Changes in student reasoning about graphical work during introductory physics

The role of path independence, endpoints, and conservative forces in explanations

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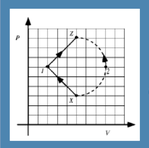
Abstract

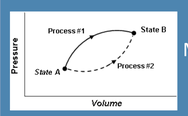
In a study on student understanding of graphical representations of work, students in introductory calculus-based physics were presented with a force-position graph (*F-x*) that showed two different mechanical processes with identical initial and identical final values for force and position. The task, to compare the works done in each case, was administered at three points along the two-semester instructional sequence to probe differences in student responses and reasoning and compare findings to results from analogous questions in thermodynamics. Answer prevalence varied little across administrations; however, the reasoning students used showed variation. Analysis of reasoning used showed a higher use of "area under the curve" for a correct response, and a more prevalent invocation of "path independence" or "conservative forces" for the major incorrect interpretation, with instruction. These findings support earlier speculation that thermodynamics students associate work with conservative forces due to introductory instruction.

Student difficulties with graphical interpretations of thermodynamic work

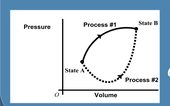
Graphical comparisons of work on *PV* diagrams



Loverude *et al.*, 2002



Meltzer, 2004



Clark *et al.*, 2014

Common incorrect response: Works are equal

Introductory: 25%-40% (Loverude et al. 2002); 25%-30% (Meltzer 2004)

Upper level: ~40% (Pollock et al. 2007)

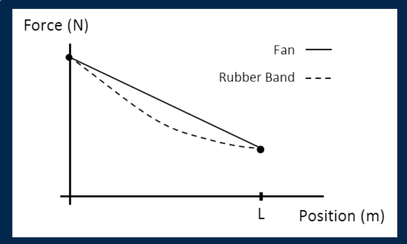
"… work is not affected by the path"
"the works are equal, they start and end in the same state"
"same change in volume"

Previous researchers attributed difficulties with thermodynamic work to introductory (mechanics) instruction

"It is possible that these students were over-generalizing their experience with conservative forces in their mechanics courses." (Loverude *et al.* 2002)

"Certainly, the fact that mechanics courses frequently highlight the path-independent work done by conservative forces may contribute to this confusion" (Meltzer, 2004)

Mechanics context: *F-x* graph work comparison



Two methods of propelling a cart are being tested. The first uses a stretched **rubber band** while the second uses a **fan.** The graph [to the left] shows the size of the net force experienced by the cart as it travels away from the start point along a track of length *L*.

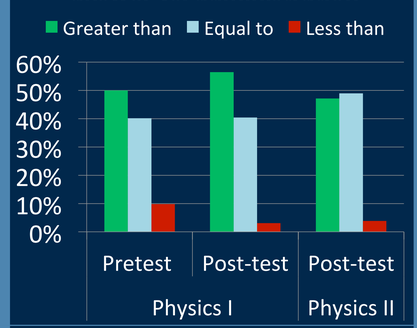
Is the net work done on the Fan cart >, <, or = to the net work done on the Rubber Band cart?

Investigating the effect of introductory instruction on energy and conservative forces on student answers about work in a graphical context.

- Designed to be isomorphic to the P-V diagram task from Meltzer (2004) and adapted by Pollock et al. (2007) and Clark et al. (2014), to focus on the interpretation of the graphical representation of work.
- Expected to elicit analogous difficulty with path dependence of thermodynamic work (Loverude et al. 2002, Meltzer 2004, Pollock et al. 2007).
- Deliberately circumnavigates several difficulties that have been reported previously with mechanical work (Loverude 2002, Lindsey 2009):
  - associating the sign of work with the coordinate system
  - failing to recognize that work on or by a system has the same magnitude
  - failing to consider displacement of force application point appropriately

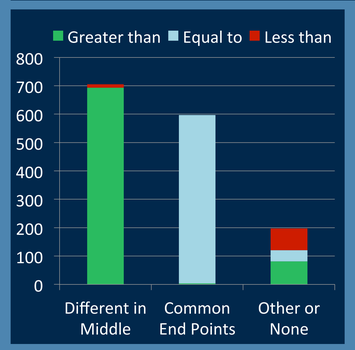
Population (not matched)	*N*
Physics I Pre	582
Physics I Post	585
Physics II Post	336

F-x Work Comparison: answer vs. administration



no significant shift in correct / incorrect distribution as a result of instruction (V < 0.10)

Explanation features



87% of explanations attend explicitly to two key features

- The middles are different
- The ends are the same

High correlation between explanation and response

- 98% of "middle" explanations in $W_{Fan} > W_{Band}$
- 99% of "end points" explanations in $W_{Fan} = W_{Band}$

Conclusions

Increased prevalence in conservative / path independent *reasoning in mechanics context over introductory sequence*
(Note: trend continues on pretests in post-introductory physics and engineering thermodynamics courses)

- Suggests some *end point / path independent* reasoning in thermodynamics originates from application of ideas from introductory courses

Confirms prior speculation in literature

Answer prevalence unchanged over course of introductory instruction, but explanation distribution shows systematic shifts among categories

Equal to: fewer *same distance*, more *end point*

Greater than: fewer *greater force,* more *area*

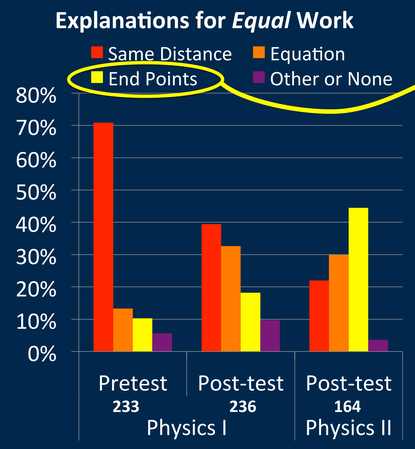
- Suggests that instruction provides plausible concepts and ideas to apply to correct or incorrect responses (*cf. transfer in* (Schwartz et al. 2005))
- Common endpoints become (remain) *salient distracting feature* (Heckler 2011) as result of instruction on conservative forces

Equal responses and *End Point* reasoning

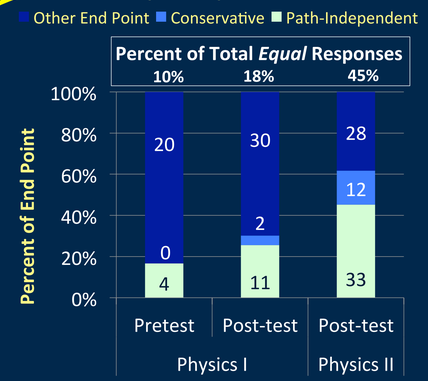
Reasoning categories for *Equal to* responses

- *Same Distance*
- *Equation: W = Fd* & [*Same End Force* and/or *Same Distance*]
- *End Point:* same end points on graph (see below)

Explanations for *Equal* Work



***End Point* reasoning: Specific phrases**



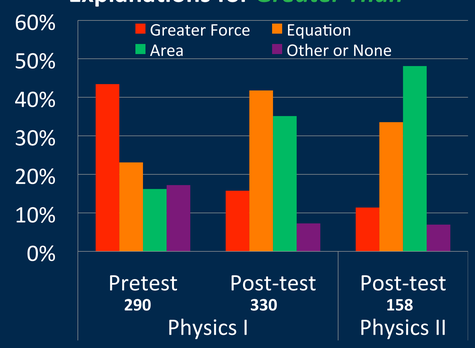
Higher prevalence of *end point* reasoning for *equal* response
More *conservative / path-independent* reasoning within *end point*

Reasoning about correct response

Reasoning categories for *Greater than* ("middle") responses

- *Greater force*
- *Equation: W = Fd* & *Greater Force*, sometimes with *Same Distance*
- *Area:* area under curve and/or integral (equation)

Explanations for *Greater Than*



Higher prevalence of *area* reasoning for correct response

Explanations shift from more intuitive/incomplete to more sophisticated *for both correct and incorrect comparisons*

References

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