Students' Ideas About Entropy and the Second Law of Thermodynamics*

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Thermodynamics Project

- Objectives: (a) To investigate students' qualitative understanding of entropy, the second law of thermodynamics, and related topics in a second-semester calculus-based physics course*; (b) To develop research-based curricular materials
- In collaboration with John Thompson at the University of Maine on investigations in an upper-level undergraduate thermal physics course

**Previous work on related topics: M. Cochran (2002)*

Fall 2004 Course Design

- Primarily traditional physics instruction
  - some use of a personal response system
- Thermodynamics was the last topic covered in the course
- Concepts concerning the 2nd Law were discussed in the context of heat engines during one lecture, and in a separate 30 minute lecture on the entropy of a system

Pretest

- A series of four questions was administered to nearly all recitations during the first week of class to assess students' understanding of concepts in calorimetry and thermodynamics.
  - Question 3: Change in entropy during a spontaneous process

Spontaneous Process Question

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

Spontaneous Process Question

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A. During this process, does the entropy of the **system** [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 **surroundings** [$S_{surroundings}$] *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 Entropy Question

2004 Introductory Physics

Pretest Results

(*N*=179)

	Increase	Decrease	Remain the same	Not determinable
S_{system}	30%	20%	9%	38%
$S_{surroundings}$	26%	18%	9%	40%
S_{total}	15%	1%	72%	8%

Blank responses omitted from the sample

Pretest Results

[$N = 179$]

- 72% of students indicated that the total entropy (*system* + *surroundings*) would remain the same
- 34% of student responses were consistent with some sort of "conservation" principle
  - e.g., A. Increases, B. Decreases, and so C. Stays the same

Pretest Results

[$N = 179$]

- 15% of students indicated that the total entropy (*system* + *surroundings*) would increase

BUT…

- Only 4% gave a correct response for all three parts

Final Exam Question

[$N = 539$]

A question similar to the pretest was administered on the final exam.

Final Exam Question

[$N = 539$]

A subsystem A is in thermal contact with its environment B, which together comprise an isolated system. Consider the following situations:

I. Entropy of system increases by 5 J/K; entropy of the environment decreases by 5 J/K.

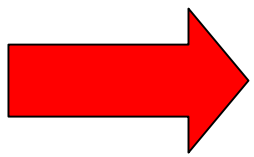
II. Entropy of system increases by 5 J/K; entropy of the environment decreases by 3 J/K.

III. Entropy of system increases by 3 J/K; entropy of the environment decreases by 5 J/K.

IV. Entropy of system decreases by 3 J/K; entropy of the environment increases by 5 J/K.

Which of the above four situations can actually occur in the real world?

A. I only
B. II only
C. III only
D. II and III only
E. II and IV only



A. 54%
B. 5%
C. 7%
D. 4%
E. 30%

Pre- and Post-Instruction Comparison

- The results of the final-exam question are most directly comparable to the responses on part C of the pretest:

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.***

S_{TOT} stays the same	
Pretest	Final Exam
72%	54%

S_{TOT} increases	
Pretest	Final Exam
15%	**30%**

Correct answer

Interview Data

[$N = 8$]

- We conducted hour-long interviews with student volunteers after the completion of the entire course.
- Students were asked to respond to a series of questions focusing on the properties of entropy in irreversible processes, the concept of entropy as a state function, and the second-law constraint on maximum efficiency of a heat engine.

Final Exam Question

A subsystem *A* is in thermal contact with its environment *B*, which together comprise an isolated system. Consider the following situations:

I. Entropy of system increases by 5 J/K; entropy of the environment decreases by 5 J/K.
II. Entropy of system increases by 5 J/K; entropy of the environment decreases by 3 J/K.
III. Entropy of system increases by 3 J/K; entropy of the environment decreases by 5 J/K.
IV. Entropy of system decreases by 3 J/K; entropy of the environment increases by 5 J/K.

Which of the above four situations can actually occur in the real world?

A. I only
B. II only
C. III only
D. II and III only
E. II and IV only

Final Exam Question

Full-class response

S_{TOT} stays the same	
Pretest	Final Exam
72%	54%

S_{TOT} increases	
Pretest	Final Exam
15%	**30%**

- 5 out of 8 students (63%) gave the correct answer (S_{TOT} increases) on the final exam question during interviews
- 3 students specifically stated that I, II, and IV were all possible answers, but chose "II and IV only" since they felt it was the best option offered

General Observations

- Students associated entropy with common textbook nomenclature, such as disorder ($N = 3$) and randomness ($N = 3$).
- 6 out of 8 students made a connection between heat transfer and entropy at some point during the interview.
- Previously reported 1st Law misconceptions* were observed and did, in some instances, contribute to incorrect responses concerning entropy.

**Loverude, Kautz, and Heron (2002); Meltzer (2004)*

Comparison between Introductory and Upper-level Students

A nearly identical pretest was administered in an upper-level thermal physics course

Spontaneous Process Question

[Introductory-Course Version]

3. 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*, 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 **surroundings** [$S_{surroundings}$] *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 Entropy Question

[Correct Responses]	2004 Introductory Physics (Pretest) (N=179)			
S_{system}	38%			
$S_{surroundings}$	40%			
S_{total}	15%			

Responses to Entropy Question

[Correct Responses]	2004 Introductory Physics (Pretest) (*N*=179)	2004 Thermal Physics (Pretest) (*N*=12)		
S_{system}	38%	50%		
$S_{surroundings}$	40%	50%		
S_{total}	15%	92%		

Responses to Entropy Question

[Correct Responses]	2004 Introductory Physics (Pretest) (*N*=179)	2004 Thermal Physics (Pretest) (*N*=12)	2004 Thermal Physics (Post-Instruction Interviews) (*N*=17)	
			correct	with correct explanation
S_{system}	38%	50%	76%	47%
$S_{surroundings}$	40%	50%	88%	76%
S_{total}	15%	92%	100%	100%

Responses to Entropy Question

[Correct Responses]	2004 Introductory Physics (Pretest) (*N*=179)	2004 Thermal Physics (Pretest) (*N*=12)	2004 Thermal Physics (Post-Instruction Interviews) (*N*=17)	
			correct	with correct explanation
S_{system}	38%	50%	76%	47%
$S_{surroundings}$	40%	50%	88%	76%
S_{total}	15%	92%	100%	100%

Conclusions

- Students appear to have an idea that the total entropy during a natural process remains unchanged ("conserved"?)
- Student confusion concerning the relationships among S_{system}, $S_{surroundings}$, and S_{total} during a naturally occuring process seems very resistant to instruction