Energy Is Not a Substance

A student watches a block slide across the floor and stop, and says the energy is gone — it had some, it used it up, and now it has none. You tell the student that energy is conserved: it has not been destroyed. The correction is true. The student nods, writes it down, and goes on thinking the energy is gone. The block has stopped. The visible motion is gone.

The failed correction is the teaching problem. The word “conserved” lands inside a picture in which energy is a stuff stored in the object, and inside that picture it means the stuff is still there to be seen. The stopped block says plainly that it is not. So “energy is conserved” sounds either wrong, or like a rule to recite rather than a fact to believe. The student is not mishearing you. The trouble is the picture, not the words.

What kind of quantity energy is

That picture deserves to be named, because part of it is right and part of it is wrong, and the two are easy to confuse. The right part is that energy is a definite amount that has to be accounted for. A student who feels that there is a quantity here, one you can have more or less of and that has to balance, has hold of something true. That is a quantity, not a stuff, and the distinction is the whole of the difficulty. The wrong part is what the student takes the quantity to be: a visible substance that an object holds and then spends. Words like “store” and “transfer” can be useful. The trouble starts when they become a picture of stuff lodged inside one object.

Richard Feynman drew the line a student needs here. Some conserved quantities are easy to picture as counts. Electric charge is one: it comes in countable units, and you can in principle tally them. Energy does not come in units of that kind. It can be measured — in joules, in calories, in kilowatt-hours, in a dozen other units — but it is not made of countable conserved bits. It is, in his framing, a number you calculate from several rules, one for kinetic energy, one for gravitational potential energy, one for thermal energy, and so on. When the right terms are included, the total remains the same. There is no object that the number counts.

Feynman’s block analogy helps, but only if its limit is kept. Picture an account of something you cannot fully see: you infer how much is present from its effects, adding a new term each time it turns up somewhere new. Then take away even the part where the quantity is ever seen at all. With energy there are no blocks; the terms are calculated from features you can measure, not found by spotting pieces of energy. The total holds.

Where “used up” comes from

This is where the everyday picture goes wrong, and how it goes wrong is not the answer teachers usually give. The block slides and stops. Its kinetic energy has gone into the motion of the atoms in the block and the floor. A surface that looks smooth is, close up, atoms packed together, and sliding sets them jostling — a jostling that stays behind as a rise in temperature usually too small to feel.

Two things have to be said, and saying only one is the mistake. First, nothing was destroyed. The energy that seemed to vanish is in the thermal motion of the atoms; it was missing from the student’s account only because the student left that term out. Put it in, and it balances.

Second, the student is reacting to a real loss. The organised motion of the block, which could have driven something, has become the scattered, microscopic motion of countless atoms, which cannot easily be turned back into organised motion. The energy is conserved; its usefulness is not. That is why “lost” feels right even though the number is intact: a useful form was lost, even though the energy was not destroyed. Telling the student that energy is never used up is the wrong correction, because it denies that loss. The correction that holds is to replace “used up” with “transformed into a less useful form” — the total stays intact, and the loss is still named.

Why it is hard to teach

The difficulty has the same shape as the difficulty with force and with inertia. The everyday evidence supports the wrong picture, and the replacement is harder to hold. Here it is harder than usual, because it is not a hidden thing but an abstract total. A student told that force is not carried along inside a thrown ball can at least picture the correction. Energy offers no single object to picture, and a number with no object-like referent is a hard thing to believe in.

So the familiar situation arises. A student works a conservation problem correctly, writes that the total energy before equals the total after, and in the next breath says the block ran out of energy. The calculation and the belief do not interfere with each other. Getting the arithmetic right is not the same as giving up the substance, and the law can be recited fluently by someone who still thinks energy is consumed.

What this means for teaching

The move is not to say “energy is conserved” more often. A student may already be able to repeat that sentence while keeping the substance picture underneath. The move is simple to state and hard to execute: name the picture, keep the part that is right, and replace the part that is wrong. Keep the instinct that energy is a definite amount to account for. Drop the idea that it is a visible substance, that it sits inside one object, and that the energy itself is used up.

In practice, one question to ask while reading answers: is the student conserving a number, or imagining a substance? A student who writes $mgh = \frac{1}{2}mv^2$ may be doing no more than using a formula, with the substance picture still in place underneath. A student who says “the energy went into heat” is closer, but still vague; in school answers, “heat” easily becomes one more word for stored stuff, when the accurate statement is that the thermal energy of the block–floor system increased. A student who says “the block’s kinetic energy decreased, and the block–floor system’s thermal energy increased” is conserving a number.

A force is not something an object owns. Energy is not a stuff an object spends. In both cases, the student’s everyday picture is coherent enough to survive a correct rule. The work is to make the replacement visible.

This article draws on Richard Feynman, The Character of Physical Law (MIT Press, 1967), especially Lecture 3, “The Great Conservation Principles,” for its account of energy as a conserved quantity, and on physics-education research on substance-based conceptions and energy reasoning — including Reiner, Slotta, Chi, and Resnick on the substance schema, diSessa on knowledge in pieces, and Chabay, Sherwood, and Arons on energy teaching.