

## **Introductory and advanced students' difficulties with thermodynamic work**

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2024 Physics Education Research Conference Proceedings, pp. 286-292, doi:[10.1119/perc.2024.pr.Meltzer](https://doi.org/10.1119/perc.2024.pr.Meltzer)

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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 work. We analyze data from 12 introductory and advanced physics classes at four different higher education public institutions in the US in which the survey was administered in-person to more than 1000 students. The specific concepts discussed include (1) recognizing and applying the path-dependent nature of work, and (2) interpreting work as area under the curve on a PV diagram. We find that not only introductory but also advanced physics students have some common difficulties with these concepts even after traditional lecture-based instruction. Our results are consistent with prior research findings but extend them to large numbers of students at both introductory and advanced levels and to several new problem contexts not previously investigated.

D. E. Meltzer, M. J. Brundage, and C. Singh, Introductory and advanced students' difficulties with thermodynamic work, 2024 PERC Proceedings [Boston, MA, July 10-11, 2024], edited by Q. X. Ryan, A. Pawl, and J. P. Zwolak, doi:[10.1119/perc.2024.pr.Meltzer](https://doi.org/10.1119/perc.2024.pr.Meltzer).