Grades 9-12

Interpreting Graphs with Confidence and Ease!

Learning Objective:

Students will:

- collect and analyze uniform motion data from a dune buggy.
- identify dependent and independent variables.
- create large graphs that can be easily interpreted by using adding machine tape.
- develop the relationship between a uniform motion car and a displacement vs time graph.
- compare a uniform motion graph to a nonuniform graph.
- learn how graphs form the basis for equations students will learn in other STEM classes.

Vocabulary includes independent variable, dependent variable, rate of change, speed, slope of a line, y-intercept, velocity and acceleration.

Standards Alignment:

CCSS.Math.Content.6.RP.A.2: Understand the concept of a unit rate a/b
CCSS.Math.Content.6.RP.A.3.b: Solve unit rate problems including those involving unit pricing and constant speed.
CCSS.Math.Content.8.EE.B.5: Graph proportional relationships, interpreting the unit rate as the slope of the graph.
CCSS.Math.Content.8.F.B.4: Construct a function to model a linear relationship between two quantities. Determine the rate of change and initial value of the function from a description of a relationship or from two (x, y) values, including reading these from a table or from a graph. Interpret the rate of change and initial value of a linear function in terms of the situation it models, and in terms of its graph or a table of values.
CCSS.Math.Content.8.F.B.5: Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear). Sketch a graph that exhibits the qualitative features of a function that has been described verbally.

Overview

Kinematics, the study of motion, is typically addressed in elementary school science. Many students have a rudimentary understanding of motion but may be unable to differentiate among the terms describing an object's motion as either uniform or nonuniform. This lesson provides background knowledge to help teachers understand how those "mysterious" physics equations are derived, how to measure speed of a tumble buggy (uniform) and ask to compare to acceleration (nonuniform). Uniform motion means the object is traveling the same distance during repeating time intervals, like a driver using cruise control on a car. For example, it may be moving a distance of 5 cm each second so after 2 seconds it will have travelled 10 cm, and after 3 seconds 15 cm. Nonuniform motion is when the object travels different distances during repeating time intervals. The object may be getting faster, slower, or a combination but it is more difficult to predict where the object will be after a few seconds unless the rate of change

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(speed) is consistent (i.e. acceleration). For example, a car entering a highway usually speeds up or accelerates, which means it covers more distance each second.

Materials:

Constant motion cars such as dune buggies
Pull back or friction cars
Fan cart
Strips of paper such as adding machine tape
Markers, coins, washers, or sticky notes
Measuring tape or meter stick
Optional: metronome or some type of timer

Engage

Choose a starting position on the floor. Have students place a running constant motion Tumble Buggie and either a readied friction toy car or fan car next to the constant motion car. When instructed to release them allow the cars to travel along the floor simultaneously.
Have students answer the following questions:

- What variables are being compared to describe an object's motion?
- What are the similarities between the motions?
- What is the difference between the motion of the battery-operated car and the pull back or friction toy car?
- If the distance was increased what would be the effect between the motions of the two toys?

A literary piece that may be mentioned is the Tortoise and the Hare. Another analogy is to have students explain the differences between a track student competing in the 100 m dash to that of a students who runs the 1600 m race

Explore

1. Use the adding machine tape to mark the distance a constant speed dune buggy motion for a given unit of time, a second.
2. Tape approximately 2 meters of a paper strip to the floor with painters/masking tape at the ends.
3. Assign roles to members of the group as follows:
    - Timer: role is to count out rhythmically, so each count is approximately 1 second (does not have to be exactly 1 second, just consistent). Note the tumble buggies have flashing lights that may assist with making a unit time measurement.
    - Dune Buggy Driver: role is to start the dune buggy when everyone is in place and hold the buggy near the starting line of the tape before the timer counts down to a release time. "3…2…1…go". Gently place the car near the tape when the timer says "go". If the car veers to one side, gently tap it with a stick or your foot to try to keep it in a straight path. When the car reaches the end of the tape, pick it up and turn it off.

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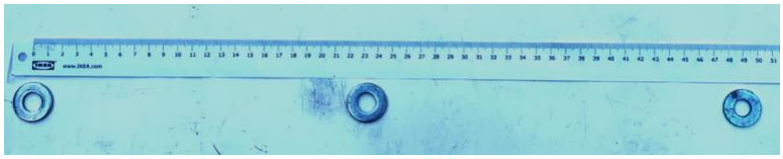
- 4 to 6 marking judges: the marking judges need to spread out evenly over the projected course (i.e. along the tape). On the timer's count, the judges should mark where the front of the dune buggy is located as the buggy reaches their position. It is typically easier for each judge to only a single location as the car passes them. The marks can be made on paper with a marker or by placing a washer, coin, or sticky note to indicate the location at each count.

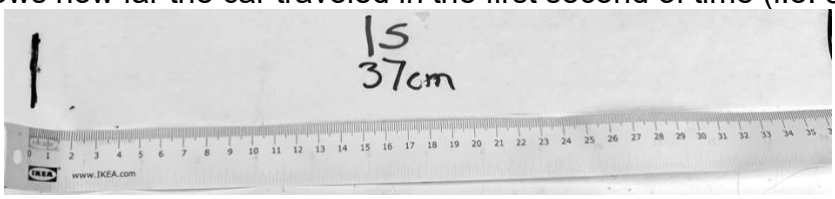
Note: it may take more than one trial to get the rhythm and marking synchronized. Remind students to not "anticipate" where the car will be, but instead only put a mark when they hear the count/timer.

Below are samples: 1) using washers along a measuring tape, 2) marking dots, 3) using small sticky notes.



4. If coins or washers were used to indicate locations, mark the location of the washer's on the paper (i.e. draw the center of the washer or draw around the coin).
5. Number each "mark" with the corresponding count, starting with 0 (where the car started such as 0, 1s, 2s, etc.).
6. Measure the total distance the car traveled after each period/second and record it on the paper at the appropriate mark (see sample below). Be sure to write the total distance on the paper AT THE MARK where the distance was measured.
7. Measure the distance between EACH mark and write it on the tape.
8. Transfer the data collected to a data table shown below.
9. Cut the paper strips so each strip represents the distance the car traveled in the given increment of time (i.e. one count or second). See Sample Data.
10. Compare the size of the cut strips of paper.

Sample below shows how far the car traveled in the first second of time (i.e. 37 cm).



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Sample Data from Dune Buggy

Note: the number on the far left is the total distance traveled. The measurements in the middle of the strip indicate the distance traveled each second.



Time (count or second)	Total Distance Travelled	Distance travelled each second
0	0	0
1	37 cm	37 cm
2	75 cm	38 cm
3	117 cm	42 cm
4	156 cm	39 cm
5	194 cm	38 cm

Explain/Teacher Notes

1. Have students compare the strips (i.e. for each interval or second) within their own group as well as with other groups.
2. Which of the variables interval distance(displacement) or time is the dependent variable? Which is the independent variable?
3. How are the interval strips similar? How are interval strips different? Discuss with your group as to why there may be discrepancies.
4.

Note: there will be slight variations in the distance travelled each second by the car. Variables can be due to the rhythm of the cadence director and/or accuracy for placement of markers. Clarify the terms independent and dependent variable for students if the students are not familiar with the terms.

The **independent variable** is the variable that is controlled in the experiment. In this case it is the time interval. The **dependent variable** is the variable being tested and measured in the scientific experiment. In this experiment it is the distance(displacement) interval. Students changed the independent variable, time interval, and observed the effect on the dependent variable, interval distance(displacement). Note. When distance and displacement are in the same direction the two are equivalent.

5. What conclusions can be made from the data that has been collected? Cite evidence to support your conclusions.

The cars cover about the same distance for each time interval. This is constant velocity or non-accelerated motion.

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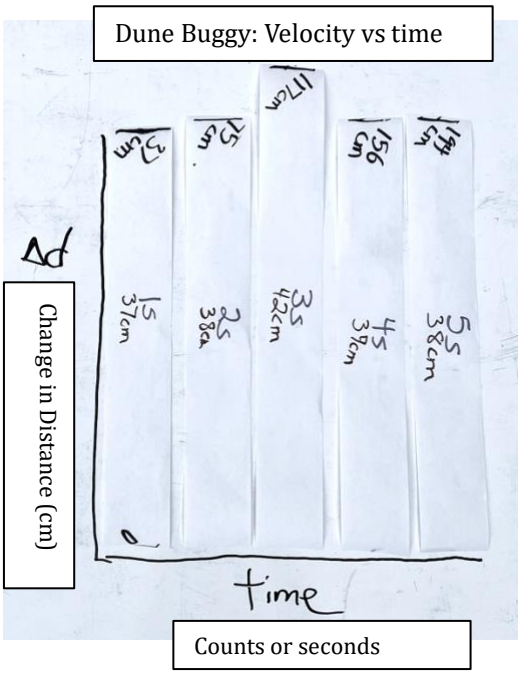
6. Have students use the strips of paper to make a “bar graph” on their tables. Discuss the units for this “graph” and the title of the graph.



The y-axis is the change in distance, or the distance covered during each interval of time. The x-axis represents each interval of time. The title of the graph would be “Change in distance vs time interval” OR “Velocity vs time”. Note the graphs will appear relatively “constant” or “consistent” in the distance they travelled during any time period. This means the dune buggy was not accelerating because it was travelling the same speed and covering the same distance during each time interval, much like having a cruise control set on an automobile. Acceleration is **nonuniform motion**.
NOTE: The change in distance (Δd) is NOT the same as **total** distance travelled. This is a velocity vs. time graph because velocity =*(Δd/Δt)*. To find the distance travelled, one would multiply the average velocity x Δt *or* $d = vt$. Plotting the total distance travelled would show that the total distance increased each second because the object was farther down the path being travelled.

Equation Derivations:
Velocity is the change in distance (i.e. y-axis) divided by the change in time (i.e. the x-axis). In the above example, the car travelled 37 cm in the first second so the Δd=37 cm and Δt = 1. Velocity =*(Δd/Δt), so the velocity at the end of the first second is 37cm/sec and the car travelled a distance 37 cm. One could also say the car was displaced 37 cm from the starting point.*
For the second time period, the car travelled 38 cm, so the Δd=38 and t=1. Since velocity =*(Δd/Δt) the car’s velocity is 38 cm/sec for the 2nd period of time and the car travelled an additional 38 cm. The car is now displaced 75 cm from the starting point.*

If you want to know the average velocity you take the total change in distance and total time, so it would be V_{av} *=(Δd/Δt) = (75cm)/2 sec.= 37.5cm/sec*

If one wanted to use the graph to determine how far the car travels in a given time, one can take the area of the strips (length x width) or Δd*t. To get the total distance travelled during the first two seconds, one would add the distances (37cm + 38 cm = 75cm).

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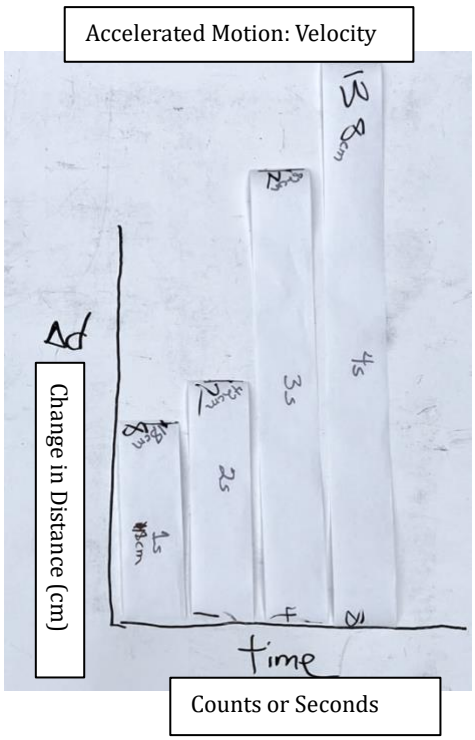
Extend

1. If time permits have students repeat the above procedure using a fan cart or a pullback friction car.
2. If time is not available have students predict what a graph would look like if the motion was nonuniform (i.e. it was accelerating or getting faster).
3. Draw the prediction as a motion graph. See Sample Graph for accelerated motion. The graph shows that the object (car) travels more and more distance each second as indicated by the strips getting longer and longer.
4. Have students use the graphs below to determine the average velocity of each motion shown.
5. Have students compare their approach with other students or groups.





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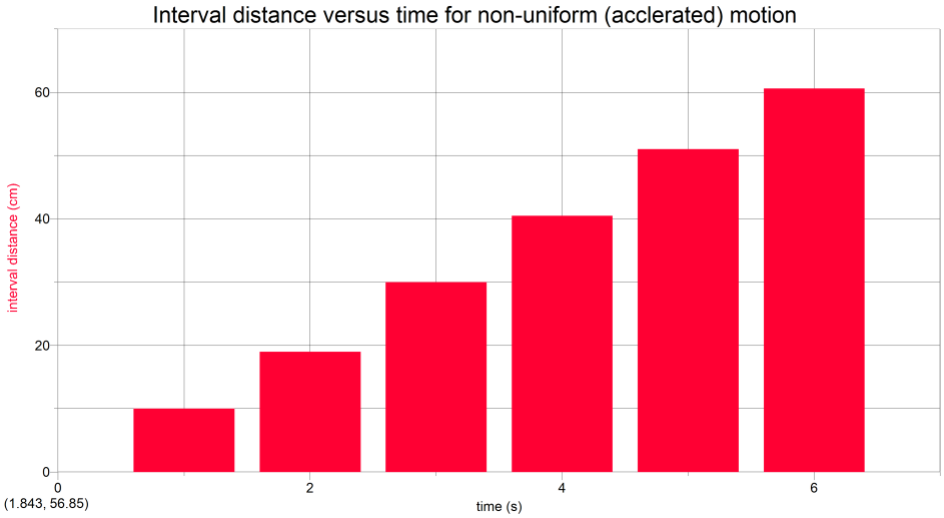
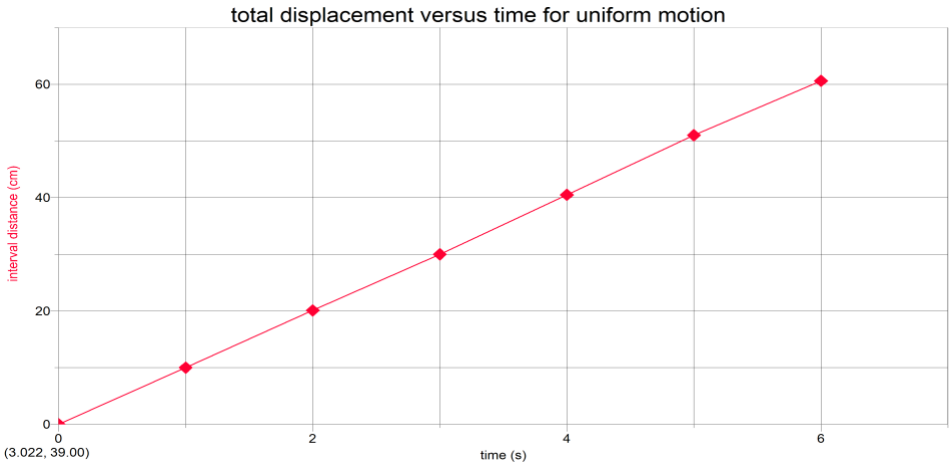


Evaluate:

1. Given the graph below, students calculate the slope of the total displacement versus time graph.

$V_{av} = \Delta d/\Delta t$ This is a linear relationship and the slope of a displacement versus time graph is the average velocity and is constant. The y intercept is 0 cm. The y intercept is the point at which the line intersects with the vertical or y axis of the graph.



2. Describe the motion depicted by the graph shown.
3. Is it linear?
4. How would this object be traveling?
5. Would this graph represent a sprinter or a long-distance runner? Justify your response.

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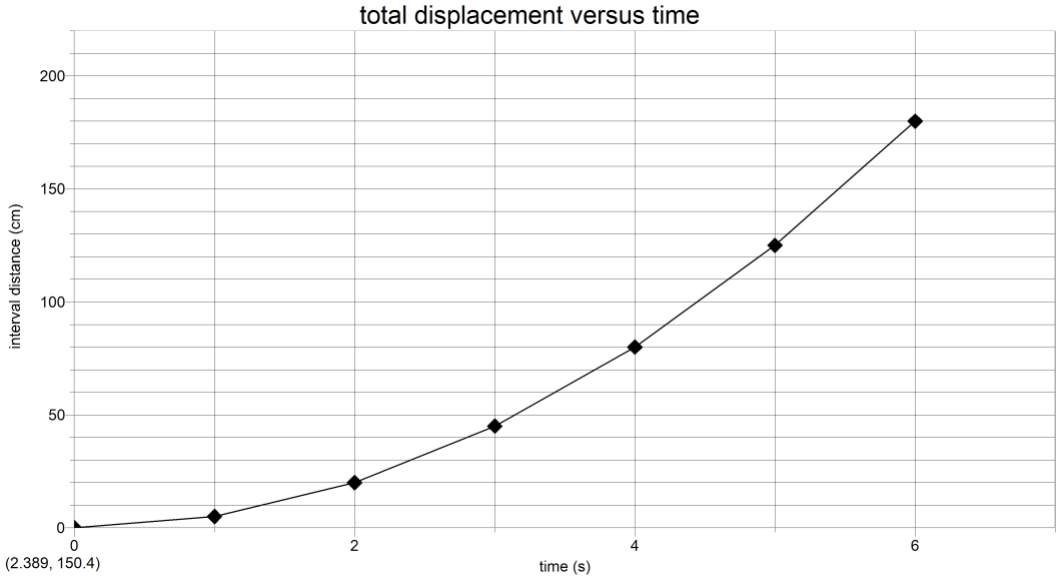
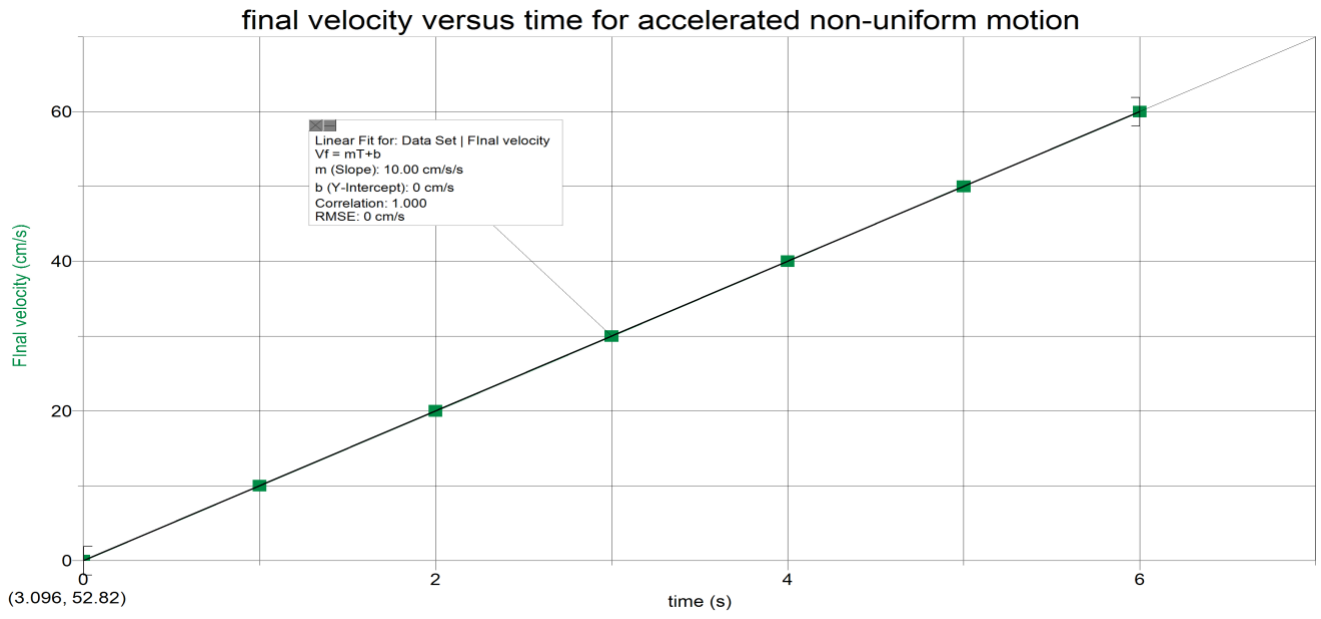


This graph is not linear. The curve is a quadratic or squared relationship. The object is accelerating. The displacement interval and velocity are increasing with time. This is a graph that would be representative of a sprinter coming off the blocks at the beginning of a race.

In this instance the formula for the displacement is $d = 5t^2$ When 5 is ½ the rate of acceleration of 10 cm/s^2. A velocity versus time graph corresponding to this displacement graph is shown. The slope of a velocity versus time graph is the rate of acceleration. $a = \Delta v/\Delta t$. A constant or uniform acceleration graph is linear. The area under the graph is the total displacement or distance traveled.



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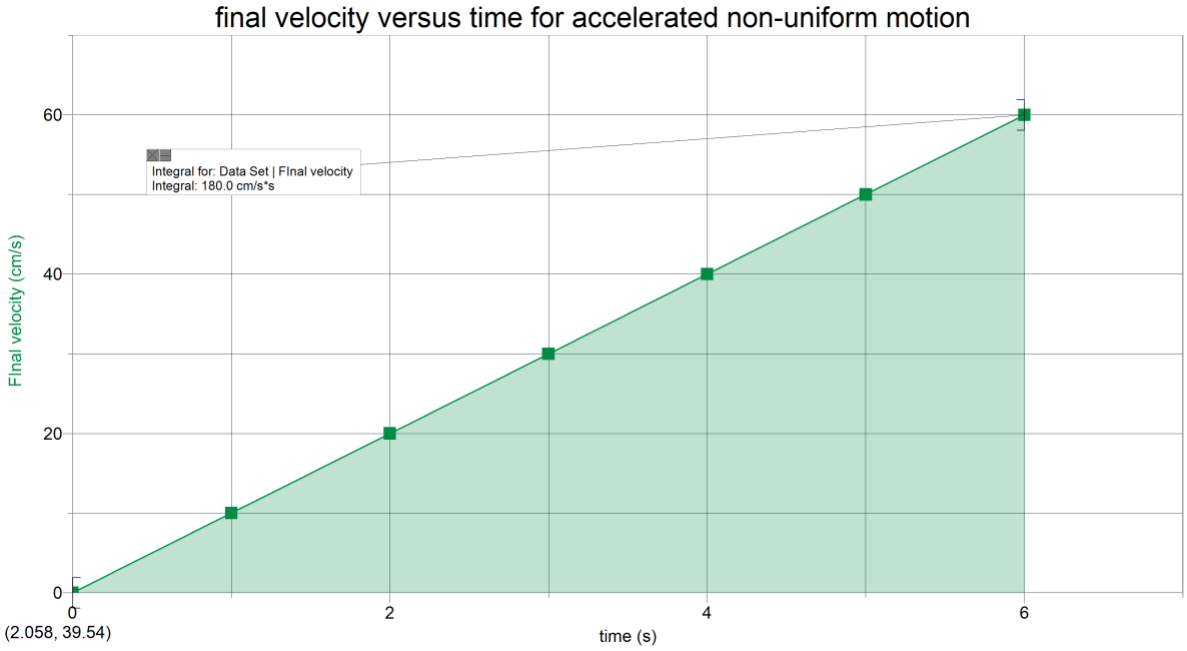

Graphs produced using Vernier Graphical Analysis.

Additional Resources:

Distance-time graph activity: http://graphs.mathwarehouse.com/distance-time-graph-activity.php

Position-time graphs: http://www.physicsclassroom.com/class/1DKin/Lesson-3/The-Meaning-of-Shape-for-a-p-t-Graph

Speed and velocity: http://hypertextbook.com/physics/mechanics/velocity/

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