THAT'S FAST!

Facilitator's Guide • Section 5.1

SCIENCE TOPIC OUTREACH POSTERS

INTRODUCTION

Whether from traveling in a vehicle or from racing across the playground at recess, the concept of speed is one that students of nearly all ages have encountered. While most can express what the concept of "fast" means, many do not understand how speed is actually defined. Moreover, many do not have a good understanding of the vast range of speeds that we encounter, or know about. Since "fast" is a relative concept, it is instructive (and fun) to investigate the speeds of different things students know about. "That's Fast!" introduces the basic definition of speed, giving simple examples in units that the students can relate to. It then provides examples of things that we think of as being "fast," and provides other examples of things that are much faster. In this way, students are introduced to the importance of comparison. Using the natural interest that students have in ranking things, a graphical illustration of objects that cover a very large range of speeds is presented. (IMPORTANT NOTE: The graph increases in steps that are factors of 10.) Finally, the notion of a maximum speed (the speed of light) is introduced.

The primary points covered in the poster are:

- **Speed** is a measurement of the distance an object travels in a fixed amount of time. Typical units are miles per hour, or kilometers per hour.
- **The maximum speeds** reached by different animals differ by a large amount—nearly a factor of 500.
- **The speed of sound** is very fast, but not nearly as fast as the Space Shuttle in orbit.
- **The Earth is moving** as it orbits the Sun, and its speed is higher than anything we typically encounter in our everyday experience.
- **Nothing can travel faster than the speed of light.** Even the speed of the Earth in its orbit is much slower than the speed of light.

BACKGROUND SCIENCE

The rate at which objects move is a fundamental concept in science. The basic definition of speed is deceptively simple because most of us are familiar with its units (e.g., miles per hour, or kilometers per hour), yet knowledge of the speeds at which different things travel, and of the very large range of speeds that are encountered in nature, can be challenging. Moreover, this vast range in observed speeds can make it difficult, or almost meaningless, to make comparisons.

The notion of speed or velocity is probably one of the earliest encounters that students have with something defined by an equation: speed = distance/time ($s = d/t$). This is implicit in the units we use to measure speed, and is it simple algebra to rearrange this definition to perform equivalent calculations: the distance traveled is equal to the speed multiplied by the time traveled at that speed ($d = s*t$); the time required to travel a given distance is the distance divided by the speed of motion ($t = d/s$).

BACKGROUND SCIENCE (continued)

It is important to note here (though it is not a concept covered on the poster) that "speed" and "velocity", though often used interchangeably, are not actually the same thing. Speed measures the distance traveled in a given amount of time. Velocity measures this as well, but also the direction of the motion. Newton's first law of motion explains that in the absence of any net force, an object in motion will remain in motion at a constant velocity. That is, it will maintain the same speed and direction unless a force acts to change this; changing either the speed or the direction of motion requires a force. Newton's second law of motion tells us that the more massive an object is, the larger the force required to change its velocity by a given amount will be. Getting a pebble to go from zero to 60 mi/hr requires a much smaller force than getting an elephant to do the same!

The speeds at which different animals travel can differ dramatically. A tortoise, who carries a shell of protective armor, travels at a very slow pace—but plenty fast enough given that it subsides on vegetation. A Peregrine falcon needs to be able to swoop down from the sky and catch small mammals for food; it needs to be fast! The speeds of these two animals are so different, they are difficult to directly compare. But the difference is nowhere near as extreme as the comparison between other speeds encountered in nature. We know from calling to someone at the other end of the playground that sound travels much faster than we can run. It travels so fast, in fact, that to many it seems that it takes no time at all for sound to travel from one place to another. It does take time, though, and we can notice this when we watch lightening during a storm and discover that the sound of the thunder often lingers several seconds behind the flash of the light.

As impressive as the speed of sound may be, the Space Shuttle needs to move faster than this to remain in orbit around the Earth. Compared to how fast the Earth moves in its orbit around the Sun, though, the Shuttle's speed is somewhat modest. Still, it does take a full year for the Earth to go around the Sun. Nothing is infinitely fast. Even light travels at a finite speed. This was first discovered in 1676 when the astronomer Ole Roemer noticed that the emergence of one of Jupiter's moons from eclipse occurs later when the Earth is farthest from Jupiter than when it is closest. This is because it takes time for the light to cover the additional distance. The speed of light through empty space is incredibly fast (300,000 km/s); it takes just over 8 minutes for light from the Sun to travel to Earth. Still, this delay is significant. When we send planetary probes out into the Solar System, we communicate with them through radio waves, which travel at the speed of light. When the probes reach Saturn, for example, it takes over an hour for its signals to reach us.

A foundation of Einstein's Theory of Special Relativity is that nothing can travel faster than the speed of light in a vacuum; this is the effective speed limit for the Universe!

FUN FACTS

- The Peregrine falcon is the world's fasted bird. It can fly at speeds greater than 80 km/hr (50 mph), and reach speeds higher than 160 km/hr (100 mph) when diving.

- The first official speed limit for automobiles in the United States was 12 mi/hr (19.2 km/hr), adopted in Connecticut in 1901.

FUN FACTS (continued)

- In the most powerful accelerators ever built on Earth, subatomic particles are accelerated to speeds in excess of 99.9999% the speed of light.

- Light travels more slowly through air or water than through a perfect vacuum. While it is impossible for anything to travel faster than the speed of light in a vacuum, it actually is possible for things to travel faster through other materials, such as water, than light can. For example, if a cosmic-ray particle from space that is traveling at nearly the speed of light suddenly enters a pool of water, it will be moving faster than light can travel through water. (The speed of light in water is about 25% slower than in a vacuum.) If this happens, the particle forms the electromagnetic equivalent of a "bow wave" in front of a fast-moving boat, and the result is the emission of bluish-colored light called "Cherenkov radiation." Astronomers use specialized telescopes on the ground, made of pools of water, to detect flashes of this Cherenkov radiation that identify the presence of energetic cosmic rays.

- While light travels very, very fast, it still takes more than 8 minutes for it to travel from the Sun to the Earth, and more than an hour for it to reach Saturn. In fact, typical distances in astronomy are so large that they are measured in light years—the distance that light would travel in a year. The nearest star, other than the Sun, is more than 4 light-years away, while the nearest large galaxy (Andromeda) is more than 2 million light-years away!

- Astronauts left mirrors on the moon when they visited. By bouncing pulses of light from laser beams off of these mirrors, and measuring how long it takes for them to return, the distance to the moon can be measured to an accuracy of about a centimeter.

- While the race between the tortoise and the hare might seem like a complete mismatch, in one beat of its heart a tortoise can travel nearly seven times its own length. A hare is "faster"—in one beat of its heart it travels about 13 times its own length—but the difference isn't as great as one might think given that a tortoise carries its house on its back!

COMMON QUESTIONS OR MISCONCEPTIONS

- A potential source of confusion is the scale used on the graph that is displayed on the poster. This so-called "logarithmic scale" does not have equal steps. Instead, each step shown is a factor of 10 larger than the previous. It is worth pointing this out to students, and establishing a dialog. Why is a scale like this chosen? It is because of the large range of speeds that are displayed. Think of what the plot would look like if it was plotted in equal steps from zero to the speed of light.

- Can anything travel faster than the speed of light? No, nothing can travel faster than light travels through a vacuum.

COMMON QUESTIONS OR MISCONCEPTIONS (continued)

- Students might ask how we know that nothing can travel faster than the (vacuum) speed of light. This is the result of a rather surprising property of light. If you are on a train and throw a ball forward, its speed relative to the ground is equal to the speed it is moving away from you plus the speed at which the train is moving relative to the ground. So, you might think that if you see a train coming toward you, with a headlight on the front, the speed of the light would be equal to the speed at which the light left the headlight plus the speed of the train. Experiment after experiment, however, has shown that this is not the case. Regardless of the motion of the source, the observed speed of its light is always the same. In his Special Theory of Relativity, Einstein started from the assumption that the speed of light in a vacuum is always the same, regardless of the motion of the source, based on the results of these experiments. He found that this implies that the faster an object is moving, the more it resists acceleration; its inertial mass increases with speed. The closer its speed gets to the (vacuum) speed of light, the more its inertial mass increases, making it harder to make it move faster. The theory predicts that it would take an infinite amount of energy to get a body with non-zero mass all the way up to the speed of light. This increase of inertial mass with speed has been confirmed by many experiments at particle accelerators.

- Is speed the same thing as velocity? No, not exactly. Velocity is a quantity that describes both the speed and direction of an object's motion. Two objects can have the same speed, but their velocities are different if they are traveling in different directions. We have been careful to describe rates of motion here with the term "speed," but at this stage it is not important to be adamant about differentiating between speed and velocity. If students ask, this is a concept that can be explained, but it isn't necessary to correct them if they use the term "velocity."

- As noted above, the concept of speed actually involves use of an equation. It is often assumed that students will be able to rearrange the equation to calculate distance given the speed and time traveled (or the time required to travel a certain distance at a given speed). This is very often not the case. We encounter these concepts so often (e.g., estimating how long it will require to travel to another town on the highway) that we develop the capability of doing the calculation even though we don't realize we are really doing algebra in our heads. Young students often have not developed sufficient familiarity to make this jump, making such calculations difficult (but certainly worth working through, slowly).

DEMONSTRATIONS AND ACTIVITIES

- **Field and track.** Just as students love to make ranked lists, always trying to find something that exceeds the top, they also like to race one another. Certainly one can extend the "That's Fast!" concepts to races on the playground. But a better exercise might be to have students measure actual speeds. This can be done with a simple stopwatch (most digital watches, and even some cell phones, have such features) and a running area for which a fixed distance has been measured off and marked. Students can simply measure the time required to run the fixed difference, and then calculate the speed of the runner. For added fun, one could include measurements using bicycles, running backwards,

DEMONSTRATIONS AND ACTIVITIES (continued)

- or other variations. Or, have students work in groups, measuring the speed of another group doing a chosen activity–hopping on one foot, doing backward somersaults, crawling on their bellies (but they better remember that the other group gets to choose their activity next!).

- **Baseball speed.** Attempting to measure the speed of a pitched baseball using the technique above would prove hopeless. It is instructive to let the students try this, because it will make them appreciate that new techniques are needed to measure different speed ranges. In this case, a possible technique would be to use a digital camera to record the action of a student throwing from the pitcher's mound to home plate on a baseball field (or some other well-defined distance). The camera will need to be placed such that it can record the entire distance. Using movie-editing software, the students can identify on which frame the ball left the pitcher's hand, and on which frame the ball crossed home plate. (They may have to estimate to a fraction of a frame if, for example, the ball is just approaching the plate in one frame and is then just past the plate in the next.) Using the frame-time of the camera, this can then be used to calculate the speed.

  The VLC media player (http://www.videolan.org/vlc/), which is a free program available for Window, Mac OS X, and Linux platforms, can be used for such an activity. One merely loads the movie from the camera (using whatever software is generally used for such a task) and then opens the video file with VLC. This opens a frame displaying the video, with a Run/Pause button and a slider to move back and forth in the video file. One can advance by one frame at a time by typing the letter "e" on the keyboard. In this way, one can identify the frame at which the ball leaves the pitcher's hand, and then count how many frames go by until the ball crosses home plate.

  If the frame-time of the camera is not known, it can be determined in VLC. There is a timer in the lower right hand corner, but it displays only to one-second accuracy. Advance through frames (typing the letter "e") until the time digit increases by one. Now carefully count how many frames one needs to advance until the timer advances by one more second. This is the frame-rate in frames/second. (Better accuracy is achieved by counting how many frames are required to advance a larger amount of time—e.g., 3 to 5 seconds—and then dividing by the number of seconds).

  Example: If it takes 90 frames to advance 3 seconds, then the frame rate is 30 frames/second. Suppose that the distance from the pitcher to home plate is measured to be 40 feet, and that you determine that it takes 17 video frames for the ball to reach home plate. This corresponds to (17 frames)/(30 frames/s) = 0.57 seconds. The speed is then (40 ft)/(0.57 s) = 70.2 ft/s. This corresponds to (70.2 ft/s)*(3600 s/hr)*(1/5280 mi/ft) = 47.9 mi/hr.

- **Planes, trains, and automobiles.** Students can estimate the speeds at which planes and trains travel by looking at travel schedules and distances between destination points. Most airlines, for example, provide departure and arrival information for flights. Using other resources (e.g., Google Earth) one can determine the distance between the destinations and use this information to calculate the speed.

DEMONSTRATIONS AND ACTIVITIES (continued)

(Remember to take into consideration any changes in time zones.) This provides an important opportunity to discuss average speed. Planes, for example, are slower during takeoff and landing, and train travel may include intermediate stops. By calculating the speeds in miles per hour or kilometers per hour, the students can compare with typical automobile speeds with which they are familiar.

RESOURCES

http://nationalzoo.si.edu/Animals/AnimalRecords/default.cfm
Smithsonian's National Zoo has a great list of speed records for different animals.

http://www.teachertube.com/viewVideo.php?video_id=105246&title=Newton_s_First_Law_of_Motion&vpkey=
Have some fun with Newton's first law.

http://www.lpi.usra.edu/lunar/missions/apollo/apollo_11/experiments/lrr/
The Lunar and Planetary Institute explains how lasers are used to measure the distance to the Moon.

http://en.wikipedia.org/wiki/Cherenkov_radiation
See pictures of Cherenkov radiation from energetic particles moving through water.