From Dot Motion to Graphing Velocity

Lesson Overview

This lesson is "**Lesson 1**" in a 3-lesson series exploring motion. In this lesson, students will generate initial ideas about motion, explore motion through dot data, record position and time data and prepare to observe a motorized cart moving at constant velocity in one direction. The observations and data collected are for 1 D Kinematics only, where acceleration is constant or, is nonexistent (i.e. values of 0 or greater). Students will first, describe the motion qualitatively, then quantitatively with graphs and finally with equations. They will compare calculations from their data and graphs with those from the equations. They will create a story that will serve as a model of 1D Kinematics. The1 D Kinematics formulas align with the general mathematics formulas for linear and quadratic rates of change:

- Linear equations in slope-intercept form: y = mx + b; 1D Kinematics: $v = at + v_0$ & $d = ½\ vt + d_0$ *(this variable is usually = to zero and is not represented in general physics 1 D Kinematic equations – it is show here to be representative of the linear equation).*
- Quadratic equations in standard form: y = ax^2 + bx + c; 1D kinematics: $d = at^2 + vt + d_0$ *(again usually = 0 so its omitted – shown here to be representative of the quadratic equation)*

Where **d** is final position, **d_0** is initial position (arbitrary, usually zero), **t** is time final, **t_0** is initial time, **v** is velocity final, **v_0** is initial velocity, and **a** is acceleration (for this investigation constant). Recommended The Physics Classroom 1 D Kinematics for Teacher background - http://www.physicsclassroom.com/Physics-Tutorial/1-D-Kinematics

NOTE: This lesson has been written for use without precision equipment. However, if you possess PASCO, Vernier, Pocket Lab, or other equipment – i.e. photogates, light sensors, radar, spark-timer, tickertape-timer, etc... It is recommended that you use them to produce precision data following the procedure for data collection. The rest of the lesson plan can be used with the data to develop the skills knowledge and characteristics presented in the Profile of the SC Graduate.

Prerequisite knowledge

Students should be able to *(for 1 dimensional motion)*:

- Identify and accurately graph independent and dependent variables
- Identify and contrast vector and scalar quantities.
- Identify and contrast distance, displacement, and position
- Identify frames (points) of reference.
- Identify changes to distance, displacement and position when a frame of reference changes
- Add and subtract vectors
- Use a line of best fit on a graph of plotted data

Alignment

Science Standards

H.P.2A.3 Use mathematical and computational thinking to apply formulas related to an object's displacement, constant velocity, average velocity and constant acceleration. Interpret the meaning of the sign of displacement, velocity, and acceleration.

H.P.2A.4 Develop and use models to represent an object's displacement, velocity, and acceleration (including vector diagrams, data tables, motion graphs, dot motion diagrams, and mathematical formulas).

H.P.2A.5 Construct explanations for what is meant by "constant" velocity and "constant" acceleration (including writing descriptions of the object's motion and calculating the sign and magnitude of the slope of the line on a position-time and velocity-time graph).

Science and Engineering Practices

H.P.A.2 Develop and use models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.

H.P.1A.5 Use mathematical and computational thinking to (1) use and manipulate appropriate metric units, (2) express relationships between variables for models and investigations, and (3) use grade-level appropriate statistics to analyze data.

H.P.A.6 Construct explanations of phenomena using (1) primary or secondary scientific evidence and models, (2) conclusions from scientific investigations, (3) predictions based on observations and measurements, or (4) data communicated in graphs, tables, or diagrams.

Crosscutting Concepts (from the SDE instructional unit resources document)

3. **Scale, proportion, and quantity**: The National Research Council (2012) states that "in considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance" (p. 84). The ideas of ratio and proportionality are important here along with being able to predict the effect of a change in one variable on another. For example, how will the speed of an object change if the time traveled is increased but the distance remains the same?

Math Standards

ACE.2 Create equations in two or more variables to represent relationships between quantities. Graph the equations on coordinate axes using appropriate labels, units, and scales.

FIF.8 Translate between different but equivalent forms of a function equations to reveal and explain different properties of the function.

SPID.7 Create a linear function to graphically model data from a real-world problem and interpret the meaning of the slope and intercept(s) in the context of the given problem.

Standards for Mathematical Practice

SMP.2 Reason abstractly and quantitatively.

SMP.3 Construct viable arguments and critique the reasoning of others.

SMP.4 Model with mathematics.

ELA Writing

Standard 6: Write independently, legibly, and routinely for a variety of tasks, purposes, and audiences over short and extended time frames.

> 6.1 Write routinely and persevere in writing tasks over short and extended time frames, for a range of domain-specific tasks, and for a variety of purposes and audiences.

ELA Communication

Standard 1 Interact with others to explore ideas and concepts, communicate meaning, and develop logical interpretation through collaborative conversations; build upon the ideas of others to clearly express one's own views while respecting diverse perspectives.

> 1.2 Initiate and participate effectively in a range of collaborative discussions with diverse partners; build on the ideas of others and express own ideas clearly and persuasively.
>
> 1.4 Engage in dialogue with peers and adults to explore meaning and interaction of ideas, concepts, and elements of text, reflecting, constructing, and articulating new understandings.
>
> 1.5 Synthesize areas of agreement and disagreement including justification for personal perspective; revise conclusions based on new evidence.

Connections

Content Area (2 or more) Connections

- Algebra II / Precalculus
- Physics

Content Connections

The use and graphing of linear functions in mathematics is the cornerstone skill of this lesson; without that context, the content for 1 D Kinematics is incomplete.

Active Learning Strategies (for Purposeful Reading, Meaningful Writing, and Productive Dialogue)

- Quick Write
- Squared Pairs
- Exit Ticket
- Think-Pair-Share
- Frayer Model

Computational Thinking

The following computational thinking (CT) skills are used during this lesson:

- Logically organizing and analyzing data
- Representing data through abstractions such as models and simulations
- Automating solutions through algorithmic thinking (a series of ordered steps)
- Confidence in dealing with complexity
- Persistence in working with difficult problems
- The ability to deal with open ended problems
- The ability to communicate and work with others to achieve a common goal or solution

Lesson Plan

Time Required – Three 55-min class periods

Disciplinary Vocabulary –

average velocity, kinematics, frame or point of reference, constant velocity, instantaneous velocity, displacement, velocity, acceleration, constant acceleration, position, acceleration due to gravity, graphing, x-axis, y-axis, variable, average, constant, independent and dependent variables, slope, line of best fit, linear, quadratic, and rate (of change).

Materials Needed:

- Smooth flat surfaces (10-15 meters for each group)
- Meter sticks – 2 per group
- Painter's tape (1 roll per group) *(NOTE: blue painters tape from a home improvement store – doesn't leave a residue like masking tape)*
- Stop watches (1 per group) (accuracy to at least 1/10 of a second) – *Smart phones work exceptionally well*
- Graph Paper
- Copies of "Dot Motion Diagrams" (1 per group) (OR use diagrams generated by students)
- Copies of "Frayer Model" Templates (1 per student)
- Copies of "Motion of Motorized Cart Activity" (1 per group)
- Preparing for Lesson 2: Constant velocity cart (1per group of 3-4 students) *(Carts can be purchased for around $10. For example Arbor Scientific $8.50 https://www.arborsci.com/constant-velocity-car.html)*

- Preparing for Lesson 2: 10 Colored pencils (if you have groups of 4 you will need 2 identical sets), 4 markers and a pair scissors per group
- Preparing for Lesson 2: Pack 1 two-meter piece of butcher paper cut into equal length strips, one per group *(e.g. cut the butcher paper lengthwise so that each group gets a 2m long strip of paper)*
- Preparing for Lesson 2: 1 tablet or smartphone per group of 2-3 students. Each device with either the Fast Burst Camera Lite App for Android *(Chromebooks and smartphones)* or iPhone Burst *(comes with most iPhones and iPads*) but can also be downloaded. ***FYI iPhones and iPads with burst CAN NOT be adjusted they are set at 10fps therefore android devices are preferred b/c you can 20fps and therefore more data points.***
- Preparing for Lesson 2: Computers, laptops, tablets or other devices with photo viewing software of app (Paint is fine) and screens large enough to take measurements.
- OPTIONAL – Grid lined chart paper

Formative Assessment Strategies:

- Computer/Tablet/Smart Phone Simulations & Interactives: **The Physics Classroom**: http://www.physicsclassroom.com/Physics-Interactives/1-D-Kinematics & **pHet Interactive Simulations**: https://phet.colorado.edu/en/simulation/legacy/moving-man

Misconceptions:

Students have difficulty connecting motion graphs to physical concepts:

- Differentiating between slope and height
- Relating the graph of one variable with another [(i.e. position, velocity (rate of change in position) and acceleration (rate of change in velocity)]
- Matching narrative information with related features on a graph
- The meaning of the area under the graph
- Representing continuous motion with a line or curve
- Differentiating between the shape of the graph and the path of motion
- Negative velocity and acceleration & **constant acceleration (free fall – biggest misconception in 1D Kinematics)**

Safety Note(s): Students should wear appropriate safety equipment. *See MSDS and operating/safety instructions for all equipment and tools used.*

The is a 5E multiday lesson, daily opening and closing is up to the instructor – where time might be a factor we have included "re-engagement" and Exit Tickets. There is a suggested number of periods beside each "E" in the lesson plan – However, it is not advisable to move onto the next part until students have had enough time to process the current information**.**

Day One

Engage:

- Ask students to do a Quick Write "What you know about motion?". *NOTE: This should include some of the information listed in 'prerequisite knowledge'.*

- Have them Pair-Share (if odd number of students have a trio) & then square the pairs (you might have a quartet if odd # of students)
- Have the squares use their combined information about motion to develop a list of terms use to describe and/or measure motion.
- In round robin style:
    1. Each group will share 1 term at a time
    2. Record the term *(NOTE: Use something that can be put up and taken down for each class – like an electronic word wall – so that they can add to it)*
    3. As each group shares a term all other groups look for and mark off that term or similar terms.
    4. If a group has no new terms to add to the list, they PASS–
    5. Continue until all groups pass.

Explore:

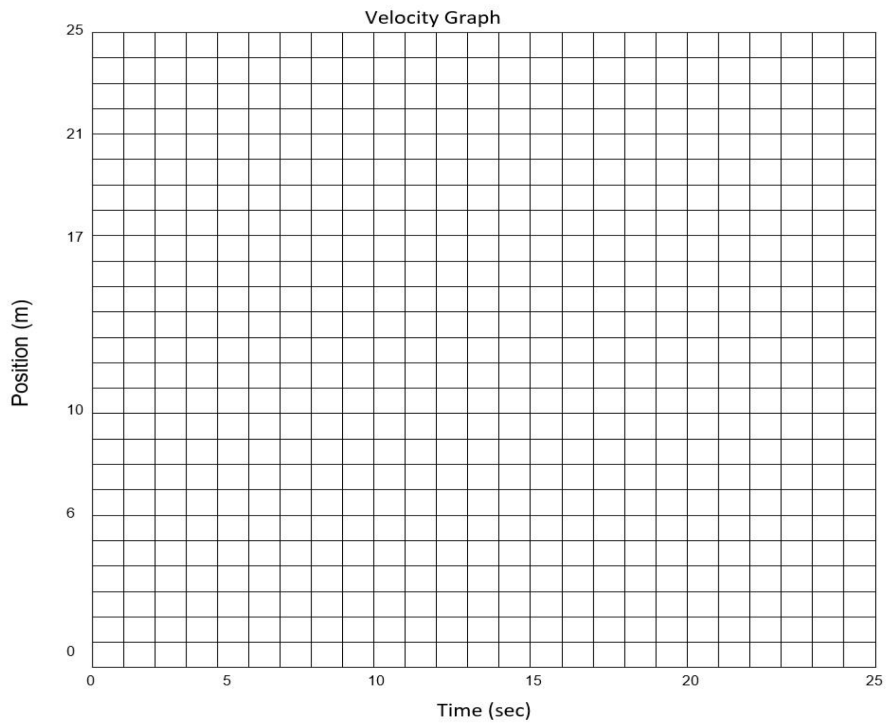
- Place students in groups of 3-4 (Or keep them in their squares)
- Pass out the blue and red dot motion diagrams. Groups should be instructed to:
    - Dialogue about what might be happening in the diagrams.
    - Groups choose **one** of the four dot diagrams to match *(OR they can be assigned)*
    - Explain the activity: *(Note: you need a lot of floor space for this activity)*
        - Assign roles –A walker -the person imitating the motion; Recorders – the person(s) who puts tape on the floor, marking the position of the walker; And a timer – the person that calls out each second.
        - Have students use the timer and blue tape to mark the position of the walker every second of the match procedure
        - Pass out the materials and student sheets (*NOTE: this contains much more detail about the process and procedure the students follow*)
        - Assist student groups as needed
    - Have groups share out 1 of the following:
        - A problem they had and how they solved it
        - Something new they learned while doing the procedure
        - How the activity has reinforced something they already knew
- Exit Ticket – 3 stars and wish
        - 3 stars – 3 things that went well or that they enjoyed
        - Wish – something they need to master

Day Two

Explain:

- Re-engage students – Career Connection – Think Pair Share – Ask students to think about the following – How might an air traffic control use information from a motion graph? (NOTE: Students need only share with their partners – this should not take more than about 5 min.)

- Use a dot motion graph that they have not seen (you can use one off the white card except "b" – it's the same as the blue with 10 dots) and demonstrate how it would look as a velocity graph i.e. a position vs time graph.
  - Use a large grid that you can write on as you 'think aloud' and model for the students.



  - This is a rate graph, so be sure students know with rates time goes on the x axis. Graph each dot as point and tell the students the time interval is 1 second (*NOTE: If you want to make this more challenging use a time interval of 5 seconds in which case the graph is the perfect scale – otherwise it is too large*)
  - Pass out graph paper to each student and have them graph 2 of the dot motion graphs (2 separate graphs) – One from the blue card and one from the red card – Assist students individually as needed and note any common errors.
  - Address common errors with the whole class.
  - Groups then collaborate and edit where necessary.
  - A volunteer should model graphing one of the four dot motion diagrams. Select a volunteer from different groups to model each of the 3 remaining dot motion diagrams.

Day Three

Extend:

- Pass out more graph paper and have them consider a different frame of reference. For most student the frame of reference has them at the origin, motion is moving away from or in front of them. So you would ask them what changes on the graph if the frame of reference has the motion of the object coming toward them

- Pass out two Frayer Model Templates to each student and have them write "velocity" in the middle of one of them and "acceleration" in the middle of the other.
- Ask students to think about matching the dot motion diagrams and how that activity might be used to explain these terms.
  - Be sure that they address frame of reference and direction and what these do to the sign of the data and to the placement on the graph
- Have students share their ideas with their group and record information on the templates: (*NOTE: Make sure they know to leave room in the boxes b/c they will be using them several times in future lessons.)*
  - If students are familiar with the Frayer model have them add information to it.
  - If students are not familiar with the Frayer model adding SOME information to the characteristics of both templates using a few ideas from the groups – Then have groups add to characteristics and to other boxes.

Evaluate:

- Pass out one white card to each group
- Give each student a piece of graph paper
- Each student in the group selects a different dot motion diagram
- Each student individually graphs the dot motion diagram
  - (Differentiation: Present an alternative time interval (i.e. 2s, 5s, 3s, 7s etc…) to groups or individuals for added challenge. Encourage struggling students to first verbalize what they think is happening in the dot motion diagrams.)
  - Have students record on their individual graphs where they are having difficulties – and collect them from students
- Pass out the Motion of a Motorized Cart Activity and have students read the procedure and assign their roles while you review their graphs and work with students that are struggling with the graphing. (Be sure the groups are aware that they are responsible for ensuring everyone in the group understands they procedure, their role and the data being collected. *The activity will actually be completed during LESSON 2 of this series.)* NOTE: If you are still working with individual students when individuals have finished reading – have groups complete the set-up portion of the activity and then the physical set-up.
- Return graphs to the students that did not require individual or small group assistance.
- Add the following terms
  - Constant velocity – motion does not change direction or magnitude
  - Constant acceleration – motion changes direction or magnitude or both but at the same rate – Velocity changes at the same rate
    - Example – Gravity
    - Non-Example – Applying the gas (+ if the frame of reference is the car) or brakes in a car (- if the frame of reference is the car). Deceleration is simply a negative acceleration from the specified point of reference.

- Remove the term deceleration if present – revisit frame of reference if necessary
- Revisit Frayer Models – students should be able to add to their operational definition as well as to their characteristics; *NOTE: Students will also revisit their Frayer Models in the other lessons within this series*

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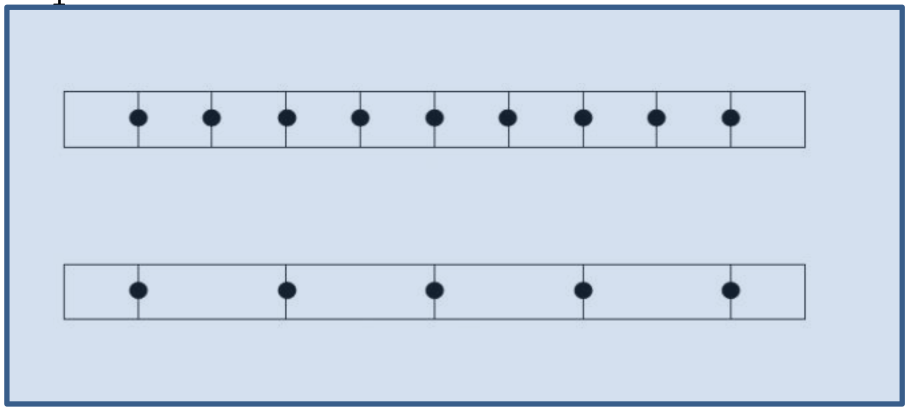

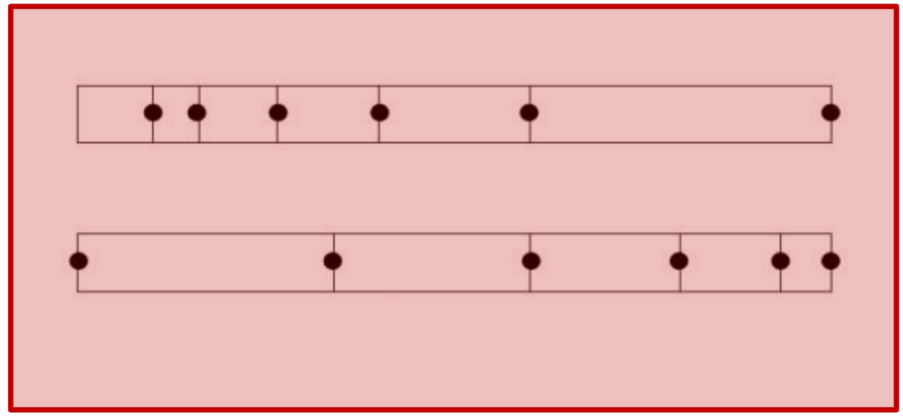

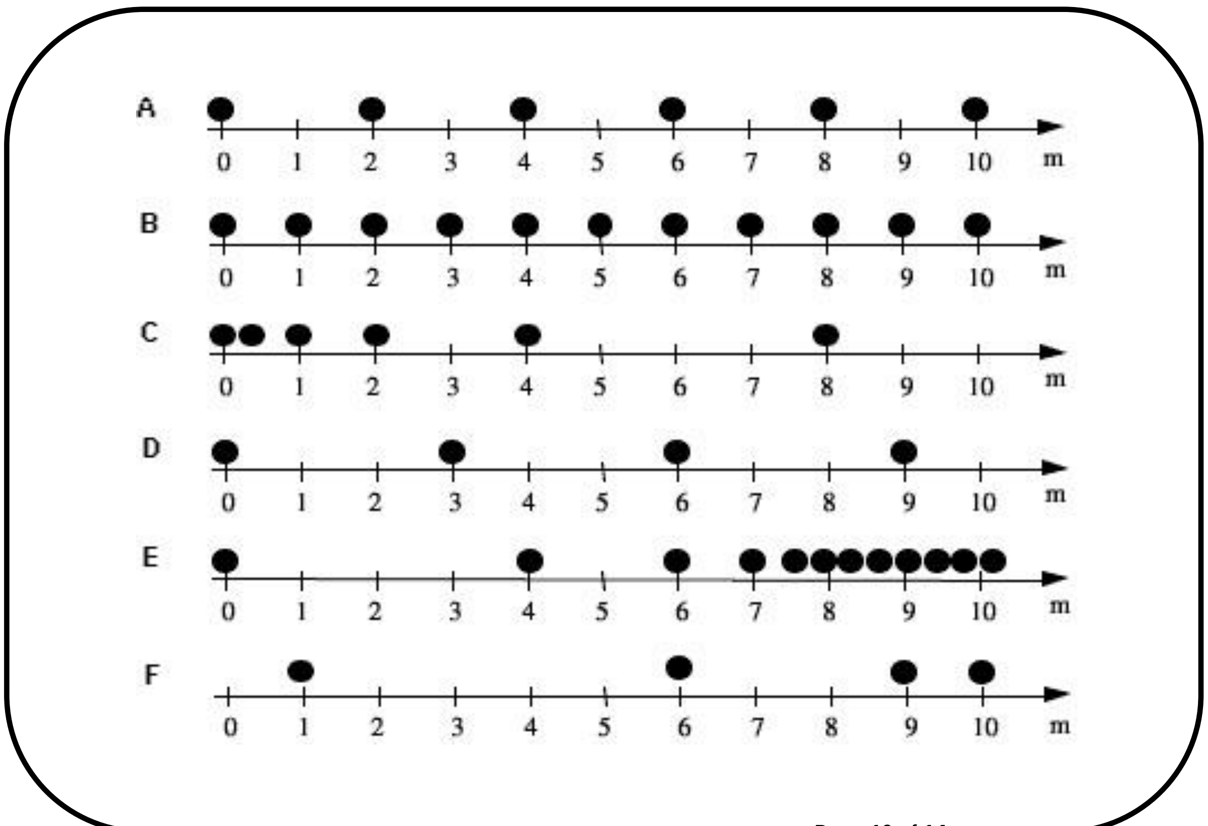
A
0 1 2 3 4 5 6 7 8 9 10 m
B
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C
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D
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E
0 1 2 3 4 5 6 7 8 9 10 m
F
0 1 2 3 4 5 6 7 8 9 10 m

Circle the dot motion diagram you are matching:

Blue with 10 dots	Red with dot closest at beginning
Blue with 5 dots	Red with dot closest to the end

Materials:	Roles:
• Blue tape	The Walker – Replicates the motion
• Meter Stick	The Recorder(s) – Marks the position of the walker with the blue tape
• Timer*	Timekeeper – Tells the Recorder(s) when to mark the position

* Timer can be a cell phone timer or a stopwatch or anything else accurate to 1/10th of a second

Procedure:

1. As a group decide how the walker will move to match the diagram.
2. The time interval for the dot motion diagram is 3 seconds.
3. Use a ruler to determine the position at each time interval – use the scale: 1cm = 1m.
4. When ready the timekeeper will start the timer while saying "start" to the walker.
5. The walker will begin making the motion discussed by the group.
6. The timekeeper will call out the time intervals: 3 seconds, 6 seconds, 9 seconds, 12 seconds etc … until all the marks for dot motion diagram have been placed on the floor.
7. The markers will mark the walkers position on the floor using pieces of blue tape at each interval the timekeeper calls.
8. As a group look at your dot motion diagram (the one on the floor created with the blue tape) and compare that to the dot motion diagram on the card.
9. If the dot motion diagrams do not resemble each other:
   a. Try and discover what you need to change
   b. Discuss the changes and ensure everyone knows what it is that is changing and
   c. Repeat steps 4 - 9
10. If the two dot motion diagrams are the same (similar) show the teacher and take a photo of it and upload it or email it to your teacher – be sure to include your information in the file name if you upload it or include that information in the email.
    a. Markers will now record the motion of the walker
    b. Repeat steps 4 – 9 except instead of marking the position of the walker the markers will describe the motion of the walker between each time interval. For example, between 3 seconds and 6 seconds the walker increased velocity by one step to the right.

Results and conclusions: Discuss as a group and be prepared to share.

1. How did frame of reference play a part in your matching? If it did not play a part, explain why.
2. What can you add to your Frayer model for velocity? Acceleration?
3. What was most difficult for you? What did you do to resolve it AND what might you do differently if given the change to repeat this?

Motion of a Motorized Cart Activity Sheet

Purpose:

- To use graphing as a model representing an object's motion (position, displacement, velocity and acceleration).
- To develop an operational definition for constant velocity.

Materials per group:

motorized cart	meter stick or metric tape
2 m of butcher paper & blue tape	graph paper
10 colored pencils or markers	stopwatch or smart phone timer

Description:

You will observe and measure the motion of a motorized cart by marking its position along a strip of butcher paper at regular time intervals. Note that you can adjust the speed of the cart using the small dial - find a speed that works well for you and then do not change the cart's speed during the remaining trials. The speed you choose should make it easy to mark the paper at the time interval given.

Once you have a record of the cart's motion on the butcher paper, you can measure and record its position in a data table and construct a position vs. time graph for the cart's motion. You can then create a velocity (position vs time) graph. The procedure is similar to the procedure we used to match the dot motion diagrams.

Although you will work as a team during this lab, each student will be assessed on their own individual graph and operational definition of velocity (Frayer Model).

Procedure:

Setup:

1. Fasten the 2-meter strip of butcher paper to your lab table with tape.
2. Place the motorized cart beside the tape, near one end. Mark the cart's starting position on the tape.
3. Adjust the speed of the cart so that it takes at least 30 seconds for the cart to move the length of the tape.
4. Assign the following roles:
    a. Time Keeper – starts the timer at the same time telling the driver to release the cart and calls out regular time intervals
    b. Driver – releases the cart from the starting position when instructed by the time keeper.

   c. Marker(s) – Records the carts position on the butcher paper at each time interval. (If you have 2 people marking be sure they have the same color)

5. As a group decide on a time interval to mark your cart's positions (HINT: you will be using this interval to graph and later to make calculations).

   Time interval: _______ seconds

6. As a group create a data table for recording 10 trials, position in meters, time in seconds and displacement (change in position) in meters. And enter the time intervals. For example, if the chosen time interval is 7 seconds and it takes the cart 49 seconds to get to the end, then enter 7, 14, 21, 28, 35, 42 and 49. The data table will need to accommodate 7 positions for each trial.

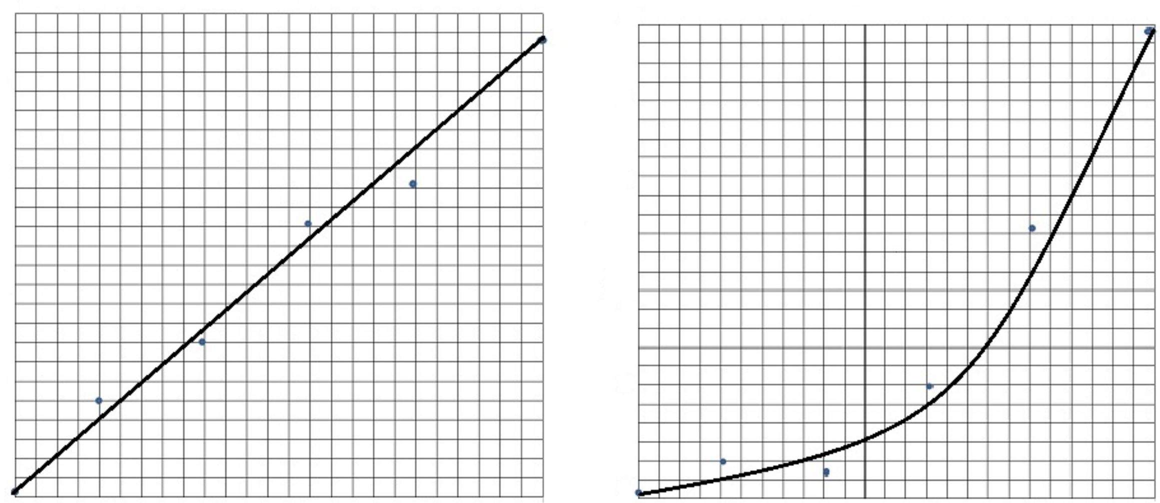
Data Collection:

1. You may want to make a couple of practice runs to get everyone coordinated. The paper has another side if you need it.
2. The timer starts and tells the driver to release the cart at the same time.
3. The timer calls out the timer interval and the marker, marks the position of the cart at that interval on the butcher paper. If you are using 2 timers be sure that both colored pencils are the same or similar colors.
4. ON the first trial write the time interval near each dot (This will help with recording position data with time data).
5. Repeat steps 7 - 9 using a different color pencil for each trial until you have 10 trials. (The different colors will help with distinguishing one trial from another.)

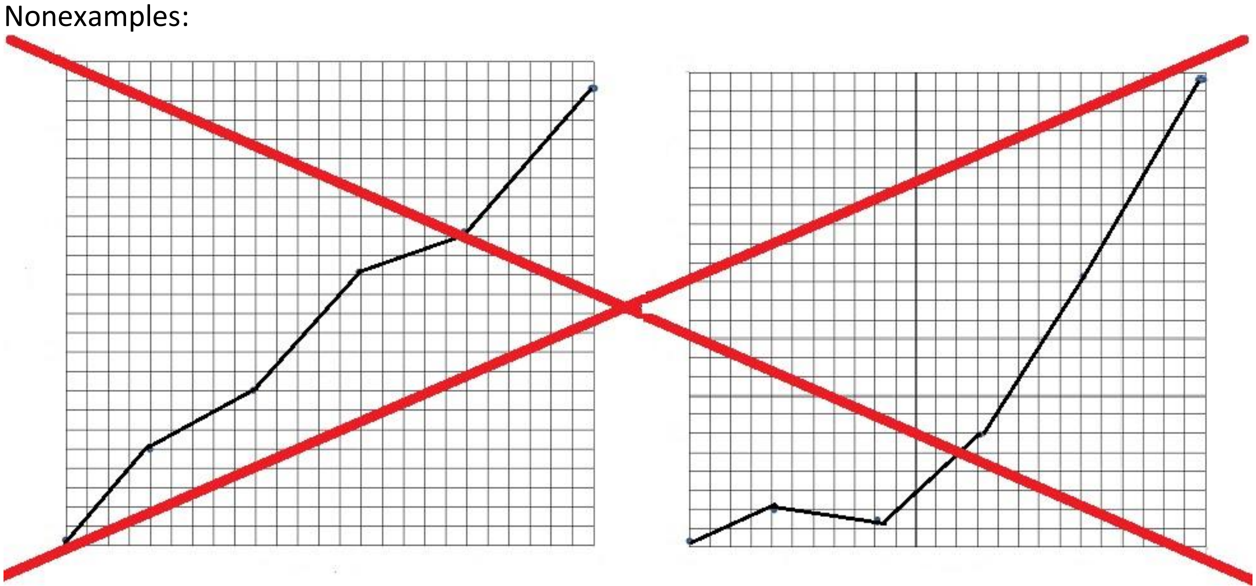
Analysis:

1. Measure each position of the cart from the start.
   a. Measure from the start to each to each colored dot – the different colors represent the different trials.
   b. It does not matter which color you assign to a trial, but it does matter that you keep the measurements for one trial, one color. For example, if on the third time we used a red pencil, we can assign red as trial one but when we enter the positions for trial one we only measure from the start to each RED dot and enter that data into the
2. Record your position data for each trial next to its corresponding time interval.
3. Calculate the average position at each time interval.
4. Plot the average of each position/time data pair on a position vs. time graph.
   a. Remember to label the graph and both axis.
   b. Include the proper units for each axis.
   c. You may ask your group members questions to assist you, BUT you must draw and label your own graph and plot the (time/position) ordered pair for each time interval
5. Draw a best fit line for the data points on your graph. See the examples below – Do your points fit best to a line or a curve?

Examples of Best Curves:



Nonexamples:



6. Calculate the slope using the y-intercept formula (y=mx + b). BE SURE TO KEEP THE UNITS!!!
7. Calculate the slope using the graph (rise/run OR $(y_2 - y_1)/(x_2 - x_1)$)
8. Substitute the independent and dependent variables into the y intercept formula – d is used to represent the position and d_0 represents the position at time = 0sec t is time and slope is velocity.

Results and Conclusions:

1. How does the displacement compare to the position? Why?
2. What does a linear velocity graph tell us about the motion of an object?
3. What does the slope of the graph tell us?