Dynamics of Student Learning of Thermodynamics Concepts

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Our Goal: 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.

Initial Hurdle:

Different approaches to thermodynamics in physics and chemistry

- ***For physicists:***
  - Primary (?) unifying concept is transformation of ***internal energy U*** of a system through heat absorbed and work done;
- ***For chemists:***
  - Primary (?) unifying concept is ***enthalpy H***

    [H = U + PV]

    (ΔH = heat absorbed in ***constant-pressure*** process)

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":*

Physics Diagnostic

- Given in second semester of calculus-based introductory course.
- Traditional course; thermal physics comprised 18% of course coverage.
- Diagnostic administered in last week of course:
  - Fall 1999: practice quiz during last recitation; *N = 186*
  - Fall 2000: practice quiz during final lecture; *N = 188*

Samples of Students' Answers

(All considered correct)

"DU = Q – W. For the same DU, the system with more work done must have more Q input so process #1 is greater."

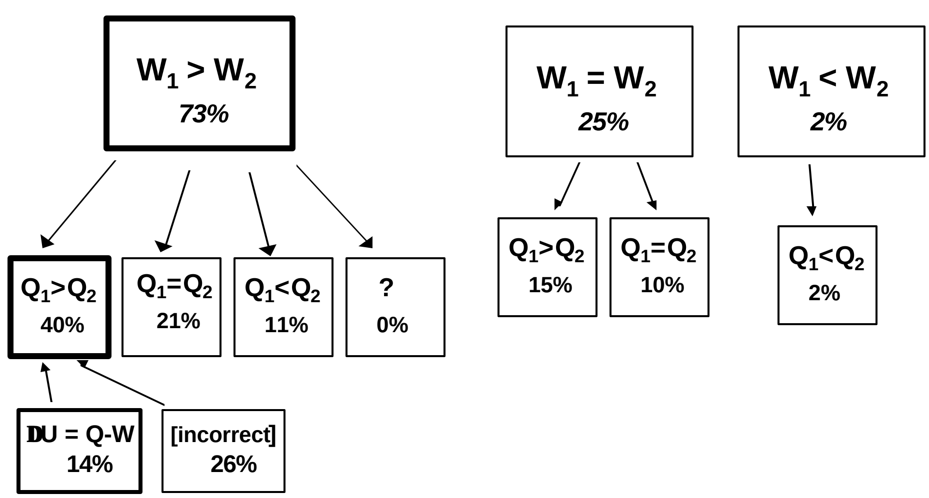
"Q is greater for process 1 since Q = U + W and W is greater for process 1."

"Q is greater for process one because it does more work, the energy to do this work comes from the Q_{in}."

"U = Q – W,   Q = U + W,   if U is the same and W is greater then Q is greater for Process #1."

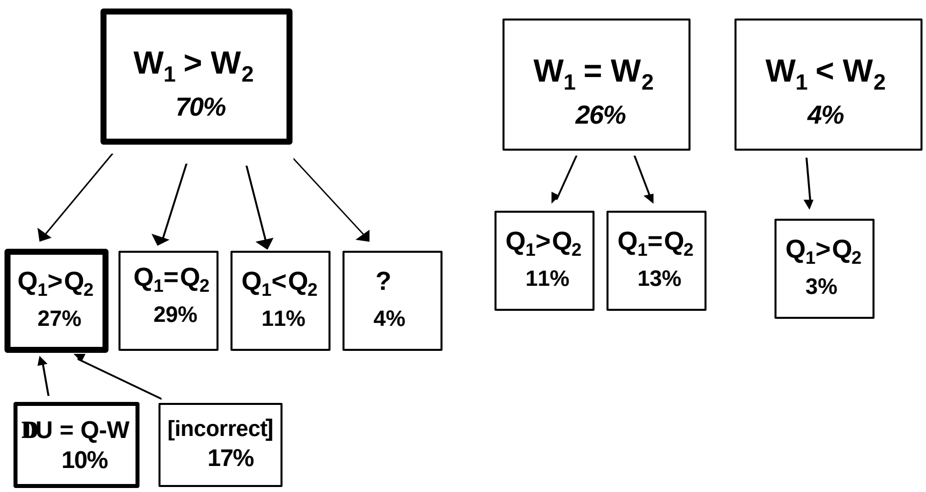
Results, Fall 1999

[N = 186]



Results, Fall 2000

[N = 188]



Students' Reasoning on Work Question

[Fall 2000: N = 188]

- Correct or partially correct 56%
- Incorrect or missing explanation 14%
- Work is independent of path 26%
  (majority explicitly assert path independence)
- Other responses 4%

Of the students who correctly answer that $W_1 > W_2$:

[Fall 2000: 70% of total student sample]

- 38% correctly state that $Q_1 > Q_2$
- 41% state that $Q_1 = Q_2$
- 16% state that $Q_1 < Q_2$

Of the students who assert that $W_1 = W_2$:

[Fall 2000: 26% of total student sample]

- 43% correctly state that $Q_1 > Q_2$
- 51% state that $Q_1 = Q_2$
- 4% state that $Q_1 < Q_2$

Relation Between Answers on Work and Heat Questions

- Probability of answering $Q_1 > Q_2$ is almost independent of answer to Work question.

  [However, correct explanations are only given by those who answer Work question correctly.]

- Probability of claiming $Q_1 = Q_2$ is ***slightly*** greater for those who answer $W_1 = W_2$.

- Probability of justifying $Q_1 = Q_2$ by asserting that "*Q is path-independent*" is ***higher*** for those who answer Work question correctly.

  ➔ Correct on Work question and state $Q_1 = Q_2$: 61% claim "Q is path-independent"

  ➔ Incorrect on Work question and state $Q_1 = Q_2$: 37% claim "Q is path-independent"

Reasoning for $Q_1 = Q_2$

[Fall 2000: 43% of total student sample]

- Q is independent of path 23%
  - *"same start and end point"*
  - *"same end point"*
  - *"path independent"*
- Other explanations 5%
- No explanation offered 15%

Note: Students who answered Work question correctly were more likely to assert path-independence of Q

Reasoning for $Q_1 = Q_2$

[Fall 2000: 43% of total student sample]

Student Response	***Proportion of sub-sample***
• Q is independent of path – *"same start and end point"* – *"same end point"* – *"path independent"*	53%
• Other explanations	12%
• No explanation offered	35%

Note: Students who answered Work question correctly were more likely to assert path-independence of Q

Reasoning for $Q_1 > Q_2$

[Fall 2000: 40% of total student sample]

- $\Delta U_1 = \Delta U_2 \Rightarrow Q_1 > Q_2$ *[correct]* 10%
- Q higher because pressure is higher . . . 7%
- $Q = W$ (and $W_1 > W_2$) 4%
- Other explanations 8%
- No explanation offered 12%

Note: Only students who answered Work question correctly gave correct explanation for $Q_1 > Q_2$

Reasoning for $Q_1 > Q_2$

[Fall 2000: 40% of total student sample]

Student Response	***Proportion of sub-sample***
• $\Delta U_1 = \Delta U_2 \Rightarrow Q_1 > Q_2$ *[correct]*	24%
• Q higher because pressure is higher	18%
• Q = W (and $W_1 > W_2$)	9%
• Other explanations	20%
• No explanation offered	29%

Note: Only students who answered Work question correctly gave correct explanation for $Q_1 > Q_2$

Reasoning for $Q_1 < Q_2$

[Fall 2000: 12% of total student sample]

- Essentially correct, but sign error. 4%
- Other explanations 5%
- No explanation offered 3%

Students' Reasoning on Heat Question

[Fall 2000: N = 188]

- Correct or partially correct 15%
- Q is independent of path 23%
- Q is higher because pressure is higher . . . 7%
- Other explanations 18%
  - $Q_1 > Q_2$: 8%
  - $Q_1 = Q_2$: 5%
  - $Q_1 < Q_2$: 5%
- No response/no explanation 36%

Note: Only students who answered Work question correctly gave correct explanation for $Q_1 > Q_2$

Of the students who correctly answer that $Q_1 > Q_2$:

[Fall 2000: 40% of total student sample]

- 66% correctly state that $W_1 > W_2$
- 28% state that $W_1 = W_2$
- 7% state that $W_1 < W_2$

Of the students who assert that $Q_1 = Q_2$:

[Fall 2000: 43% of total student sample]

- 67% correctly state that $W_1 > W_2$
- 31% state that $W_1 = W_2$
- 1% state that $W_1 < W_2$

Responses, Fall 1999 (*N = 186)*

	$W_1 > W_2$	$W_1 = W_2$	$W_1 < W_2$
$Q_1 > Q_2$	75	28	1
$Q_1 = Q_2$	39	18	0
$Q_1 < Q_2$	21	1	3

Responses, Fall 2000 (*N = 180)*

	$W_1 > W_2$	$W_1 = W_2$	$W_1 < W_2$
$Q_1 > Q_2$	50	21	5
$Q_1 = Q_2$	54	25	2
$Q_1 < Q_2$	21	2	0

Responses, 1999-2000 combined
(*N = 180)*

	$W_1 > W_2$	$W_1 = W_2$	$W_1 < W_2$
$Q_1 > Q_2$	125	49	6
$Q_1 = Q_2$	93	43	2
$Q_1 < Q_2$	42	3	3

Conclusions from Physics Diagnostic

- ≈ 25% believe that Work is independent of process.
- Of those who realize that Work is process-dependent, 30-40% appear to believe that Heat is ***independent*** of process.
- ≈ 25% of all students ***explicitly*** state belief that Heat is independent of process.
- There is only a partial overlap between those who believe that Q is process-independent, and those who believe that W is process-independent.
- ≈ 15% of students appear to have adequate understanding of First Law of Thermodynamics.

Conjectures from Physics Diagnostic

- Belief that Heat is process-independent may not be strongly affected by realization that Work is ***not*** process-independent.
- Understanding the process-dependence of Work may strengthen belief that Heat is ***independent*** of process.

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

- Second-semester course; 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: $\Delta G_{T,P} < 0$
  - Standard free-energy changes
- Written diagnostic administered to 47 students (11% of class) last day of class.
- In-depth interviews with eight student volunteers

Results from Chemistry Diagnostic

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

- 65% of students recognized that change in internal energy was same for both processes.
- 11% of students were able to use First Law of Thermodynamics to correctly compare Work done in different processes.

Summary

Fewer than one in six students in both chemistry and physics introductory courses demonstrated clear understanding of First Law of Thermodynamics.