## WHY USE THE WORK-ENERGY THEOREM?

I don't understand the much ado by Legge and Petrolito[1] in the April issue of AJP. For that matter, I have never understood why anyone would worry students about something called the work-kinetic energy theorem. It clearly does not apply to most energy transfers, which turn one form of energy into another, usually not involving kinetic energy. Work is just one way of transferring energy. The energy can go to and from springs, gravitational fields, electric fields, etc. To find out who is doing the work, ask who is getting paid. No pay, no work. Therefore, friction cannot do work. You don't plug friction into the wall socket or feed it gasoline or steak. Certainly it cannot do negative work, a concept that can only bewilder the innocent. Perhaps at the junior level it is useful to identify negative work if there is no other way to keep track of which system is doing what, but not for freshmen.

As for emphasizing the model nature of point particle mechanics, why not describe real blocks and pulleys and take account of friction and internal energy? The seeming paradoxes cited by Legge and Petrolito,[1] like most paradoxes, are just cases of sloppy bookkeeping. In the case of the block being dragged a distance $x$ by a force $F$, the only person doing any work is the one pulling with $F$. Friction just lies there, soaking up all the work that was done. Another illusion of a paradox is the cited case of the putty sticking on the wall. Here the kinetic energy turns into internal energy, and apparently all is well, as long as we do not use the work-kinetic energy theorem. But what about conservation of momentum?

Would students want to be paid for holding a chair at arm's length for one hour? Certainly. Therefore, are they being paid although doing no work? But they are doing work. Note the quivering muscles.

I am reminded of the hotel clerk who charges three salesmen $30 for a $25 room. Realizing he has overcharged, he sends the bell-hop up with five one dollar bills. The bell-hop keeps two of them. Thus each salesman has paid $9, making $27, the bell-hop has $2, making a total of $29. Where is the extra dollar? Same principle.

[1]K. A. Legge and J. Petrolito, "The use of models in problems of energy conservation," Am. J. Phys. **72**, 436–438 (2004).

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## WORK AND ENERGY

In the September issue[1] of AJP, Clifford Swartz writes, ''To find out who is doing the work, ask who is getting paid'' (or perhaps better, to keep focused on immediate energy transfers: ''ask who is paying''). While it is correct to define work as an energy transfer between an agent and a recipient, this is not always the best starting point in an introductory course. For example, suppose I drop a ball. If the system is chosen to be the ball alone, work is done on it as it falls. We immediately recognize this simply because a net gravitational force is acting on the ball while it moves, and *not* because of an energy transfer viewpoint. In fact, the latter involves some subtle issues. What agency does the work? The Earth does not pay; it in fact gains a small amount of kinetic energy as the ball falls. It is the *gravitational field* that pays—the total energy stored in the gravitational field decreases as the kinetic energies of the ball and Earth increase. But it would be a stretch to ask a novice to contemplate how a gravitational field stores and releases energy.

Turning next to Swartz's example of friction, consider a block sliding on a table to rest, where the system is the block. He states, "Friction cannot do work" and I believe he correctly intends that we should not reify friction and instead would probably say it is the *block* that does the work. (In the lab frame, it cannot be the *table*, if we are to avoid the concept of "negative work.") The block loses bulk kinetic energy, some of which ends up as internal energy of the table (and, to a lesser extent, of the atmosphere) and the rest as internal energy of the block. The block loses energy in one form and gains some in another form. Does this mean the block is both paying and getting paid and is thus doing work on itself?

We can find Swartz's answer in his claim that a student *does work* to hold a chair at rest in midair. He bases this on the fact that the student was paid in the past (say by the steak she ate yesterday). One could similarly argue that the block was paid by the push it received to get it moving and thus *does work* even if the block alone warms up. (A better example here is a symmetric head-on inelastic collision between two identical balls of putty.) But overall claiming that *work is done* in such cases is inconsistent with the first law of thermodynamics considered *instant by instant* in time (and not just averaged over long periods).

I would prefer to say that the student is not doing work on the chair, but that instead *parts* of the student are doing *internal* work on other *parts* of the student. Both the negative and positive assertion in this sentence can be easily understood using a force-displacement analysis. No work is done on the chair because no part of it undergoes a net displacement. Swartz's appeal to the quivering muscles focuses attention on the internal forces and displacements. This perspective is more enlightening than is a consideration of yesterday's steak. There is a danger of getting so focused on the issue of work as a payment that one loses sight of the relation between work and motion.

To summarize the larger issue in my mind, I lament the currently fashionable trend to minimize the connections between force and energy concepts. There remain good examples of problems in texts such as Chabay and Sherwood[2] that are efficiently solved by exploiting these connections. We impoverish our students if we require them to consider energy forms and payments exclusively, when a force-displacement analysis (aka "work-energy theorem") would add to their understanding. Why can't we teach both?

[1]C. Swartz, "Why use the work-energy theorem?" Am. J. Phys. **72**, 1145 (2004).
[2]R. W. Chabay and B. A. Sherwood, *Matter & Interactions I: Modern Mechanics* (Wiley, New York, 2002), Chap. 7.

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## RESPONSE TO THE LETTER TO THE EDITOR BY CARL E. MUNGAN

With regard to the application of the "work-energy" theorem, I had written a letter to the editor of AJP disparaging the use of the theorem in introductory physics. [C. Swartz, "Why use the work-energy theorem?" Am. J. Phys. **72**, 1145 (2004)], Carl Mungan now responds with further comments, and I will reply with a few ripostes. It seems to me that the controversy spins around factors of pedagogy and emphasis on defining systems. I think that students at high school or college level should not be bothered with fine details of systems until they make a formal study of them in thermodynamics. By doing so we avoid seeming paradoxes involving negative work.

If a student pulls a block at a constant speed, the student is doing work for which he should be paid. The work $(Fx)$ is transformed into thermal energy, raising the temperature of the block and the table. No work is transformed into kinetic energy, which remains constant. In thermodynamic terms, $W=\Delta U$, and in a molecular model, the internal thermal energy goes into the kinetic and potential energy of the molecular structure.

When the student stops pulling the block, it slows down and its kinetic energy turns into thermal energy. One equals the other; both are positive. The magnitude of this energy is $\frac{1}{2}mv^2=|F_{\text{friction}}||x|$. Note that if we were to claim that this is negative work and add it to the positive kinetic energy, the block would end up with zero energy—but hotter. A student, so persuaded, should rush to the patent office.

If a ball falls toward Earth, its increasing kinetic energy comes from the gravitational energy of the Earth–ball system. That energy came from the student who raised the ball in the first place. It was then stored in the gravitational field. Beginning students can understand the existence of gravitational potential energy. After all, a few months later in the standard course they will be studying electric and magnetic fields. To make fields tangible, let them play with magnets or let them raise and drop a ball.

When a student holds a chair, the twitching muscles do work pushing the chair up a slight amount, storing the energy momentarily in the gravitational field. Then the chair sinks down a bit, and the student has to push it up again. Alternatively, the student can put the chair on a table and then no further work need be done and no one has to be paid.

There are good examples of this approach in *Teaching Introductory Physics* by Swartz and Miner, published by Springer-Verlag.

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