Topic: Velocity acceleration and forces. **Grade Level:** 9-12

Title: Modeling kinematics with Marble Marble Coaster Jumps

Standards:

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.** [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [*Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at nonrelativistic speeds.*]

- **HS-PS2-2:Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.** [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [*Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.*]

Crosscutting Concepts:

Cause and effect
Systems and System Models

Science and Engineering Practices:

Using Mathematics and Computational Thinking
Analyzing and interpreting data

Nature of science:

Science Models, Laws, Mechanisms and Theories Explain Natural Phenomena

Common Core:

ELA/Literacy -

RST-11.12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-LS4-2)
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS4-2)
WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS4-2)
SL.11-12.4	Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. *(HS-LS4-2)*
RST-11.12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS4-5)

Mathematics

MP.2	Reason abstractly and quantitatively. (HS-PS2-2)
MP.4	Model with mathematics. (HS-PS2-2)
HSN.Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS2-2)
HSN.Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *(HS-PS2-2)*
HSN.Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS2-2)
HSA.CED.A.1	Create equations and inequalities in one variable and use them to solve problems. (HS-PS2-2)
HSA.CED.A.2	Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. *(HS-PS2-2)*
HSA.CED.A.4	Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. *(HS-PS2-2)*

Timeline: All classes 50 min

- Engage Day 1
- Explore Day 2 Day 3
- Explain Day 4 Day 5 Day 6
- Elaborate Day 7 Day 8
- Evaluate Day 9

Background:
This lesson is intended to target specifically the kinematics of an object in an effort to alleviate misunderstandings so that students can better develop their understanding of dynamics in the future lessons. Emphasis will be placed on the vector nature of acceleration and velocity because any change in these measurements is because of an outside force to be explained in the future.

This lesson was developed as an introduction to a unit covering Kinematics and Dynamics. It is also intended to start students in the process of collecting data and graphing it. The lessons can be modified depending on students skills and experience with data collection, analysis, interpretation and presentation.

Justification:
While all students have experience with moving objects in their daily lives there are a great deal of misconceptions when it comes to truly explaining and understanding motion. While students at the Highschool level can easily recite Newton's laws and the difference between speed and velocity and can talk about acceleration they don't really understand it as can easily be demonstrated by attempts to apply their knowledge to new situations or scenario. By focusing on really describing and understanding kinematics students will translate that experiential knowledge to understanding dynamics.

Objectives:

Measure motion of objects
Graphically present motion of objects
Model the velocity and acceleration of objects

Supplies:

1:1 device, copies of paperwork or directions in LMS (Google classroom, etc).
Paper, Marbles, tape, poster paper colored pencils
Basketball, tennis ball(s)

Documents Included below:

- Questioning and Discussion worksheet
- Roller Coaster Jump Directions
- Velocity acceleration measurement worksheet
- Moving man and marble Graphs
- Gallery walk Worksheet
- YouTube Evaluation Direction Worksheet

5E Lesson sequence:

Engage:	**What is Teacher Doing?**	**What are Students Doing?**
Day 1	Guiding questions and introducing ideas	Generating questions and Sharing their ideas.
~10 min	Share the following image. https://i.ytimg.com/vi/eYDjV7ajuMo/hqdefault.jpg Start with what questions or ideas do you have? Leading with ideas about: Is this possible/safe? Would you ride? Why or why not? How would you describe the motion of the coaster that could make this possible?	Using Question and Direction Worksheet Looking at image writing questions following QFT
~5 min	Introduce idea of making a marble coaster out of paper and tape with the goal of making the marble jump off? What will change how it jumps?	Students are drawing the idea of what a jump would look like?
~10 min	Discuss what the commonalities are for making a marble jump. The limitations that exist for this situation (Opportunity to share engineering design process, necessary to adjust timeline if this is introduced)	Think pair share
~15 min	Energy skate park Playground mode is	Experimenting with the track

	introduced. Students are encouraged to manipulate a “track” to see what results of a jump. Collect some data to inform their design and testing their own marble coaster. Circulate to encourage formalizing ideas. Encourage use of the grid.	and jump of the skater in the park. Looking at what variables they can manipulate and what data they are collecting.
~5 min	Encourage students to plan for building their paper marble coaster track for next class. What is their plan and question they are trying to answer	Using Roller Coaster Directions Worksheet Drawing and writing a plan.
Explore:	**What is Teacher Doing?**	**What are Students Doing?**
Day 2	Facilitating and helping students be focused in their plans	Building and testing ideas.
~5 min ~35 min ~10 min	Directing students to supplies and encouraging a productive plan and direction for student building. Encourage students to use phones to record video (slow motion) record time and distance ball travels, angle of ramp, distance and lengths. Facilitating Wrapping up and making sure students have a plan for collecting good data for following class	Using Roller coaster Directions Writing notes and questions. Building and testing Writing notes and questions.
Day 3	Guiding	Testing
~5min ~40 min ~5 min	Establishing guidelines and directions Facilitating and encouraging *(At this point depending on prior instruction make plans to talk about data and units. Adjust timeline as necessary.)* Wrapping up and checking in	Using Rollercoaster jump directions: Listening and asking questions. Testing and Collecting data Making plans to finish with data.

Explain:	**What is Teacher Doing?**	**What are Students Doing?**
Day 4	Instructing and supporting	Graphing and CER
Whole class *This lesson may need to be extended in time because of CER and Graphing depending on Skill and comfort*	Depending on experience with graphing and writing CERs lessons and instruction will necessitate modifying the timeline. Graphs will be made to present data collected and than used in CER. This will be a simple and straightforward CER students will make claim based on data collected in testing their marble coaster jumps.	Making graphs Finalizing their claim Completing CER with data collected from roller coasters.
Day 5 ~5min ~15min ~10min ~15min	Ask students to explain how velocity of ball on their track could be measured? Using drawings of track and made up data practice calculating velocity of marble. Introduce concepts/vocabulary Constant velocity Average Velocity Speed Vector Acceleration Important to emphasize directionality of motion at this point. Really encouraging thoughts about Velocity and Acceleration as linear.	Use Velocity and Accelertion Measurement sheet Mark distance ball traveled on the track each unit time (1/10th of second) Compare motion of a “ball rolling down a track” by drawing dots in the number lines. How does the downhill track compare to horizontal track? Why?
Day 6 ~20 min ~15 min	Depending on Tech availability (moving man may not work on Chromebooks) use PhET Moving man simulation as a way to show graphing of kinematics. Have students draw a graph of the marbles velocity on distance time graph.	https://phet.colorado.edu/en/simulation/legacy/moving-man Graphing Sharing and taking notes

	Finalize what this looks like as a class Have students draw.	Graphing
~15 min	Have students draw acceleration on a velocity time graph.	Sharing and taking notes
	Finalize as a class what this looks like	Graphing
Elaborate:	**What is Teacher Doing?**	**What are Students Doing?**
Day 7	Guiding questioning and introducing new ideas	Questioning, illustrating and explaining
~20 min	Dropping Basketball and tennis ball.	Watching, taking notes and questioning. (if there are enough materials all experimenting)
~30 min	Model of velocity and acceleration of two balls	Creating an illustrated model on poster paper.
Day 8		
~5 min	Show video https://www.youtube.com/watch?time_continue=11&v=4IYDb6K5UF8	Asking questions in notebooks.
~20 min	Have students draw interactions of tennis balls labeling constant velocity and acceleration when present using arrows to show directionality and magnitude.	Drawing in notebook
~15 min	Introduce Momentum equation by asking students what two factors affect the amount of “motion” in an object.	Taking notes
~5 min	Pick youtube vid for tomorrow’s evaluation	Searching for Videos
Evaluate:	**What is Teacher Doing?**	**What are Students Doing?**
Day 9	Facilitating	Questioning and explaining
~20 Min	Discussion about how thought has changed about velocity and Acceleration Which method of visually representing velocity and acceleration worked best for you. Explain why	Gallery walk of basketball Tennis ball models
~30 min	Find aYoutube video of an object in	Narrating either in script form

	motion (athlete, sports car etc.) narrate the motion of the object in the video.	written or with a screen-cast.

Asking questions

Observe the following Roller coaster jump

1. First step is to generate as many questions as you can how to make a rolling object jump. Do not Judge the questions, do not stop to answer questions, and write as many questions as you can.
    a. Is this possible? Why or why not?

        Focus on what would be necessary to make the Coaster do this think about motion.

2. Next mark questions as either Open or Closed questions

3. Look at the questions and think about changing open questions to closed and closed questions to open.

4. Compare your questions with 2 other peoples questions and discuss similarities and differences

        Write down 2 similarities and 2 differences.

5. Work with a partner to rank the questions from from based on priority. Give a reason for the priority of the ranking.

Follow your teacher's directions to start thinking about a track to make a vehicle “marble” jump.

- In your notebook draw the shape a jump would be
- How could this “track” be made from paper?

Compare your design with another person

- What are the limitations of the design
- What are the variables that could be changed and effect the results of the jump?

Open the Energy Skate Park Simulation

- Use the playground mode and experiment with a partner
- Look for different things you could change about a ramp/jump
- Write down some basic data in your notebook

Now look at the directions for the Roller Coaster Jump Lab.

6. After looking at the Roller Coaster Jump Directions refine a workable question based on the expectations of your assignment.

7. Finalize an open question that you and your partner will be answered using the Marble coaster track that you and your partner are going to build. There must be data that you can collect.

Roller coaster Directions
You will be designing a jump for a marble. The end product will be a brief CER with graphs presenting what you found.

Goals:
- Observe different things which will affect the Marbles ability to jump.
- Demonstrate an understanding of data collection
- Demonstrate an understanding of Graphing data
- Report your understanding of an object in motion in a CER

Materials
Cardstock, tape, marbles of various sizes and materials, meter sticks, stopwatches, (phones could be used for recording results and timing)

Define Question:
Be clear and specific what are your changing and what are you measuring.

Design your track:
(make a specific drawing)

Write: How does the design of your track help to answer your question?

Write: Detailed procedures to follow when testing and collecting data.

Experiment and Collect Data: Organize a data chart in Google Sheets think about how you are going to graphically represent your data.

Record Observations: Write down observations about the experiment, think about recording any variable or problems which got in the way of collecting your data.

Create a Graph: Create a complete graph using Google Sheets.

Write you CER:

Using the question your generated in the first class
And the data and observations you collected while experimenting with your marble coaster.
Including your graph as one piece of evidence

Complete a short written, well organized CER.

Velocity and Acceleration Measurement Worksheet

Now that you have observed and experimented with an object in motion (your marble coaster) we need to talk about quantify motion. The three main measurements we are going to focus on are Speed Velocity and Acceleration. I expect that you have heard these terms before but we now need to think about truly defining and understanding them. It is going to be important to understand these concepts to apply them in future science lessons.

Goals:

- Identifying Speed Velocity and Acceleration of an object
- Measuring and Quantifying motion
- Comparing Speed, velocity and Acceleration
- Modeling velocity and Acceleration

Tasks:

1. Following the example of your teacher draw 2 number lines in your notebook using a pen.
    a. One will be horizontal (parallel to a paper edge)
    b. One will be diagonal
2. Using a pencil draw a marble starting on each track.
    a. On the horizontal track imagine the ball rolling and taking a picture of it each 1/10 of a second.
    b. Draw the location (in pencil) for each “picture”
    c. Do the same thing for the Marble rolling “down” the diagonal track.
3. Compare your drawings with 2 other people.

Following along with the teachers directions take record notes and ideas in your Notebook

4. Open the Moving Man Simulation
    a. Record notes, observations, Questions and ideas in your notebook at you manipulate the Moving man
        i. Turn on the vector arrows.
    b. Compare your notes with another person
5. Focus on the graphs that are created when moving the man back and forth.
6. Use the playback feature and watch the recorded motion and how the different graph lines change

Continue on back

Following the directions of your teacher draw axis in your notebook like the teacher does. These will be used to show graphically the motion of objects.

7. Draw a graph in your notebook showing distance and time of a marble on the horizontal track and the diagonal track.
    a. Compare with another student
    b. Correct (if necessary your graph in your notebook when the class has come to a consensus.
8. Draw a graph showing the velocity and time of the marble on the horizontal and diagonal tracks.
    a. Compare with another student
    b. Correct (if necessary your graph in your notebook when the class has come to a consensus.
9. Explain what you learned about Velocity and Acceleration using examples from the class.

Gallery Walk Worksheet.

Your classmates are an excellent resource for helping you to understand the concepts in class. If every person put an honest effort into trying to understand the class content, carefully illustrating it and than asking thoughtful questions of each other we can all benefit and improve our understanding of explaining and describing object motion.

Goals:

- Compare models and how your classmates showed velocity and acceleration
- Evaluate classmates understanding and illustrations by asking critical questions
- Reflect on your own understanding

Directions:

1. Make a new partner different from the one you were with to make the model of the tennis ball basket ball phenomena
2. View all of the different poster models
3. Ask questions to better understand the posters presented.
4. Record ideas that are different or similar to the ones your presented.
5. As a class discuss and record notes about the motion of the tennis ball and basketball
6. In your notebook Explain which method of describing velocity and acceleration was most helpful to you in understanding the idea.
    a. Share this with 2 classmates

YouTube Video Motion Narration Worksheet

This is your personal opportunity to explain the motion of an object. You are going to carefully select a video showing a moving object (car, football player, tennis ball etc.) and then narrate the motion of the object using proper terminology.

Goals:

- Demonstrate your knowledge of speed Velocity and acceleration

Directions:

1. Carefully select a video portraying an object moving. The simpler the better but it is your choice.
2. Watch the video and record examples of velocity and Acceleration
    a. It will take some time and you may need to stop and rewatch the video
    b. Write a simple outline or script explaining the motion of the object in the video
        i. Include times in the video in your script/outline
    c. You may either submit your carfully written script typed out or record a screencast of your voice narrating the motion.