Why Newton's First Law Is Hard

Many students believe that motion needs a cause. A moving object keeps moving because something keeps it moving; remove the cause and it slows and stops. They won't say it in those words, but it governs how they answer — why a thrown ball slows on the way up, why a puck slides to a halt, why the bob at the top of a swing is "trying" to come down.

This belief isn't a careless mistake, and it isn't confined to students who struggle with physics. It is close to the physics through which motion was explained for about two thousand years, and that account was good enough that the best minds working on motion took most of that time to get past it. How they got past it is worth a teacher's attention, because it shows what you are really asking a student to give up when you teach the first law.

Start with the argument that kept the Earth still. Drop a stone from a tower and, to ordinary observation, it lands at the base. If the Earth were turning, you might expect the ground to slide eastward as the stone fell, so that it landed well to the west. It doesn't. For centuries this was treated as strong evidence that the Earth does not move, and the reasoning was not foolish. A released stone has nothing pushing it sideways. If motion needs a cause, a stone with no sideways cause cannot keep up with a moving ground — so it would be left behind, and it isn't. The flaw in that argument is not the logic but the physics underneath it. And a version of that physics is what many of your students still carry.

Why the old view held

It is worth setting out what the old view actually held, because its grip comes from its internal logic, not from ignorance. In Aristotle's physics, heavy bodies fall because they move toward their natural place, the center of the Earth, which sits at the center of the universe. Motion is of two kinds. Natural motion carries a body to its proper place. Everything else is violent motion, and violent motion needs a mover acting the whole time it lasts. Stop pushing the cart and it stops. Motion that is not natural requires a sustaining cause.

That is the instinct many students are running. They have never read Aristotle and are not Aristotelians, but the underlying idea — that sustained motion needs a sustaining cause — is the same, and it is built from the same evidence. In ordinary life, things do slow down and stop when you stop driving them.

The version they hold is closer to a later repair of Aristotle than to Aristotle himself. Aristotle had to explain why a thrown stone keeps moving after it leaves the hand, and his answer — that the displaced air rushes around and pushes it from behind — left an obvious difficulty. Later thinkers moved the cause inside the object instead: the throw deposits an internal push, an impetus, that the stone carries and slowly spends. That is almost exactly what a student means by "the force of the throw." The repair was real progress, but it kept the assumption that mattered — that motion has to be kept up by a cause, whether the cause sits outside the object or inside it.

Within Aristotle's system the Earth had to be at rest, and the dropped stone confirmed it. The view was coherent. That is why it lasted, and why a student holding a version of it will not drop it just because you state the correct rule.

Why new facts were not enough

Copernicus set the Earth moving around the Sun, but left the old physics in place underneath. He gave a rearranged astronomy with no adequate account of how a moving Earth could carry its stones, air, and Moon along instead of leaving them behind. He had changed where the Earth sits without touching the physics that made its motion look impossible.

Galileo's telescope did more damage. It showed a cratered Moon, the phases of Venus, four moons around Jupiter, and the Milky Way resolved into stars — and these made the heavens look like the same kind of matter as the Earth, which broke the old Aristotelian-Ptolemaic picture. But none of it proved the Earth moves. Every one of those sights could also fit a compromise in which the Earth stood still, the Sun and Moon circled the Earth, and the planets circled the Sun.

The lesson is one teachers half-know already. A new fact does not remove a working explanatory system. A student can accept every demonstration you show and keep the underlying belief intact, because the belief is doing more for them than any one fact can undo. The old physics was the same. It outlasted new facts because it was a whole system, and only another system could take its place.

What Galileo got, and what he didn't

Galileo began building that replacement, and the part he built is the part you teach directly. He saw that motion shared by everything in a system is invisible from inside it: a ball dropped from the mast of a moving ship lands at the foot of the mast, because it shares the ship's motion. The dropped stone shares the Earth's motion the same way. He also showed that a projectile follows two motions at once — a steady horizontal motion that continues on its own, and a vertical motion that accelerates downward.

That decomposition is what you ask students to perform, and it is the part they resist. The horizontal motion has no sustaining cause and needs none; it simply persists. In the idealized case, the vertical motion is the only part that changes. A student running the old instinct cannot see why the horizontal motion keeps going with nothing driving it — and that is the whole difficulty, the same one Galileo had to work through.

But he did not finish it. The motion he allowed a free body to keep was motion across the Earth's surface, which is motion along a circle around the Earth's center. He still treated the circle as a natural, self-sustaining motion. He had freed horizontal motion from needing a cause, but only on the Earth's surface, and only in a circle.

What Kepler supplied

Kepler, working from Tycho Brahe's observations, found that the planets travel on ellipses, sweep equal areas in equal times, and link period to distance by a fixed rule. He got there because he refused to discard an eight-arc-minute gap between the best circular orbit and the data — a gap several times larger than Tycho's observational error. He had given the heavens an exact mathematical order, but no physics for why that order held; the force he reached for to explain it did not yet give the right physics.

So the position was this: Galileo had part of the mechanics of motion on the Earth, Kepler had the shape of motion in the heavens, and nothing connected them.

What Newton changed

Newton's decisive step is the one that matters for your classroom, and it is not the apple. He took uniform motion in a straight line, continuing forever, as the natural state of a body — the state it holds when nothing acts on it at all.

Nothing on Earth shows this. Everything a student has watched is pushed, dragged, rubbed, or slowed; nothing moves freely in a straight line for long. The motion the first law describes has never been seen in its pure form. Galileo did not state it in general because he stayed close to a physical picture of motion on and around the Earth, not an abstract straight line through empty space. Descartes had stated the straight-line idea before Newton. Newton's step was to make it the baseline of a working dynamics: an unobserved, idealized motion from which everything real could be treated as a departure.

This is why the first law is hard to teach, and it is worth telling students directly. You are not asking them to memorize a fact about the world. You are asking them to accept that the natural state of motion is one they do not meet in ordinary experience, and then to treat everything they have seen — the ball that slows, the cart that stops — as that ideal motion with forces acting on it. Their instinct says motion needs a cause. The first law says uniform motion needs no cause, and only a change in motion does. That is not obvious, was not obvious to anyone for two thousand years, and should not be taught as if it were.

The rest follows once the first step is taken. If straight-line motion is what a free body does, any bending of that path needs a cause. An orbit bends constantly, so something must pull the orbiting body toward the center the whole time. The Moon is pulled toward the Earth by the same force that brings the stone down; in the precise sense the first law makes available, the Moon is falling, and its sideways motion carries it around the Earth as it falls. The same law reaches the planets, the tides, and the return of the comets, and the old division between an earthly physics and a heavenly one closes.

What this means for teaching

When a student says a thrown ball "still has the force of the throw" in it, that is not a careless answer to be marked wrong and moved past. It is an impetus-like idea — the old assumption that sustained motion needs a sustaining cause, with the cause now lodged inside the ball. Stating the correct rule will not remove it, just as stating Copernicus did not remove the old mechanics.

The teaching lesson is the same. The old view was not beaten by a single fact. It was replaced by a different account of what needs explaining — one in which motion continues on its own and only change calls for a cause. The work is to make that replacement visible: to name the student's instinct, grant that it is reasonable, show precisely where it fails, and put the harder idea in its place. A belief that took two thousand years to dislodge will not be dislodged by one contradiction. It has to be seen first, and then replaced.

This article draws on I. Bernard Cohen, The Birth of a New Physics (W. W. Norton, 1985), and on standard accounts of impetus theory, especially the line from Philoponus to Buridan.