Motion, Speed and Velocity

Changes in Space and Time

Description

Mechanical engineers are often engaged in the creation, modification and maintenance of machines and mechanisms. Machines transform energy, or change the direction and rate of applied forces in order to produce useful amounts of work. The term Work refers to the application of force through a given distance. Expressed as a algebraic statement, Work = Force x Distance. Since this implies movement, it is clear that motion is an essential component of mechanical assemblies. This lesson serves as an introduction to basic concepts and the technical literacy associated with motion.

Terms, Concepts and Definitions

Review and Define These Terms

Position	Distance	Position-Time Graph
Vector	Displacement	Constant Velocity
Average Velocity	Speed	Velocity
Slope	Instantaneous Position	Speed-Time Graph
Instantaneous Velocity	Scalar	Work

Materials/Equipment/Supplies/Software

Pen/Pencil	Paper (graphing)	Tape Measure
Calculator	Spreadsheet Program (optional)	Selected GEARS-IDS Components
		Stop Watches (4-8)

Objectives

Students who participate in this lesson will

- Discriminate between speed and velocity
- Measure and calculate speed and velocity
- Evaluate and create speed and time graphs
- Understand and use the technical vocabulary of motion.

Mechanisms in Motion

Machines are designed to produce useful work by changing (transforming) energy from one form to another, or by changing the direction of forces and movement. The term **Work** is a scientific concept, it does not refer to your after school job or the chores you are asked to do at home. Work is the product of a force (*A Push or a Pull*) acting over a specified distance. Work =Force x Distance.

Describing Motion

Movement is characterized by a change in place or position. This change in place or position is called a displacement. The displacement alone will not provide enough information to determine the position of a moving object. In order to accurately define the position of a moving object, it is necessary to know the direction of the moving object as well as the displacement or distance it traveled.

Quantities that represent only one value or magnitude like distance, are called scalar quantities. Quantities represented by 2 numbers, such as magnitude and direction are called vectors quantities. Magnitude is another word for size and can be used to represent length, time, weight etc.

Speed and Distance are Scalar Quantities

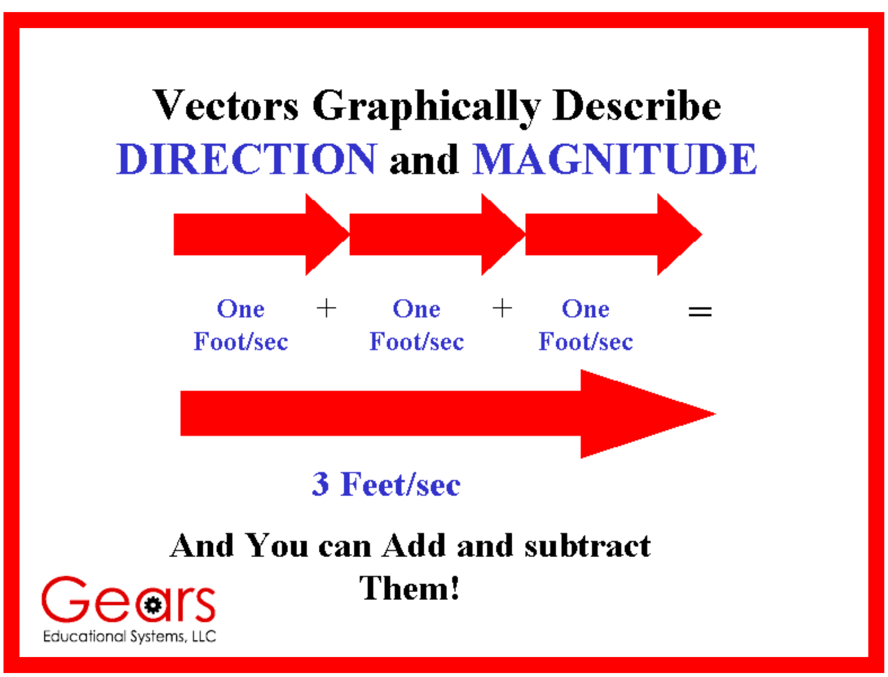
Speed and distance are scalar quantities that only describe magnitude; 88 ft/sec, 60 mph, and 26.82 meters/sec are all equivalent (scalar) values that have only magnitude.

Speed and Distance can be described algebraically as in a formula:

$$\text{Speed} = \frac{\Delta\text{Distance}}{\Delta\text{Time}} \quad \text{and} \quad \text{Distance} = \text{Speed x Time}$$

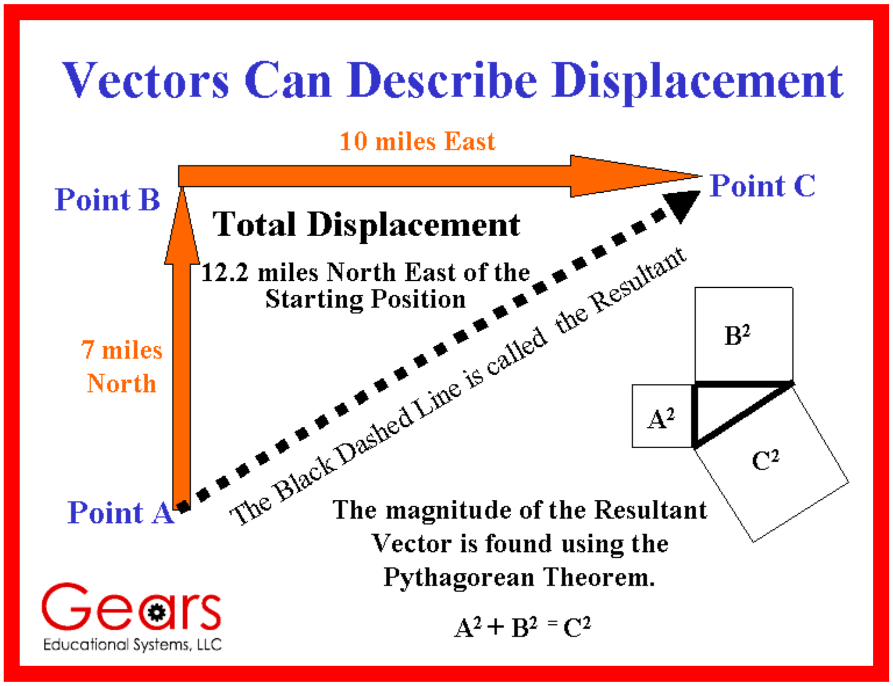
Speed and distance can also be described graphically using Vectors. Vectors are lines that describe the **magnitude and direction** of a moving object. Using vectors it is possible to (graphically) sum individual components of motion.

Vector Quantities Describe Displacement and Position



Vector Addition and Subtraction

Vector quantities can be graphically added or subtracted. By using the same conventions assumed for number lines and the Cartesian coordinate system Vectors can describe positive and negative displacements or movements. Vectors pointing right represent positive values, and vectors pointing left represent negative values.



The Resultant

Vectors can also be used to resolve the displacement that results from two or more separate displacements. (Remember velocity is a vector quantity that describes both the magnitude and direction of the motion) The illustration below describes how a single vector can be used to resolve two distinct velocities. A vector that describes the net displacement of two or more vector quantities is called The Resultant.

Vectors Are Easy to Draw

Vectors are graphical (arrow) symbols that represent direction and magnitude. The length of the vector represents the magnitude, and the direction is illustrated by the arrow.

Average and Instantaneous Speed and Velocity

Objects that move are changing position. This change in position is not always uniform. A moving object can move at varying rates from very slow to very fast.

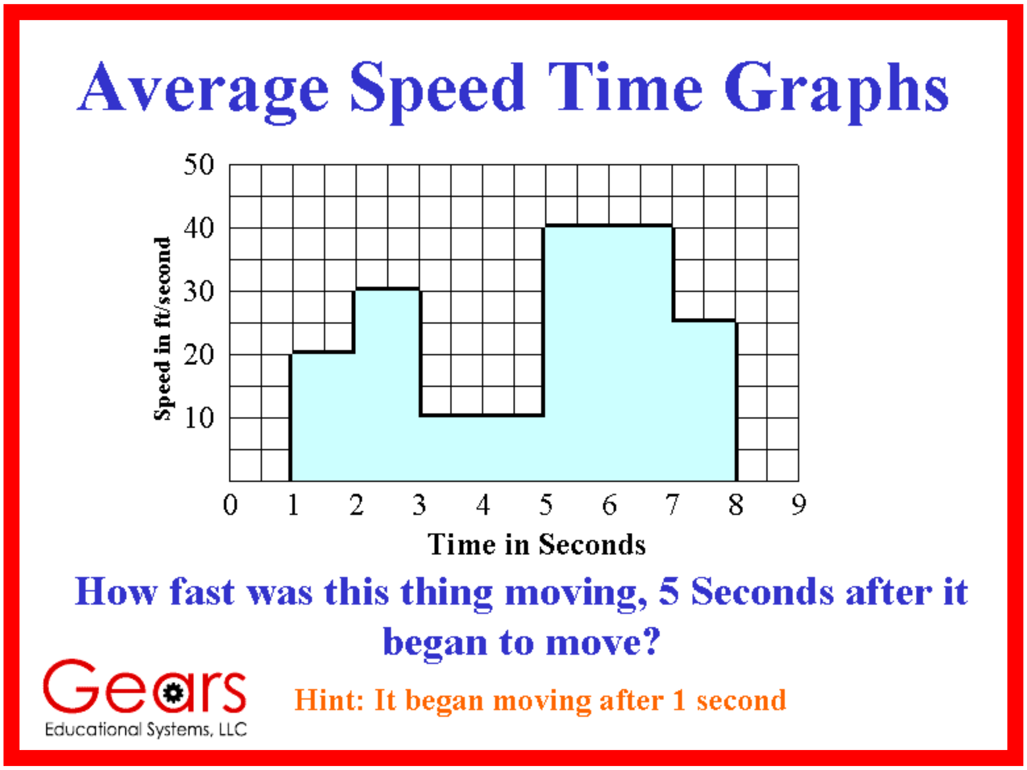
Imagine a car traveling from Plymouth Rock in Massachusetts to the Old North Church in Boston. This is a linear distance of 45 miles. The paths or roadways connecting these two points are decidedly not linear. The direction and the rate of motion of the car are constantly changing as the car moves from secondary roads to the interstate and encounters increasing traffic.

The distance between the car's start and finish point remained constant, while the car's rate of motion or velocity (Speed in a given direction) varied through out the trip. If this trip took 1 hour, then the average speed was 45 miles per hour, and the average direction was North. However, it is clear to see that the car was traveling at many different speeds and directions throughout the trip. The speed and direction of the car at any given time during the trip is the instantaneous velocity.

Moving objects have specific positions and velocities at specific times; these are referred to as instantaneous position and instantaneous velocity.

Instantaneous speed or velocity can be graphically illustrated with Speed-Time Graph. The Illustration below is a plot of instantaneous speeds at various points in time.

Average Speed



Average Speed: The Relationship Between Changes in Position and Changes in Time

When a mechanism or a robot moves from one point to another, it undergoes a change in position or displacement. As the mechanism changes position, there is also a corresponding change in time. The relationship between the change in distance and the change in time describes the speed or velocity of an object. The Rate of displacement can be calculated using a simple formula:

$$\mathrm{V}_{\mathrm{avg}} = \frac{\Delta d}{\Delta t} = \frac{d_1 - d_2}{t_2 - t_1}$$

The Greek symbol delta (Δ) is used to symbolize “change” or a “change in”. In this example delta describes a change in distance, which is displacement. Displacement can be either negative or positive and can be represented as a vector.

Average Velocity

Average Velocity can be calculated by dividing the total change in distance over the total change in time or:

$$v_{avg} = \frac{\Delta d}{\Delta t} = \frac{d_2 - d_1}{t_2 - t_1}$$

Instantaneous Speed and Velocity

Refers to the speed or velocity of an object at a particular instant in time. Speed and velocity change over time. An increase or decrease in speed is called an acceleration. During an acceleration, or deceleration, the speed of an object changes from moment to moment. An instantaneous velocity is a "Snapshot" of a the speed or velocity of an object at a single moment.

Example: An object that is dropped undergoes a continual increase in speed. Simply put, it continues to fall faster and faster as time goes on. We call this an acceleration. If we wanted to know how fast that object was moving at a particular instant in time, we would be asking for an instantaneous speed or velocity. If instead we asked for the total time and distance of the fall, we would be asking for the average velocity.

Note: Speed and velocity are commonly described by both kilometers (km) and meters (m) or miles (mi) and feet (ft) for distance and hours (hr) and seconds (s) for time. Examples of units of measurement for velocity could be kilometers per hour (km/hr), meters per second (m/s) or feet per second (ft/s) and miles per hour (m/hr). For this reason it is important that students and teachers locate and use a convenient calculator or conversion program. There are many available on the internet. One useful resource is http://www.onlineconversion.com/

Calculate Speed and Velocity

The formula for average velocity can be described with a simple equation and solved easily if you have any two of the three required values.

Example:

A GEARS-IDS™ game playing robot can move from its starting position to a position 20 ft away, in 4 seconds. What is the average velocity (V_{avg})of this robot?

First list the variables:

V_{avg} Unknown

$d_1 = 0$ ft
$d_2 = 20$ ft
$t_1 = 0$ sec
$t_2 = 4$ sec

Find the right equation and substitute in the values:

$$V_{avg} = \frac{\Delta d}{\Delta t} = \frac{d_1 - d_2}{t_2 - t_1}$$

Solve the equation:

$$v_{\text{avg}} = \frac{\Delta d}{\Delta t} = \frac{d_1 - d_2}{t_2 - t_1}$$

$$v_{avg} = \frac{\Delta d}{\Delta t} = \frac{20\,ft. - 0\,ft}{4\,\text{sec}. - 0\,\text{sec}}$$

$$v_{avg} = \frac{20\,ft}{4\,\text{sec}}$$

$$v_{avg} = 5\,ft/\text{sec}$$

The robot's average velocity between 0 and 20ft is 5 ft/sec.

What it this average velocity in meters/sec?

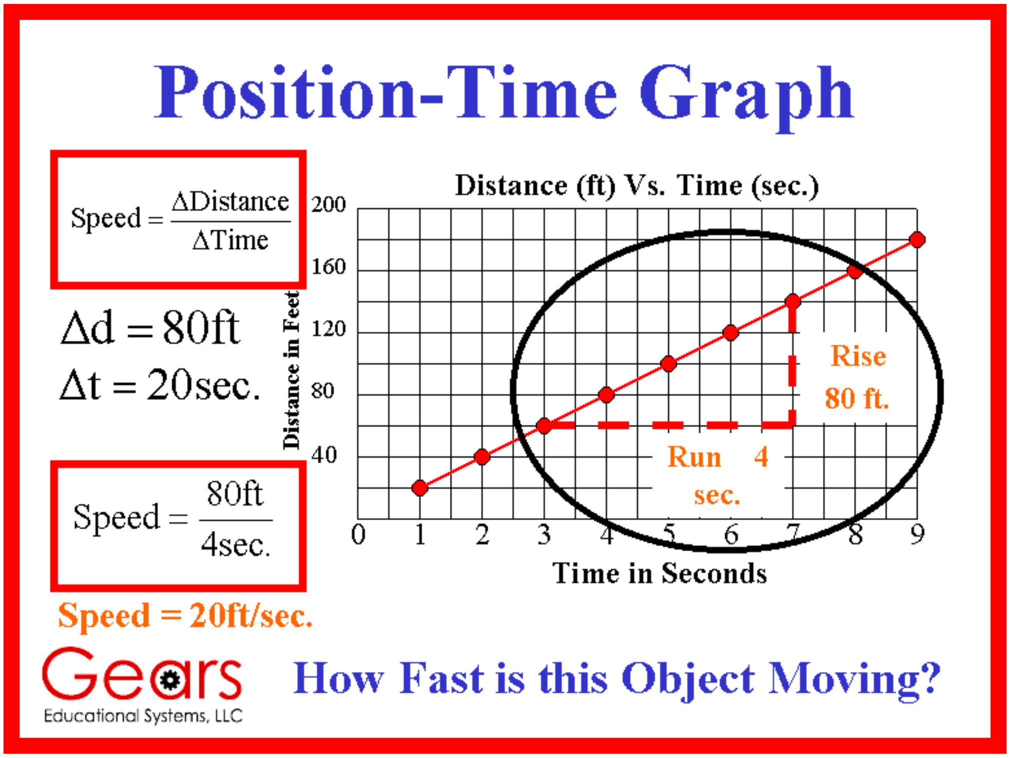
To solve this problem you will need to convert the previous answer to meters per second. Convert feet to meters or use an online converter such as www.onlineconversion.com

The answer is approximately 1.2 m/s.

At this speed, how long in time would it take for this robot to go 100 m?

Using the same steps above we declare all the variables. We figure out the best way to solve for time.

It would take 83 seconds to travel 100m at 1.2 m/s.)



Position Time Graphing

Being able to visually see motion through the use of graphs will help in understanding velocity, time and distance. Collect some data on the position and time of a moving object and use a spread sheet to record and graph the data. Use the format below to record your information.

If you take a minute to study the formula for average velocity, it becomes obvious that velocity is the change in distance divided by the change in time, or Δd / Δt. If distance is plotted on the y axis, and time on the x axis, then the distance formula is similar to the formula for the slope of a line.

$$\text{Slope} = \frac{\text{Rise}}{\text{Run}} = \frac{\Delta d}{\Delta t}$$

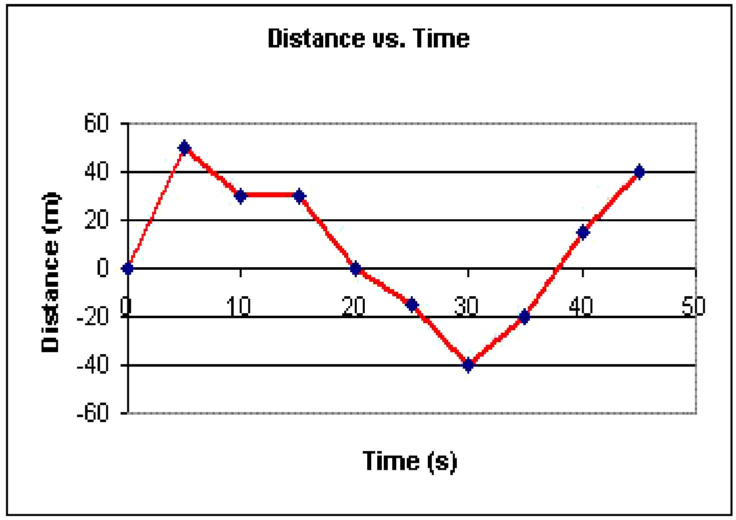
If a the robot has the same velocity for all of the timed intervals, then the graph of the line will be straight indicating the robot has a constant velocity.

Speed vs. Velocity

We sometimes here these words interchangeably but what is the difference between speed and velocity? Is there one?

Earlier in this lesson it was discussed that scalars and vectors have something called magnitude or size, speed is the magnitude of velocity. Velocity has magnitude (speed) and direction, positive direction (+) or negative direction (-).

Distance (m) vs. Time (s)	
Time	Distance
0	0
5	50
10	30
15	30
20	0
25	-15
30	-40
35	-20
40	15
45	40



The Robot in the example graph above moves in both the positive and negative direction over a time of 0 to 45 seconds. The slope of the line between 2 points represents velocity. Analyzing a specific time interval will allow us to better understand the direction and speed of this robot.

We will be using the average velocity formula to calculate and understand direction and speed.

1) The graph indicates that the robot moved 50 feet (away) from the starting point in 5 seconds. What was the robots average velocity in the time period between 0 and 5 seconds?

$$V_{avg} = \frac{(50-0)}{(5-0)}$$

The "Delta t" or change in time was 5 seconds. The change in position or displacement was 50 feet. The formula for average speed is:

Average Speed = Change in Distance/ Change in time

We can shorten this to:

Average Speed = Distance/time

The average robot speed in the first 5 seconds was 50 ft/sec.

Suggested Activities

Easier Activities

1.) Build one or several GEARS-IDS Mobile Chassis. Direct drive, and chain and sprocket reduction, measure the average velocity of the mobile chassis. This information will be valuable when you design a robot to play a game.
2.) Using a bicycle or several bicycles, set up a measured straight line course. Have student volunteers run the course on the bikes while others time them. Calculate the average velocities of the
3.) Roll a round (rubber) ball down the hallway. Calculate the average speed of the ball.

More Advanced Activities

1.) Build a relatively long pendulum apparatus using the GEARS-IDS components. Use the 3" Hex wheel as the initial pendulum weight. Set the pendulum to swinging. Using a stop watch, calculate the period of each swing. Change the weight of the pendulum, and the length of the pendulum and weight. Determine the relationship(s) between pendulum weight, length and period .
2.) Construct a long "U" shaped ramp 10-16 feet long. A 2x4 with cardboard sides will work well. Mark off 2 foot intervals along the edge of the ramp. Incline the ramp so one end is 2 feet above level. (This could mean one end was two feet above the floor). Assign a student with a stop watch to record the time at each 2 foot interval. Position a small round ball at the top of the ramp. Release the ball and allow it to roll down the ramp under gravity assist only. Record the rolling time to each interval. Create a Distance-Time graph using the interval distances and times recorded. Record the average velocity at each interval marked on the ramp. What determinations can you make from the graph? What is the average velocity of the ball over the entire length of the ramp?

Worksheets

Worksheets can be downloaded from the Learning tools section in each of the lessons

1.) Speed and Velocity Work Sheet

Develops insight into motion problems through graphing and analyzing time and displacement data.

2.) Using Vectors

This worksheet gives students the opportunity to use a resultant vector to resolve the position of a moving object after 5 successive moves.

Links and Resources

Online Conversion Calculator useful for converting common measurements expressed in different systems. www.onlineconversion.com

Assessment

Calculating Average Speed

This worksheet can be used as a quiz, test or in class work sheet assignment.

Communicate Your Understanding of Speed and Velocity

This worksheet can be used as a quiz, test or in class work sheet assignment.

Student Response/Journal Entry

Maintain all assignments, notes, quizzes and worksheets in chronological order.