Case File 13

Life in the Fast Lane: Using skid marks to determine vehicle speed

Estimate the speed of a vehicle from the length of its skid marks.

Car Chase Dead Ends
Police left empty handed as thieves escape on pier

HARBERTVILLE, Friday: Downtown was thrown into chaos last night as a dramatic police chase snarled traffic and sent pedestrians diving for cover. The chase was a result of a robbery at the First United Bank on Maple Blvd. Three burglars robbed the bank and escaped in an unmarked black luxury sedan.

The pursuing officers could not determine the exact make and model of the car or read the dealer's license plate taped to the back window. The police lost sight of the vehicle after the thieves reached the waterfront, skidded to a stop near the end of the pier, and turned into the adjacent loading docks.

The only evidence left at the scene was the car's skid marks. Police have located three cars that match the general description of the getaway car and that were purchased recently from Luxury Motors, the city's only luxury car dealer. Police are now working to narrow the list of suspects.

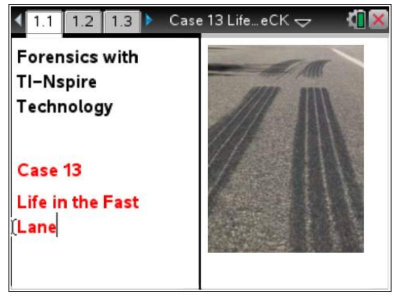
TO: Chief Detective
FROM: Crime Scene Investigatory Team

Please examine the attached photo of vehicle skid marks, recorded as 738 ft. We estimate that the vehicle was moving at top speed before skidding.

The following persons recently purchased similar sedans that fit the description of the getaway car. Their top speeds are noted.

D. J. Bitterman: Barrington Twister, top speed 105 mph
Latoya Sikes: SMC Shade, top speed 115 mph
Anwar Al-Dosari: Turner Black Bolt, top speed 140 mph

About the Lesson



- This lab introduces the coefficient of friction and uses it to determine the speed of a vehicle from the distance of its skid.
- Teaching time: one or two 45 minute class periods

Science Objectives

- Determine the speed of a vehicle before its brakes were applied.
- Determine the coefficient of friction between a vehicle and a road surface.
- Convert between SI units and Imperial units.
- Rearrange equations to solve for different variables.

Activity Materials

- TI-Nspire™ technology
- *Case 13 Life In The Fast Lane.tns* file
- *Case_13_Life_in_the_fast_lane_Student.doc* student activity sheet
- Vernier Dual-Range Force Sensor with Vernier EasyLink™ or TI-Nspire Lab Cradle
- heavy toy car or cart

TI-Nspire™ Navigator™

- Send out *Case 13 Life in the Fast Lane.tns* file.
- Monitor student progress using Class Capture.
- Use Live Presenter to spotlight student answers.

Teacher Notes and Teaching Tips

- The student activity sheet and .tns file contain the complete instructions for data collection. All assessment questions are also included in both places giving you the flexibility to either collect the .tns files with student data/answers (using TI-Nspire Navigator) or the student activity sheet.
- Preparing the vehicle and computing the coefficient of friction should take about 20 minutes. Depending on how steadily the students pull the vehicle, it may take significantly longer.
- It is important that students zero the force sensor before each force measurement because the sensor is affected by small movements.
- You may want to review balance of forces and Newton's laws of motion with the students before they begin the lab.
- If the vehicle you use is fairly lightweight, you may need to add some weight to make its slide and skid more stable and true.
- Use a smooth surface (not carpet) to slide the vehicles on. This will enable the students to pull the vehicle with more-constant force and reduce the error in their calculation of μ.
- If time permits, you can have the students repeat the experiment on different kinds of surfaces, such as carpet or wood. They could also experiment with different weights in the vehicle. This should help to reinforce the meaning and applications of the coefficient of friction.

Background

If skid marks are present at the scene of an accident, one member of an investigative team is dispatched with a tool, called a trundle wheel, which looks like a walking cane with a small tire on the bottom. This tire is attached to a device similar to a pedometer. It counts the number of times the tire rotates and converts that number into distance traveled, in meters. In this way, the investigator can accurately follow the path of the skid mark and determine its length.

From the length of the skid mark, it is possible to estimate the speed of the vehicle at the start of the skid. This calculation is based on Newton's laws of motion and the formula for the kinetic energy of a moving body. The derivation of the formula is as follows:

$$F_f = \mu mg$$

$$E_k = \tfrac{1}{2}mv^2 = F_f\, d$$

$$\tfrac{1}{2}mv^2 = (\mu mg)d$$

$$v = \sqrt{2g\mu d}$$

Where *v* is the speed (velocity) at the start of the skid, *m* is the mass of the vehicle, *g* is the acceleration due to gravity (9.8 m/s^2 or 32 ft/s^2), μ is the coefficient of friction, F_f is the force of friction, E_k is kinetic energy, and *d* is the length of the skid mark.

Notice that, in the final equation, the weight of the vehicle does not appear. Only the speed of the car, the acceleration due to gravity, and the coefficient of friction—which is related to the vehicle's tires and the road's surface—determine the stopping distance.

Allow students to read the forensics scenario on the first page of the student activity sheet.

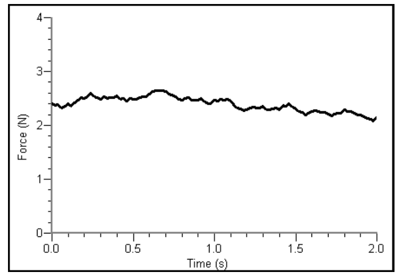
Procedure

Part 1 – Determining the Coefficient of Friction
Move to page 1.2–1.9.

Students will follow the directions in the student worksheet or .tns file. In order to model a vehicle that is skidding and not rolling, be sure the students prevent its wheels from rotating. If they are using a Hall's carriage, have them insert a tight rubber band between the axles. If they are using a toy car, instruct them to stuff tissue in the wheel wells. Make sure that the vehicle slides, without the wheels moving, when pushed along.

Remind students that the student pulling the vehicle should continue pulling at a constant speed until data collection has ended. **Note**: Make sure the Force Sensor remains flat on the surface at all times. If the sensor is lifted off the surface, the force readings will be inaccurate.

The graph will look similar to the one shown. The force will look uneven because the range on the *y*-axis is small. As long as they pull with a constant force, their results should be fine. If their graphs have any spikes or dips that are much larger than the rest, have them collect a new set of data.



Part 2 – Finding Speed from Skidding Distance

Students use the speed equation to calculate the speed that the vehicle was traveling when it crossed the starting line and began to skid. The speed equation is:

$$v = \sqrt{2g\mu d}$$

Where v is velocity (speed) at the start of the skid, g is acceleration due to gravity (9.8 m/s^2 or 32 ft/s^2), μ is the coefficient of friction, and d is the distance (in meters) the vehicle skidded before stopping.

Note: Be sure that their measurement units are consistent with one another.

Evidence Record

SAMPLE DATA
Using a Hall's Carriage

	Value
Average Sliding Friction (N) (Equal to average force used to pull vehicle)	0.5770
Average weight of vehicle (N)	2.092
Coefficient of friction, μ $\mu = \frac{\text{Sliding friction (N)}}{\text{Weight of vehicle (N)}}$	0.276

Trial Number	Skidding Distance (m)	Speed (m/s)
1	0.158	0.925
2	0.192	1.02
3	0.226	1.11

Case Analysis

Have students answer the following questions on the handheld, on their activity sheet, or both.

Q1. Rearrange the speed equation to solve for *d*, the skidding distance. Show your work.

$$v = \sqrt{2g\mu d}$$

Answer: $v^2 = 2g\mu d$

$$d = v^2 \div 2g\mu$$

Q2. In most cases, an accident investigator cannot accurately compute μ, the coefficient of friction. However, tests have been done to establish a range of values for μ that apply to most situations. In general, the coefficient of friction for a car on an asphalt road is between 0.5 and 0.9. Using this information and the equation from question 1, fill in the final two columns in the table below. **Note:** 1 mph = 1.47 ft/s.

Answer:

Coefficient of Friction	Speed of Car (m/s)	Speed of Car (mph)	Skidding Distance (m)	Skidding Distance (ft)
0.5	13.41	30	18.35	60.2
0.9	13.41	30	10.19	33.4
0.5	20.12	45	41.31	136
0.9	20.12	45	22.95	75.3
0.5	26.82	60	73.40	241
0.9	26.82	60	40.78	134
0.5	40.24	90	165.23	542
0.9	40.24	90	91.79	301

Q3. In general, what happens to the skidding distance when the speed doubles?

Answer: Stopping distance more than doubles.

Q4. Give an example of a real situation in which the smaller coefficient of friction (0.5) may apply.

Answer: Wet or icy road, old tires, tires that are incorrectly inflated, bad brakes

Q5. Give an example of a real situation in which the larger coefficient of friction (0.9) may apply.

Answer: Dry road, new and properly inflated tires, good brakes

Q6. Using the length of the skid marks from the crime scene report, calculate the range of possible speeds of the getaway car, in miles per hour, assuming the smaller coefficient of friction is correct.

Answer: $v = \sqrt{2g\mu d} = \sqrt{2 \times 32 \times 0.5 \times 738} = 153.7 \text{ ft/s} = 104.6 \text{ mph}$

Q7. Using the length of the skid marks again, calculate the range of possible speeds of the getaway car, in miles per hour, assuming the larger coefficient of friction is correct.

Answer: $v = \sqrt{2g\mu d} = \sqrt{2 \times 32 \times 0.9 \times 738} = 206 \text{ ft/s} = 140 \text{ mph}$

Q8. Considering the conditions of the road and the getaway car, which coefficient of friction do you think most likely applied during the car chase? Explain your answer.

Answer: The car was new, so the tires were probably new, but the road was probably wet due to the rain. Answers may vary, but students should clearly support their arguments.

Q9. Based on your answer to Question 8, which suspect's car was most likely involved in the car chase?

Answer: Answers will vary, depending on the answer to Question 8. Given the uncertainty in the coefficient of friction, any one of the three may be the culprit.