Q: How Do We Determine "Cause and Effect?"

By Bill Robertson

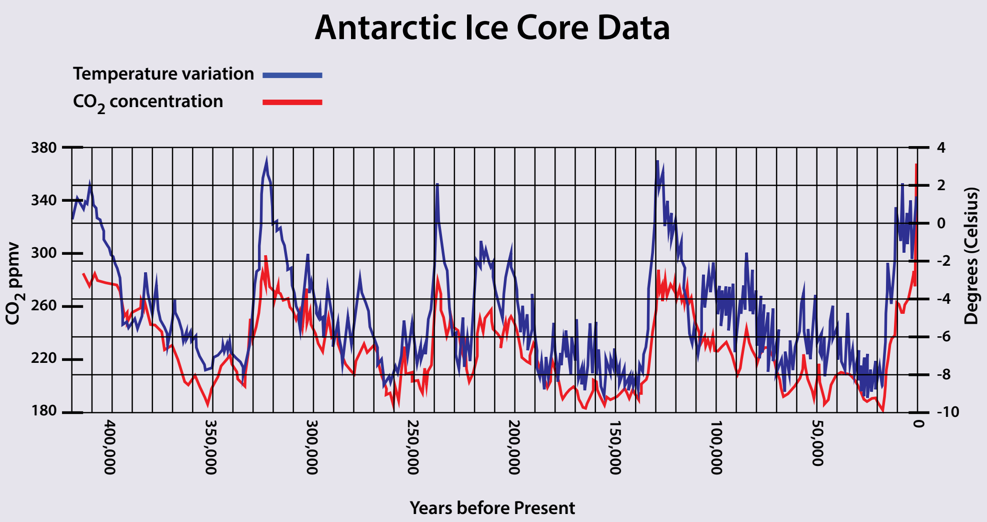
A: At first glance, the concept of cause and effect seems rather simple. One thing (the cause) happens, resulting in the occurrence of another thing (the effect). I come up behind you and scream (the cause) and you jump in the air (the effect). By the way, be careful about doing this kind of thing. Long ago when I was a fry cook, someone scared me and got hot grease thrown on them. No lasting injuries. Anyway, although the concept of cause and effect might seem simple, it isn't in many cases. While researching student understanding of cause and effect for this column, I came across the following: A child wanted to understand mold growing on bread. His mother explained that the mold grew on the bread, causing it to go bad. The child thought that the bread "went bad" first, resulting in mold growing on it. Think about that situation. To analyze it, you have to define what you mean by bread going bad, and you have to investigate what it is that causes mold to grow on bread. For that matter, what is mold? Is it *possible* that something happens in bread as it gets older that causes mold to grow on it? Sure it is, though that's not a scientifically accepted explanation. So, even a "simple" cause-and-effect relationship might not be simple. Throughout the column, I'll address examples of cause and effect and how they relate to science instruction.

"Washing your car will make it rain—science or superstition? We investigate on the next 'Cause and Effect.'"

Let's start with a common problem students—and people in general—have in confusing correlation with cause and effect. Consider the following two statements: (1) blankets and jackets cause things to be warm, and (2) ice and snow cause cold weather (only applies in certain parts of the country!). When you put on a blanket or a jacket, you tend to get warmer, but do blankets and jackets cause things to be warm? Easy to test. Place a thermometer on a table and note the reading. Then cover the thermometer with a blanket and see what happens to the reading on the thermometer. No change, right? That's because blankets don't cause things to be warm, at least not directly. A blanket, or a jacket, placed over a person, helps slow the transfer of heat from the person to the surroundings, and in fact helps create a layer of warm air between the person and the blanket that helps warm the person. Testing whether ice and snow cause cold weather simply requires a bit of observation. Wait until you have a really cold day when there's no ice and snow around. How could the day be cold without the ice and snow causing it? Because ice and snow *don't* cause the weather to be cold. The two often are correlated, but it's not a cause-and-effect relationship. Of course, it's easy to see why students might think that ice and snow cause cold weather. If you fill a container with ice, the container gets cold. But that's not how weather works.

There are lots of examples of correlations that people assume are cause-and-effect relationships. Sometimes, as with the above examples, you can design simple activities to determine whether or not you have a cause-and-effect relationship. Other times, as with the example of mold and bread, it's not so easy. It would be quite difficult to design an activity to determine whether some invisible process occurs in bread that makes it "go bad," resulting in the growth of mold.

FIGURE 1.



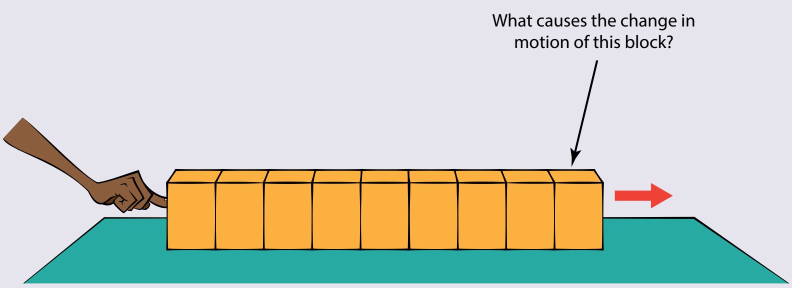
(This graph is not an exact replica of ice core data. It is slightly simplified so it is easier to read, but the general patterns are the same as in the actual data.)

One way to analyze relationships between variables is to graph the variables over time. Figure 1 shows a facsimile of the variation of atmospheric temperature and atmospheric carbon dioxide content over a period of hundreds of thousands of years. These data come from indirect determinations that come from ice core samples in Antarctica and Greenland. There is clearly a correlation between temperature and carbon dioxide content in the graph shown.

Now, because the current understanding among climatologists is that increases in carbon dioxide content in the atmosphere *cause* increases in global temperature, you will often hear people claim that such a relationship is evident in ice core data. However, by taking a close look at the graph, you'll see that sometimes changes in carbon dioxide content *precede* changes in temperature (compare rises, drops, and spikes), and sometimes changes in carbon dioxide content come *after* changes in temperature. So, simply by looking at the data, we obviously have a correlation, but, because we firmly believe that effects come after causes in time, no clear cause and effect. Before anyone gets upset, I'm not deriding global warming theory. There are many explanations for the apparent lack of a cause-and-effect relationship in these data. It's just that the data alone don't demonstrate that relationship.

And speaking of graphs, there's a practice in science education that just might be confusing students regarding cause and effect. It's the practice of defining independent and dependent variables. In an experiment, we define the independent variable as the one we consciously vary and the dependent variable as the one we measure. Suppose you have a wind-up car, and you graph how far the car goes (the dependent variable) versus the number of times you turn the key (the independent variable). Clearly, the independent variable is the cause and the dependent variable is the effect. But now suppose you have an electronic device that measures the speed of the car, and you want to graph that versus how far the car has traveled. So, you consciously measure out different distances for the car to travel,

FIGURE 2.



and call this your independent variable. Then, for each distance traveled, you measure the speed at the end of the distance, and call this your dependent variable. Because of the words "independent" and "dependent," you might be tempted to think that the distance traveled caused the speed. But that's not true at all. Distance traveled, and speed at the end of that distance traveled, are correlated. One doesn't cause the other. The lesson here is to be very careful about using the terms *independent* and *dependent variable*. Often in an activity, you are simply graphing the relationship between two variables, and calling them independent and dependent can be quite misleading.

Another rather different cause-and-effect problem that occurs in science is that of "direct" cause versus "removed" cause (My terms—don't go looking in textbooks for those. If you want more formal terms, you can use "proximate" cause and "ultimate" cause). Suppose you push on the end of a line of blocks, as illustrated in Figure 2.

Obviously, all the blocks will move. What caused the last block in the line to move? Likely your answer is "you did." You're the one who pushed, and you're the reason the last block moved, so your push is the cause and the change in motion (from rest to moving) of the last block is the effect. That kind of reasoning can get you into serious trouble if you want to use Newton's laws to figure out the relationship between your push and the change in motion of the last block. To analyze the change in motion of the last block, you have to look just at the last block. What pushes the last block *directly*? Well, it's the block right next to it. And it turns out that the force the next-to-last block exerts on the last block is not the same as the force you exert on the first block. Sort of counter-intuitive, but it's true. So, it's important to look at the direct, rather than the removed, cause. For an extreme example of this, you might ask what causes tornadoes (or sharknadoes, for you SyFy fans). For a direct cause, one would look at layers of warm air and cold air and the dynamics of air masses. For a removed cause, you could simply say that the Sun causes tornadoes because the energy output of the Sun is the ultimate cause of the motion of air masses. But using the Sun as the cause doesn't help us understand much about the formation of tornadoes, so we should look for more direct causes. By the way, as I learned from the movie (yes, I watched it—I'm a big fan of really, really bad movies), sharknadoes are caused essentially by global warming.

To sum up, it's easy to attribute cause and effect when it's not applicable, either through mistakenly taking every correlation as a cause-and-effect relationship, misinterpreting the meaning of independent and dependent variables, or not focusing on direct causes. Sometimes it's easy to help students understand where they're mistaken in cause-and-effect relationships, but sometimes it's not so easy. For example, ask your students what might happen if we got rid of all the ants or bees in the world. They might not think that's such a bad idea, because likely many of them aren't fond of ants and bees, and have no understanding of what makes dead organisms "disappear," no understanding of how we get soil, and no understanding of how plants go about making more plants. Cause and effect is at the heart of a whole bunch of science, but that doesn't mean the relationships are always obvious. Hey, if it weren't sometimes difficult to teach concepts, they wouldn't be paying you the big bucks to teach science! ■

Bill Robertson **(wrobert9@ix.netcom.com)** ***is the author of the NSTA Press book series,*** **Stop Faking It! Finally Understanding Science So You Can Teach It.**