

identity.

More Mnemonics

This helps students remember the order of classification: **Keep Ponds Clean Or Fish Get Sick**. I think this is neat and the students ALWAYS remember it.

Jade Gopie, USA

A mnemonic I use to help students remember the five classes of vertebrates is: **FARM** Birds (**F** - Fish, **A** - Amphibians, **R** - Reptiles, and **M** - Mammals).

Paul Beier, USA

In remembering the order of classification, my Year 11 Biology students came up with the following suggestion: **Ken Please Come Over For Great Sex**. In the interests of school sensitivity, I suggested they change “Sex” to “Spaghetti,” and this is what we now work with. I have heard of other examples for this same task, but have found that having students create their own mnemonic is very powerful.

Grant Eyles, Victoria, Australia

This mnemonic is for the first 20 elements of the periodic table: H, He, **Little Betty Boron Causes Nothing On Freds Neck**, Na, Mg, **All Silly People Sip Chlorins Around Kym and Callie**. It not only helps students remember them, but also gives the symbols for each element. Year 9 and 10 students enjoy using it.

Bruno Testa, Beaconhills College, Victoria, Australia

Turning Around Newton’s Second Law

John Eric Goff

Lynchburg College, Lynchburg, Virginia, USA
goff@lynchburg.edu

Abstract

Conceptual and quantitative difficulties surrounding Newton’s second law often arise among introductory physics students. Simply turning around how one expresses Newton’s second law may assist students in their understanding of a deceptively simple-looking equation.

Think of the equations in physics that have made their way into the popular culture. Physics educators at all levels relish the idea that even a small part of our scientific culture pervades the society at large. One of the pitfalls of this widespread knowledge is that students entering the study of physics may have deeply ingrained

misconceptions that can take years to correct. An example of this is Einstein's famous $E = mc^2$ equation from special relativity. Einstein's equation rolls off the tongue of most nonscientists, even if they have no idea what the equation means. Introductory physics students can enter a first physics course in high school or university with that equation in their heads. When an instructor tries to include a little modern physics at the end of an introductory course, students may have a tough time understanding that while an object's energy can change, its mass is an invariant. The equation $E = mc^2$ that students know so well is better written as $E_0 = mc^2$, though that will likely never make it to the popular culture. With the understanding that E_0 is the *rest* energy, the equation makes more sense (Okun, 1989). Had students never heard of $E = mc^2$, they may not have the erroneous belief that an object's mass increases with increasing speed. What I propose in this paper is that there may exist similar problems with Newton's second law.

Before many students ever encounter a physics class in high school, they are taught something about Newton's laws. Most people have heard the phrase "action - reaction," even if they have no basic understanding of Newton's third law. The second law is often taught in physical science courses in the lower grade levels. The equation $F = ma$ rolls off the tongue for many people in the same way as Einstein's famous equation. However, simply saying " $F = ma$ " hides much of the subtlety of that deceptively simple looking equation. For one thing, one does not "speak" the vector character of the equation when saying it. Also, one does not usually say *net* force when verbalizing the equation. Lower levels of science usually make use of Newton's second law in extremely simple cases where there is only one force acting and only one direction in which an object can move. Unfortunately, as a result of the effort to introduce physics concepts early in a student's career, students can sometimes develop the impression that using Newton's second law is as easy as "plug and chug." I have noticed over the years I have taught at the university level that I have more initial success teaching Newton's laws to students who have not had high school physics compared to those who have. Most physics educators that I have spoken with over the years have had similar experiences. Even at the high school level, most physics problems tackled by students are quite simple and can be handled using a plug-and-chug approach; the statement of a problem typically gives two of the variables and asks the students to find the missing one.

Of course, when one teaches Newton's second law at the university level, one must discuss vectors, addition of vectors, coordinate systems, and other such niceties. A student who once thought dealing with Newton's second law was merely plugging two givens into a simple equation and solving for the single unknown is forced to think in a different, and more sophisticated, manner. A typical student comment I have encountered sounds something like: "Physics was easy in high school and very hard in university." The reality, of course, is that the high school approach is often too simplistic and the university approach is not really that "hard." My own

perception is that a student gets “ $F = ma$ ” so ingrained in his or her head that trying to solve university-level problems using Newton’s second law really is quite hard. Compared to a student who was never introduced to physics before coming to university, the veteran of high school physics must go through an added process of putting aside an already established notion of a “plug and chug” approach to problem solving.

My approach to solving this problem of having “ $F = ma$ ” so easily fall off the tongue is to simply turn around the equation. When I introduce Newton’s second law in my introductory university physics course, I write it as

$$m\vec{a} = \vec{F}^{(net)}.$$

Now, this may seem silly. However, I noticed several years ago that if I avoided saying “ $F = ma$ ” with students who were struggling with Newtonian physics problems, they were quicker to achieve success than if I kept saying it. I began to wonder if the ones who kept hearing me say “ $F = ma$ ” were not recalling how they did things in high school. To further aid students, I write Newton’s second law a second time in the following way:

$$\begin{array}{ccc} \text{"elsewhere"} & & \text{"picture side"} \\ & \vdots & \\ m\vec{a} & = & \vec{F}^{(net)} \end{array}$$

The idea is to convince students that there are two distinct sides to Newton’s second law. Once the students have selected a coordinate system (and remain faithful to that choice!), they write equations like $ma_x = F_x^{(net)}$ and $ma_y = F_y^{(net)}$, if the problem involves two dimensions. They learn that the single vector equation really contains more than one equation. In component form, I still use the dotted line to delineate the separate sides of Newton’s second law. The right side of the second law equation is obtained from a “picture” or a “free-body diagram.” Once the students have made a free-body diagram and broken all forces not lying completely on one of the coordinate axes into components, they simply list the forces on the right side of Newton’s second law as if they were doing “bookkeeping.”

Having completed the right side, they need to look “elsewhere” for the left side. For example, is the mass given in the statement of the problem? Are we told the object is moving in a circle? Does the object move through a gravitational field? Does the problem tell us that the object’s velocity is constant, thus meaning the acceleration is zero? Perhaps the acceleration is the unknown and the problem wants us to determine what the object’s acceleration is if it is subjected to a given number of forces.

While I do not continue writing the “elsewhere” and “picture side” labels, and making the vertical dashed line, as the course progresses, I do maintain writing Newton’s second law with the net force on the right. I even continue this practice in my classical mechanics course.

After 10 years of teaching physics to beginning students at the university level, I have found turning around Newton’s second law to be an effective way of communicating the complexities behind such a simple looking equation. I see fewer cases of students believing that there is a force “ ma ” acting on an object. This was especially a problem when centripetal motion was introduced. I used to see free-body diagrams of, say, a car going over a rounded hill and leaving the road with two downward forces on the car, one the car’s weight (fine!) and the other labeled as mv^2/r (wrong!). Students would see something like “ $F_c = mv^2/r$ is the centripetal force on an object moving in a circle” in a textbook and think that some external force “ mv^2/r ” was acting on the object. By turning around Newton’s second law and labeling the two sides, my students know that v^2/r (the acceleration, a) has to be obtained “elsewhere” (knowledge that the object is moving in a circle).

Allow me to now make this discussion more concrete by considering the following problem from a textbook popularly used in the United States. Here is the problem: “A 1000-kg sports car moving at 20 m/s crosses the rounded top of a hill (radius = 100 m). Determine (a) the normal force on the car, (b) the normal force on the 70-kg driver, and (c) the car speed at which the normal force equals zero” (Giancoli, 1998, p. 140).

Consider the two free-body diagrams in Figure 1.

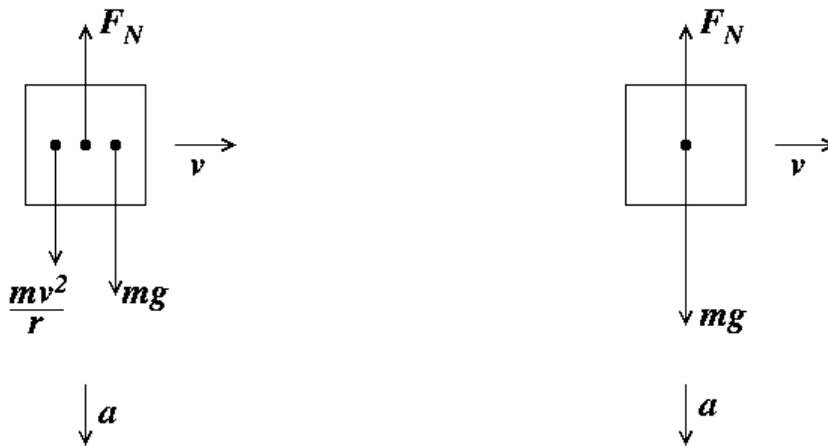


Figure 1. Two free-body diagrams for a car crossing the rounded top of a hill (left, incorrect; right, correct).

The diagram on the left is one I have seen too often from students. The one on the right is, of course, the correct free-body diagram. I teach my students to draw force vectors emanating *out* of a very simple drawing for an object (a square, in this case). They then draw the velocity and acceleration vectors, but not *on* the object. The error I have already mentioned is that many students will take a book's definition of "centripetal force" as mv^2/r to mean that such a force acts *on* the object, as seen in the incorrect free-body diagram in Figure 1. Students then get confused when writing the second law down because they do not know what to put in for a on the ma side. Some will put zero, thinking that there is no acceleration since the speed is constant (i.e., they confuse speed with velocity). In this case, students get to the "right" number, though they often have to fudge a sign to get there (try it to see what I mean!). Other students will correctly take $a = v^2/r$. However, if they use the incorrect diagram shown above, they get stuck with $F_N = mg$ and do not know what to do with part (c) of the problem! I usually ask students who make the incorrect free-body diagram to identify the entity responsible for the mv^2/r force. We know the Earth's gravity is responsible for mg and the road (in the case of the car) or the car's seat (in the case of the driver) is responsible for F_N . Usually, students see their error when they cannot think of any other objects responsible for forces.

Once I have students drawing the correct diagram, we move on to using the diagram and Newton's second law to solve the problem. Despite the fact that the stated problem is two-dimensional (the velocity and acceleration are perpendicular to each other), using Newton's second law boils down to a one-dimensional problem since all forces act along a single line. After having drawn the free-body diagram, I instruct my students to pick a direction for *positive* for the single dimension. I usually tell them that they make fewer sign errors if they go with the direction of the acceleration. However, I also tell them that the real world does not care what we physicists choose to call positive! (Students do run into sign errors when they read a word like *decelerate* and think that a must be *negative*. The acceleration is *only* negative if the chosen positive axis is opposite in direction to \vec{a} .) With *down* as positive in the diagram, the "picture side" says that $F^{(net)}$ simply becomes $mg - F_N$. Turning to the "elsewhere" side of the second law, the students must determine that, because the car moves on a circular path, $a = v^2/r$. Putting everything together then gives $m(v^2/r) = mg - F_N$. Now, the students can use this single equation to solve both parts (a) and (b) of the problem by simply inserting the relevant mass in for m and solving for F_N . I try to stress doing a little algebra before plugging in numbers; although this is tough to get across to introductory students. Holding back on numbers, solving for the normal force gives $F_N = m(g - v^2/r)$. For part (a), $F_N = 5800$ N and for part (b), $F_N = 410$ N (both with two significant digits only). If students hold off on plugging numbers in for the various parameters, they will discover in part (c) that the answer is independent of the mass. Letting the normal force go to zero means that the weight is the only force providing the centripetal force needed for the car to round the hill. If the car goes too fast, meaning too large a

v , r must increase (because mg cannot change) and the car leaves the road. Solving part (c) with $F_N = 0$ gives $v^2 = gr$, from which we obtain $v = 31$ m/s.

I will conclude this paper with a few disclaimers. There are many fine high school physics teachers who do indeed give their students a proper grounding in using Newton's second law to solve physics problems. However, my experience is that too many of my students who have taken a high school physics course have a "plug and chug" mentality when it comes to tackling physics problems. There is, of course, a "plug and chug" mentality in many of my students who have not taken high school physics. However, they are easier to acclimate to the proper way of using Newton's second law than the other students. I should also point out that my field of research is not physics education and that the experiences I write of here are limited to my own interactions with students and the scores of discussions I have had with colleagues. My goal in writing this paper is merely to offer physics educators yet one more idea for how they might better facilitate students' understanding of Newton's second law.

References

Giancoli, D. C. (1998). *Physics: Principles with applications* (5th ed.). New Jersey: Prentice Hall.
Okun, L. B. (1989). The concept of mass. *Physics Today*, 42(6), 31-36.



Ideas in Brief

Summaries of ideas from key articles in reviewed publications.

Whiteboarding

This is a useful way to gather evidence about student understanding in conjunction with a laboratory activity. It also mirrors the oral presentation process in which scientists engage at conferences.

After a lab exercise, Erekson (2004) asks each group of students to summarise (e.g., sketch the key features of a graph, rather than plotting the details) their work on a whiteboard. He prepares the 600 mm x 800 mm boards by purchasing a 2400 mm x 1200 mm sheet of shower panelling and cutting it into six pieces.

Groups are then invited to present their work to the class. Group members summarise procedures, discuss their findings, and invite questions from other students and the teacher. It is this last step that is the most valuable. Teacher questions might include: "Why . . .?" "What does . . . mean?" "What would happen if . . .?" The teacher also bounces the presenters' replies off the student audience. For example, questions such as "Do you agree with that?" and "How would you explain that?" can assess understanding across much of the class.