Recurrent Areas of Confusion in Student Learning of Thermodynamics

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Students' Evolving Concepts of Thermodynamics

- Most students study thermodynamics in chemistry courses before they see it in physics
  - at Iowa State ≈ 90% of engineering students have taken chemistry before studying thermodynamics in their physics course
- Ideas acquired in chemistry may impact learning in physics
- Certain specific misconceptions regarding thermodynamics are widespread among chemistry students

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 ΔH and ΔE is explicitly downplayed (due to small proportional difference)
- Sign convention different from that most often used in physics: $\Delta E = Q + W$ (vs. $\Delta E = Q - W$)

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.

- Only 47% of students recognized that change in temperature must be the same for both processes (since initial and final states are identical).

Detailed Analysis of Sub-sample (*N* = 325)

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

  (10% had correct answer with incorrect explanation)

- 16% stated $W_1 = W_2$ (about half because "initial and final states are same").

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

Physics Diagnostic

- Given in second semester of calculus-based introductory course.
- Traditional course; thermal physics comprised ≈ 20% 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*
  - Spring 2001: practice quiz during last recitation; *N = 279*

Samples of Students' Answers

(All considered correct)

"$\Delta E = Q - W$. For the same ΔE, the system with more work done must have more Q input so process #1 is greater."

"Q is greater for process 1 since $Q = E + W$ 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}."

Conceptual Difficulties with Work

- Difficulty interpreting work as “area under the curve” on a *p*-*V* diagram

  Only » 50% able to give correct explanation for $W_1 > W_2$

- Belief that work done is independent of process

  About 15-25% are under impression that work is (or behaves as) a state function.

Conceptual Difficulties with Heat

- Belief that heat absorbed is independent of process

  About 20-25% of all students explicitly state belief that heat is path independent

- Association of greater heat absorption with higher pressure (independent of complete process)

- Use of “compensation” argument, i.e., “more work implies less heat” and vice versa.
  - *Many students use argument without regard to ΔE*
  - *Some students use “opposite” sign convention, $\Delta E = Q + W$*
  - *Others use correct sign convention, but make mathematical sign error*

Difficulty with First Law of Thermodynamics

- Only about 15% of all 645 students were able to give correct answer with correct (or partially correct) explanation based on first law of thermodynamics
  - ⇨ *very little variation semester to semester*
- Proportion of correct answers virtually identical to that found in chemistry course

Patterns Underlying Responses

- Of students who answer $W_1 = W_2$, about 50% incorrectly assert $Q_1 = Q_2$
- Of students who *correctly* answer Work question ($W_1 > W_2$), about 35% *also* assert $Q_1 = Q_2$

Justifications Given by Students Who Incorrectly Assert $Q_1 = Q_2$

- Students who answered Work question correctly *usually* claim “heat is independent of path”
- Students who answered Work question *incorrectly* usually do *not* claim “heat is independent of path”

Conjectures Regarding Dynamics of Student Reasoning

- Belief that heat is process-independent may not be strongly affected by realization that work is *not* process-independent.
- Understanding process-dependence of work may strengthen mistaken belief that heat is *independent* of process.

Summary

- No more than ≈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 links between conceptual problems need further study.