science and Technology, Ames, IA 50011, USA; e-mail: tgreenbo@iastate.edu; and David E. Meltzer, Department of Physics and Astronomy, Iowa State University of Science and Technology, Ames, IA 50011, USA; e-mail: dem@iastate.edu

Student understanding of heat and thermal phenomena has been the subject of considerable investigation in the science education literature. Published studies have reported student conceptions on a variety of advanced topics, but calorimetry – one of the more elementary applications of thermochemical concepts – has apparently received little attention from science education researchers. Here we report a detailed analysis of student performance on solution calorimetry problems in an introductory university chemistry class. We include data both from written classroom exams for 207 students, and from an extensive longitudinal interview series with a single subject who was herself part of that larger class. Our findings reveal a number of learning difficulties, most of which appear to originate from failure to understand that net increases and decreases in bond energies during aqueous chemical reactions result in energy transfers out of and into, respectively, the total mass of the resultant solution.

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Calorimetry Problem on Final Exam

The following reaction takes place at constant pressure in an insulated calorimeter: 1.00 L of 2.00 M $Ba(NO_3)_2$ solution at 25.0°C was mixed with 1.00 L of 2.00 M Na_2SO_4 solution at 25.0°C. The final temperature of the solution after mixing was 31.2°C. Assume that all solutions had a density of 1.00 g/mL and a specific heat of 4.18 J/g-°C.

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Calculate the heat of reaction (in kJ).

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Calculate the heat of reaction (in kJ).

Difficulties with Calorimetry Problems

- About 15-20% of students did not realize the need to use $q = mc\Delta T$.
- About 25% of all students did not realize that mass m refers to total mass of solution in container.

[Among others….]

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  - *tendency to associate "m" with reactants only, instead of with total mass undergoing temperature change*

Examples from Interviews

Q: *What are you measuring with the thermometer?*

Sophia: The heat is rising in the solution because something is letting off heat but it is going into solution. There is a transfer of heat. It is going from one object to another.

Q: *And what is that object to the other?*

Sophia*:* It is from one chemical to the other but I am not sure which is giving it off and which is absorbing it.

This represents an incorrect generalization from the *physics* context

Student Understanding of Entropy and the Second Law of Thermodynamics in the Context of Chemistry

- Second-semester course at Iowa State University; covered standard topics in chemical thermodynamics:
  - Entropy and disorder
  - Second Law of Thermodynamics:

    $$\Delta S_{universe} \,[= \Delta S_{system} + \Delta S_{surroundings}] \geq 0$$

  - Gibbs free energy: $G = H - TS$
  - Spontaneous processes: $\Delta G_{T,P} < 0$

- Written diagnostic administered to 47 students (11% of class) last day of class.

- In-depth interviews with eight student volunteers

Students' confusion:
apparently conflicting criteria for spontaneity

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- $\Delta G_{T,P} < 0$ criterion, and equation $\Delta G = \Delta H - T\Delta S$, refer only to properties of the ***system****;*

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- $\Delta G_{T,P} < 0$ criterion, and equation $\Delta G = \Delta H - T\Delta S$, refer only to properties of the ***system;***
- $\Delta S_{universe} > 0$ refers to properties ***outside*** the system;

Students' confusion: apparently conflicting criteria for spontaneity

- $\Delta G_{T,P} < 0$ criterion, and equation $\Delta G = \Delta H - T\Delta S$, refer only to properties of the ***system;***
- $\Delta S_{universe} > 0$ refers to properties ***outside*** the system;

  → *Consequently, students are continually confused as to what is the "system" and what is the "universe," and **which one** determines the criteria for spontaneity.*

Overall Conceptual Gaps

- There is uncertainty as to whether a spontaneous process requires entropy of the ***system*** or entropy of the ***universe*** to increase.

- There is uncertainty as to whether $\Delta G < 0$ implies that entropy of the ***system*** or entropy of the ***universe*** will increase.

Example: Student Learning of Thermodynamics in Chemistry and Physics

Example: Student Learning of Thermodynamics in Chemistry and **Physics**

Example: Student Learning of Thermodynamics in Chemistry and **Physics**

[with John Thompson and Warren Christensen]

- Introductory Course

  (general physics for engineers)

- Intermediate Course

  (sophomore-level thermal physics, mostly physics majors)

- Advanced Course

  (junior/senior-level thermal physics course for physics majors)

Spontaneous Process Question

For each of the following questions consider a system undergoing a naturally occurring ("spontaneous") process. The system can exchange energy with its surroundings.

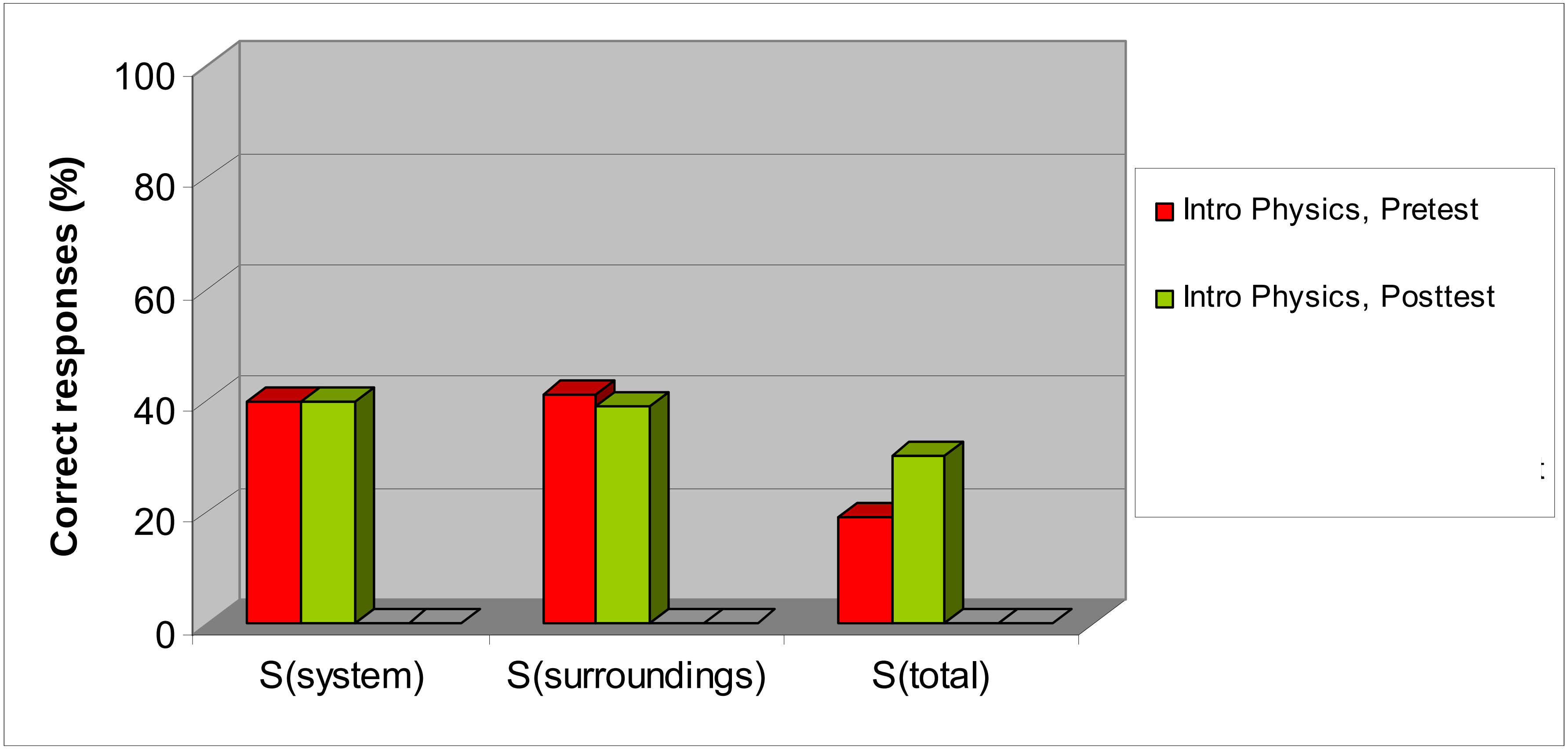
A. During this process, does the entropy of the **<u>system</u>** [S_{system}] *increase*, *decrease*, or *remain the same*, or is this *not determinable* with the given information? ***Explain your answer.***

B. During this process, does the entropy of the **<u>surroundings</u>** [$S_{surroundings}$] *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.***

Responses to Spontaneous-Process Questions

Introductory Students



Less than 40% correct on each question

Introductory Physics Students' Thinking on Spontaneous Processes

- Tendency to assume that "system entropy" must *always* increase

- Slow to accept the idea that entropy of system plus surroundings ***increases***

  - *Most students give incorrect answers to all three questions*

Introductory Physics Students' Thinking on Spontaneous Processes

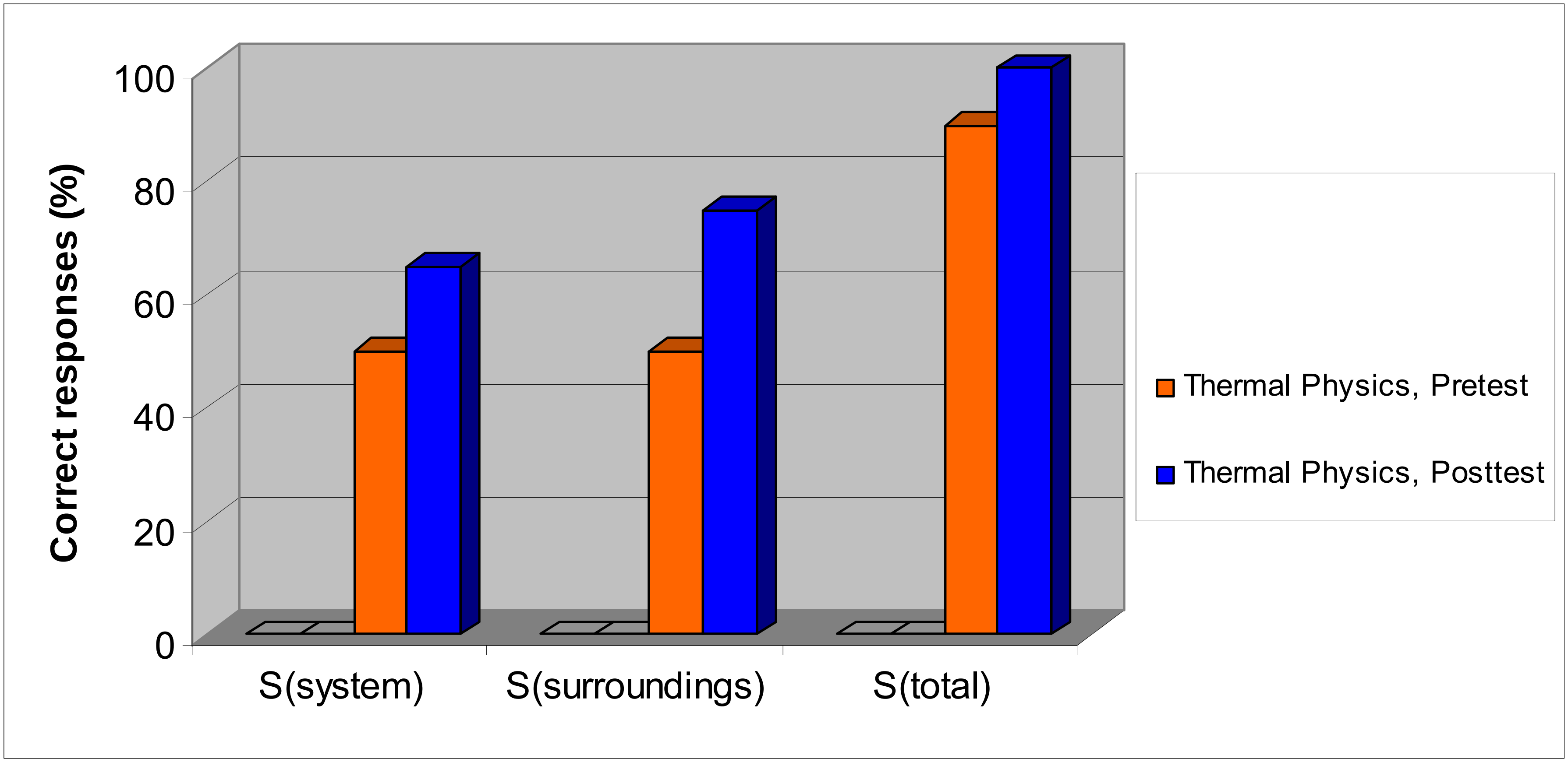
- Tendency to assume that "system entropy" must *always* increase

- Slow to accept the idea that entropy of system plus surroundings ***increases***

  - *Consistent with findings of Thomas and Schwenz (1998) in physical chemistry course*

Responses to Spontaneous-Process Questions

Advanced Students



Thermal Physics Posttest: Interactive Engagement, no focused tutorial

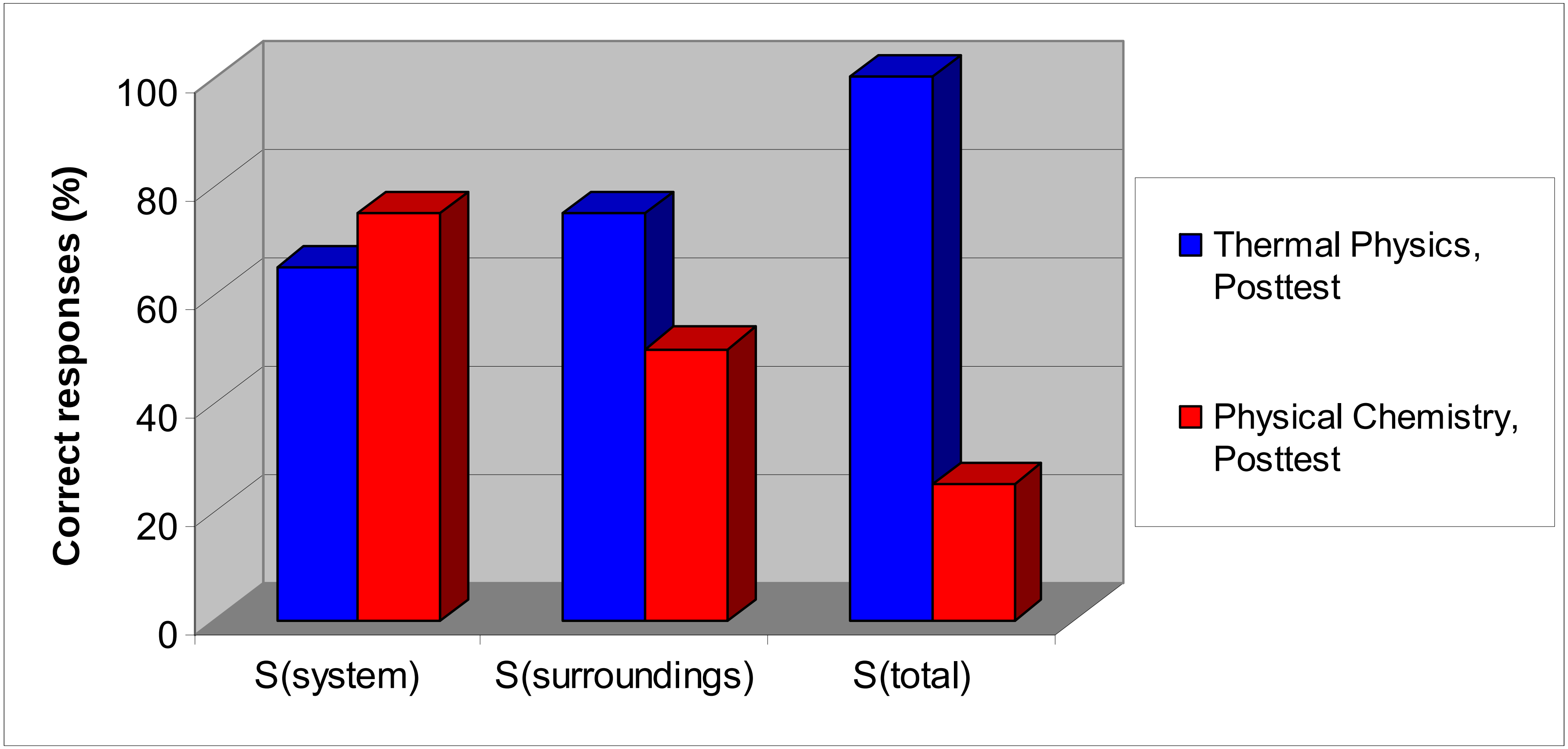
Thermal Physics Students' Thinking on Spontaneous Processes

- Readily accept that "entropy of system ***plus*** surroundings increases"
  - in contrast to introductory students

- Tendency to assume that "system entropy" must *always* increase
  - similar to thinking of introductory students

Responses to Spontaneous-Process Questions

Thermal Physics Students vs. Physical Chemistry Students: Posttest



[Physical Chemistry, U. Maine, 2005; consistent with Thomas and Schwenz (1998)]

Summary

- Interdisciplinary research in STEM education is necessary in order to maximize the impact of pedagogical advances.

- Researchers in different fields must learn each others' language, and should assume that nearly everything is at least *somewhat* different in the different fields.

- Ultimately, long-term interdisciplinary education research projects have the potential to have significant impact on undergraduate STEM education.