Patricia Blanton, Column Editor
Department of Physics and Astronomy, Appalachian State University, Boone, NC 28608; blantonp@appstate.edu

How I Misunderstood Newton's Third Law

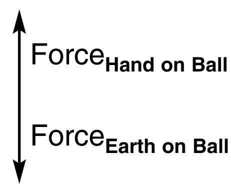
Mark J. Hughes, Physics Teacher, Magnolia High School, 2450 W. Ball Road, Anaheim, CA 92804; mjhuges@hughesmark.com

Every teacher is faced with the task of helping students develop accurate understanding of the physics concepts that govern the world around us. Whether you are a beginning teacher or a seasoned veteran, this year will present you with many situations in which you will be required to rethink the way you understand many concepts you thought you knew very well. Mark Hughes, a physics teacher from Anaheim, shares such an experience with us.

It's a subtle nuance and one I'm sad to say I missed the first dozen times around. But when the realization came to me this last summer — what Newton was really saying with his third law — I smiled because I felt that I caught a fleeting glimpse into the laws that govern our world.

One of our Modeling Physics Workshop leaders, Mike Turner, was nonchalantly standing in the back of the room holding a ball when he asked a question that would definitely catch my attention these days: "What forces are acting on the ball as it lies motionless in my hand?" The class quickly spouted, "Gravity and the normal force," — what I know now to be a technically correct but dangerous choice of words.

The class of high school physics teachers was led to operationally define gravity and the normal force and, with a little coaxing, was able to rewrite the normal force as the *force exerted by the hand on the ball* up, and the force of gravity as the *gravitational field*[1] *force exerted by the Earth on the ball* down.



I didn't immediately notice the way Mike rephrased Newton's third law to read "All forces come in pairs, equal in magnitude, but opposite in direction." So far, nothing had happened in the last few minutes that I hadn't seen countless times before in undergraduate coursework — the teacher asked a question and the students answered with authoritative confidence.

Then something happened that was unfortunately lacking in my education until that point — my professor probed a little and found a gaping hole in my conceptual understanding. "What is the force that is equal and opposite the *gravitational field force exerted by the Earth on the ball*?" We adopted his convention and said in unison, "The *force exerted by the hand on the ball*."

Not being the type of man to want to break our spirit, Mike didn't tell us right away that we were all dead wrong. He simply dropped the ball and asked a series of follow-up questions:

"Let's say this ball is in free fall, what forces are acting on it?"

Now we were left with only the *gravitational field force exerted by the Earth on the ball.*

And when asked "What is the force that is equal and opposite the *gravitational field force exerted by the Earth on the ball*?" a second time, we faltered. We then quickly added the *force exerted by the air on the ball*. But the ball was accelerating, so the forces acting on the ball could not possibly be equal. What then could it be?

Turns out that the force that is equal and opposite the *gravitational field force exerted by the Earth on the ball* is the *gravitational field force exerted by the ball on the Earth*. The ball accelerates toward the Earth, and the Earth accelerates toward the ball. The forces are always directed toward each other, are always equal, and always opposite in direction. The equal and opposite forces were acting on different objects altogether.

↑ $\text{Force}_{\text{Ball on Earth}}$

We were finally on track; we saw our misconception and quickly rectified the situation when he asked again. Confident that we understood, we exchanged glances with each other and were ready to move on. Mike was patient enough to pause though, and he asked, "Then what is the force that is equal and opposite the *force exerted by the hand on the ball* ?" I'm glad everyone was feeling self-conscious at that point, for anyone could have seen the blood rush to my face from the embarrassment of not knowing.

Agent-Object Notation

Agent-object notation is the convention I have been using to label forces in my diagrams. Instead of speaking of forces such as "gravity" and "friction," the agent causing the force is identified and the object it is acting on is explicitly stated. Gravity is the field force of the Earth on the ball. Friction would be the parallel force of a surface acting on an object. Is this extra work? Absolutely. Is it an unnecessary waste of valuable time? Not at all.

Not only is agent-object notation useful in eliminating pseudoforces such as inertia and centrifugal forces from free-body force diagrams, it provides a quick and easy way of finding "paired forces." Simply interchange your agent and your object. For example, the *gravitational field force of the Earth acting on the ball* has as its pair the *gravitational field force of the ball acting on the Earth.* The paired force to the *contact force of the hand on the ball* is the *contact force of the ball on the hand.*[2]

↓ $\text{Force}_{\text{Ball on Hand}}$

↑ $\text{Force}_{\text{Hand on Ball}}$

If you do find that your students manage to slip a "force of inertia" into their diagrams, ask them to tell you what the agent of the force is. When they cannot come up with an agent, they often remove it from their diagram.

Paired forces[3] are forces that act on different objects, never on the same. They can be found by interchanging the agent and the object. The force exerted by a man on a car is paired with the force exerted by the car on a man. Those two forces are always equal and opposite — always.

You can eliminate forces from diagrams if their forces cannot be found. Consider the horizontal component of a projectile's velocity. If the students choose to adopt your convention, they still might mistakenly include "the force of inertia on the ball," but far fewer are willing to pair that pseudoforce with "the force of the ball on inertia." If they agree that "the force of the ball on inertia" cannot possibly exist, then the "force of inertia on the ball" cannot exist either.

The Test

I wanted desperately to believe that my students would not suffer a fate similar to myself, so I questioned them: "A man is trying to push a big rig up a steep hill, but the big rig is beginning to overtake him and he is slipping back down. Is the big rig pushing on the man harder than the man is pushing on the big rig?" Try this question with your students and let me know if they respond to you with "Of course the big rig is pushing harder!" or "The force exerted by the truck on the man is the same as the force exerted by the man on the truck."

Acknowledgments

This article is based on the experience I had last summer at the University of North Carolina, Greensboro. It actually all began with a book on a desk, but I'd like to thank Mike Turner, Jason Lonon, and Terri McMurray, who all helped to clear up this misconception.

Notes

1. Contact forces exist when one object exerts a force on another only when in direct contact. Field forces exist where one object exerts a force on another at a distance.
2. For a more thorough treatment of agent-object notation, see Aronld Arons, *Teaching Introductory Physics* (Wiley, New York, 1997).
3. Paired Forces are used to denote "3rd law paired forces" as described by Arons.