



## Science Objectives

- Students will determine what factors affect the friction between two surfaces.
- Students will relate the forces needed to drag different shoes across a table at a constant speed.
- Students will develop an understanding of the forces needed to start the motion of shoes with different soles.

## Vocabulary

- acceleration
- force
- kinetic friction
- mass
- Newton's Laws
- static friction

## About the Lesson

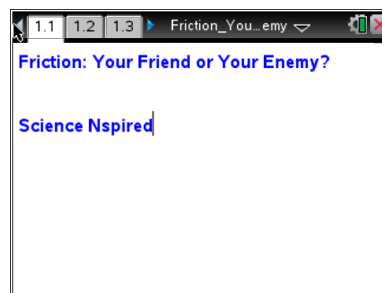
- This lesson simulates the static and kinetic friction of different shoes being dragged across an inclined plane.
- As a result, students will:
  - Manipulate values for force in different situations.
  - Measure static and kinetic friction data.
  - Determine the coefficients of static and kinetic friction.
  - Apply Newton's Laws to solve problems.

## TI-Nspire™ Navigator™

- Send out the *Friction\_Your\_Friend\_or\_Your\_Enemy.tns* file.
- Monitor student progress using Screen Capture.
- Use Live Presenter to spotlight student answers.

## Activity Materials

- *Friction\_Your\_Friend\_or\_Your\_Enemy.tns* document
- TI-Nspire™ Technology
- Vernier Dual-Range Force sensor
- Vernier EasyLink™ or Go!® Link interface
- hiking boot, sneaker, and dress shoe, all same size
- copy of student worksheet
- string, and pen or pencil



## TI-Nspire™ Technology Skills:

- Download a TI-Nspire document
- Open a document
- Move between pages
- Capture data with probes

## Tech Tips:

Access free tutorials at <http://education.ti.com/calculator/spd/US/Online-Learning/Tutorials>

## Lesson Files:

### Student Activity

- *Friction\_Your\_Friend\_or\_Your\_Enemy\_Student.doc*
- *Friction\_Your\_Friend\_or\_Your\_Enemy\_Student.pdf*

### TI-Nspire document

- *Friction\_Your\_Friend\_or\_Your\_Enemy.tns*



## Discussion Points and Possible Answers

### Problem 1: Kinetic and Static Friction for a Hiking Boot

Students use a force sensor to collect data on the forces required to start a shoe moving and to keep it moving at a constant speed. They use these data to determine the coefficients of kinetic and static friction between the shoe and the table. They compare the frictional forces on three different types of shoes to study the effects of surface texture on frictional force. Finally, they solve several problems involving kinetic and static friction.

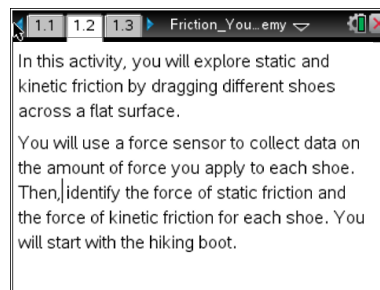
#### Move to pages 1.1 and 1.2.

1. Students will use a Vernier Dual-Range Force sensor to collect force data. Make sure the switch on the force sensor is in the  $\pm 10$  N position.
2. Students should connect the force sensor to the EasyLink interface (if students are using TI-Nspire handhelds to collect data) or to the Go! Link interface (if students are using TI-Nspire computer software to collect data). Students should not connect the EasyLink or Go! Link interface to their handheld or computer yet.
3. Next, students should connect the string to the hiking boot. If the boot has a hanging loop on the back of the heel, students can tie a loop of string through that loop. Otherwise, students should tie the loop of string around the lower laces of the boot. The loop of string should be placed so that the boot can be dragged across the table or floor with its sole completely touching the table or floor.

Have students answer the questions on the activity sheet.

- Q1. Do you think you will need a larger force to start moving the shoe or to steadily drag the shoe across the table?

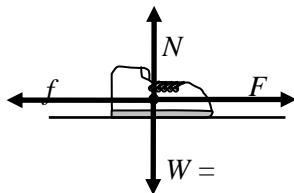
**Sample Answer:** The force necessary to start the motion is larger than the force needed to steadily drag the shoe, since static friction is larger than kinetic friction.





Q2. What forces act on the shoe when you pull the string? Draw a force diagram for the shoe.

**Sample Answer:** The free-body diagram is the same for the shoe at rest and when the shoe is dragged at constant speed. The only difference is that while the shoe is at rest, the force of friction is static, and while the shoe is moving at a constant speed, the force of friction is kinetic. A sample force diagram is shown below.



If the speed of the shoe is constant from Newton's second law we know that the forces must be balanced. Therefore, the following relationships apply:

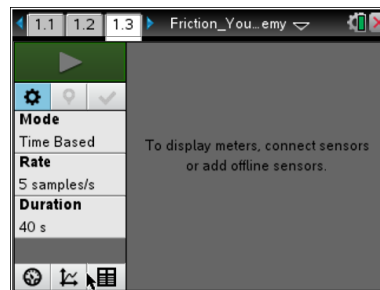
$$F - f = 0$$

$$N - W = N - mg = 0$$

When the shoe is at rest,  $f$  in the diagram and equation above is  $f_s$ , the force of static friction; when the shoe is in motion,  $f$  is  $f_k$ , the force of kinetic friction.

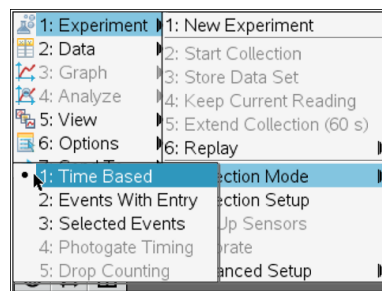
### Move to pages 1.1–1.3.


- Students should open the file *Friction\_Your\_Friend\_or\_Your\_Enemy.tns*, and read the first two pages, and while on page 1.3 connect the EasyLink or Go! Link interface to their handhelds or computer. The DataQuest application should be ready for capturing force data.
- Students should select the graph tab.
- Students should wait for the force reading to stabilize, and then zero the sensor (**Menu > Experiment > Set Up Sensors > Zero**). Then, they should use the string loop to hang the hiking boot from the hook on the force sensor, and wait for the reading to stabilize. This stable reading is the weight of the hiking boot. Students should record the reading as the weight of the hiking boot.
- Students should remove the boot from the force sensor, wait for the reading to stabilize, and then re-zero the sensor. They should clear any data stored in the device (**Menu > Experiment > New Experiment**). Students should place the boot at one end of the table or floor.
- Students should set up the data collection for a time graph (**Menu > Experiment > Collection Mode > Time Based**). They should set the time between samples to 0.02 sec and the experiment length to 5 sec.

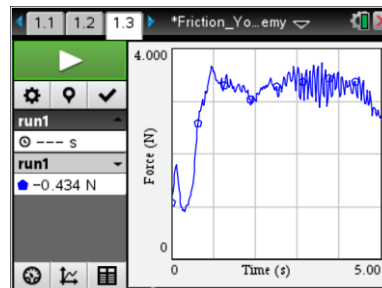




9. Before students start the data collection, they should connect the string to the force sensor and practice several times dragging the boot across the table at a constant speed. They should be able to maintain the constant speed for at least 4 sec.



10. Once they can drag the boot steadily, students can collect a data set. When they are ready, students should start the data collection by selecting **Start Data Collection**  and then carefully pull the string until the boot starts moving. Continue dragging the boot across the table at a constant speed for at least 4 sec. When the data collection has ended, a scatter plot should be displayed on the DataQuest application.



11. Once students have collected a clean data set, they should disconnect the EasyLink or Go! Link interface.

Have students answer the questions on the activity sheet.

Q3. Determine the force of static friction on the hiking boot from the graph of your data.

**Sample Answer:** The force of static friction is equal to the maximal pulling force needed to start the motion of the shoe. It is the maximum value of the force on the graph right before it drops down. To find this value, students should use the **Graph Trace** tool (**Menu > Trace > Graph Trace**) to trace the data points. When they reach the maximum force value, they should press **enter** to mark the point. For the sample data set shown, the maximum force is 3.1 N. Students' actual answers will vary. Encourage students to compare their answers and discuss possible reasons for any differences.



Q4. Determine the force of kinetic friction on the hiking boot from the graph of your data.

**Sample Answer:** The force of kinetic friction is equal to the pulling force when the shoe is dragged across the table at a constant speed. It is approximately equal to the average value of the force in the region of the graph that is roughly horizontal. To determine this value, students should construct a horizontal line parallel to the x-axis (**Menu > Construction > Parallel**). They should then drag the line so that it represents the average of the horizontal portion of the graph. The force of static friction is the y-intercept of the line. Students can use the **Coordinates and Equations** tool (**Menu > Actions > Coordinates and Equations**) to find the equation for the line. For the sample data set shown, the average pulling force is 2.9 N. Students' actual answers will vary. Encourage students to compare their answers and discuss possible reasons for any differences.

Q5. Derive an equation for the coefficient of friction in terms of the pulling force and the weight of the boot. Use this equation to calculate the coefficients of kinetic and static friction for the hiking boot.

**Sample Answer:** From the law of friction,  $i = \frac{f}{N}$ .

Substituting from Newton's 2<sup>nd</sup> law, this equation becomes  $i = \frac{F}{mg} = \frac{F}{W}$ .

Students' calculations of the coefficients of kinetic and static friction will vary. Encourage students to compare their results and discuss any differences. The sample data shown were collected using a hiking boot with a weight of 5.7 N. Therefore, the calculations are as follows:

$$i_s = \frac{3.1}{5.7} = 0.54$$

$$i_k = \frac{2.9}{5.7} = 0.51$$

(Note: If time allows, you may wish to have students repeat this activity, but increase the weight of the boot by adding rocks or other weights to it. They should be able to use their data to confirm the law of friction.)

Q6. Compare the coefficients of kinetic and static friction for the hiking boot.

**Answer:** The coefficient of kinetic friction is smaller than the coefficient of static friction.

### Problem 2: Kinetic and Static Friction for a Sneaker



Move to pages 2.1 and 2.2.

12. Students should read the text on page 2.1. Then, they should repeat Steps 4 and 5 from Problem 1.
13. Students should use the blank DataQuest application on page 2.2. Students should wait for the reading to stabilize, and then zero the force sensor. Then, they should find the weight of the sneaker as you did with the hiking boot in Step 6 of Problem 1. They then should remove the sneaker from the force sensor and place it on the floor or table.
14. Students should repeat Steps 8–11 from Problem 1.

Have students answer the questions on the activity sheet.

- Q7. Determine the force of static friction on the sneaker from the graph of your data.

**Sample Answer:** For the sample data set shown, the maximum force is 1.9 N. Students' actual answers will vary. Encourage students to compare their answers and discuss possible reasons for any differences.

- Q8. Determine the force of kinetic friction on the sneaker from the graph of your data.

**Sample Answer:** For the sample data set shown, the average pulling force is 1.7 N. Students' actual answers will vary. Encourage students to compare their answers and discuss possible reasons for any differences.

- Q9. Use the equation you derived in Question 5 to calculate the coefficients of kinetic and static friction for the sneaker.

**Sample Answer:** The sample data shown were collected using a sneaker with a weight of 3.4 N. This leads to the following calculations:

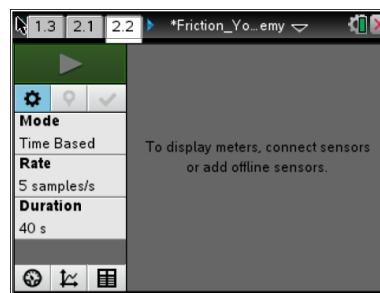
$$i_s = \frac{1.9}{3.4} = 0.56$$

$$i_k = \frac{1.7}{3.4} = 0.50$$

Students' calculations of the coefficients of kinetic and static friction will vary. Encourage students to compare their results and discuss any differences.

- Q10. Compare the coefficients of kinetic and static friction for the sneaker.

**Answer:** The coefficient of kinetic friction is smaller than the coefficient of static friction.

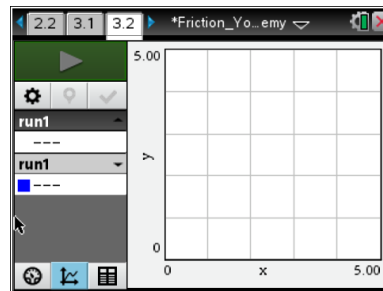




#### Problem 3: Kinetic and Static Friction for a Dress Shoe

##### Move to pages 3.1 and 3.2

- Students should read the text on page 3.1. Then, they should repeat Steps 4 and 5 from Problem 1.
- Students should use the blank DataQuest application on page 3.2. Students should wait for the reading to stabilize, and then zero the force sensor. Then, students should find the weight of the dress shoe as you did with the hiking boot in Step 6 of Problem 1. They should then remove the dress shoe from the force sensor and place it on the floor or table.
- Students should repeat Steps 8–11 from Problem 1.



Have students answer the questions on activity sheet.

- Q11. Determine the force of static friction on the dress shoe from the graph of your data.

**Sample Answer:** For the sample data set shown, the maximum force is 1.4 N. Students' actual answers will vary. Encourage students to compare their answers and discuss possible reasons for any differences.

- Q12. Determine the force of kinetic friction on the dress shoe from the graph of your data.

**Sample Answer:** For the sample data set shown, the average pulling force is 1.1 N. Students' actual answers will vary. Encourage students to compare their answers and discuss possible reasons for any differences.

- Q13. Use the equation you derived in Question 5 to calculate the coefficients of kinetic and static friction for the dress shoe.

**Sample Answer:** The sample data were collected using a dress shoe with a weight of 2.3 N. This leads to the following calculations:

$$i_s = \frac{1.4}{2.3} = 0.61$$

$$i_k = \frac{1.1}{2.3} = 0.48$$

Students' calculations of the coefficients of kinetic and static friction will vary. Encourage students to compare their results and discuss any differences.



Q14. Compare the coefficients of kinetic and static friction for the dress shoe.

**Answer:** The coefficient of kinetic friction is smaller than the coefficient of static friction.

Q15. Which shoe has the largest coefficient of static friction? Which has the smallest? Which has the largest coefficient of kinetic friction? Which has the smallest?

**Sample Answer:** Student answers will vary depending on the actual shoes they used. For the sample data set, the hiking boot has the lowest coefficient of static friction and the dress shoe has the highest. The dress shoe has the lowest coefficient of kinetic friction, and the hiking boot has the highest. Encourage students to discuss whether their answers agree with their predictions and to identify possible sources of error and inaccuracy in their data. The most common sources of error are inconsistent pulling speed, uneven motion of the shoe (e.g., "bouncing" as it is pulled), and the imprecision inherent in fitting a best-fit line "by eye."

Q16. What is the most likely explanation for the differences in coefficients of friction between the three shoes?

**Answer:** Students should identify the textures and compositions of the soles of the shoes as the main factors affecting coefficients of friction. Soles made of hard plastic typically have lower coefficients of friction than soles made of resin or soft rubber. Rough, rugged soles generally have higher coefficients of friction than smoother soles.



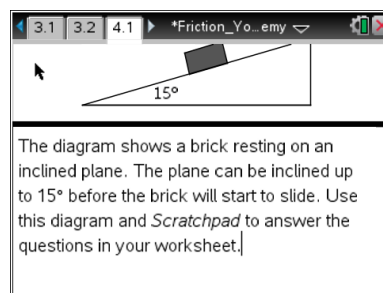


#### Problem 4: Applications and Problem Solving

Move to pages 4.1.

18. Students should read the text on page 4.1.

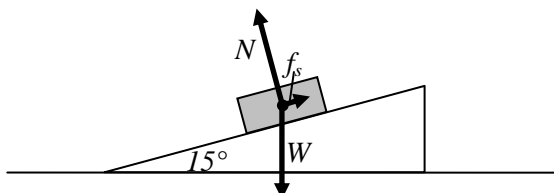
19. Students should study the diagram. They should use *Scratchpad* to help them solve the problems below.



Have students answer the questions on the activity sheet.

Q17. What keeps the brick from sliding down the ramp? Draw a force diagram for the brick.

**Sample Answer:** The force of static friction between the brick and the surface of the ramp keeps the brick from sliding down the ramp. At  $15^\circ$ , the static friction is maximum and is exactly equal to the component of the brick's weight acting parallel to the surface of the ramp. A sample force diagram is shown below.



Q18. Write equations for the components of the brick's weight that act parallel and perpendicular to the ramp.

**Answer:** The component that is parallel to the ramp's surface is given by  $F_{\text{par}} = W \cdot \sin(15^\circ)$ . The component that is perpendicular to the ramp's surface is given by  $F_{\text{perp}} = W \cdot \cos(15^\circ)$ .

Q19. Find the coefficient of static friction between the surface of the ramp and the brick.

**Answer:** The brick is in static equilibrium, so  $\vec{N} + \vec{W} + \vec{f}_s = 0$ .  $F_{\text{par}}$ , which is  $W \cdot \sin(15^\circ)$ , acts in the opposite direction to  $f_s$ , the static frictional force.  $F_{\text{perp}}$ , which is  $W \cdot \cos(15^\circ)$ , acts in the opposite direction to  $N$ , the normal force. Because the brick is in static equilibrium,  $N - W \cdot \cos(15^\circ) = 0$  and  $f_s - W \cdot \sin(15^\circ) = 0$ .

Therefore,  $N = W \cdot \cos(15^\circ)$  and  $f_s = W \cdot \sin(15^\circ)$ . This leads to the following calculation:

$$\mu_s = \frac{f_s}{N} = \frac{W \sin(15^\circ)}{W \cos(15^\circ)} = \tan(15^\circ) = 0.27.$$



Q20. If the ramp is inclined a little more, the brick starts sliding down the ramp. Is it sufficient to decrease the angle of the ramp back to  $15^\circ$  to stop the brick from sliding? Explain your answer.

**Answer:** As soon as the brick starts sliding, the frictional force becomes a kinetic frictional force. Kinetic friction is less than static friction. Therefore, the kinetic friction on the brick will not be enough to hold the brick on the ramp at  $15^\circ$ , and if the ramp is brought back to  $15^\circ$ , the brick will continue sliding down the ramp. You would need to decrease the angle more to stop the brick from sliding. If time allows, you can let students try this experiment with the shoes they used in the activity to confirm their findings about the difference between kinetic and maximum static friction.

#### TI-Nspire Navigator Opportunities

Use TI-Nspire Navigator to capture screen shots of student progress and to retrieve the file from each student at the end of the class period. The student questions can be electronically graded and added to the student portfolio.

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### Wrap Up

When students are finished with the activity, pull back the .tns file using TI-Nspire Navigator. Save grades to Portfolio. Make sure the concept of balancing torques is firm in their understanding and not balancing forces.

### Assessment

- Summative assessment will consist of questions/problems on the chapter test.