Observations of General Learning Patterns in an Upper-Level Thermal Physics Course

David E. Meltzer

College of Teacher Education and Leadership, Arizona State University

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

Thermal Physics: Course and Students

- **Topics:** Approximately equal balance between classical macroscopic thermodynamics and statistical thermodynamics (Texts: Sears and Salinger; Schroeder)
- **Students enrolled** [$N_{initial}$ = 14 (*2003*) and 19 (*2004*)]
  - ≈ 90% were physics majors or physics/engineering double majors
  - ≈ 90% were juniors or above
  - all had studied thermodynamics (some at advanced level)

Course taught by DEM using lecture + interactive-engagement

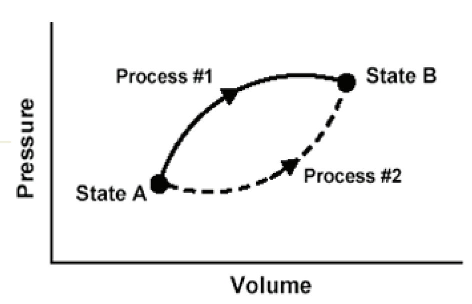
Performance Comparison: Upper-level vs. Introductory Students

- 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

Contrast Between Thinking of Introductory and Upper-Level Students Regarding Key Concepts

- Performance of upper-level students on most problems (e.g., first-law of thermodynamics) was comparable to that of high-performing introductory students.
- Even students who had taken upper-level engineering thermodynamics courses encountered significant difficulties in understanding fundamental concepts.
- Despite overall similar performance, on certain specific concepts upper-level students were noticeably more sophisticated than introductory students (e.g., recognizing that total entropy must *increase* in a spontaneous process).

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:



[In these questions, ***W*** represents the work done ***by*** the system during a process; ***Q*** represents the heat ***absorbed*** by the system during a process.]

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

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

Responses to Diagnostic Question #1 (Work 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)
$W_1 = W_2$	30%	22%	21%

Confusion regarding work among Thermal Physics students was comparable to that among introductory students.

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%

Performance of Thermal Physics students was comparable to that of interview volunteers among introductory students.

Upper-level Students Demonstrated Superior Ability to do Qualitative Reasoning

- Upper-level students were quicker to generalize over specific contexts with a unifying concept, while introductory students tended to focus on pattern-matching.
- Upper-level students were less likely to become bogged down in problem minutiae such as instructions, descriptions of apparatus, etc.
- Upper-level students relied *less* on purely mathematical arguments (e.g., referring to an equation) than did introductory students while working identical problems.

Upper-level Students Demonstrated Greater Facility in Using Multiple Representations

- Upper-level students found it easier than did introductory students to interpret meaning of diagrams, bar charts, and other graphical material, even in novel contexts.
- Upper-level students were more comfortable in making use of multiple representations (verbal, diagrammatic, etc.) to express their own thinking; they showed less reliance on purely mathematical forms of reasoning.
- Even less well-prepared upper-level students demonstrated facility with multiple representations.

Upper-level Students Utilized Active-Learning Curricular Materials More Effectively

- Upper-level students made more effective use of guided-inquiry worksheets originally developed for use with introductory students:
  - worked through problems faster, more thoroughly, and required less guidance from instructors
  - showed less confusion in interpreting instructions
- Consistent with observations made among students in introductory courses, both highly favorable and highly unfavorable reactions toward interactive-engagement techniques were displayed by upper-level students.
  - 10-15% unfavorable rating on evaluations matched that found in introductory algebra-based course.

Upper-Level Students Manifested Modified Forms of Common Learning Difficulties

- Although upper-level students made more effective use of qualitative reasoning when dealing with relatively familiar concepts, when dealing with less familiar problems they relied more on algebraic/quantitative reasoning—sometimes successfully, sometimes not.
- In numerous cases, upper-level students demonstrated startlingly high degrees of confusion regarding basic concepts that—earlier in the same course—they had presumably mastered.

Issues Associated with Engineering Students

- Generally, were unfamiliar and uncomfortable with providing explanations for reasoning in problem-solving; tendency to "plug and chug" typically greater than that of physics majors;
- Persistent tendency to employ notation and formulations learned in engineering courses, even when they conflicted with those used in the thermal physics course;
- Even graduate-level student had difficulties with fundamental concepts;
- Overt expressions of dissatisfaction with course and instructional methods more common than among physics students.

General Observations

- Interpretation of explanations for reasoning given by engineering students must take into account their different backgrounds and notational conventions;
- In general, upper-level students have additional "baggage" of preconceptions regarding concepts, terminology, and instructional methods; these must be recognized and addressed.