Friction: Your Friend or Your Enemy? – ID: 11121

By Irina Lyublinskaya

Time required
45 minutes

Topic: Force and Motion

- *Construct and interpret a free-body diagram.*
- *Measure or calculate the frictional force and the coefficient of friction between two surfaces.*

Activity Overview

In this activity, students explore static and kinetic friction by dragging shoes with different types of soles across a table at a constant pace. They use a force sensor to collect data on the force applied to each shoe. They use these data to determine the force needed to start the shoe moving (static friction) and to keep the shoe moving (kinetic friction). They then determine the coefficients of static and kinetic friction for each shoe.

Materials

To complete this activity, each student will require the following:

- *TI-Nspire™ technology*
- *Vernier Dual-Range Force sensor*
- *Vernier EasyLink™ or Go!® Link interface*
- *string*
- *hiking boot, sneaker, and dress shoe, all same size*
- *copy of student worksheet*
- *pen or pencil*

TI-Nspire Applications

Graphs & Geometry, Notes, Calculator

Teacher Preparation

Students should be familiar with Newton's laws, the relationship between the coefficient of friction and the frictional force, and the concept of motion with constant speed. This will help students set up the equation describing the motion of the shoe with constant speed.

- *Students will need a long, flat, relatively smooth surface to pull the shoes over. A large table is ideal, but a tile or wood floor will also work.*
- *The screenshots on pages 2–11 demonstrate expected student results. Refer to the screenshots on page 12 for a preview of the student TI-Nspire document (.tns file). Pages 13–16 show the student worksheet.*
- ***To download the .tns file, go to education.ti.com/exchange and enter "11121" in the search box.***

Classroom Management

- *This activity is designed to be **student-centered**, with the teacher acting as a facilitator while students work cooperatively. The student worksheet guides students through the main steps of the activity and includes questions to guide their exploration. Students may record their answers to the questions on blank paper or answer in the .tns file using the Notes application.*
- *The ideas contained in the following pages are intended to provide a framework as to how the activity will progress. Suggestions are also provided to help ensure that the objectives for this activity are met.*

- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

The following questions will guide student exploration during this activity:

- Why can you keep the motion of the shoe constant while applying constant force to it?
- Can you compare the coefficients of static and kinetic friction?

The goals of this activity for students are a) to observe and compare the forces needed to start the motion of shoes with different soles, b) to observe and compare the forces needed to drag different shoes across a table at a constant speed, and c) to determine what factors affect the friction between two surfaces. 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.

Problem 1 – Kinetic and static friction for a hiking boot

Step 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 ± 10 N position.

Step 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.

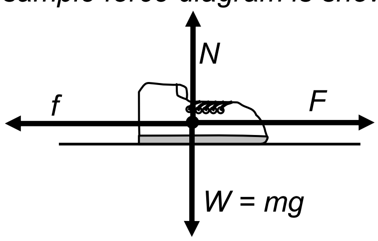
Step 3: Next, students should connect the string to the hiking boot. If the boot has a hanging loop on the back of the heel, students can tie a loop of string through that loop. Otherwise, students should tie the loop of string around the lower laces of the boot. The loop of string should be placed so that the boot can be dragged across the table or floor with its sole completely touching the table or floor. Then, students should answer questions 1 and 2.

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

A. *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.

A. *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.*



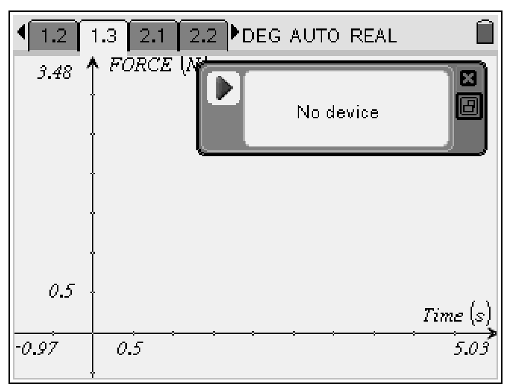
If the speed of the shoe is constant, from Newton's second law we know that the forces must be balanced. Therefore, the following relationships apply:

$F - f = 0$

$N - W = N - mg = 0$

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.*

Step 4: Next, students should open the file **PhysWeek08_Friction.tns**, read the first two pages, and then connect the EasyLink interface to their handhelds (or the Go! Link interface to their computers). A force data collection display should appear.

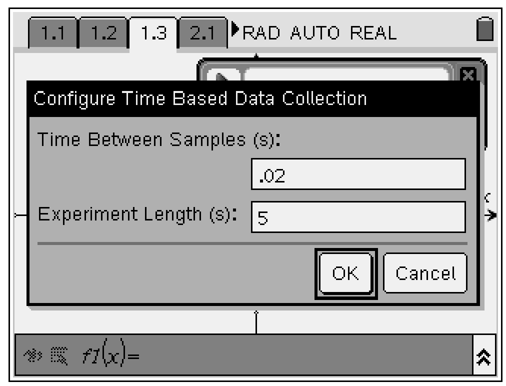


Step 5: Students should select **Menu > Experiment > Display Data In > New Graphs & Geometry.** A new *Graphs & Geometry* page with a data collection box should be automatically inserted in the .tns file. (Note: When students connect the interface to their handheld or computer, a dialog box may appear asking them what type of application they want to insert the data collection box in. If this occurs, students should select *Graphs & Geometry* from the menu and click OK.)

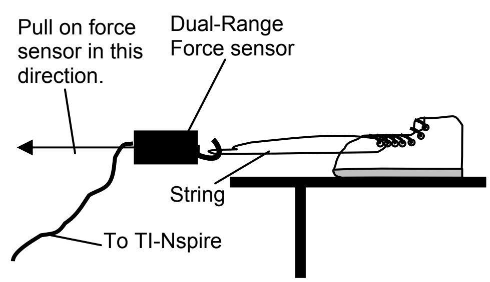
Step 6: Students should wait for the data collection display to stabilize and then zero the force sensor (**Menu > Sensors > Zero**). Then, they should use the string loop to hang the hiking boot from the hook on the force sensor. Once the reading stabilizes, students should record the reading as the weight of the hiking boot. Note: Throughout this activity, students should record forces to the nearest tenth of a newton.

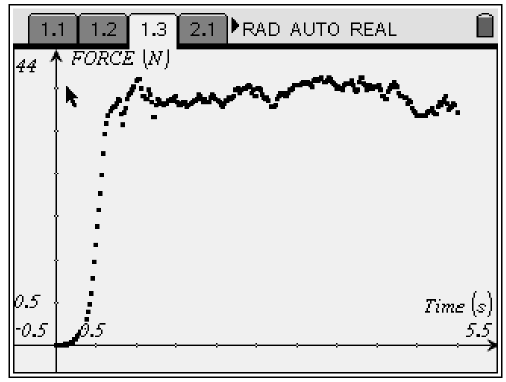
Step 7: Next, students should remove the hiking boot from the force sensor. They should then re-zero the force sensor (once the reading has stabilized) and clear any data stored in the device (**Menu > Data > Clear All Data**). They should place the boot at one end of the table or floor.

Step 8: Next, students should set up the device to produce a time graph (**Menu > Experiment >Set Up Collection > Time Graph**). They should set the time between samples to 0.02 sec and the experiment length to 5 sec.



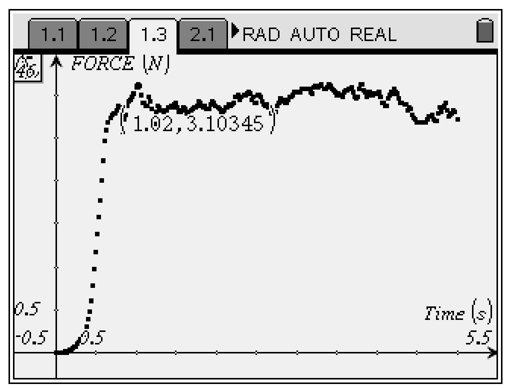
Step 9: Before starting data collection, students should hook the loop of string with the hook on the force sensor and practice several times dragging the shoe with a constant speed, as shown to the right. They should be able to maintain the constant speed for at least 4 sec.





Step 10: When they can drag the boot steadily, students can collect a data set. The "play" button (►) should be highlighted in the data collection box. If this is the case, students need only click (press) to begin data collection. If the play button is not highlighted, students should press tab until it is selected. They should start the data collection and then carefully pull the force sensor until the boot starts moving, dragging the boot across the table at a constant speed. When data collection has ended, a scatter plot will be displayed on the *Graphs & Geometry* page. If the collected data do not have a clear peak, followed by a region of relatively constant force (as shown to the right), students can repeat the experiment. To avoid storing too much data on the device, students should discard previous data before collecting a new data set.

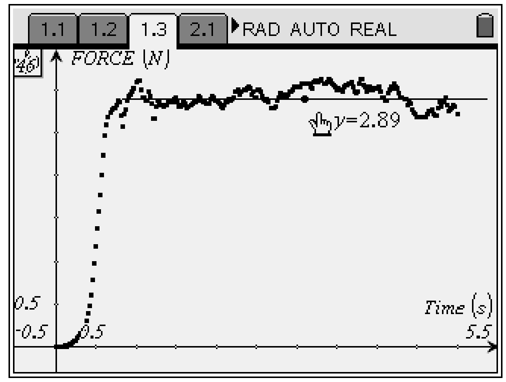
Step 11: Once students have collected a reasonably good data set, they should close the data collection box and disconnect the EasyLink or Go! Link interface. They should then answer questions 3–6.



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

A. *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.



A. *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.

A. *From the law of friction,* $\mu = \frac{f}{N}$*. Substituting from Newton's second law, this equation becomes* $\mu = \frac{F}{mg} = \frac{F}{W}$*. 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:*

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

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

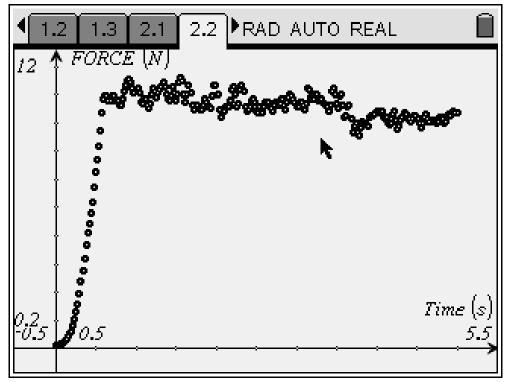
(Note: If time allows, you may wish to have students repeat this activity, but increase the weight of the boot by adding rocks or other weights to it. They should be able to use their data to confirm the law of friction.)

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

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

Problem 2 – Kinetic and static friction for a sneaker

Step 1: Next, students should move to page 2.1 and read the text there. Then, they should repeat steps 4 and 5 from problem 1.

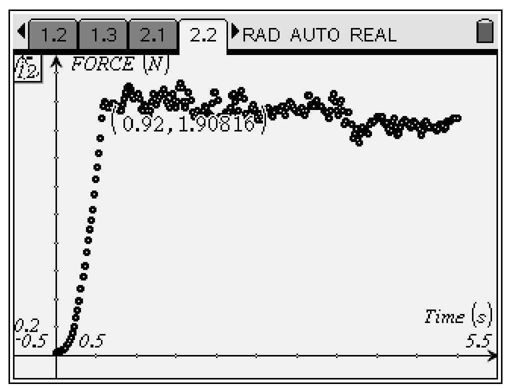


Step 2: A *Graphs & Geometry* page with a data collection box should be inserted automatically. Students should wait for the force reading to stabilize, and then they should zero the force sensor. Then, students should find the weight of the sneaker as they did with the hiking boot in step 6 of problem 1. They should then remove the sneaker from the force sensor and place it on the floor or table.

Step 3: Students should repeat steps 8–11 from problem 1. They should then answer questions 7–10. (Note: Students may have more difficulty getting a clean data set for lighter-weight shoes. It is OK for the data to be slightly messy. Alternatively, you can have students add weight (rocks or other objects) to the lighter shoes to make the data cleaner.)

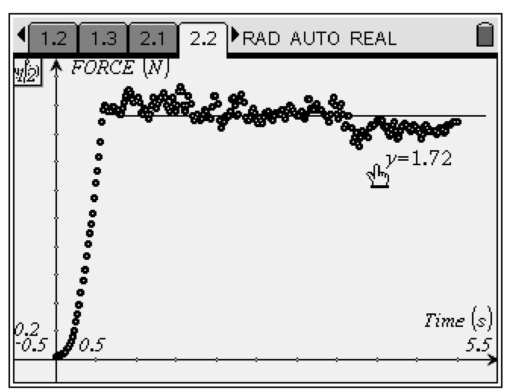
Q7. Determine the force of static friction on the sneaker from the graph of your data.

A. *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.

A. *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.

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

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

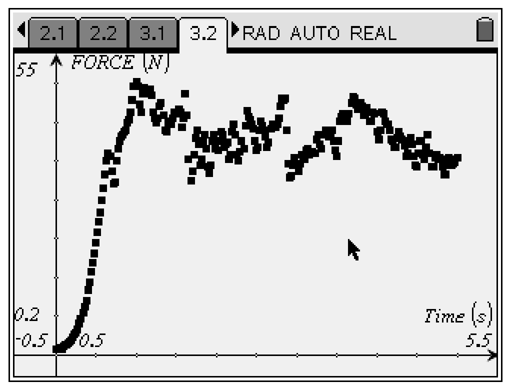
$$\mu_k = \frac{1.7}{3.4} = 0.50$$

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.

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

Problem 3 – Kinetic and static friction for a dress shoe



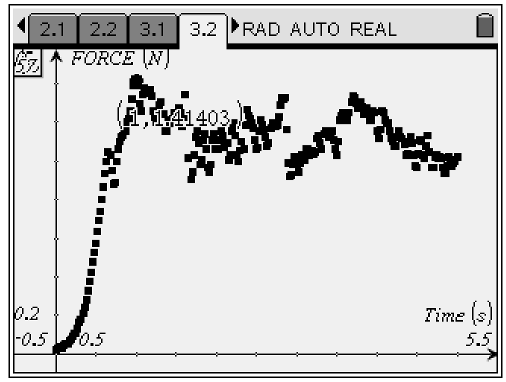
Step 1: Next, students should move to page 3.1 and read the text there. Then, they should repeat steps 4 and 5 from problem 1.

Step 2: A *Graphs & Geometry* page with a data collection box should be inserted automatically. Students should wait for the force reading to stabilize, and then they should zero the force sensor. Then, students should find the weight of the dress shoe as they 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.

Step 3: Students should repeat steps 8–11 from problem 1. They should then answer questions 11–16.

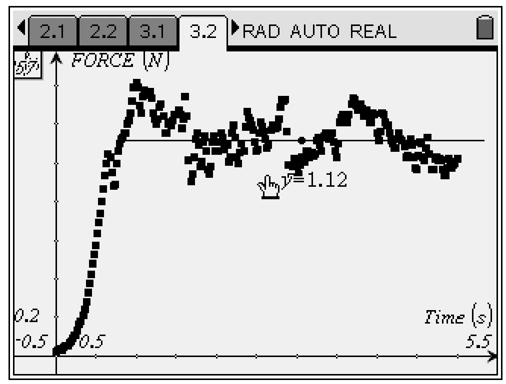
Q11. Determine the force of static friction on the dress shoe from the graph of your data.

A. *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.

A. *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.

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

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

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

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.

A. *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?

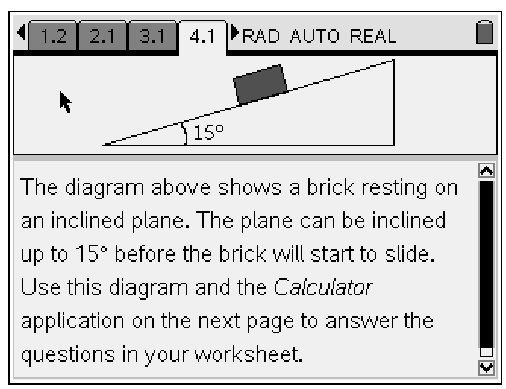
A. *Student answers will vary depending on the actual shoes they used. For the sample data set, the hiking boot has the lowest coefficient of static friction and the dress shoe has the highest. The dress shoe has the lowest coefficient of kinetic friction, and the hiking boot has the highest. Encourage 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?

A. *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

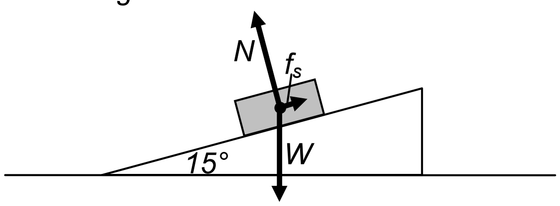
Step 1: Next, students should read the text on page 4.1, which describes the following scenario: A brick was put on a ramp, and the ramp was inclined until the brick was no longer at rest. The maximum angle that the ramp reached just before the brick started to slide was 15°.



Step 2: Students should study the diagram and then answer questions 17–20. They should use the *Calculator* application on page 4.2 to help them solve the problems.

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

A. *The force of static friction between the brick and the surface of the ramp keeps the brick from sliding down the ramp. At 15°, 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.

A. *The component that is parallel to the ramp's surface is given by F_{par} = W·sin (15°). The component that is perpendicular to the ramp's surface is given by F_{perp} = W·cos (15°).*

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

A. *The brick is in static equilibrium, so* $\vec{N} + \vec{W} + \vec{f}_s = 0$. F_{par}, *which is W·sin (15°), acts in the opposite direction to* f_s, *the static frictional force.* F_{perp}, *which is W·cos (15°), acts in the opposite direction to* N*, the normal force. Because the brick is in static equilibrium, N – W·cos (15°) = 0 and f_s – W·sin (15°) = 0. Therefore, N = W·cos (15°) and f_s = W·sin (15°). This leads to the following calculation:*

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

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° to stop the brick from sliding? Explain your answer.

A. *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°, and if the ramp is brought back to 15°, 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.*

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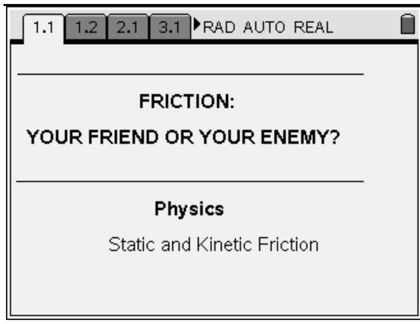
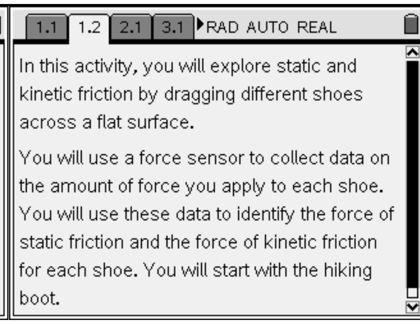
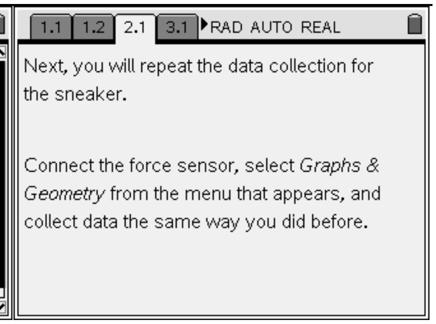
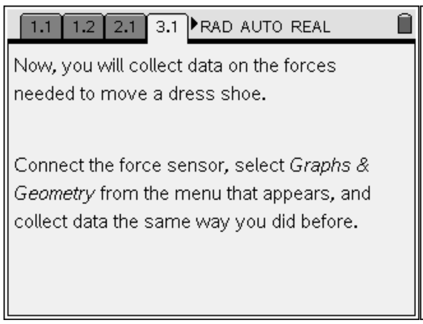
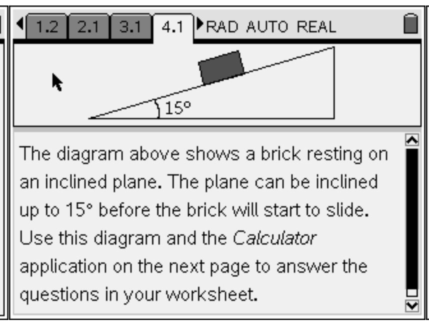
(Student)TI-Nspire File: *PhysWeek08_Friction.tns*

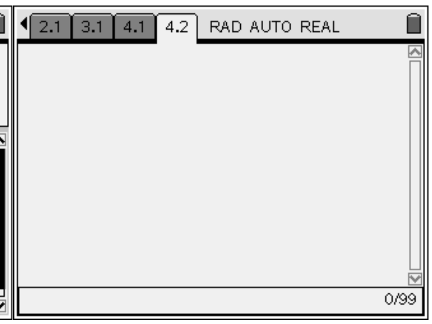












Friction: Your Friend or Your Enemy?

ID: 11121

Name ______________________

Class ______________________

In this activity, you will explore the following:

- *the similarities and differences between static and kinetic friction*
- *how the properties of two surfaces affect the friction between them*

In this experiment, you will study static and kinetic friction. The law of friction states that the force of friction on an object is directly proportional to the normal force acting on the object. This law is true for both kinetic friction (f_k) and static friction (f_s) and can be represented by equations like the ones below:

$$f_s = \mu_s N$$

$$f_k = \mu_k N$$

In these equations, μ_s and μ_k are coefficients of static and kinetic friction, respectively, and N is the normal force.

In this activity, you will measure the force used to drag shoes with different types of soles across a table. You will explore the force required to a) start the shoes moving and b) maintain their motion with constant speed. You will use these data to determine the forces of static and kinetic friction, respectively, on the shoes. You will then compare the coefficients of friction for different shoes. Finally, you will apply your knowledge of friction to solve some problems.

Problem 1 – Kinetic and static friction for a hiking boot

Step 1: You will be using a Vernier Dual-Range Force sensor to collect force data. Make sure the switch on the force sensor is in the ±10 N position.

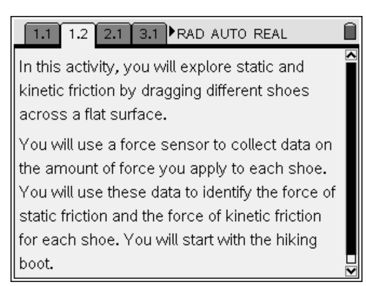
Step 2: If you are using the TI-Nspire handheld for data collection, connect the Dual-Range Force sensor to the EasyLink interface. If you are using TI-Nspire computer software to collect data, connect the Dual-Range Force sensor to the Go! Link interface. Do not connect the EasyLink or Go! Link interface to the handheld or computer yet.

Step 3: Connect the string to the hiking boot. If the boot has a hanging loop on the back of the heel, tie a loop of string through that loop. Otherwise, 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. Then, answer questions 1 and 2.

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

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

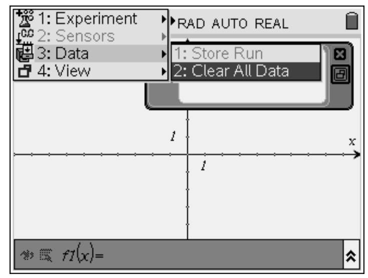
Step 4: Open the file **PhysWeek08_Friction.tns**, read the first two pages, and then connect the EasyLink or Go! Link interface to your handheld or computer. A force data collection display should appear.



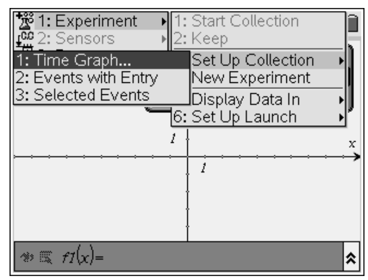
Step 5: Select **Menu > Experiment > Display Data In > New Graphs & Geometry.** A dialog box should appear asking what type of application you want to insert. Use the NavPad to select *Graphs & Geometry*. Then, press (tab) until the OK button is highlighted and press (enter). A new *Graphs & Geometry* page should be inserted.

Step 6: Wait for the force reading to stabilize, and then zero the sensor (**Menu > Sensors > Zero**). Use the string loop to hang the hiking boot from the force sensor. Wait for the reading to stabilize. This stable reading is the weight of the hiking boot. Record the weight of the boot in your notebook.

Step 7: Remove the boot from the force sensor, wait for the reading to stabilize, and then re-zero the sensor. Clear any data stored in the device (**Menu > Data > Clear All Data**). Place the boot at one end of the table or floor.

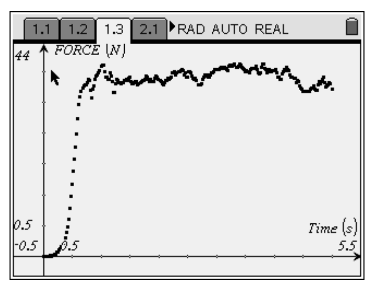


Step 8: Set up the data collection for a time graph (**Menu > Experiment > Set Up Collection > Time Graph**). Set the time between samples to 0.02 sec and the experiment length to 5 sec.



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

Step 10: Once you can drag the boot steadily, you can collect a data set. The “play” button (►) should be highlighted in the data collection box. If this is the case, you only need to click (press (click)) to begin data collection. If the play button is not highlighted, press (tab) until it is selected. When you are ready, start the 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 *Graphs & Geometry* page.



Step 11: Once you have collected a clean data set, close the data collection box and disconnect the EasyLink or Go! Link interface. Then, answer questions 3–6.

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

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

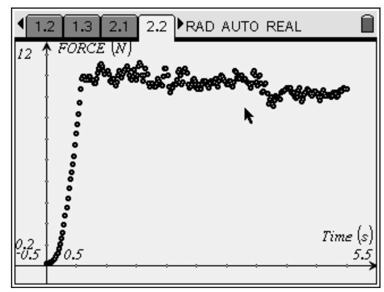
Q5. Derive an equation for the coefficient of friction in terms of the pulling force and the weight of the boot. Use this equation to calculate the coefficients of kinetic and static friction for the hiking boot.

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

Problem 2 – Kinetic and static friction for a sneaker

Step 1: Move to page 2.1 and read the text there. Then, repeat steps 4 and 5 from problem 1.

Step 2: A data collection box should appear on the screen. Wait for the reading to stabilize, and then zero the force sensor. Then, find the weight of the sneaker as you did with the hiking boot in step 6 of problem 1. Then, remove the sneaker from the force sensor and place it on the floor or table.



Step 3: Repeat steps 8–11 from problem 1. Then, answer questions 7–10.

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

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

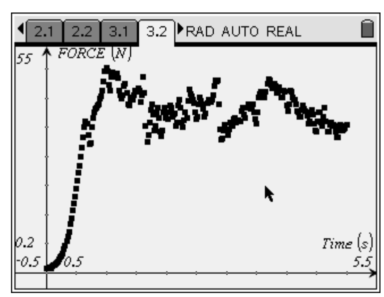
Q9. Use the equation you derived in question 5 to calculate the coefficients of kinetic and static friction for the sneaker.

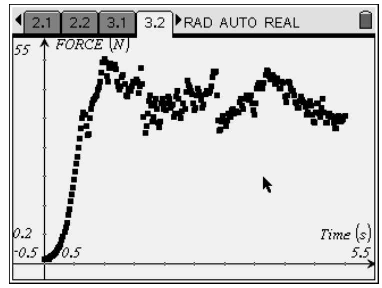
Q10. Compare the coefficients of kinetic and static friction for the sneaker.

Problem 3 – Kinetic and static friction for a dress shoe

Step 1: Move to page 3.1 and read the text there. Then, repeat steps 4 and 5 from problem 1.

Step 2: A data collection box should appear on the screen. Wait for the reading to stabilize, and then zero the force sensor. Then, find the weight of the dress shoe as you did with the hiking boot in step 6 of problem 1. Then, remove the dress shoe from the force sensor and place it on the floor or table.





Step 3: Repeat steps 8–11 from problem 1. Then, answer questions 11–16.

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

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

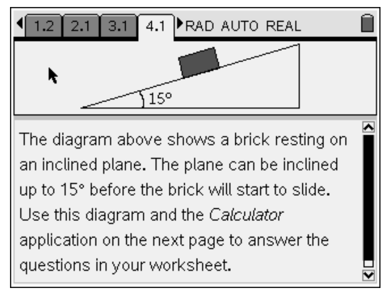
Q13. Use the equation you derived in question 5 to calculate the coefficients of kinetic and static friction for the dress shoe.

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

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?

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

Problem 4 – Applications and problem solving



Step 1: Read the text and study the figure on page 4.1.

Step 2: Answer questions 17–20. You can use the *Calculator* application on page 4.2 to help you solve the problems.

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

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

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

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° to stop the brick from sliding? Explain your answer.

