Stop Faking It!

Finally Understanding Science So You Can Teach It

Force & Motion

By William C. Robertson, PhD

Illustrated by Brian Diskin

NSTA press
National Science Teachers Association

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Arlington, Virginia

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Preface

When I was back in college, there was a course titled Physics for Poets. At a school where I taught physics, the same kind of course was referred to by the students as Football Physics. The theory behind having courses like these was that poets and/or football players, or basically anyone who wasn't a science geek, needed some kind of watered-down course because most of the people taking the course were—and this was generally true—SCARED TO DEATH OF SCIENCE.

In many years of working in education, I have found that the vast majority of elementary school teachers, parents who home-school their kids, and parents who just want to help their kids with science homework fall into this category. There are lots of "education experts" who tell teachers they can solve this problem by just asking the right questions and having the kids investigate science ideas on their own. These experts say you don't need to understand the science concepts. In other words, they're telling you to fake it! Well, faking it doesn't work when it comes to teaching *anything*, so why should it work with science? Like it or not, you have to understand a subject before you can help kids with it. Ever tried teaching someone a foreign language without knowing the language?

The whole point of the *Stop Faking It!* series of books is to help you understand basic science concepts and to put to rest the myth that you can't understand science because it's too hard. If you haven't tried other ways of learning science concepts, such as looking through a college textbook, or subscribing to *Scientific American*, or reading the incorrect and oversimplified science in an elementary school text, please feel free to do so and then pick up this book. If you find those other methods more enjoyable, then you really are a science geek and you ought to give this book to one of us normal folks. Just a joke, okay?

Just because this book series is intended for the nonscience geek doesn't mean it's watered-down material. Everything in here is accurate, and I'll use math when it's necessary. I will stick to the basics, though. My intent is to provide a clear picture of underlying concepts without all the detail on units, calculations, and intimidating formulas. You can find that stuff just about anywhere. Also, I'll try to keep it lighthearted. Part of the problem with those textbooks (from elementary school through college) is that most of the authors and teachers who use them take themselves way too seriously. I can't tell you the number of times I've written science curriculum only to have colleagues tell me it's "too flip" or "You know, Bill, I just don't think people will get this joke." Actually, I don't really care if you get the jokes either, as long as you manage to learn some science here.

Speaking of learning the science, I have one request as you go through this book. There are two sections titled *Things to do before you read the science stuff* and *The science stuff*. The request is that you actually DO all the "things to do" when I ask you to do them. Trust me, it'll make the science easier to understand, and it's not like I'll be asking you to go out and rent a superconducting particle accelerator. Things around the house should do the trick.

As you go through this book, you'll notice that just about everything is measured in *Système Internationale* (SI) units, such as meters, kilometers, and kilograms. You might be more familiar with the term *metric units,* which is basically the same thing. There's a good reason for this—this is a science book and scientists the world over use SI units for consistency. Of course, in everyday life in the United States, people use what are commonly known as English units (pounds, feet, inches, miles, and the like). The only time I'll use English units is when it would be silly to do otherwise, such as giving the speed of a car in miles per hour rather than kilometers per hour. If SI units really baffle you, there are a few easy conversions you can make to English units. There are about 1.6 kilometers in a mile, there are about 3 feet in a meter, and a 1 kilogram mass has a weight of about 2 pounds.

The book you have in your hands, *Force and Motion,* deals with—get ready for a surprise—force and motion. I'll address how to describe the motion of things as well as how Isaac Newton viewed the relationship between forces, and between forces and changes in motion. Then, after two chapters on the force of gravity and circular motion, I'll do my best to pull most of the ideas together by describing how you would go about getting a rocket ship to the Moon. You will notice that this book is not laid out the way these topics might be addressed in a high school or college textbook. That's because this isn't a textbook. You can learn a great deal of science from this book, but it's not a traditional approach.

One more thing to keep in mind: You actually CAN understand science. It's not that hard when you take it slowly and don't try to jam too many abstract ideas down your throat. Jamming things down your throat, by the way, seemed to be the philosophy behind just about every science course I ever took. Here's hoping this series doesn't continue that tradition.

Acknowledgments

The *Stop Faking It!* series of books is produced by the NSTA Press: Claire Reinburg, director; Carol Duval, project editor; Linda Olliver, art director; Catherine Lorrain-Hale, production director. Linda Olliver designed the cover from an illustration provided by artist Brian Diskin, who also created the inside illustrations.

This book was reviewed by Lynn Cimino-Hurt (Flint Hill School, Virginia); Terri Matteson (Estrella Mountain Elementary School, Arizona); and Daryl Taylor (Williamstown High School, New Jersey). Thanks also to Beth Daniels for supporting the publication of this series.

About the Author

Bill Robertson is a science education writer, teaches online math and physics for the University of Phoenix, and reviews and edits science materials. His numerous publications cover issues ranging from conceptual understanding in physics to bringing constructivism into the classroom. Bill has developed K–12 science curricula, teacher materials, and award-winning science kits for Biological Sciences Curriculum Study, The United States Space Foundation, The Wild Goose Company, and Edmark. Bill has a master's degree in physics and a Ph.D. in science education.

About the Illustrator

The soon to be out-of-debt humorous illustrator Brian Diskin grew up outside of Chicago. He graduated from Northern Illinois University with a degree in commercial illustration, after which he taught himself cartooning. His art has appeared in many books, including *The Golfer's Personal Trainer* and *5 Lines: Limericks On Ice*. You can also find his art in newspapers, on greeting cards, on T-shirts, and on refrigerators. At any given time he can be found teaching watercolors and cartooning, and hopefully working on an ever-expanding series of *Stop Faking It!* books. You can view his work at *www.briandiskin.com.*

The *Stop Faking It* series brings you *sci*LINKS, a new project that blends the two main delivery systems for curriculum—books and telecommunications—into a dynamic new educational tool for children, their parents, and their teachers. *sci*LINKS links specific science content with instructionally-rich Internet resources. *sci*LINKS represents an enormous opportunity to create new pathways for learners, new opportunities for professional growth among teachers, and new modes of engagement for parents.

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1. First, a cadre of undergraduate science education majors searches the World Wide Web for interesting science resources. The undergraduates submit about 500 sites a week for consideration.

2. Next, packets of these web pages are organized and sent to teacher-webwatchers with expertise in given fields and grade levels. The teacher-webwatchers can also submit web pages that they have found on their own. The teachers pick the jewels from this selection and correlate them to the National Science Education Standards. These pages are submitted to the *sci*LINKS database.

3. Scientists review these correlated sites for accuracy.

4. NSTA staff approve the web pages and edit the information provided for accuracy and consistent style.

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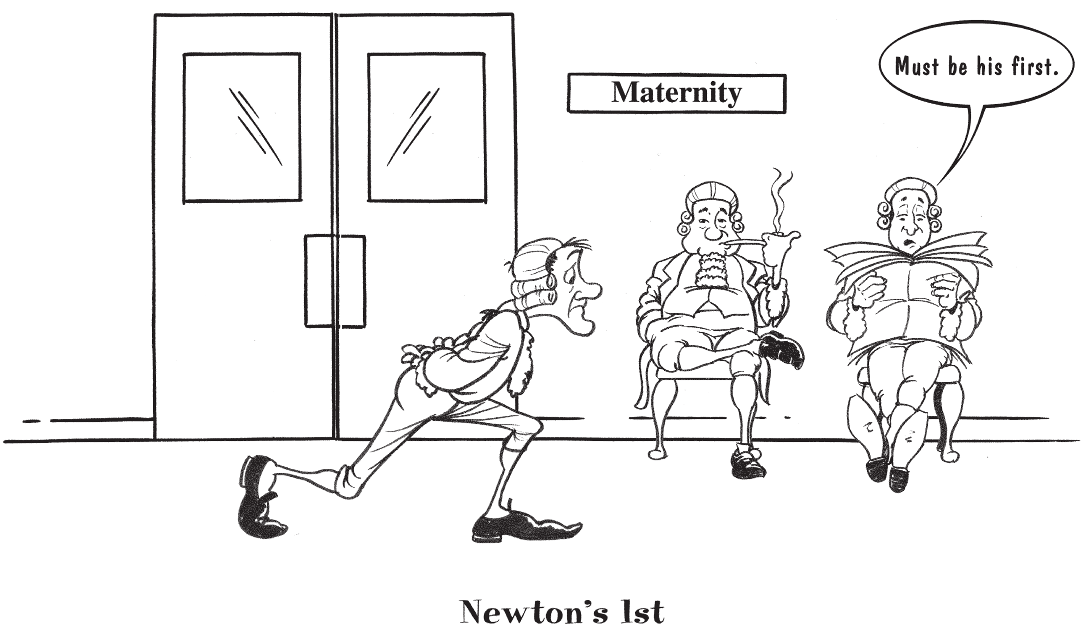
1
Chapter

Newton's First One

This first chapter deals with one of the most basic principles of motion, which happens to be known as Newton's first law. Not coincidentally, it has something to do with Isaac Newton. It's a nice law to start out with because it doesn't require any math and, after all, it is the first law. Just about every textbook I've seen spends very little time on Newton's first law, presumably because it's so basic and obvious. You'll find out, though, that at least part of the law is far from obvious.

This chapter is also our first step toward understanding what science knowledge you need to plan a trip to the Moon. Not that you necessarily wanted to go to the Moon, but since each chapter builds on previous ones, the Moon-trip chapter (the last one) seemed a fun way to tie everything together. So if you thought you were going to skip around and maybe hit the Moon trip before going through everything else, forget about it!

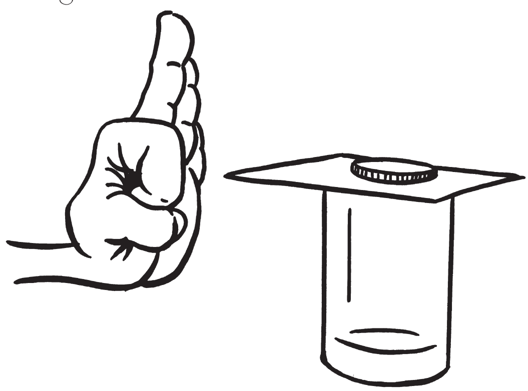


Newton's 1st

Things to do before you read the science stuff

Center an index card over the top of a glass, and place a coin in the middle of the index card (on top might be a good place). Using just one or two fingers, flick the card from the side.

Figure 1.1



If you do your flicking just right, the card should fly to the side and the coin should fall into the glass. Ah, yes, science is magic.

Now place the coin on a flat, level surface. Watch it for a while, say about five minutes. Notice whether or not it starts moving all by itself.

The science stuff

You have just demonstrated for yourself the first part of Mr. Newton's first law, which is that **objects tend to remain at rest unless you hit them**. Okay, so Newton didn't say it that way. I'll give you the fancy language later. Hopefully the coin didn't move as you watched it on the flat surface. The index card didn't stay where it was because you hit it, but the coin on top of the card stayed where it was (because you didn't hit it), at least until gravity pulled it into the glass.

Easy stuff, right? Told you science wasn't hard.

More things to do before you read more science stuff

Grab a few things from around the house—some you can roll across the floor (a ball, a toy car, a rolling pin, a glass) and some you can slide across the floor (a book, a block of wood, that fruitcake left over from the holidays—yes, it *is* frightening that Uncle Wally hasn't left yet.) Roll and slide these things across various *level* surfaces, such as tile and carpet. Watch carefully what happens. What do they do? Speed up, slow down, stop, keep going forever? Go outside and try it where you've got lots of room to check out that keep-going-forever thing.

More science stuff

Time to introduce the second part of Newton's first law, which is that **objects in motion tend to stay in motion until something hits them** (again my words, not Isaac's). That means that once something is moving, it will keep moving forever, without anything pushing it along, until something else pushes or pulls on it. Of course you just saw that happen with all the objects you were rolling and sliding across the floor. Then again, maybe you didn't see that happen.

In discussing this idea with folks, I usually challenge them to give an example of *any* object in their daily lives that keeps on moving forever without anything pushing it along. Some clever person always says "a two year old." Nice try, but a two year old doesn't move by him or herself. The kid needs a floor doing some pushing to even walk (see Chapter 5), and this is fueled by all the sugar he or she had for breakfast. The deep thinkers in the audience usually mention "time" as something that moves forever without a push. True, but time doesn't count as an object. We're talking your garden-variety touchable things. Finally, someone always mentions that things keep cruising along without a push in outer space. It always amazes me that I run into so many people who consider a trip to outer space to be a part of their everyday life.

So if Newton's first law doesn't apply to everyday life, what good is it? Well, it really does apply to everyday life, but we'll have to explore a bit further to see how. The reason I bring up the issue at this point is to show that science concepts don't always make sense when you first come across them. That can get in the way of understanding what they're about. I guess that what goes through lots of people's heads is something like this: "Okay, this concept doesn't fit with my everyday experience, so that means there's not a lot of common sense in science. There must be some strange reasoning process going on here, and I don't get it. I suppose I can just memorize this stuff and get through the best I can." I don't want you to think that way, so instead of presenting science concepts as facts that you would understand if you only had a brain, I'll try to show you how those wacky scientists came up with the ideas in the first place. The next activity will get us moving along that line. In the meantime, keep the following in mind.

People who develop science concepts *make them up*. These ideas are *not* handed down from deities on high. Science concepts hang around, not because they're always simple and obvious, but because they work, meaning that they help us understand and predict things. That said, it's not as if you can come up with any old explanation and call it a valid scientific theory. There are conventions for evaluating theories to determine how good they are. Suffice it to say that the theories presented in this book have been around a while and have stood the test of time.

Even more things to do before you read even more science stuff

Grab a ruler or yardstick, a marble or a ball bearing, and about a meter-long section of your kid's Hot Wheels track. If you don't have access to kids' toys, just use anything you can find that's flexible and will allow a marble to roll along it. What works well is a section of clear, plastic tubing (try the hardware or plumbing supply store) and a ball bearing that's small enough to roll freely inside the tubing.

Find a friend or family member to help you with this next part. Hold the track in a U shape[1] so the lowest part just touches a table top or a floor. (Check out Figure 1.2.) Now measure the *vertical* distance from the floor or table to one end of the track. For the directionally challenged, that vertical distance is shown in Figure 1.3.

Figure 1.2

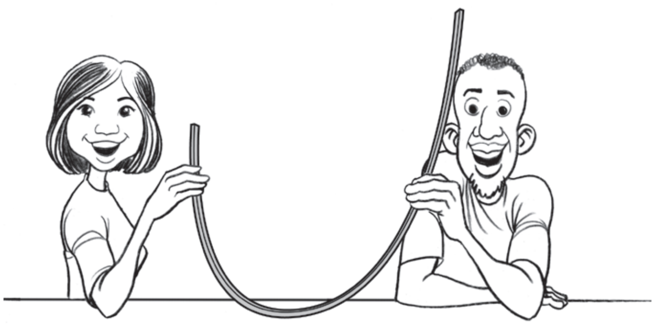
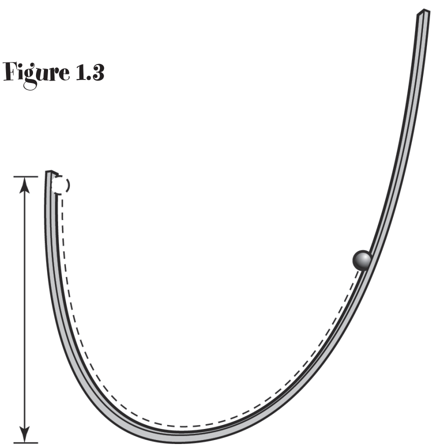


Figure 1.3



If your memory isn't great, write this distance down. You'll need to keep this one side of the track at that same vertical distance as you do the next few things. With your accomplice helping you hold the track in a U shape with the bottom of the U touching the table or floor, and holding your end at the vertical distance you've measured, drop the marble at the top of that end of the track (Figure 1.4).

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[1] There should be quite a bit left over on one end, so I guess this is really more of a J shape.

Figure 1.4

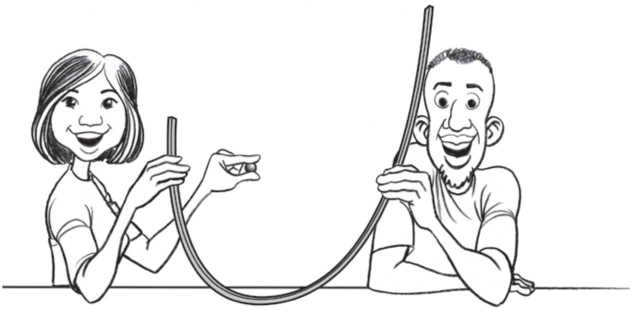
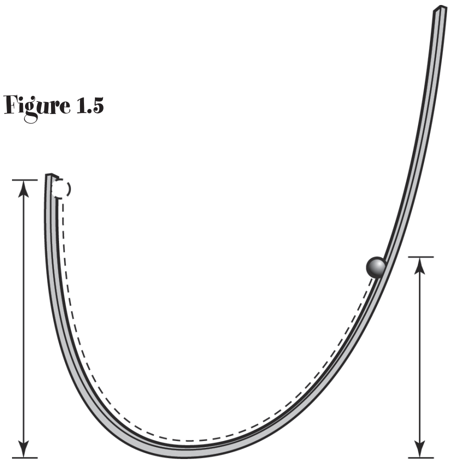


Figure 1.5



Watch what the marble does. It should roll back and forth for a while and finally come to rest. Now do this a few more times, but notice where the marble stops *the first time* before it goes back in the other direction. When you've done it enough times that the marble seems to stop in just about the same place each time, measure the vertical distance from the table or floor to this point on the track (Figure 1.5).

Now that you're good at this procedure, you get to repeat it. Only this time change the shape of the track so the second side of the U is lowered a bit. (Look at Figure 1.6.) As you repeat things, make sure your starting height is the same as it was the first time you did it (Figure 1.7).

Figure 1.6

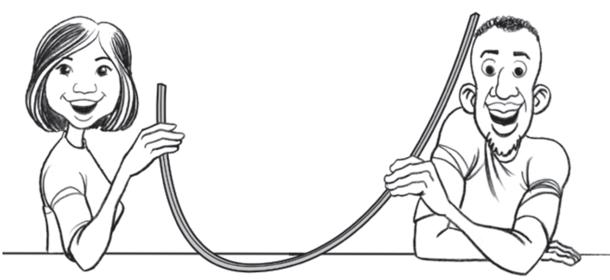


Figure 1.7

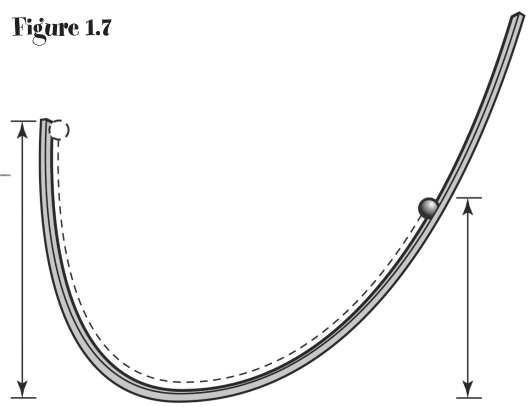
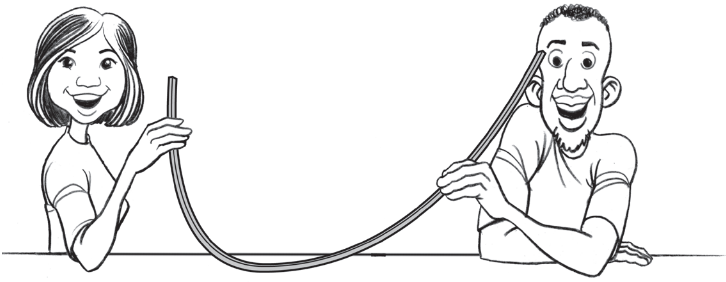


Figure 1.8



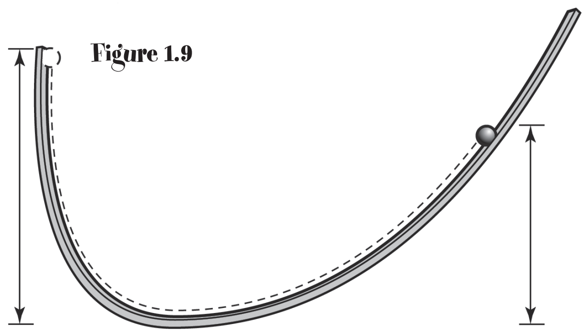


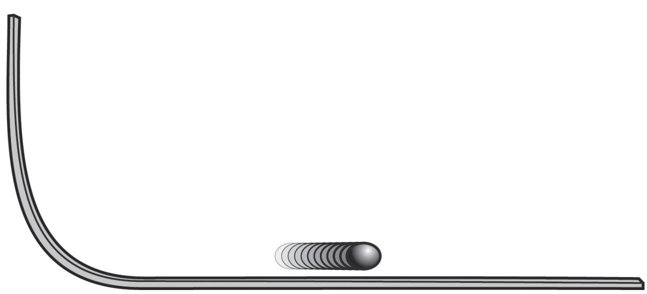
Figure 1.9

Now lower the second side of the U even more and repeat (Figures 1.8 and 1.9).

If you were doing this in a science course or were teaching a science course, the last thing anyone should do at this point is talk about what *should* have just happened in your little experiment. But hey, this is a book and I've got to get on with things, so here's what should have happened. No matter what the shape of the track, the marble should have risen to just about the *same vertical distance* each time. You probably didn't get exactly the same distance each time, but if you were within a few centimeters, that's good enough.

Now assuming you did get the result that the marble rises to the same height each time, no matter what the shape of the track, see if you can answer the following question. If the track were shaped like an L (see Figure 1.10) and the bottom part of the L were infinitely long (going on forever), how far would the marble travel before turning around and going back?

Figure 1.10



Even more science stuff

Because your experiment worked out just exactly as I told you it should (science experiments always work, don't they?), you could make up a general rule for how the marble behaved. That rule might go like this: No matter what the shape of the track, the marble will travel along the far side until it reaches a vertical distance of (*enter your distance here*), at which point it will turn around and go back. If you buy that rule, then your answer to the question about the L-shaped track has to be something like this: Since the marble will travel until it reaches that certain vertical distance, and with an L-shaped track the marble will *never* reach that vertical distance, the marble will travel on forever.

All right, so maybe you wouldn't have reached that conclusion. If it makes sense to you now, that's enough. Turns out it made sense to a guy named Galileo (the activity you just did is often referred to as Galileo's ramps) and then Newton just incorporated it into his first law. So that's how the motion part of Newton's first law came about. Later I'll get to why it doesn't seem to work so well in the real world. For now, we're ready for a complete statement of Newton's first law, which is that **things tend to keep on doing whatever they're doing until something else hits them**. This means that any time there's a change in an object's motion, a push or hit from something else caused it. Changes in motion refer to starting, stopping, speeding up, slowing down, and even just changing direction. There are some examples at the end of this chapter.

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Topic: forces

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It can get to be a real pain to say things like, "Hey, Wilma, looks to me like that thing over there tends to keep on doing what it's doing more so than that other thing over there." So there's a special term that refers to an object's tendency to keep on doing what it's doing—**inertia**. It's hard to change the motion of an object with lots of inertia and it's easy to change the motion of an object with very little inertia. Objects with very little inertia: mosquitoes, black-eyed peas, and dust mites. Objects with lots of inertia: elephants, mountains, and government-run agencies.

The term "hit" is also a bit too restrictive. It turns out that you can change an object's motion by pushing it or pulling it or nudging it or blowing on it or any number of other things, all of which are referred to as **forces**.

Armed with all the "proper" terms, maybe Newton's original wording of the first law might not seem so strange: **"Every object persists in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by forces impressed on it."** You go, Isaac.

Now what about the real world, where everything comes to rest? Newton's explanation is that things come to rest, not because they naturally do that, but because forces act on them to bring them to rest. A common one is the force of **friction**, which is the push things give to each other when they rub together. In Newton's world, if you could eliminate friction, then you'd see more things keep on moving in a straight line. If you played air hockey as a kid, then you saw what can happen when there's very little friction around. One push-off doesn't help you slide across a carpet very well because there's a lot of friction between your feet and the carpet. That same shove on a pair of ice skates, though, will get you a lot farther because there's not much friction around.

Figure 1.11

Just so we're straight on things, Newton's first law *does* hold true in the real world, as long as you can account for all the forces, like friction, that might affect things. You'll probably go nuts trying to understand the first law by thinking about situations where there aren't any forces around, because there are almost always lots of forces around. If you really want to cling to the idea that objects tend to come to rest rather than stay in motion, though, you're in good company. That's what Aristotle thought, and word is he wasn't a stupid guy.

Chapter Summary

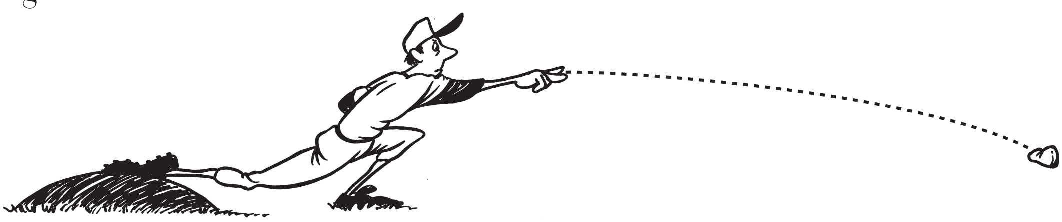
- Objects tend to keep on doing whatever they're doing (staying at rest or staying in motion) unless something else exerts a force on them. This is known as Newton's first law.
- Inertia is the name given to an object's tendency to keep doing what it's doing.
- Newton's first law only makes sense when *all* forces, including friction, are accounted for.

Applications

1. You throw a rock and it hits the ground. What does Isaac say about this? Probably nothing, because he's been dead for a really long time. But how does his first law apply?

   Well, while the rock is in your hand, its inertia just sort of keeps it there until a force acts on it. You provide that force by throwing the rock. A common mistake people make is to think that the force you exerted on the rock

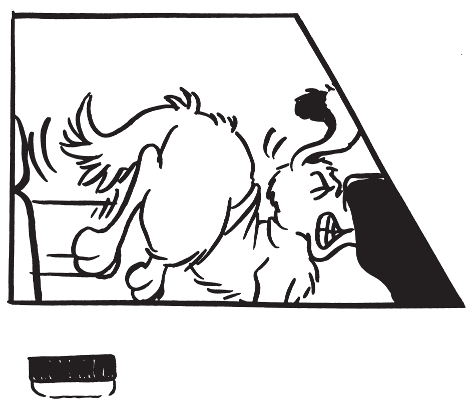
Figure 1.12



must be staying with it; otherwise it wouldn't keep moving. But according to the first law, the rock will keep moving because of its inertia. It doesn't need a force to keep doing what it's already doing. Of course the rock doesn't keep doing what it's doing. It immediately starts to fall to the ground, which means a change in direction and, if you observe carefully, an increase in speed. The force that's causing this change in motion is the Earth's gravity (more on gravity later). When the rock hits the ground it stops—another change in motion. This time it's the ground exerting a force on the rock to cause the change. By the way, if the idea of an inanimate object like the ground exerting a force on something bothers you, you're going to be bothered at least until Chapter 5.

2. You and the dog are riding in the car when you slam on the brakes. Rover, who was in the back, ends up licking your face. Why? Well, you and the car and Rover are cruising along at 30 miles per hour, all of you dutifully obeying Newton's first law. When you hit the brakes, friction (a force) between the road and the tires changes the motion of the car from moving to not moving. Your seat belt exerts a force on you and changes your motion from moving to not moving. Rover doesn't have a seat belt or anything else to exert a significant force on him, so

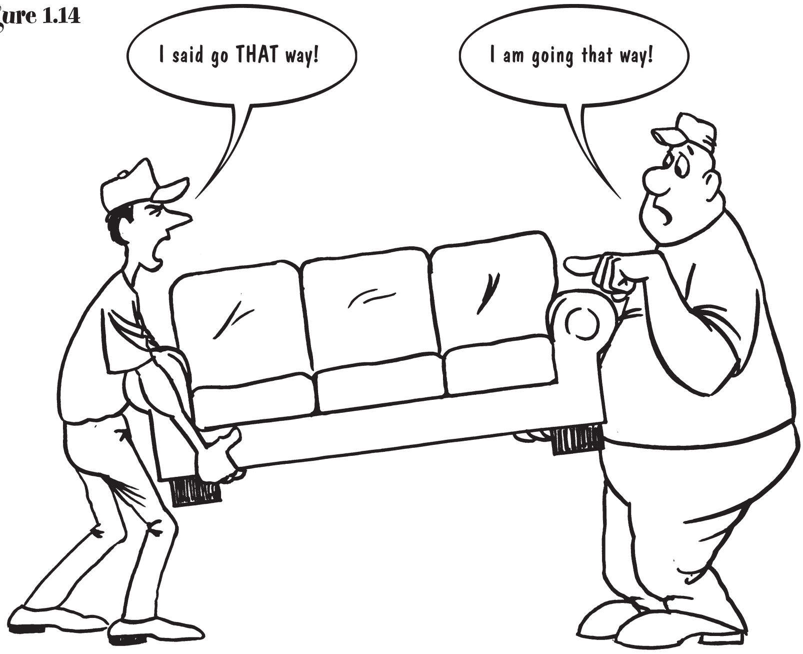
Figure 1.13



he keeps doing what he was doing, which is traveling in a straight line at 30 miles per hour.

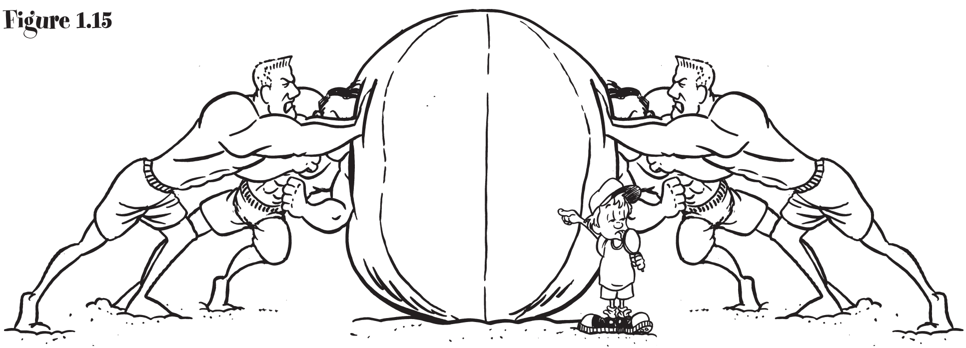
3. Two people push equally hard on opposite sides of a large couch and the couch doesn't go anywhere.

Figure 1.14



Because of the couch's inertia, it's going to stay at rest until a force is exerted on it, right? But aren't the two people exerting a force on it? Yes and no. Because the forces are equal and they act in opposite directions, they cancel each other out and it's the same as no force at all. Starting now, you should think in terms of what is called **net force**. Net force means what's left over when you figure in all the effects of different forces acting on something. So if you have five people pushing on something and four of those forces cancel each other, the net force, and the only one you and Isaac Newton should worry about, is the fifth force.

Figure 1.15



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Stop Faking It!

Finally Understanding Science So You Can Teach It

FORCE & MOTION

Intimidated by inertia? Frightened by forces? Mystified by Newton's laws of motion? You're not alone—and help is at hand. The *Stop Faking It!* series is perfect for science teachers, home-schoolers, parents wanting to help with homework—all of you who need a jargon-free way to learn the background for teaching middle school physical science with confidence.

With Bill Robertson as your friendly, able—but somewhat irreverent—guide, you will discover you CAN come to grips with the basics of force and motion. Combining easy-to-understand explanations with activities using commonly found equipment, this book will lead you through Newton's laws to the physics of space travel. The book is as entertaining as it is informative.

Best of all, the author understands the needs of adults who want concrete examples, hands-on activities, clear language, diagrams—and, yes, a certain amount of empathy.

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Grades 3–8