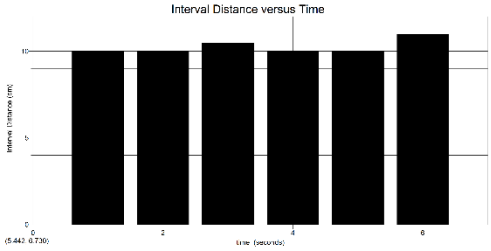
Kinematics with Fan Carts: Uniform versus Accelerated Motion

Engage:
The interval distance versus time graph shown is of a toy car moving to the right. What interpretation could be given to this car's motion?



Imagine a person pushing a car. Suppose several more people start to push the same car in the same direction. How would this affect the speed of the car?

https://www.gettyimages.com/photos/people-pushing-car

LO: Students will:

- collect and analyze uniform motion data from a dune buggy and nonuniform motion with a fan cart.
- identify dependent and independent variables.
- create large graphs that can be easily interpreted by using adding machine tape.
- observe that if $F_{net} = 0$ N motion is uniform. Newton's First Law
- observe that if $F_{net} \neq 0$ N motion is non-uniform. Newton's Second Law.
- Interpret graphs of position vs. time, velocity vs. time, and acceleration vs. time for uniform motion and nonuniform motion, including slopes and areas under the graph.

Standards Alignment

NGSS HS-PS2-1:Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
CCSS 3.MD.B.3 Draw a scaled bar graph to represent a data set.
Colorado State Standards:
SC.HS.1.4: Newton's second law and the conservation of momentum can be used to predict changes in the motion of macroscopic objects.
SC.HS.1.4.a: Students can: Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
CCSS.Math.Content.HSS-ID: Interpreting Categorical and Quantitative Data
CCSS.Math.Content.HSS-ID.A: Summarize, represent, and interpret data on a single count or measurement variable

Background Knowledge

Kinematics, the study of motion, is typically the first area of physics content addressed in most high school curricula. Although many students have a rudimentary understanding of motion they may be unable to differentiate among the terms describing an object's motion as either uniform or nonuniform. Examination of the graphical difference between motion that has a constant speed (uniform motion with the constant motion buggy) and accelerated or nonuniform motion (with the fan carts), provides background knowledge to help students understand the derivation of the "mysterious" physics equations describing kinematics. The fan cart experiment provides a segway to Newton's Laws of Motion bridging kinematics to dynamics.

The following are some common misconceptions students may have with respect to kinematics:

- Velocity is the same concept as speed.
- Two objects at the same position have the same velocity.

• Velocity and acceleration mean the same thing.
• Acceleration and velocity are always in the same direction and an object with no velocity can have no acceleration.

Materials: 3 small fans, dynamics cart, cardboard for fan carts, constant motion buggy, stopwatch, adding machine tape, washers or sticky notes, measuring tape, ruler and graph paper (Optional) motion detector.

Explore:

1. Secure approximately 2 m of adding machine tape to the floor.
2. Assign tasks to members of the lab group.
    a. Person 1 timing for the experiment. This person will approximate 1 second intervals. Cadence must be consistent. The timer will audibly instruct markers and starter.
    b. Person 2 places the running uniform motion buggy at the starting position when directed.
    c. 5 or 6 "markers. These members are spaced along the tape. As the buggy approaches a location. the person will place a washer or a sticky note at the front of the buggy as the buggy passes their location and when the timing person instructs them to do so.
3. Using scissors cut the paper tape at the location of the washers/sticky notes.
4. Measure the respective lengths for the time intervals.
5. Record the interval lengths and total length on a data table for calculations.

Measured Data

Time interval (seconds)	Interval distance (cm)	Total distance (cm)
0		
1		
2		
3		
4		
5		
6		

6. Produce a graph by taping the "paper tapes" in successive time intervals

Explain;

1. Compare your interval strips within your group and with other lab groups. How are the strips similar? How are the strips different?
2. What might account for the discrepancies with length.
3. What conclusions can be made from the data that has been collected? Cite evidence to support your conclusions.
4. Based on the respective interval lengths per time interval, how would one define average velocity per interval?
5. What mathematical relationship does the velocity in cm/s indicate?
6. Using the measured data in the previous data table complete a calculated data table.

Calculated Data

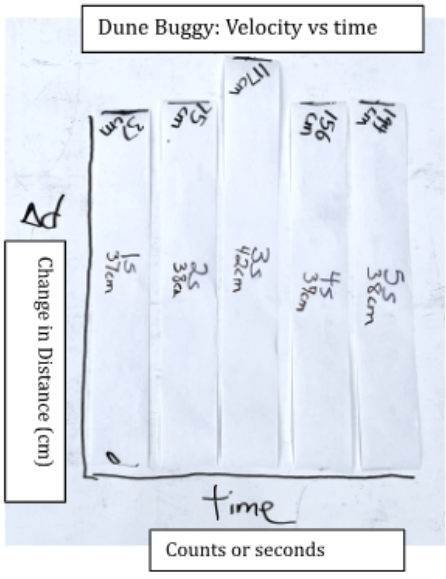
Time interval (s or count)	Interval distance cm	Interval velocity cm/s	Total distance cm	Velocity for total distance cm/s
0	0	0	0	0
1				
2				
3				
4				
5				
6				

Explain/Teacher Notes

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.

There will be slight variations in the distance traveled each second by the car. Variables can be due to the rhythm of the cadence director and/or accuracy for placement of markers.

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



Have students examine the a "bar graph" on the 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 traveled during any time period. This indicated that the dune buggy was not accelerating because it was traveling the same speed and covering the same distance during each time interval, much like having a cruise control set on an automobile.

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 traveled 37 cm in the first second so the $\Delta d=37$ cm and $\Delta t = 1$. Velocity $=(\Delta d/\Delta t)$, *so the velocity at the end of the first second is 37cm/sec and the car traveled 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 traveled 38 cm, so the $\Delta d=38$ and $t=1$. Since velocity $=(\Delta d/\Delta t)$ *the car's velocity is 38 cm/sec for the 2nd period of time and the car traveled 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 $V_{av} =(\Delta d/\Delta t) = (75cm)/2$ *sec.= 37.5cm/sec*

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

Extend: Fan Cart Physics:

1. Secure 4 sections of approximately 3 m of adding machine tape to the floor.
2. Place 3 fans on a piece of cardboard and affix the cardboard to the dynamics cart.
3. Assign tasks to members of the lab group.
    a. Person 1 timing for the experiment. This person will approximate 1 second intervals. Cadence must be consistent. The timer will audibly instruct markers and starter. This time frame may need to be reduced due to the acceleration of the cart.
    b. Person 2 places the running fan cart at the starting position when directed. This person will be responsible for turning on the fans to the highest setting and orienting the fans as instructed.
    c. 5 or 6 "markers. These members are spaced along the tape. As the fan approaches a location the person will place a washer or a sticky note at the front of the fan cart as the fan passes their location and when the timing person instructs them to do so. Note: as the object accelerates students will need to move along the tape to record data for successive intervals.
3. Using scissors cut the paper tape at the location of the washers/sticky notes.
4. Measure the respective lengths for the time intervals.
5. Record the interval lengths and total length on a data table for calculations.

Measure Data

Number of fans on	Distance traveled (cm)	Interval distance cm	Time (s) or counts
1			
2			
3			
2 fans on in opposite directions			

Note: With accelerated motion starting from rest the average velocity is in the middle of the interval.

$V_{average} = \frac{Vintial+Vfinal}{2}$ since the initial velocity is 0 cm/s $V_{final} = 2V_{average}$. $V_{average} = \frac{Interval\ distance}{interval\ time}$

When dealing with the total average velocity and total final velocity remind students that they must sum the distances from the beginning to the end of each segment and sum the time intervals as well prior to doing the calculations.

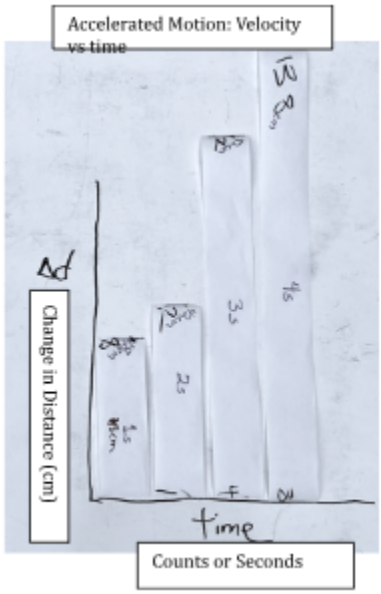
Calculated data

Number of fans on	Segment	Average interval velocity cm/s	Final interval velocity cm/s	Total average velocity cm/s	Total final velocity cm/s
1	1				
	2				
	3				
	4				
	5				
	6				
2	1				
	2				
	3				
	4				
	5				
	6				
3	1				
	2				
	3				
	4				
	5				
	6				
2 fans on in opposite directions	1				
	2				
	3				
	4				

	5				
	6				

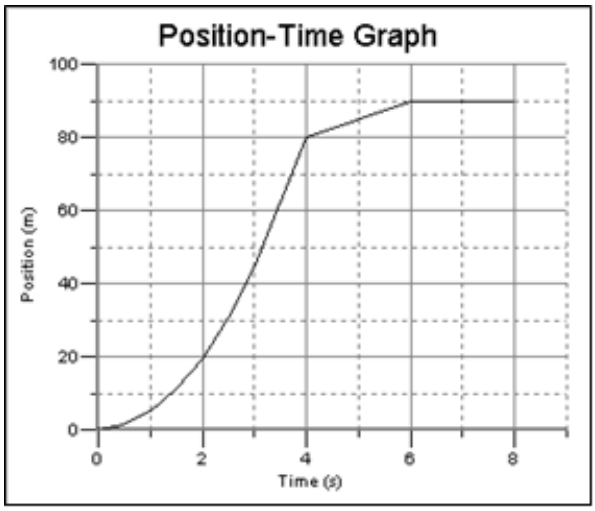
Explain:

1. What happens to the velocity of the cart as the number of "on" fans increases?
2. What does the graph of position vs. time (**x vs t**) indicate about the cart's speed?
3. Chose one data set from the fans and make a graph of total final velocity vs time graph.
4. What does the velocity vs. time (**v vs t**) graph indicate?
5. Calculate the slope of the velocity versus time graph. What does this slope indicate?



Acceleration is **nonuniform motion**.
NOTE: The change in distance (Δd) is NOT the same as **total** distance traveled. This is a velocity vs. time graph because velocity $=(\Delta d/\Delta t)$. To find the distance traveled, one would multiply the average velocity x Δt or d=vt. Plotting the total distance traveled would show that the total distance increased each second because the object was farther down the path being traveled.

The graph shown is a sample graph for accelerated motion. This would mean the object (car) would travel more and more distance each second.



Evaluation: Using the graph describe the motion of the three segments using the terms, constant motion, accelerated motion and no motion. Justify responses.

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/
Speed and velocity misconceptions: http://memo.cgu.edu.tw/yun-ju/cguweb/SciEdu/Publication/20080221CASE/YJChiuCASE2008%20FullPaper.pdf
Newton's laws: http://www.physicsclassroom.com/Physics-Tutorial/Newton-s-Laws
Build a fan cart: http://www.exo.net/~donr/activities/Fan_Cart.pdf