Factors Affecting Friction

Synopsis

This is an exercise about friction that is meant to follow the exercise **Sliding and Stuttering**. Using the same experimental apparatus of the previous exercise, students design and conduct experiments to answer two questions, "Does the weight of an object affect the amount of friction between it and surface it slides upon, and if so, how?" and "Does the amount of surface in contact affect the amount of friction between an object and the surface it slides upon, and if so, how?"

Objectives

After conducting these experiments, students will be able to explain that, counter to what one might think, the amount of surface area in contact does not affect the amount of friction measured between two materials; while weight, on the other hand, has a direct affect on the amount of friction generated when an object slides across a surface. Students will also practice conducting experiments in which just one variable is manipulated at a time, and be able to describe why it is important to do so when conducting a scientific investigation.

This exercise addresses Competency Goal 4 of the *NC Standard Course of Study* for eighth grade, "The learner will build an understanding of motion and forces." This exercise specifically addresses Objective 4.04, "Determine how the force of friction retards motion," and Objective 4.07, "Apply Newton's Laws of Motion to the way the world works: Inertia."

Materials and Procedures

- You will need the following materials that were used in the exercise **Sliding and Stuttering**:
  - spring scales, one per student group
  - coffee cups, one per student group
  - tape
  - scissors
- string
- Cardboard or poster board, enough for about one square foot per group
- Styrofoam™ picnic plates, about three per group, and/or stiff glossy paper or laminated paper; enough for about one square foot per group
- Several standard weight sets, ranging from about 25 - 200 g. If these are not available, you can substitute large metal washers tied together in groups to make up weights of about 25, 50, 100, and 200 g, or plastic bags filled with pennies, sand, gravel, nails or similar objects. Two groups of students can share a set of weights, if necessary.
- Photocopies of the Information for Students pages.

Note that students are asked to design and conduct their own experiments; step-by-step information is not provided, and the questions they are asked are all open-ended. Since students will have recently completed **Sliding and Stuttering**, however, they should not have any difficulty designing this round of experiments using the previous exercise as a model. Nevertheless, you probably should plan on one class period (about 45-50 minutes) for designing and conducting the experiments, and a second class period for data analysis and discussion. As students create their data tables, be sure they make room to record both the static and kinetic friction measurements, like they did in the previous exercise, **Sliding and Stuttering**. Then, after collecting their data, they can make a line graph for each of their experiments. They can include both measurements on one set of axes by using different symbols for the two types. If time allows, after students have tested one surface material, *e.g.*, poster board, for the affects of area, ask them to repeat the experiment with a different material, *e.g.*, Styrofoam™. Doing so would help them be able to generalize their conclusions about the affects of area in contact on friction. When students are ready to graph their data, check to be sure that they set up their graphs correctly. Since they were testing to see if the amount of friction measured depended on the amount of area that was in contact, the frictional force is the dependent variable and thus belongs on the Y-axis of the graph. Area is the independent variable and therefore goes on the X-axis. Likewise, for their second experiment, weight is the independent variable and therefore goes on the X-axis. You may need to review with students how to find the area of a circle ($A = \pi r^2$) and how to find the area of a ring ($A = \pi R^2 - \pi r^2$, where R is the outer radius of the ring and r is its inner radius).

Discussion and Extensions

Ask your students what they can conclude about the effect of area on friction. They probably will be surprised to find that it has no affect, in other words, the lines connecting their data points should be roughly horizontal. Of course, since they probably expected to measure higher friction with greater areas in contact, some may have managed to pull their spring scales in such a way as to actually get higher measurements! This provides an excellent opportunity to discuss the concept of *experimenter bias*. If necessary, students can be invited to repeat their experiments to see if they can convince themselves that area does not affect friction.

Most likely, students will demand an explanation. However, it would be best to postpone such discussion until after a look at their results for the weight experiments.

Ask your students what they can conclude about the effect of added weight on friction. They should find that more weight results in higher frictional forces. Ask them to explain why this happens. If they need help, ask them what they think the two surfaces involved would look like under a microscope.

It shouldn't be hard for students to come up with ideas that explain why adding weight to the container results in more friction. The additional weight presses the peaks and valleys of one surface more firmly into the valleys and peaks of the other surface, so more force is required to disengage them and set the body in motion. Similarly, more force is required to keep the body in motion when gravity acting on the added weight tends to re-engage the peaks and valleys.

Returning to their graphs of weight versus friction, students should be able to fit reasonably straight lines between the data points on their graphs, as well as the point (0,0). This should be true for both their static and kinetic friction data, although the slopes of the lines will probably be slightly different. (The line for the static friction data should be a little steeper). If your students have some experience with algebra, they can derive linear equations relating the added weight to the frictional force obtained.

The slope of the line corresponds to the *coefficient of friction* for the two particular surfaces involved. In physics and engineering, the coefficient of friction is denoted by the Greek letter mu (μ), followed by either the subscript s or k. Thus, μ_s and μ_k represent the coefficients for static and kinetic friction, respectively. The force F needed to overcome friction and set a body of weight W in motion on a flat surface is given by $F = \mu_s W$. Likewise, once the body is in motion, the force needed to keep it in motion is $F = \mu_k W$.

Every pair of surfaces has a unique, empirically obtained set of coefficients. For example, dry steel on dry steel has a static coefficient of about 0.6 and a kinetic coefficient of 0.4. When oil or grease is added, the coefficients drop to about 0.1 and 0.05, respectively. These coefficients were obtained by measuring the force needed to move an object made of steel resting on a flat steel surface, and then dividing that force by the weight of the steel object. In other words, the equation given above was rearranged to give $\mu = F/W$.

Students can use the data they collected to determine the coefficients of friction between their cups and the table top. They can do this in either of two ways. First, they can calculate the slopes of their "best fit" lines connecting the data points in their graphs, as mentioned above. Or, they can use their data tables to divide the average force they obtained at each weight by the corresponding weight. They will need to do this division for both the static forces and the kinetic forces. After they have done these divisions for each weight tested, they can find the average values of the quotients they obtained. Thus they will end up with two average values: the coefficient of static friction and the coefficient of kinetic friction.

Students might be interested in knowing about coefficients of friction for other combinations of materials. Since it is mainly engineers who use these values, most of the ones found in reference materials are related to machinery and automotive applications. Some examples are given in the table below:

Contacting Surfaces	**Coefficient of Friction (Static or Kinetic)**
Rubber tires on dry concrete	1.02 (kinetic)
Rubber tires on wet concrete	0.97 (kinetic)
Wood on wood	0.25 - 0.5 (static)
Wood on brick	0.6 (static)
Glass on glass	0.9 - 1.0 (static)
Diamond on diamond	0.1 (static)
Graphite on steel	0.1 (static)
Nylon on nylon	0.15 - 1.25 (static)
Metal on ice	0.02 (kinetic)

Be sure to point out how the coefficient of friction between a car's tires and the pavement is reduced when the pavement is wet; this is why most drivers slow down on wet roads to avoid skidding. Advise your students to remember this fact after they get their driving licenses!

Some of the other friction coefficients may be surprising, such as the comparison between glass and diamond. Ask your students to speculate on why these two materials, which are similar in appearance, have such different coefficients of friction. They might want to do a little library research in an effort to find out why. They should easily be able to find information about what these materials are made of, but it is unlikely they will be able to find out much about how they behave with respect to friction. (Some information about graphite is given in **Sliding and Stuttering**, however.) In fact, many aspects of friction are still poorly understood (and are being researched by scientists and engineers throughout the world). Nevertheless, the similarities and differences between these three materials are such that students should be able to come up with some plausible explanations, or hypotheses. Again, a good experiment raises as many questions as it answers!

But there is an answer to why the area in contact doesn't affect the friction force measured. Returning to the equations for friction, $F = \mu_s W$ and $F = \mu_k W$, we can see that friction only depends on weight of the object being moved and the coefficient of friction that exists between the two surfaces. The amount of surface area in contact does not appear in the equations anywhere. So that is the theoretical answer to why area doesn't matter in friction.

For a *mechanistic* answer, consider that as long as there are *some* surface imperfections present on one or both surfaces, friction will occur. And as long as a few peaks and valleys are getting hung up on each other, it makes no difference if other peaks and valleys are also getting hung up simultaneously -- as long as these additional peaks and valleys aren't bigger than the original set of *some* peaks and valleys. The force required to free up *any* number of peaks and valleys is the force needed to free up the *largest* of the peaks and valleys. No matter how many smaller peaks and valleys there are, the larger force is enough to free up all of them. The coefficient of friction between two surfaces, because it is empirically derived and based on numerous experiments, reflects the largest peaks and valleys typical of the two surfaces involved. So, as long as the surfaces are relatively uniform, meaning they don't change in microscopic texture from one region to another, the amount of area in contact doesn't affect the frictional force.

Information for Students

Do larger objects encounter more friction as they slide across a surface than smaller objects made of the same material? For example, if you dragged a miniature version of your coffee cup along a table top, would you measure the same amount of friction as you did for your standard coffee cup in the **Sliding and Stuttering** exercise?

To answer this question you need to make sure that the area in contact is the only thing that changes in this experiment. But, wouldn't the smaller coffee cup weigh less than the larger one? What if weight makes a difference in the amount of friction you measure? If you did the experiment and found that the large cup encountered more friction, you wouldn't know whether the greater amount of friction was due to its larger size, or the fact that it was heavier.

Remember, if you want to test the effects of one variable (in this case, size), you must make sure you haven't changed any other variables at the same time (such as weight). So, when comparing objects of different sizes, weight is a variable you must *control*. When dragging cups around, one way to help control the weight "problem" is to design your experiment so that even if you change the size a lot, the weight will change only a tiny bit.

In this case, you can modify the bottom surface of your cup by attaching a narrow ring, about a centimeter in width, of cardboard, poster board, or Styrofoam™. This would give you a small amount of surface area in contact with the table. You could then attach a wider ring for more surface area in contact. Or, you could attach an entire circle of cardboard, the same size as the bottom of the cup, for even more surface area. You can use your spring scale to weigh your coffee cup when it has each of these different rings and circles attached, and you should find that the total weights differ by only a few grams.

Of course, it would also be a good idea to find out if weight actually does affect friction. So far we have just assumed that it *might*. It is easy to change the weight of your cup, simply by putting objects of different weight, one at a time, into the cup. This is easiest to do if you have a set of standard weights, ranging from smaller (*e.g.*, about 25 g) to larger (*e.g.*, about 200 g).

So, your task is to design and conduct two experiments. The first one should answer the question, "How does the amount of area in contact affect the amount of friction between an object and the surface it slides upon?" The second experiment should answer the question, "How does weight affect the friction between a sliding object and the surface it slides upon?" You can use the same materials and basic methods that you used in the **Sliding and Stuttering** exercise.

Before you start, be sure that for each of your two experiments you can give good answers for the following questions:

1. How will you try to answer the question(s) above?
2. How many trials will you do?
3. How will you record your data?
4. How will you report your results graphically?
5. What will be your control(s)?
6. What is your hypothesis?

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