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Investigating introductory and advanced students' difficulties with entropy and the second law of thermodynamics using a validated instrument

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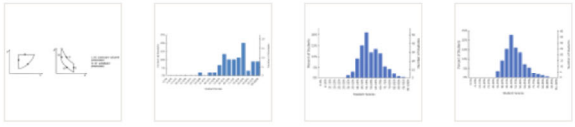
ABSTRACT

We use the Survey of Thermodynamic Processes and First and Second Laws-Long (STPFaSL-Long), a research-based survey instrument with 78 items at the level of introductory physics, to investigate introductory and advanced students' difficulties with entropy and the second law of thermodynamics. We present an analysis of data from 12 different introductory and advanced physics classes at four different higher education public institutions in the United States in which the survey was administered in person to more than 1000 students. We find that a widespread unproductive tendency for introductory students to associate the properties of entropy with those of energy leads to many errors based on an idea of "conservation of entropy," in which entropy increases are *always* balanced by equal entropy decreases. For many of the more advanced students (calculus based and upper level), we detect a tendency to expect entropy increases even in processes in which the entropy does *not* change. We observed a widespread failure to correctly apply the relationship $\Delta S = Q_{\text{reversible}}/T$, either by using it for *irreversible* processes to which it does not apply or by applying it incorrectly or completely neglecting it in reversible processes to which it does apply. We also noted that many introductory students are simply not aware that total entropy must increase in any "spontaneous" heat transfer process. Students at all levels were very frequently found to be confused that while net entropy ($\text{system} + \text{reservoir}$) in reversible isothermal processes does not change, the entropy of the working substance itself does indeed increase or decrease depending on whether the process is an expansion or compression. Our findings are broadly consistent with prior research findings in this area, expanding upon them and revealing previously unreported aspects of students' thinking. Moreover, our results reflect several new problem contexts in addition to those reported in prior research, and our sample population includes large numbers of both introductory and advanced students. Our detailed findings related to common student difficulties with entropy and the second law of thermodynamics before and after traditional instruction in college physics courses can potentially help instructors of these courses improve student understanding of these concepts. These findings can also be valuable for developing effective research-based curricula and pedagogies to reduce student difficulties and help students develop a solid grasp of these fundamental thermodynamic concepts.



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