Student Understanding of the Approach to Thermal Equilibrium

Michael Loverude, Department of Physics, California State University Fullerton

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Project Outline and Team

Work is part of an ongoing project to study student learning of topics in thermal physics and develop instructional materials based on the research. Primary project goals are to

- Investigate student understanding of key topics in thermal physics
- Develop 15 tutorials with supporting materials on target topics
- Assess & document effectiveness of curriculum and revise as needed

DUE 0817335 is a Collaborative Project with collaborators

- John Thompson, Donald Mountcastle, Maine
- David Meltzer, Arizona State University
- Warren Christensen, North Dakota State University

What is Thermal Physics?

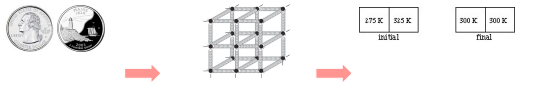
The term 'thermal physics' describes a course that includes thermodynamics (primarily macroscopic descriptions of systems) and statistical physics (extrapolating macroscopic effects from the collective behavior of the many constituent parts).

At CSUF, *Thermal Physics* is a core course for physics minors and majors

- Small enrollment lecture course, typically 10 ± 5 students
- Meets 2 x 75 minutes, Spring semester
- Assumes completion of introductory sequence only, no thermo prior

Motivation for Project

Schroeder course motivates 2nd law of thermodynamics through sequence



Coin flips / binomial — Einstein model of a solid — Macroscopic entropy $dS = dQ/T$

Multiplicity Ω — Equilibrium ⟶ max Ω — $\Delta S_{univ} \geq 0$

Research goals & methods

For key concepts in thermal physics, we seek to

- Develop and validate questions to probe student understanding
- Document student understanding after standard instruction
- Identify key learning difficulties and instructional interventions

Using

- Written and online assessment questions
- Semi-structured student interviews

Some Prior Research

Granville, *J Chem Educ* 1985.
Kesidou & Duit, *J Res Sci Teach* 1993.
Thomas & Schwenz, *J Res Sci Teach* 1998.
Bucy, Thompson, and Mountcastle, *PERC Proceedings* 2005.
Cochran & Heron, *Am J Phys* 2006.
Christensen, Meltzer, and Ogilvie, *Am J Phys* 2009.

For More Information

See http://thermoper.wikispaces.com/ or contact mloverude@fullerton.edu

Research Questions

If we consider the thermal interaction of two blocks, there are a number of ways to analyze the situation. In the order they are taught in the course text:

Calorimetry: energy is conserved, $C_1\Delta T_1 = C_2\Delta T_2$
Statistical physics: closed system evolves to the state that maximizes Ω
Macroscopic entropy: $dS \geq dQ / T$, spontaneous processes maximize entropy

- Can students apply each of these approaches to distinguish physical from non-physical processes?
- What approach is most productive for students, and which is most likely to be chosen?
- Is there any evidence of the success or failure of the hybrid thermal physics approach?

Ideas invoked by students in interview responses:

Entropy is a measure of disorder

$S = k \ln \Omega$

Entropy is conserved

Equilibrium is a more orderly state

Entropy goes opposite of energy

Calliope: Well if we think about, if I think about a gas, and its kind of forced to be a way, and it takes energy to keep it that way, then it naturally goes back, spontaneously, so I'm gonna say [entropy] decreased.
There was some sort of energy to make it be there in the first place.

Calliope: You can't just, entropy, you can't just, I can't really remember, but I want to say, it's like energy, like you can't create it or destroy it, it can't just come out of nowhere.

Calliope: Well, if entropy comes with disorder, and it goes to its more natural state, then my room's entropy would *increase*, the messier it would get.
I: So your natural state, or a system's natural state, is that a high-entropy state or a low-entropy state?
Calliope: Hm. [pause] I want to say, low. No! Well, if they're inversely proportional, then yes.

J & H preferred the statistical point of view, but most students couldn't use it to explain even when prompted.

Jason: I'd never heard entropy described in a multiplicity sense, like a statistical sense, it made so much more sense, because every time you hear disorder, and I hear that from people who, like don't know anything about physics, it's just disorder, but I don't think they know what that means. I never knew what that meant.

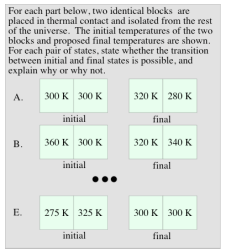
Jason: I feel like [the equilibrium state] would be more orderly, if anything. … It feels like everything's moving to the most likely position because, that's just how it is.

I: I don't want to put words in your mouth, but it sounds like you're saying that the most probable state is more orderly and not more disorderly. Is that what you mean?
Jason: Yes, yes. That's the way the world tends to work, stuff tends to follow probability

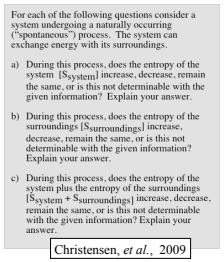
Many students shift between ideas on entropy, sometimes within a single statement…

I: So E is one that you said was possible. Which has more order overall, the initial state or the final state?
Gladius: I think this one has more disorder. The initial state. Because it's not happy, it's not where it wants to be. Whereas, the final state, you know, everything is equal, it's kind of like a, like a stable environment.
I: Which situation would you say has more entropy, the initial or the final?
Gladius: I want to say that they both have the same. Yeah.
I: Is that consistent with what you said about order or disorder? Or should it be?
Gladius: No it's not. Because I said this one would be more disordered, so this one should have more entropy. But I wouldn't know how to describe that.

Research Tasks


For each part below, two identical blocks are placed in thermal contact and isolated from the rest of the universe. The initial temperatures of the two blocks and proposed final temperatures are shown. For each pair of states, state whether the transition between initial and final states is possible, and explain why or why not.

A. 300 K | 300 K (initial) — 320 K | 280 K (final)
B. 360 K | 300 K (initial) — 320 K | 340 K (final)
E. 275 K | 325 K (initial) — 300 K | 300 K (final)


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 system [S_{system}] increase, decrease, remain the same, or is this not determinable with the given information? Explain your answer.

b) During this process, does the entropy of the surroundings [$S_{surroundings}$] increase, decrease, 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, remain the same, or is this not determinable with the given information? Explain your answer.

Christensen, *et al.*, 2009

***N* = 8 interviews, all physics majors, interviews 1-2 years after course completion**
N = 10+ interviews, physics / chemistry majors, interviews at end of course (S. Li)
Many written questions in *Thermal Physics* course, before and after instruction

Hestia: So, with entropy, if it's a spontaneous process, naturally occurring, the system is going to want to move towards, the, [pause, draws] It's that bell curve….where the most macro[?]states occur?

Hestia: What I don't remember is whether that corresponds to an increase in entropy or a decrease in entropy. I can actually find reasons that it's either one.

The idea that entropy is conserved is pervasive, c.f., Christensen 2009.

Jocasta: Entropy would kind of equal out, that's why I was able to say, it would come to some kind of equilibrium. It would go from a higher entropy to a lower entropy.

Jocasta: The sum of [the entropy of system + surroundings] would be the same.
I: And how do you know that would be the case?
Jocasta: [quickly] conservation of energy

Jocasta::….it went from, more entropy to less entropy, in a state of more equilibrium.
I: So is more equilibrium associated with less entropy?
Jocasta: Yes? It's just weird because whenever I think of entropy I just think of more disorder, and so whenever I look at this, it's going from a state of disorder to order, to some sort of order, so that's why I would assume, there's some kind of order in equilibrium.

The idea that equilibrium corresponds to more order, rather than less, was common in this interview sample, but has not been previously reported.