# Introductory and advanced students' difficulties with heat transfer using a validated conceptual survey instrument

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## Introduction and Methodology

There are many research-validated surveys that can be helpful to investigate understanding of introductory-level concepts such as the Survey of Thermodynamic Processes and First and Second Laws-Long (STPFaSL-Long) [1-3].

Each question focuses on individual thermodynamic variables, e.g., heat transfer, so that student understanding for that variable can be disentangled from other variables.

What kind of difficulties related to heat transfer do students at different levels have after traditional instruction?

## STPFaSL-Long

The Survey of Thermodynamic Processes and First and Second Laws-Long is a 78-question validated survey for introductory-level concepts.

Each question is related to a single thermodynamic variable, and answer options do not incorporate any alternative conceptions.

N=550 Introductory Algebra
N=492 Introductory Calculus
N=89 Upper-level

## Research Questions

What are student difficulties with heat transfer after traditional instruction?

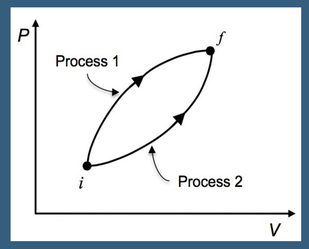
What reasoning do students provide for their incorrect responses?

[1] D. E. Meltzer, Investigation of students' reasoning regarding heat, work, and the first law of thermodynamics in an introductory calculus-based general physics course, Am. J. Phys. **72**, 1432 (2004).
[2] M. J. Brundage and C. Singh, Development and validation of a conceptual multiple-choice survey instrument to assess student understanding of introductory thermodynamics, Phys. Rev. Phys. Educ. Res. **19**, 020112 (2023).
[3] M. J. Brundage, D. E. Meltzer and C. Singh, Investigating introductory and advanced students' difficulties with change in internal energy, work, and heat transfer using a validated instrument, Phys. Rev. Phys. Educ. Res. **20**, 010115 (2024).

## Difficulties with Heat Transfer on the STPFaSL-Long

- thinking Q is a state variable
- thinking Q = 0 in an isothermal process
- thinking Q ≠ 0 in an adiabatic process
- difficulty with Q for an isobaric process
- difficulty with Q for an isochoric process

### Two Processes that Share the Same Final and Initial States




12) Compare the heat transfer in each process:

a) $Q_1 = Q_2$
b) $Q_1 < Q_2$
***c) $Q_1 > Q_2$***
d) Not enough information

| Item # | A | B | C | D | Level |
|---|---|---|---|---|---|
| 12 | 28 | 17 | ***47*** | 8 | Upper |
| | 56 | 11 | ***29*** | 4 | Int-calc |
| | 66 | 6 | ***23*** | 5 | Int-alg |

## Student Quotes:

Q12: "I think that heat transfer should be equal because they have the same starting and ending point and then it's just a difference of pressure and volume."

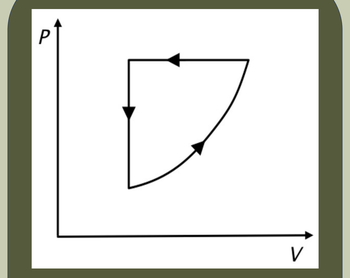
Q12: "I'm thinking if I can use that E = Q-W equation again...I'm just going to say that it's equal [Q for both processes] because they start and end in the same place. Yeah."

Q9: "heat transfer…there is none since we are coming back to the original condition at the end of the cycle."

Q 26: "But if you're returning to the same state, so would there be no change cause you are finishing where you started? I feel like that sounds more right."

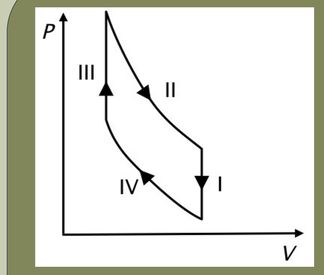
Q26: "Well, for 2 steps, there is no heat transfer. And then we have step 1 and 3… pressure… these two steps are constant volume. Pressure increases and pressure decreases, it ends in a lower pressure overall. The net heat transfer…I'm just going to say its zero..."

## Cyclic Processes




9) Net heat transfer to the gas after 1 cycle?

a) Q = 0
b) Q > 0
***c) Q < 0***
d) Not enough information




26) Net heat transfer to the gas after 1 cycle?

a) Q = 0
***b) Q > 0***
c) Q < 0
d) not enough information

| Item # | A | B | C | D | Level |
|---|---|---|---|---|---|
| 9 | 16 | 29 | ***44*** | 10 | Upper |
| | 33 | 26 | ***35*** | 6 | Int-calc |
| | 56 | 12 | ***20*** | 12 | Int-alg |
| 26 | 25 | ***52*** | 13 | 10 | Upper |
| | 37 | ***31*** | 28 | 4 | Int-calc |
| | 55 | ***16*** | 24 | 5 | Int-alg |

## Conclusions

Common student responses included:

- Q = 0 for the cyclic-process questions (items 9 and 26)
- $Q_1 = Q_2$ (item 12)

These are consistent with a belief that Q is a path-independent state variable. Many comments made during the interviews were also consistent with that view