IS2 Unit - Physics Investigation 2

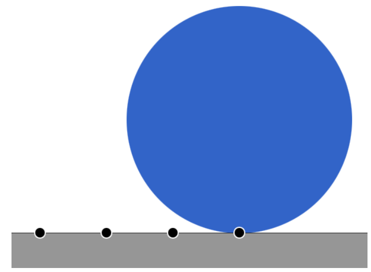
Contents

***Note: If using whiteboarding with students**, please ask students to add their pseudonyms to whiteboards to match photos of whiteboards with students participating in research.*

Activity 2.1 - How do you measure how fast something is going?

SUMMARY

Students roll a large ball, dropping sugar packets every second. Data is manually added to CODAP and analyzed to find velocity. Through this activity, students deepen experimental skills by using CODAP for data analysis using graphing, formulas, and fit lines. They discuss what it will take to produce consistency of results across experimental setups and start to realize that variability in data is normal and expected in the real world and that straight lines are not!



INQUIRY PRACTICES AND SKILLS

COLLECT	• Create a new user editable column for entering data that is not collected automatically through sensors or generated by simulations.
ANALYZE	• Identify sources of noise in data. • Identify outliers as data outside the expected range of normal variation. • Generate summary data about an experimental run using information collected at a lower hierarchical level.

STUDENT PRIOR KNOWLEDGE - Basic use of CODAP.

MATERIALS (per Group)

- Large open area with a hard surface.
- Basketball or playground ball, 10" or larger, fully inflated to minimize rolling resistance*
- Sugar packets (~10/group of students)
- Measuring tape
- Timer or Online Metronome (with sound on!)

Balls used in this investigation

Ideally you will use the same type of ball across all three activities in this investigation. The type of ball you use will determine the challenge you pose to students in the last activity of this sequence. Basketballs or playground balls work for the kickball challenge as described. You can also use harder balls such as bowling balls. Harder balls more evenly and at a more consistent velocity, though you will need to change the final activity to a collision between two balls.

Any ball used should be large enough (6-10" preferred) to be detectable by standard motion sensors starting in Activity 2. All activities presume use of a kickable ball at full inflation, though these balls must be of high enough quality to roll in a straight-ish line (example). Cheaper balls purchased online will likely either deflate and/or inflate out of round. Bowling balls can be found at local thrift stores at very low cost or online (ebay) for $10-$15 each. Smaller hard balls such as bocce or croquet balls are less expensive but may not be detectable by motion sensors.

Investigation 2 - The kickball challenge
October 11, 2019

ACTIVITY OVERVIEW (*All online pages in this activity are "**Run by Myself**"*)

1. **Ball roll with sugar packets, data collection** **40 min**
    a. Introduce the kickball challenge (figure out where to stand at 3 seconds)
    b. Describe and start ball roll activity
    c. Prompt during ball roll ONLY as needed:
        - How did you coordinating ball release, dropping packets, timing etc.?
        - How are you measuring time? When are you starting the timer? If students are having difficulty with this, consider suggesting a four count: 3-2-1-go!
        - How are you measuring distance? Where are you starting from? When?

2. **Collect and analyze data** **20 min**
    a. Project page 1 of Activity 2.1; Demo adding data, building a position-time graph
    b. Have students complete page 1 of Activity 2.1 (**Run by Myself**)

3. **Advanced data analysis and calculating velocity** **45 min**
    a. Project a student position-time graph
    b. Discuss outliers and deleting versus "setting aside" data
    c. Discuss the graph and limits of measurement tools (people, timers, tape)
        - What story does it tell about the movement of the ball?
        - When the ball leaves your hand, is the ball moving?
        - If moving at the same speed, will the ball roll forever?
    d. Discuss speed/velocity - consider deriving formula ($\Delta X/\Delta T$)
        - How do we commonly talk about speed? Units? (MPH)
        - How would you figure out average speed from here to (the store)?
        - How is this different from speed at any given moment you're driving?
    e. Demo calculation between first two data points; Add to CODAP
    f. Have students manually calculate velocities between points then go to Page 2 of the online activity (**Run by Myself**) to add velocities and build a VT graph

4. **Discuss variability and calculate run level velocities** **30 min**
    a. Project student work
    b. Discuss VT graph; Demo scaling axes
    c. Discuss use of the formula, mean(velocity), in CODAP
    d. Demo/discuss use of slope in the position-time graph
    e. Have students go to Page 3 of the online activity (**Run by Myself**) to add a movable line and find slope of their XT graph

5. **Compare velocity calculation methods** **20 min**
    a. Project student work
    b. Discuss variability between graphs - which gives you more confidence?
    c. How does the calculated average velocity compare to the velocity by slope? (agree to use slope to calculate velocity moving forward)
    d. Summarize key ideas
        - Velocity can be calculated as a number in different ways
        - Variability in experiments is normal and expected!
    e. Note that we will move to being more accurate (with sensors) and more consistent in our experiments (precise) by paying attention to our methods.

Total time 155 min

Big Picture: Velocity is not just an important matter in everyday life, it is also one of the most basic quantities in physics. Velocity is for physics what 1+1 = 2 is for math. For example, investigating velocity led Einstein to his famous principles of relativity. Pondering the nature of velocity, you might start by figuring out how fast we're moving in the Universe!

1. Ball roll with sugar packets, data collection (30 minutes)

- State that we will continue to explore experimentation by running through a series of activities that focus on objects moving at "about the same speed." Introduce the following activity by describing the kickball challenge:

    - At the end of three activities, you will be asked to stand at a distance you calculate for a kickball rolling at a certain speed. You will attempt a blindfolded kick of the ball at a certain distance you predict and will be [graded] according to your accuracy.
    - *OPTION*: Consider running a quick demonstration of rolling a ball, by hand or off a ramp, toward a blindfolded student. The student should stand perpendicular to the travel of the ball at a distance they predict the ball will be in 3 seconds.
    - Discuss: What might you need to know to solve the challenge leading toward understanding the ball's motion? Avoid formal definitions for now.

Teacher Tip: Focus on experiencing the phenomena before trying to define, in this case, a ball rolling at about the same speed. The assumption or observation of "constant" velocity and the possible observation of the ball slowing down can be discussed if it comes up with the presumption that we'll "think more about this later."

- Describe activity setup then start:

    - We will be moving to a large open area (open cafeteria, gym, hallway).
    - When we get there, find a space to roll a ball so that it moves about 5m in 5s.
    - You will drop [sugar packets] every second for 5 seconds, measure total distance to each sugar packet, and record these distances on paper..
    - You will have [15] minutes to complete at least one good ball roll and enter your data online. Go!

Teacher Tip: If you have a large class or not very much space to work in, consider using students rather than sugar packets as position markers. In this scenario, groups will need to include 7-8 students. Also, there are many alternatives to sugar packets such as scraps of paper. Different position markers present an opportunity to talk about limits to measurement. For example, paper may not fall straight down.

- After all groups have completed a successful ball roll, conduct a discussion about data collection and recording. Suggested discussion prompts:
    - How did you coordinate releasing the ball, dropping packets, taking measurements?
    - How did you measure time? When did you start the timer? If students are having difficulty with this, consider suggesting a four count: 3-2-1-go!
    - How did you measure distance? Where did you start from? How was that related to when you started measuring time?
    - How did you choose an "origin" for measuring distance? It is not critical where students define origin, just that it was consistent and relates to time zero.

Teacher Tip: Allow misconceptions (e.g. "The ball speeds up when it first leaves your hands") if present to exist for now.

Optional: Revisit or introduce Motion Maps as noted in Activity 1.2. Use the sugar packets as physical markers for motion map dots.

2. Collect and analyze data (30 minutes)

- Back in the classroom... Project page 1 of Activity 2.1. Choose a student group to provide data points for you to demo how to add data manually to a CODAP table..

- Demo how to create a position-time graph to remind students about dragging table headers to configure graph axes.

- Have students copy their own data into the CODAP table on page 1 of Activity 2.1. Make sure students choose "Run by Myself" when starting the activity so you can capture individual work for formative assessment.

Student Activity Page 1: Ball roll, data collection

(1) Collect your equipment:

- Playground ball
- 6-10 Sugar packets
- Measuring tape
- Timer and/or an [Online Metronome] (with sound turned on!)

(2) Roll your ball so that it goes about 5 meters (15 feet) in about 5 seconds, dropping a sugar packet each second. Repeat until you have at least two good runs.

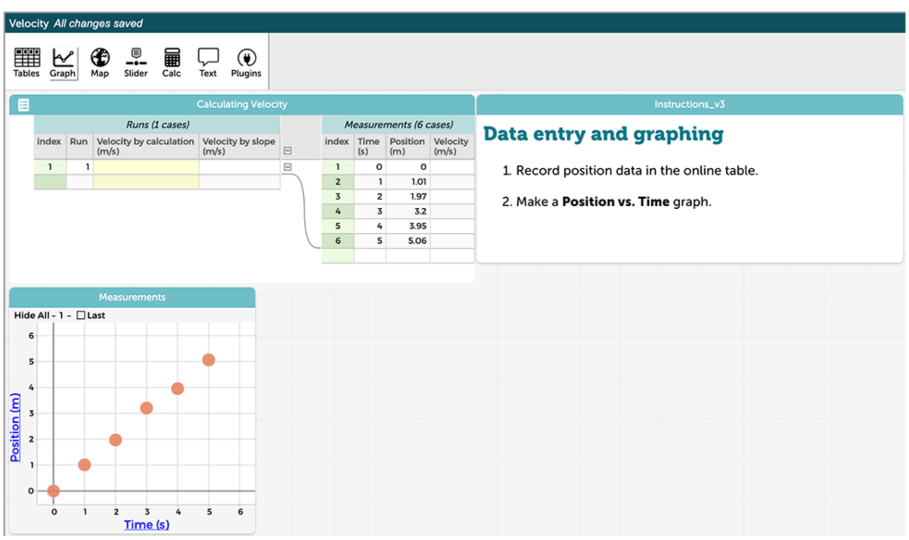
(3) Measure distance to each sugar packet from the start and write down on paper or in the interactive to the right.

Class discussion [STOP image]
Wait for instructions before continuing

Transfer data and make a graph
Open CODAP to copy data and create a Position vs. Time graph.

1. What story does the position vs. time graph tell about the movement of the ball?

INTERACTIVE



Name: CODAP velocity ball roll

[Links to Shared View, HTML Instructions]
https://codap.concord.org/releases/latest/static/dg/en/cert/index.html#shared=47610
https://inquiryspace-resources.concord.org/physics/Activity2-1-html-instructions/Instructions_v4.html

3. Advanced data analysis and calculating velocity (45 minutes)

- Discuss potential "outlier" or "bad data" issues.
    - It is likely that the first data point or two may be "off" based on the difficulty of starting the timer, placing the first marker of distance, and setting the origin.
    - Using the teacher report, bring up several graphs students created for discussion. Suggested discussion prompts:
        - Are there any data points that "stick out" or seem bad?
        - What do you think is going on there?
        - When we go to do our analysis of the motion of the ball, what should we do with these data?

NOTE: *The ball will obviously not roll at a constant velocity but will approximate constant velocity and provide a close-to-linear position-time graph. For this reason, the term "average velocity" is replaced with "velocity" in this unit except where explicitly averaging multiple velocity values.*

Technology Tip: *When the concept of "outliers" or "bad data" emerges, point out that erroneous data can be deleted or "set aside." Demo how one can select a data point in a graph or a row in a data table to delete or "set aside" (table only) as necessary. One should be hesitant to **delete** data unless they are significantly outside the expected range of normal variability.*

- Discuss the shape and meaning of the graph. Potential question prompts:
    - What story does this graph tell?
    - When the ball leaves your hand, is the ball moving?
    - What does it tell you about how the ball is moving?
        - Is the ball speeding up, slowing down, or rolling at the same speed?
        - If the same speed, will it roll forever? If not, why not?
        - Does the data show change in speed over the course of measurement? How would you know? How COULD you know?

- Discuss velocity between any two points. Consider introducing or deriving the formula for average velocity. Possible questions:
    - Discuss common ways we talk about speed, such as MPH in a car. Relate this to the graph students just created. How would you figure out average speed driving to a friend's house or on a long trip on a highway?
    - What do you need to know to calculate a speed?
      (A distance travelled and the time it took to travel that far.)
    - What units are we measuring?

- ○ How could you use the position time data you have to determine the velocity between the first and second recorded position?

- Demonstrate manual average velocity calculation with the first two points and add to the "Velocity" column in CODAP.

- Have students proceed to Page 2 of the online activity to review their position versus time graph then calculate the **velocity** between each measured position and enter this into the table. Students will then make a graph of velocity vs. time.

Teaching Tip: Hold off on formulas for now as students need to figure out and practice the calculation of average velocity first. Typing in formulas can also be tricky to start.

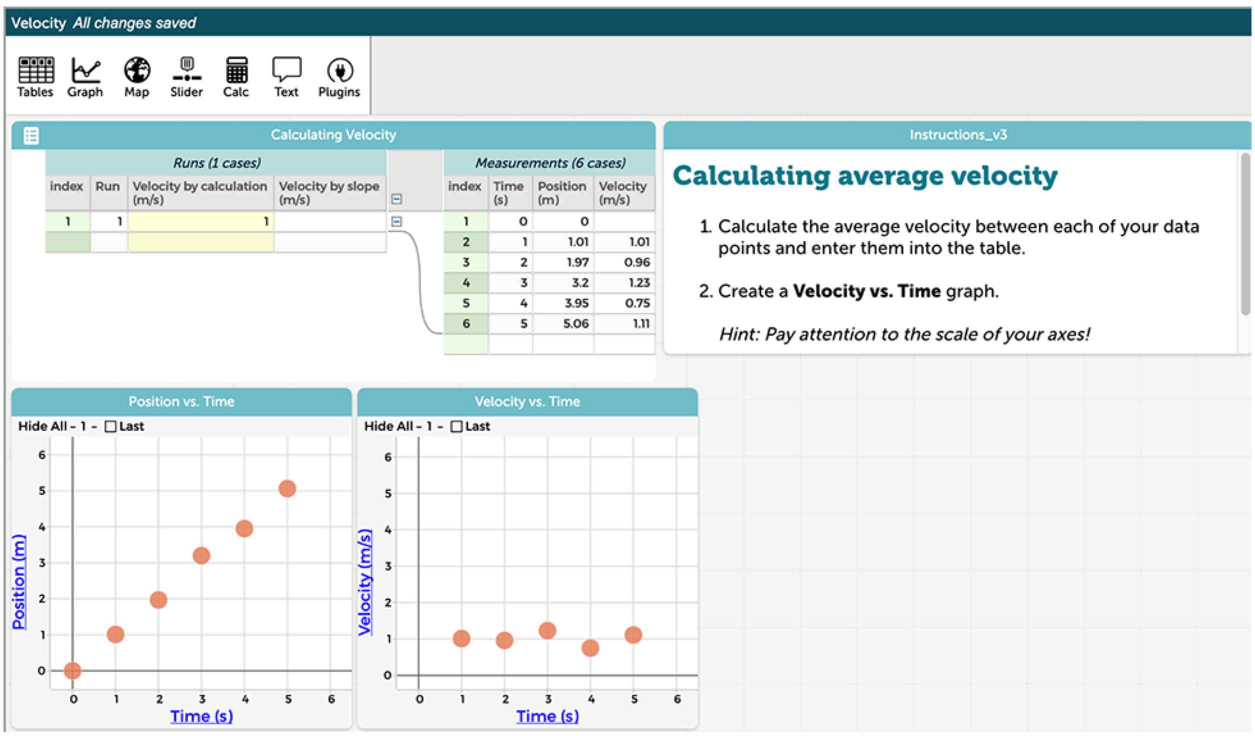
Student Activity Page 2: Calculating average velocities between points

2. What story does the position vs. time graph you created from your data tell about the movement of the ball?

Open CODAP to calculate and enter velocities for each time step and create a velocity versus time graph.

3. What story does your Velocity vs. Time graph tell about the motion of the ball? (Pay attention to your graph axes!)

INTERACTIVE - Linked to page 1 CODAP interactive



Name: CODAP Calculating velocity for each set of measurements

[Link to Shared View]
https://codap.concord.org/releases/latest/static/dg/en/cert/index.html?app=is&di-override=Instructions_v4&di=https://inquiryspace-resources.concord.org/physics/Activity2-1-html-instructions/Instructions_v4-p2.html#shared=47610

[html instructions]
https://inquiryspace-resources.concord.org/physics/Activity2-1-html-instructions/Instructions_v4-p2.html

4. Discuss variability and calculate run level velocities (30 minutes)

- Discuss variability in measurements.
  - Using the teacher report bring up one or more student documents to project as examples.
  - Possible questions:
    - Do you see a relationship in the velocity-time graph?
    - Are all the velocities in a run exactly the same? Why or why not? (relate back to the position-time graph)
    - How might we calculate a single velocity for the ball rolling on the floor in a particular run?

- Show calculation of a run-level value for velocity by showing the embedded formula and value under "Velocity by Calculation".

OPTION: Consider showing a univariate plot of velocities. If you do this, you may want to point out how the formula, mean(velocity), produces the value you see when you hover over the "Mean" line in the velocity distribution graph.

- Add a movable line to the position-time graph and discuss how slope relates to velocity.
  - Show students how to add a movable line.
  - Discuss how finding a function (like the formula for a line) is one way scientists make meaning of data.
  - Ask students to guide you to finding the best placement of the line.
  - Discuss how slope might be related to their calculations of average velocity.
    - What do you think the steepness of the line means?
    - What is slope and how do you calculate it? (rise/run, change in y / change in x)
    - What unit would you get if you calculated a slope on the Position vs. Time graph? (will get m/s which is a velocity)
    - Add a slope value (for each run) in the table.

- Have students run page 3 of the online activity to create their run-level average velocity columns and return for a discussion of the differing results.

Student Activity Page 3: Comparing velocity calculations

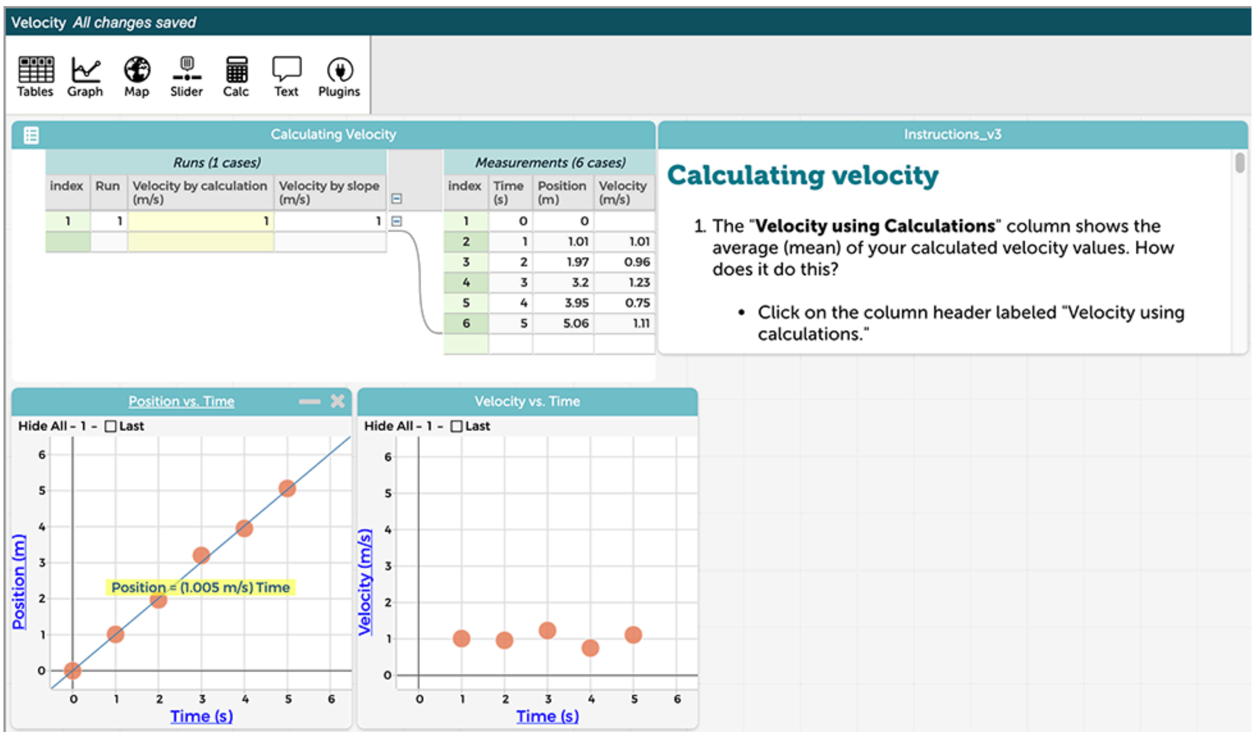
[TEXT BOX: Compare velocities]
Find the velocity of the ball by (1) noting the average of your velocity calculations, and (2) using the slope of your position-time graph. Compare these values to your velocity-time graph. Agan, pay attention to axes!

When ready, answer the question below.

5. Which calculation of average velocity do you have the most certainty in and why? Which is easiest to use?

Hit next to end the online activity and get ready for a class discussion.

INTERACTIVE - Linked to page 1 CODAP interactive



Name: CODAP finding average velocity multiple ways

[Link to Shared View]
https://codap.concord.org/releases/latest/static/dg/en/cert/index.html?app=is&di-override=Instructions_v4&di=https://inquiryspace-resources.concord.org/physics/Activity2-1-html-instructions/Instructions_v4-p3.html#shared=47610

[html instructions]
https://inquiryspace-resources.concord.org/physics/Activity2-1-html-instructions/Instructions_v4-p3.html

5. Compare velocity calculation methods (20 minutes)

- Use the teacher report to bring up one or more examples of student work to discuss the various ways velocity could be calculated. Focus on a velocity versus time graph, discuss:
    - What is the relationship of velocity over time? Does it look as expected?
    - How would you describe the variability in the graphs' points?
    - What might account for this variability?

- Discuss the various methods of calculating average velocity.
    - Which method of finding velocity do you have the most confidence in, slope or calculation? Why?
    - What are the pros and cons of each method?

      Agree as a class to use the slope method for calculating average velocity moving forward. This will allow students to identify the appropriate data in a position-time graph along which to place their movable line without having to remove extraneous data points manually.

      NOTE: Calculating using a formula at the run level includes all data, some of which may have more error than others, but is an objective measure. Slope involves some subjective measurement, but allows you to visually filter out the influence of certain data points if you think they are too far off from the range of variability found in the rest of the data.

- Wrap up and transition to next activity

    - Summarize key ideas from activity.

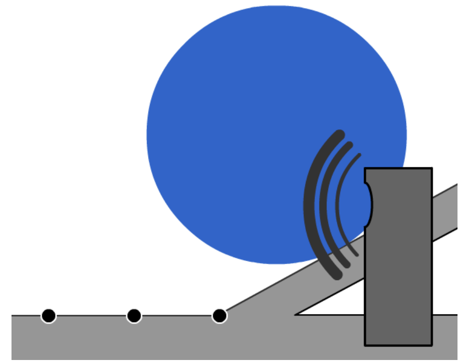
        - Data will have some natural and expected variability. Students will be expected to identify sources of "noise" in the data.
        - One should be careful about deleting data and should delete data ONLY if it is clearly understood why bad data was generated. An "outlier" that results from very careful research and is reproducible often leads to a big (or BIG, like Nobel-BIG!) prize.
        - There are often multiple ways to measure something and one needs to think carefully about how to choose a particular method.

    - End discussion by stating that we will move to use of sensors to get more precise quantitative measurements to be successful in the kickball challenge.

By measuring velocity with sugar packets dropped according to fixed time signals, students are introduced to the principle of velocity measurement in a very relatable way. This intimate knowledge may transfer to a qualitative understanding of the more sophisticated measurement tool of the motion sensor that will be introduced in the next activity.

Activity 2.2 - How can we measure velocity more precisely?

SUMMARY
This activity focuses on control of variables (COV) in experimentation. Students will do the "same" experiment, using the same independent variable and value of that variable.



Students will use motion sensors and large balls to attempt to get the same values for velocity across student groups. They'll be given minimal instructions, perform the experiment, discuss variation across experimental setups, then run the experiment again comparing variation from first to second try. Students will deepen their CODAP skills with data selection (in the sensor interactive), data cleaning, adding and moving columns, creating univariate graphs, and using basics statistics tools (mean) with graphs.

INQUIRY PRACTICES AND SKILLS

DESIGN	● Identify key variables to measure (DV), change (IV) and hold constant. ● Explore the limits, potential problems with experimental setups, and initial relationships between variables in such a way as to inform the final design of an experiment. ● Revise initial models through use of evidence from data collection and analysis.
COLLECT	● Identify limits of data collection tools and processes. ● Create a new user editable column for entering data that is not collected automatically through sensors or generated by simulations.
ANALYZE	● Using a univariate plot, describe the distribution of data and make comparisons between the center and spread of two or more univariate plots. ● Create unidimensional and bivariate graphs with a third dimension categorizing data by another parameter/variable. ● Provide appropriate rationale for discarding data from an experimental trial. ● Generate statistical measures such as mean, median, and standard deviation on graphs.

PREPARATION - Figure out a ball-ramp setup that works for your classroom. Refer for Activity 2-1 for notes on ball options.

MATERIALS ***per Group***

- Laptop with motion sensor setup
- 4' ramp with hot wheels track attached (see above)
- Basketball or playground ball fully inflated to minimize rolling resistance
- Meter stick

Investigation 2 - The kickball challenge
October 11, 2019

ACTIVITY OVERVIEW

1. **Class discussion - Measuring motion more meticulously** **15**
   a. Revisit ball roll and limits to measuring tools (sugar packets vs. sensors)
   b. Remind students about the kickball challenge
   c. Tell students that we are going to "DO THE SAME EXPERIMENT" using ramps and motion sensors to increase the accuracy and precision of our velocity measurements.
   d. Demo ball-ramp experiment
      - Give MINIMAL information
      - Demo selecting part of the data collected by the Sensor Interactive
      - Consider showing students how to add a "Velocity" column to the table
      - Consider demo of data cleaning before end of "Try 1"

2. **Collect and analyze data, first try** **30**
   a. Have students log in to page 1 of Activity 2.2 using "**Run with Other Students**" and conduct their first try of the experiment
   b. After a few groups have finished, project one group's work. Demo:
      - Data cleaning and rescale
      - Adding a movable line to find velocity
      - Adding a Velocity column to the left side of the table
   c. Have students add their slope/Velocity value to the board

3. **Discuss first try at "Doing the same experiment"** **15**
   a. Project a table and univariate graph of velocity values in CODAP
      - Copy student values from the board
      - Demo the statistics tool (ruler) and at least "Mean"
      - Consider rescaling the axis as appropriate
   b. Discuss why velocity values are so different
      - Move students toward "Control of Variables"
      - Keep focus on students - avoid the temptation to give answers
      - Ask how we could get more consistent results? Have students define a consensus procedure
      - If students bring up holding variables constant, reinforce the ideas of independent, dependent, and control variables

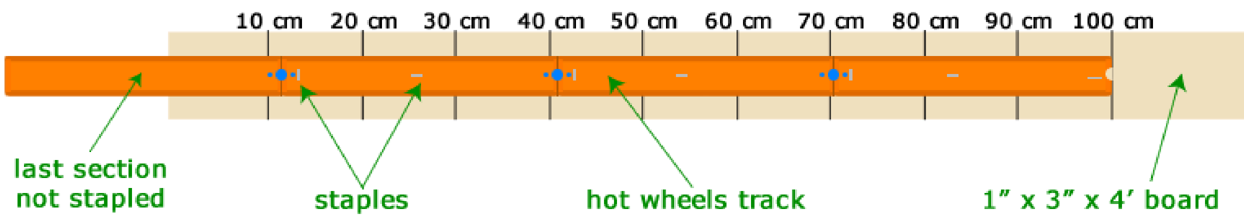
4. **Collect and analyze data, first try** **20**
   a. Have students log back online restarting at page 3 of Activity 2.2 using "**Run with Other Students**" and the new consensus procedure. Continue to the end of the online activity
   b. Have students write try 2 velocities on the board

5. **Compare velocity calculation methods** **20**
    a. Remind students that whenever they use "**Run with Other Students**" they MUST log out when done so their work doesn't get overwritten!
    b. Build a new univariate plot:
        - Enter Try 2 velocities in the same CODAP document you used for Try 1
        - Drag "Trial" to the left side of the table
        - Drag "Trial" to the left side of the univariate plot
        - Add "Mean" and "Standard Deviation" to the graph (ruler icon)
    c. Compare Try 1 and 2
    d. Note that we'll use the same consensus procedure to explore different values for our independent variable in the final activity.

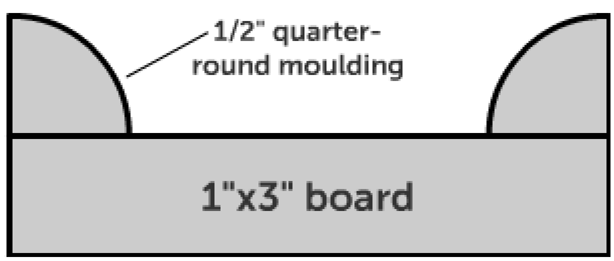
Total time 100 min

Note on building ramps

Your ramp must match your ball size. Wide U-channels such as inverted PASCO 1m or 2m tracks are ideal. You can also make your own ramps using inexpensive 1”x3” wood boards cut to 4 foot lengths. Avoid “furring strips” as these tend to warp. Add quarter-round moulding to the sides. Hot Wheels ramps will get reused in Investigation 3.



- Cut 4’ foot sections of 1” x 3” furring strips (or higher quality wood), enough for all groups.
- Nail quarter round moulding on either side of the track for use in Activity 2.
- Measure and mark every 10 cm up to 1 meter starting from the bottom of the ramp.
- Attach four 12” sections of hot wheels track starting at the 1 meter mark and running down past the end of the furring strip. This leaves about 6” of wood above the track for motion sensor placement. There will also be about 6” of track hanging off the bottom of the ramp creating a curved transition to the floor.
- Use ½” staples (⅜” are too small) and a staple gun to attach the track to the board. Staple through connectors and track parallel with the board and track for smoothest runs.



1. Intro and Demo (15 minutes)

- Start discussion by revisiting sources of variation in the ball roll activity with sugar packets.
    - Why did each of us measure a different velocity when we did the ball and sugar packet experiment? (different forces when pushing the ball)
    - What were the limits of your "measuring tool" (sugar packets and stopwatches)?
    - Why was there variation in the velocity measured from second to second? (inconsistencies in placing the sugar packets, timing, and measuring distances)

- Remind students about the kickball challenge:

    At the end of the next activity, you will be asked to kick a ball while blindfolded as the ball rolls by your foot. To do this you will calculate where to stand and have a timer that you can hear. For this to work you will need to be able to predict more precisely how a ball will roll when rolled a certain way. We will introduce some new tools to help with this.

- Tell students that we are going to "DO THE SAME EXPERIMENT" using ramps and motion sensors to increase the accuracy and precision of our velocity measurements.
    - The ramp will get the ball rolling at the same speed every time.
    - The motion sensor will give more accurate measurements for position-time data from which we can figure out velocity.

Teacher Tip - Consider referring back to 2-1 where students used their bodies as "motion sensors," dropping sugar packets every second. Consider using this opportunity to discuss "tools of science" and the quest for greater accuracy and precision, notable in physics.

- Demonstrate a playground ball rolling down a ramp held up with different sized books or equivalent.
    - Note that students will use a motion sensor but DO NOT show or note placement to allow for student variation in data collection.
    - DO remind students how to use the sensor, specifically (1) setting the toggle to cart (not person) and (2) plugging in all equipment before starting the online activity.

Teacher Tip - "PRODUCTIVE STRUGGLE": It is critical that students be given the leeway to build their ball-ramp system in different ways to provide fodder for discussion about the importance of consistency in experimental design and setup. For example, consider using books of different thicknesses to prop up the ramp. Also, do not give advice in placement or use of the motion sensor. Allow students to discover that placing bookbags (or themselves) in the path of the motion sensor adds error and/or noise to their data. Note that scaffolding has been provided to move understanding of both the practice of experimentation and concept of velocity forward.

- Project page 2 of online activity 2.2 noting that students will be using the sensor-interactive again.
    - Show students that they can move or minimize the window but must not close the window by hitting the “X” in the upper right hand corner.
    - Demo one ball roll with data selection (Sensor Interactive) and cleaning in CODAP.
        - Make sure to show selection of data in SensorInteractive
        - Make sure to demo removal of outliers.
        - You could project the video below or have a set of collected data ready for cleaning so students don’t see placement of the sensor.

Tech Tip Video: Selecting and cleaning data from Sensor Interactive in CODAP

Teaching Tip: Students will be prompted to add their own column for Average Velocity of a run on the left side of the table as well as make a position-time graph. You may want to project at least adding the new column to give students a reference.

2. Student trial, first try (30 minutes)

Have student groups gather materials, set up their ball-ramp-sensor system, then record one run of “good” data online using “Run with Other Students.” They will stay in this mode, working online as a group, for the entire activity. As students finish they will write a velocity on the board. See details in the discussion following these student pages below.

Student Activity Page 1: Design

You just observed your teacher use a ramp to start a ball rolling. In the last activity you used something like sugar packets to measure velocity. You will now use a motion sensor to get automatic and precise position and time measurements of a ball rolling on the floor. We will start by all doing the same experiment.

Before starting your first trial of what will become a class experiment, reflect on what you already know. Answer the questions below then move on to the next page to start your trial.

1. What did you observe in the class demonstration of the experiment? Add as much detail as you can.

2. Describe the setup you will be using and what you will be measuring.

3. How might you figure out velocity of the ball on the floor using your data?

Student Activity Page 2: Collect and analyze, first set of trials

Do the same ball-ramp experiment that was demonstrated by your teacher. Follow the instructions below or in the interactive. Be prepared to share your results.

[Text Box] - Collect data for your trial and analyze

(1) If you haven't already, gather materials provided by your teacher:

- Ramp
- Ball
- Motion sensor, interface box, cables, and laptop

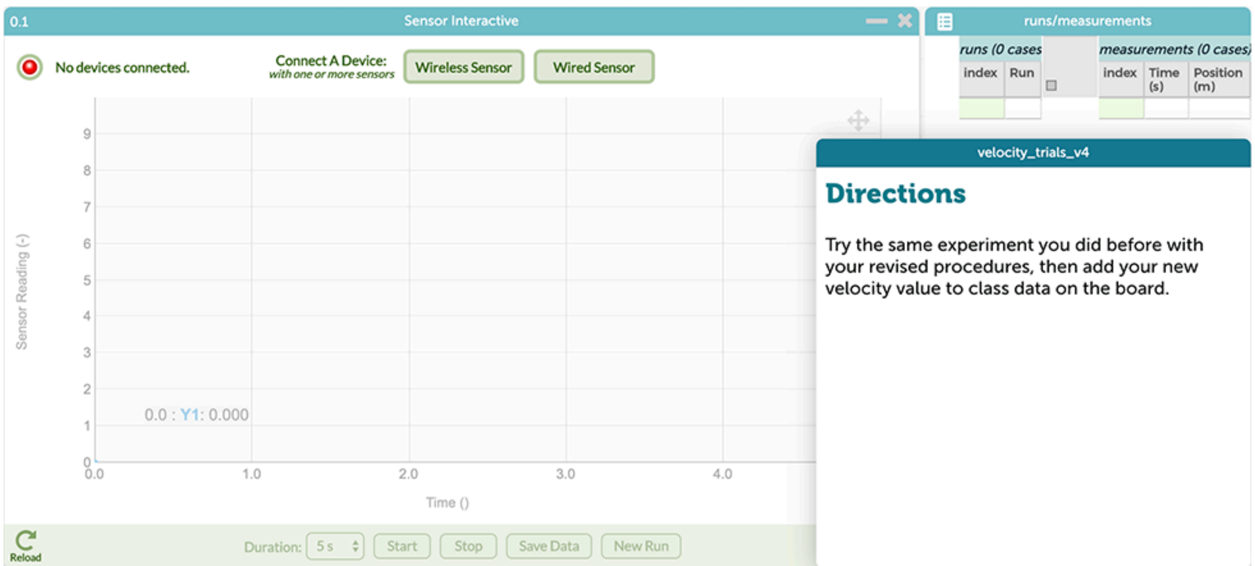
(2) Collect one run of data.

(3) Use the directions in the interactive to:

1. Make a Position vs. Time graph.
2. Add a column to the left side of the table then add the value for Average Velocity using slope from your position-time graph.
3. Place your value for velocity of the ball on the floor on the class white board.

Wait for instructions before continuing.

4. Name: CODAP constant velocity experiment 1



[Link to Shared View]
https://codap.concord.org/releases/latest/static/dg/en/cert/index.html#shared=47778

[HTML Instructions in CODAP]
https://inquiryspace-resources.concord.org/physics/Activity2-2-html-instructions/velocity_trials_v4.html

As the first few groups finish their work...

- Use the teacher report to project an example of student work for discussion. Look for the name "CODAP velocity measurement exp 1" (Question 4 in the second activity).

- Demo calculation of average velocity using slope on the Position-Time graph.
  - **Add a movable line to the position-time graph.** Use the slope to find the velocity of the ball on the floor. Discuss why this works as appropriate to your class.
  - Create a new column titled **Velocity** to the left side of the table and manually add the slope value here.

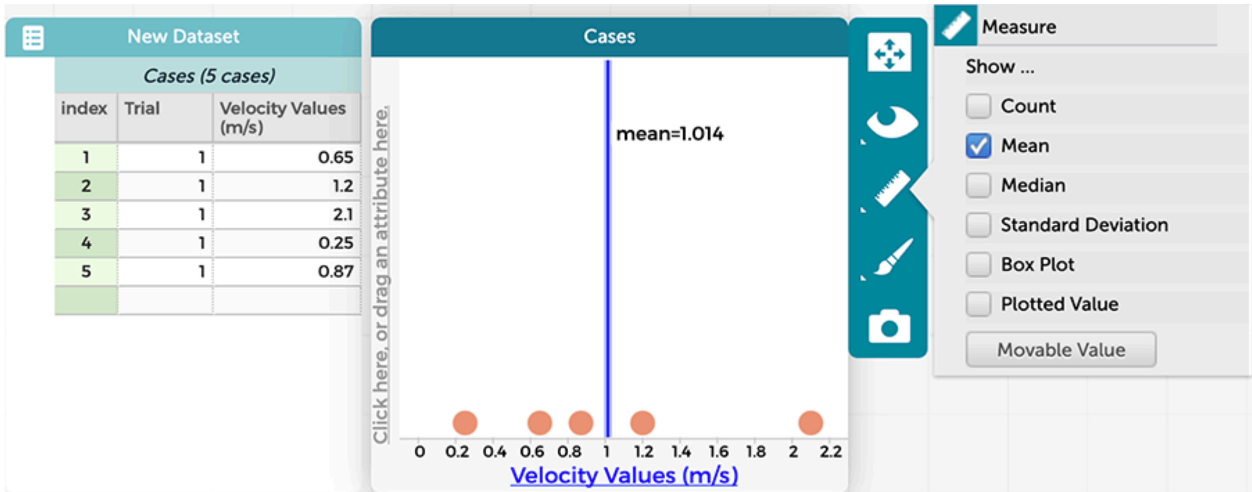
- Demonstrate data cleaning.
  - Discuss the difference between "noisy" data and "outliers" (bad data attributable to a cause) as well as when to keep, "set aside," or "delete" data cases in the table.
  - Demonstrate that highlighting a data point in the table or graph highlights the corresponding data point in the other.

Technology Tip: Deleting data is permanent. **Setting aside** data (in a data table) is temporary - data appears to be deleted but you can restore it at any time. To "set aside" data, select some table data, click on the table's eye icon, then choose "set aside…" This same icon allows you to restore the data. Note that you can only "hide/show" data in graphs.

- Give students time to finish creating graphs and/or figure out Average Velocity values if they haven't done so already. Make sure everyone writes their Average Velocity value as measured using the slope method on the board.

3. Student trial, first try discussion (15 minutes)

- Demonstrate analysis of class data with a "univariate" plot*.
  - Project a new (preferred) or pre-setup (as needed) CODAP document.
  - If new:
    - Create a table with columns for "Trial" and "Velocity Values".
    - Set units for "Velocity Values" to "m/s".
  - Copy student velocity values from the board to the table.
  - Create a univariate plot by dragging "Velocity values (m/s)" to the x-axis.
  - Add a mean line by clicking on the graph, measurement tool (ruler), and "mean". You can also add Standard Deviation or a Box Plot with explanation as appropriate.



Tech Tip: Use the resize tool in the graph window's tool palette  to autoscale graph points.

- Presuming the values vary widely, ask the class why this might be and suggest that our goal is to come up with a consensus procedure that each group will follow in a second trial to minimize variation. The goal is to help them discover the "control of variables" strategy on their own. Avoid the temptation to "tell" them!
  - Discuss differences in group setups and use of motion sensors.
  - Keep focus on student-student conversation, for example, "Does anyone have a question for this group about their set-up?"
  - Move toward a consensus procedure that better reflects doing the same experiment.
  - When students clearly state the need to hold most variables constant, mention that this is one of several explicit scientific strategies for organizing experiments and thinking. This is a good time to reintroduce, **independent**, **dependent**, and now **control** or **constant** variables.

Teacher Tip: If one or more group results are clearly outliers, use this opportunity to again discuss outliers versus noisy data and how to "set aside" these results temporarily.

4. Student trial, second try (20 minutes)

Ask groups to answer some questions online (page 3) then rerun the experiment on page 4 using the new consensus procedures they developed.

Student Activity Page 3: Iterating the experiment

Answer the questions below then move to the next page to re-run your experimental trial.

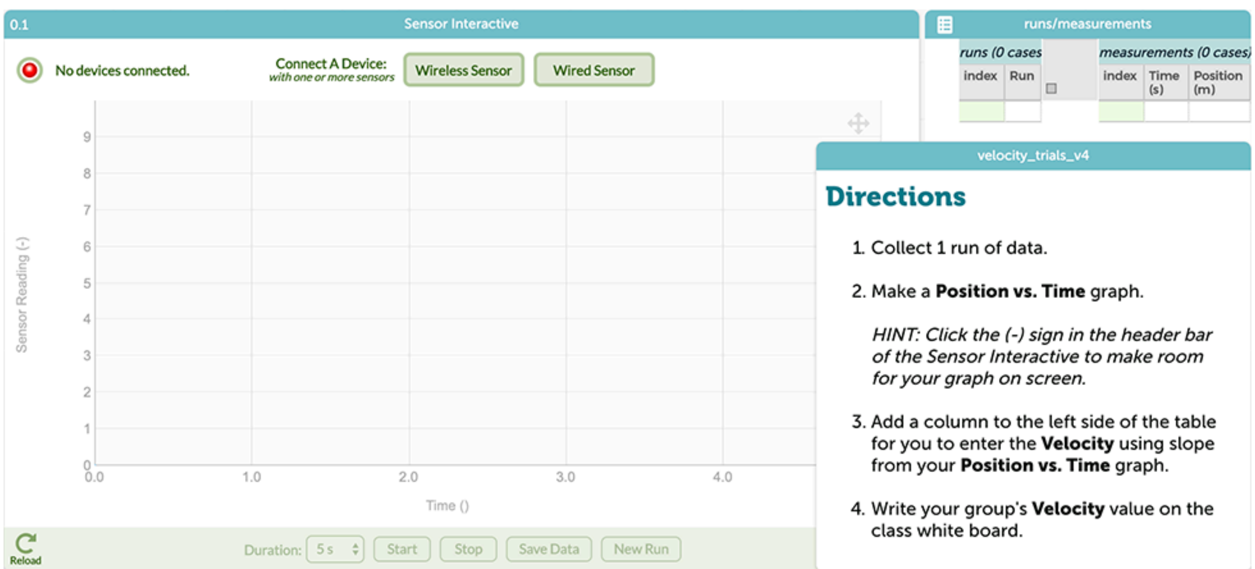
6. Why didn't everybody get the same velocity on the floor?

7. What will you change in your experimental procedure to get more consistent results across class data?

Student Activity Page 4: Collect and analyze, second set of trials

Try the same experiment you did before with your revised procedures. Then add your average velocity value to class data on the board.

Name: CODAP constant velocity experiment 2



[Link to Shared View]
https://codap.concord.org/releases/latest/static/dg/en/cert/index.html?app=is&di-override=velocity_trials_v4&di=https://inquiryspace-resources.concord.org/physics/Activity2-2-html-instructions/velocity_trials_v4_2.html#shared=47778

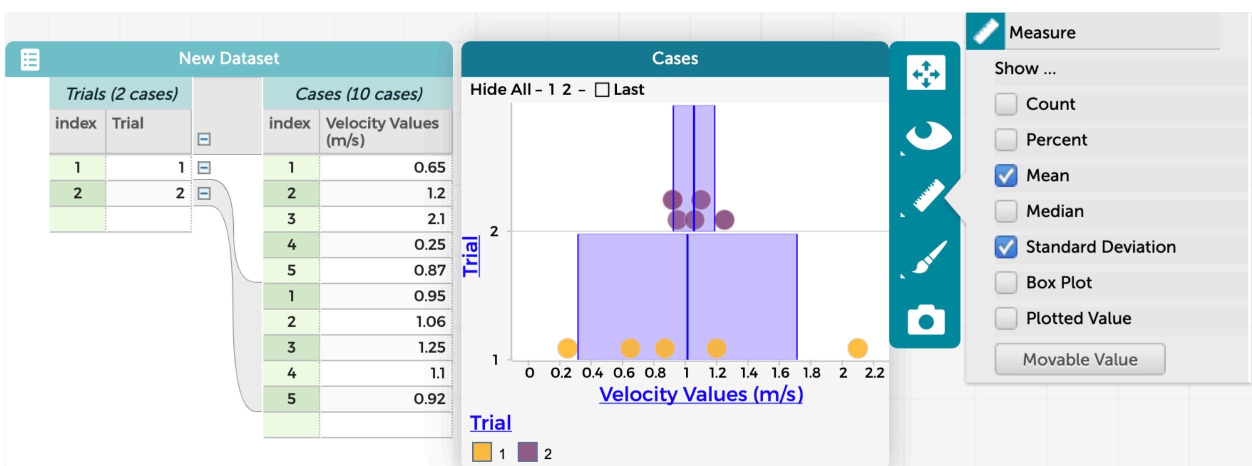
[HTML Instructions in CODAP]
https://inquiryspace-resources.concord.org/physics/Activity2-2-html-instructions/velocity_trials_v4_2.html

5. Student trial, second try discussion (20 minutes)

- Have students write their trial 2 **Velocity** values for the new run on the board.

- Again, manually enter group values into your data table to produce a univariate plot.
  - Use the same CODAP document as you did earlier in the lesson.
  - Change trial number to "2" and enter new velocity values.

- Organize data in your graph for easy viewing and analysis as seen below:
  - Drag "Trial" to the y-axis. Since "Trial" was created as a "categorical" variable (not a number), this will stack 2 univariate plots for comparison.
  - Drag "Trial" to the left side of the table to create a level of hierarchy. This allows you to quickly select all elements of a trial. Demo clicking on trial numbers and the -/+ signs between sides of the table to easily select groups of data.
  - Drag "Trial" to the center of the graph to color trials by number. Demo selecting trials by clicking on their legend name/color box.



***Tech Tip:** A true univariate plot only shows values along one axis. When you add a **categorical** variable, like "Trial" in this case, to the y-axis, and a **numeric** variable to the x-axis, CODAP will create and stack univariate plots for each category.

- Use the statistics tool (ruler) to compare means for the class values.
  - You can also explore the statistics tools of median, standard deviation, and/or box plots with or without explanation as appropriate.
  - You should see a tighter clustering of the velocity values though still some variability, providing another opportunity to talk about outliers and sources of variability in data even with more tightly controlled methodology.

  - Note that all experimentation contains a degree of uncertainty and that our goal, as experimenters, is to minimize uncertainty, measurement error, etc.

- Remind students about the kickball challenge and that we'll use our data analysis skills with CODAP to explore how changing values in one variable in the car-ramp system affects velocity on the floor.

Teacher Notes:

- Consider reintroducing this experiment in forces, energy.

Activity 2.3 - How do you know when you know?

SUMMARY
This activity uses the kickball challenge to answer the question, "How do you know how many trials are enough in an experiment?" Students explore multiple trials for one value of one variable. Class data will be combined to graph multiple values for one variable and interpolate a solution to the kickball challenge - standing blindfolded, perpendicular to the path of a rolling ball released at a calculated distance from the end of a ramp, and kicking at a calculated time depending on how the instructor sets the value of each group's independent variable.

While performing the experiment, use of the COV (control of variables) strategy for organizing an experiment will be reinforced by brainstorming independent variables, choosing one as a class to fully explore within a ball-ramp system using motion sensors, and collaborating on a common methodology for testing. Students will deepen their data analysis skills by building hierarchy in tables and using simple formulas for the first time on their own.

INQUIRY PRACTICES AND SKILLS

DESIGN	● Collect enough data to account for variability between trials. ● Collect data over a broad enough range to support claims about relationships between variables. ● Revise initial models through use of evidence from data collection and analysis.
ANALYZE	● Group data into appropriate hierarchical structures to characterize observations as experiment-level data and run-level data.
EXPLAIN	● Generate appropriate data representations to support claims related to a particular phenomenon.

PRIOR KNOWLEDGE - Students understand and have agreed on the importance of a consistent experimental setup for ball-ramp system experimentation. In addition, students should be experienced with the basics of CODAP including graphing.

PREPARATION - Select location and method for safely conducting the kickball challenge.

MATERIALS ***per group***

- Laptop with motion sensor setup
- 4' ramp (see notes in 2-2)
- 6-10" Playground ball fully inflated to minimize rolling resistance
- Measuring tape
- Blindfold or equivalent

ACTIVITY OVERVIEW

1. **Review Kickball Challenge and Velocity** **20 min**
   a. Students log in and complete page 1-2 of Activity 2.3 using "**Run by Myself**"
   b. Make sure all students have logged out of the online activity
   c. Discuss, whiteboard, and/or project:
      - Why is slope the same as velocity in an XT graph?
      - Review the kickball challenge; What do we need to know to figure out where to stand? (X=VT)
      - Share some student-invented velocity problems

2. **Ball-ramp experimental design and data collection** **40 min**
   a. Overview experiment
      - Review 2-2 and consensus procedure
      - Review possible independent variables; Choose one as a class
      - Each group will explore one value of the independent variable
   b. Decide on range and number of values of the independent variable to test
   c. Discuss the concept of trials; How many are enough? (Don't answer yet)
   d. Demo collection of one trial of data; Add [Distance up Ramp] column
   e. Have student groups run pages 3-4 of the online activity - "**Run with Others**"
   f. Once all groups have completed several trials, project/demo and discuss reporting a single velocity for each value of the independent variable

3. **Analyze group data** **30 min**
   a. Make sure all groups have logged out of the online activity
   b. Have all students log back into page 4 of the online activity as "**Run by Myself**"; Ask that students follow along with you.

> Tech Tip: CODAP Activity Summary video

   c. Project a copy of one group's work [CODAP Kickball Challenge Group Results]
   d. Review variation, outliers, and data cleaning as needed
   e. Discuss/confirm a method for reporting a single velocity value across trials
      - Remove outliers
      - Average velocity values
   f. Demo hierarchy - drag the [Distance up Ramp] column to the left
   g. Demo formulas
      - Create a new column for average velocity next to [Distance up Ramp]
      - Add the formula, mean(Velocity)

4. **Collect and analyze data, first try** **30 min**
    a. Groups report single values for velocity by [distance up ramp] on the board
    b. Have all students continue to page 5 online (still as "Run by Myself")
    c. Demo creating a table and graph of [Distance up Ramp] vs. Velocity
        - Copy student velocity values by [Distance up Ramp]
        - Demo using a "Movable Point" (ruler tool)
    d. Hand out challenge values for each group to solve for Velocity on floor

5. **Kickball challenge** **45 min**
    a. Set expectations (safety, no testing, no talking, just countdown... 3,2,1, kick!
    b. Take challenge group by group
    c. Have all students finish with reflection on page 6 online (still as "**Run by Myself**")
    d. Note that we'll next focus on movement on the ramp - changing speed

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Total time **165 min**

Technology Tip: Mechanics of formulas in CODAP

- Formulas are case sensitive and must be exact - no extra spaces!
- Demo "insert function" and "insert value". All variables and functions will be colored if correct.
- Demo "autocomplete" ... just start typing
- Note use of parentheses and "order of operations"

    REF: "PEMDAS" - Parentheses, Exponents, Multiplication, Division, Addition, Subtraction)

1. Reviewing and previewing velocity (20 minutes)

- Now that students have explored a single run in detail, explain that we will figure out how to explore a full range of velocities by changing one variable in the ball-ramp system. Describe the kickball challenge in detail:

  As a class we'll figure out an experiment that changes one variable to get the ball rolling off a ramp at a velocity between about 0.2 and 2.0 m/s. As a group, you will figure out where a blindfolded member of your group should stand, perpendicular to the path of the rolling ball, such that kicking forward at exactly 3 seconds from the ball rolling off the bottom of the ramp connects their foot to the ball.

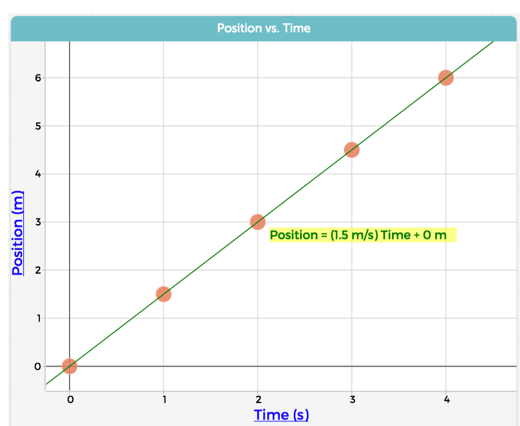
- As appropriate, ask students to complete pages 1-2 of activity 2.3 online. These pages act as a review and conceptual assessment of constant velocity. Make sure students log in with the "Run by Myself" option to capture individual work.

Teacher Tip: To solve the kickball challenge, students will need to reason through and manipulate a formula similar to V= ΔX/ΔT, specifically that X=VT. How you get here depends on you and your students. One option is to give the following online activity page or equivalent for homework as appropriate. This page is also available online as a Google Doc and as a PDF. Additional in-class or homework may be desired and/or needed.

Student Activity Page 1: Velocity review

Answer the questions below and on the next page.

1. In your own words, what is Velocity?
2. A unit for velocity is meters per second (m/s). Why does this unit make sense?
3. Why does it make sense that the slope of the line in the **Position-Time** graph also gives you velocity?
4. If a ball rolling off a ramp moves at 1.5 m/s along the floor, as shown in the **Position-Time** graph, how far will it roll in 10 seconds? Explain how you figured this out.

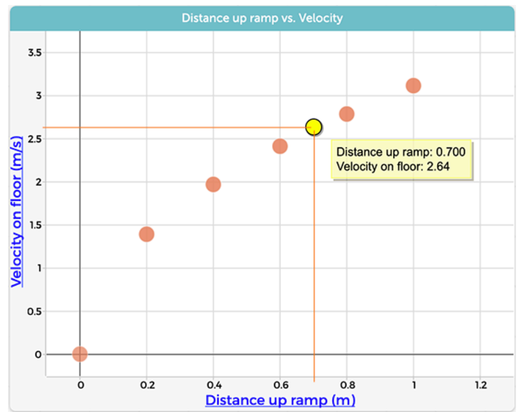


Hit "Next" to finish answering velocity questions.

Student Activity Page 2: Velocity preview

You perform an experiment measuring how fast a ball rolls on the floor after being released at different distances up a ramp. You use your results to build the graph, "Distance up ramp versus Velocity."

5. Use this graph to figure out how fast the ball will be rolling on the floor if you release it 0.7m (70cm) up the ramp.
6. You will take the kickball challenge at the end of this activity. If your teacher gives you a "**Distance up ramp**" of 0.7m (70cm) to release the ball, how could you figure out how far to stand from the ramp so you kick the ball perfectly at 3 seconds?



Reference the "**Distance up ramp vs. Velocity**" graph to explain your answer.

Time for class discussion!

Wait for teacher direction before continuing.

- Bring students back to discuss/review the concept and calculation of average velocity and how knowing both velocity and time can help solve for distance in the challenge.
- Consider using the teacher report to show one or more student-invented problems and ask for volunteers to show problems that the entire class can solve. Make sure to relate discussion directly back to the kickball challenge.
- Before continuing, tell students they MUST log out of the online activity as they will continue in groups. Confirm all students are logged out.

2. Ball-ramp experimental design and data collection (40 minutes)

OPTIONS: Experimentation before the kickball challenge allows students to explore how many trials are “enough” as well as data organization with CODAP.

This guide presumes each group will explore and run a number of trials for a single value of your independent variable [e.g. Distance up ramp]. In this scenario, class data will be messy due to human and ball variation and will typically lead to productive conversation about control of variables.

If you believe your students are not ready to learn hierarchy or formulas in CODAP, you could have each group run only one trial across a range of values of the independent variable. This option simplifies use of CODAP at the expense of exploring how many trials are “enough.”

Teacher Tip: When discussing “how many trials are enough,” avoid being prescriptive. For example, to account for limited class time, suggest groups conduct “as many trials as you think are reasonable in the next [10] minutes” rather than give a specific number such as “at least 3 trials.” Use of specific numbers will typically stick in students’ minds as a “correct answer” where, in true scientific experimentation, number of trials needed is based on statistics - it depends!

- Tell students that they will now conduct a full experiment, as a class, changing one variable in the ball-ramp system as part of the kickball challenge. Together we will collect enough data to solve the kickball challenge. Briefly review the experimentation framework.
    - What did we observe in Activity 2-2, measuring velocity of a ball rolling off a ramp?
        - Discuss inherent variation in the system e.g. ball used, ball transition to floor, bouncing, etc.
        - Confirm ball roll procedure agreed upon in Activity 2.2.
    - What can I measure?
        - Given that we need to know velocity of the ball rolling on the floor, we will be using motion sensors to collect distance-time data. Review placement of motion sensors, ways to minimize false readings, etc.
    - What can I change (in the ball ramp system to change velocity on the floor)? e.g.
        - Starting distance (or height) of the ball up the ramp
        - Angle of ramp
        - Ball used (unique properties of diameter, mass, hardness, surface, etc.)

Teacher Tip: Distance up Ramp will be the easiest and most consistent variable to change. However, depending on timing and your needs, consider giving the class agency to choose their own variable as a class or in individual groups. For simplicity we will use **Distance up Ramp** in the example text that follows.

- Ask students to agree on one variable to change, state this in the form of an investigable question, and come up with a consensus procedure as a class, including control of other variables, such that every group is able to create reproducible results. Suggested discussion prompts:
  - Which variable should we study to use in the kickball challenge?
  - What is our investigable question?
  - How can we design a procedure that we will all use so that we can get comparable results?
  - How many trials should we run for each value of our independent variable?

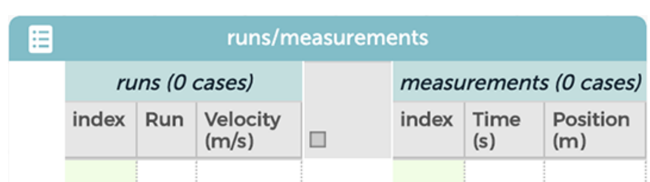
- As a class, decide how to break up values for the independent variable across groups.
  - What is the full range of values for our independent variable?
  - How many data points along that range do we need to test to be confident?
  - Decide on values to be tested and allow groups to choose (or assign if needed).

- Project page 4 of Activity 2.3 to demo the collection of one trial, and ask students, "What information is missing from the table we have here?"

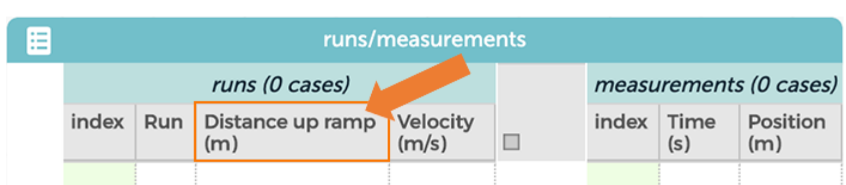
  *NOTE: **Students MUST add a column to record the value for [Distance up Ramp].** Try to draw this information from the students rather than just telling them what is needed.*

- Ask students to return to page 3 of the online activity, logging in as groups, to answer a few questions then start their experiment.

Students will start with the top data table when running Sensor-Interactive in CODAP on page 3.



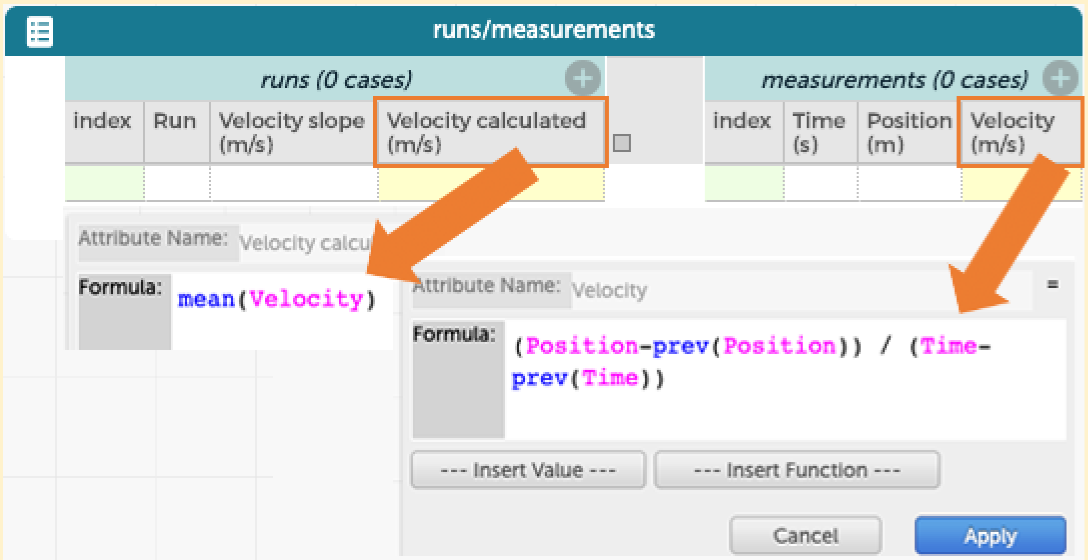
They will need to add an additional [Distance up Ramp] column between "Run" and "Velocity" before collecting data.



Differentiation - Advanced CODAP with Formulas:

If you and your students are ready for using complex formulas in CODAP, consider demonstrating automation of velocity values with or without comparing to slope.

Summary:



Details:

- Collect at least one run of data if you haven't already.
- Move the "Velocity" column to the right side of the data table and add the formula: (Position-prev(Position)) / (Time-prev(Time))
- Discuss calculation of velocity between data points - Why does this formula work?
- Note the mechanics of using a formula in CODAP:
  - Formulas are case sensitive and must be exact - no extra spaces!
  - Demo "insert function" and "insert value". Note that all variables and functions should be colored if input correctly.
  - Demo "autocomplete" for the formula above.
  - Note use of parentheses and order of operations generally (PEMDAS - Parentheses, Exponents, Multiplication, Division, Addition, Subtraction)
- Add a **"Velocity slope"** column and value for at least one run to the left side of the table.
- Add a "**Velocity calculated**" column next to "Velocity slope" with the formula mean(velocity) on the left side of the table.
- Compare velocity values from slope and calculated values. Which value gives you more confidence? Which will be easier to use when you have lots of runs?

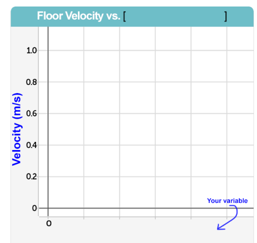
Student Activity Page 3: Design your experiment

Answer the questions below then move to the next page to start your experiment.

7. What (independent) variable will you be changing in the ball-ramp system and what values of this variable will you be testing?

8. What (dependent) variable will you be measuring in the ball-ramp system? and how?

9. Write your investigable question in the form: How does [independent variable] affect the velocity of the ball on the floor?



10. [drawing prompt] Draw a graph showing how you think changing your independent variable will affect velocity of the ball on the floor. Type the variable you are studying on the X-axis.
[text prompt] Describe what your graph predicts.
https://inquiryspace-resources.concord.org/physics/background_velocity_vs_IV.png

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Student Activity Page 4: Collect your group's data

Use this page to run your experiment. When done, hit "Next" to combine data across class groups.

Name: CODAP Kickball Challenge Group Results
[Link to Shared View]
https://codap.concord.org/releases/latest/static/dg/en/cert/index.html#shared=48916

Directions
Add a column to the left side of the table to record values for your independent variable.
Run multiple trials for each value of your independent variable.

- Build a position-time graph.
- Fit a movable line to your graph.
- Use the slope of the line to find a velocity for each trial.
- Add the velocity value for each trial to your data table under "Velocity slope".

Be prepared to discuss why you ran the number of trials you did.
https://inquiryspace-resources.concord.org/physics/Activity2-3-html-instructions/constant_velocity_challenge_v2.html

3. Analyzing group data (30 minutes)

- Once all groups have completed several trials for their value(s) of the independent variable, lead students in a plan for calculating velocity for each value of [Distance up Ramp] and sharing data across groups.

  Goal: Have students report a single value for velocity based on a measure of [Distance up Ramp]. For example, what is the velocity of a ball that is released from 0.2 m up the ramp?

Teacher Tip: Consider projecting a copy of one group's CODAP data and having all student groups follow along online. When done, students can write their velocity values on the board.

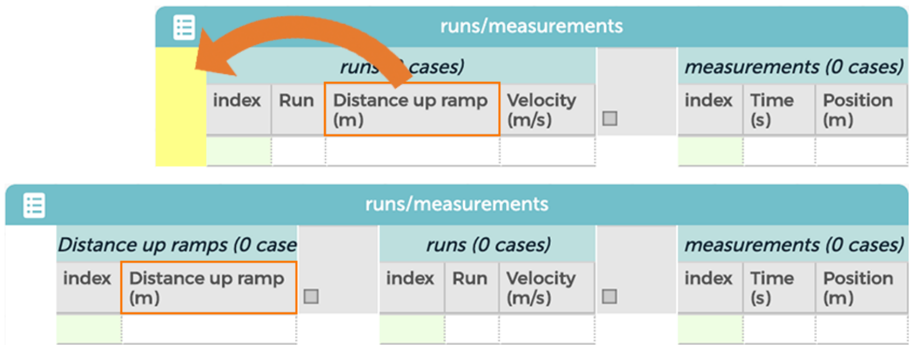
- Have ALL student groups log out of the online activity. Once you have confirmed ALL groups have logged out, have EACH student log into the activity by themselves (Run by Myself). This will insure that ALL students get experience working with CODAP. Confirm all students have logged in before continuing.

Tech Tip: CODAP Activity Summary video

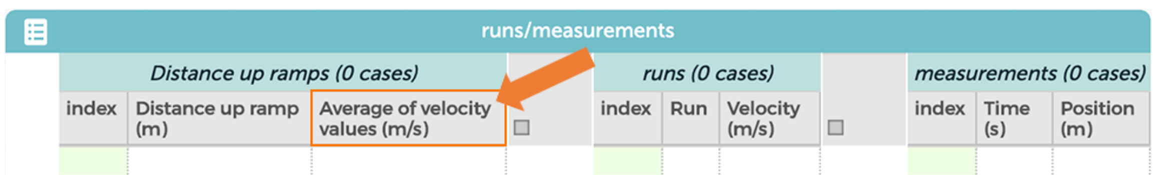
- Discuss and confirm data cleaning as needed. Expect that at least some students will still be figuring out data selection from the Sensor Interactive, removal of outliers, etc.
  - Demo/remind students that CODAP autoscales graph axes and how to rescale axes. Discuss actual differences between values to determine whether one or more points are really outliers before "setting aside" or removing data points.
  - If students decide to remove a trial, they should either delete it (trashcan icon) or use the "Set aside" option (eyeball icon) in the data table.

- Discuss and confirm a method for averaging results of trials and producing a single velocity result for each value of [Distance up Ramp]. Potential prompts:
  - How should this group combine values for velocity at [Distance up ramp]?
  - Should they average them? If so, should they include all measurements?

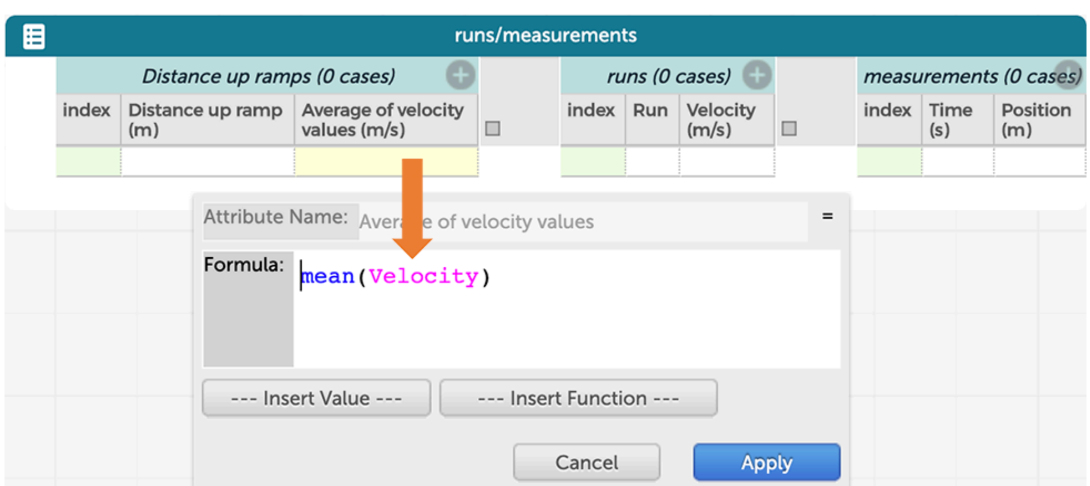
- Demonstrate adding hierarchy to a CODAP data table by dragging your column containing values of the independent variable [Distance up Ramp] to the left side of the table.



- Add a new column on the farthest left side of the data table labeled something like, "Average of velocity values." This will hold a single value for all trials at that value for the independent variable.



- Demonstrate adding a simple formula, mean(Velocity), to average velocity trials for each value of the independent variable. Note the mechanics of using a formula in CODAP:
    - Formulas are case sensitive and must be exact - no extra spaces!
    - Demo "insert function" and "insert value". Note that all variables and functions should be colored if input correctly.
    - Demo "autocomplete" for the formula above for use once you/students are comfortable with adding formulas.



4. Use class data to prepare for the challenge (30 minutes)

- Continue projecting CODAP table hierarchy and column headings for reference.

- Create a table on the board with the columns **Group, [Distance up Ramp] , Velocity Value.** Have students continue the online activity on their own, each calculating a single velocity number for their value of the Independent Variable. When the group is ready, have one group member write that value on the board.

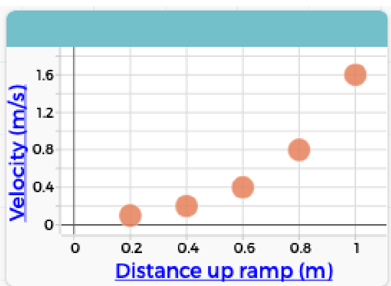
- Once all groups have contributed data, project page 5 of the online activity and co-build a table and associated graph of independent variable [Distance up ramp] versus average velocity.

- Demonstrate use of the "Movable Point" option under the statistics tool to interpolate a value between data points.

New Dataset

Cases (5 cases)

index	Distance up ramp (m)	Velocity (m/s)
1	0.2	0.1
2	0.4	0.2
3	0.6	0.4
4	0.8	0.8
5	1	1.6



  - Ask students to continue with page 5 of the online activity.
  - Students will be prompted to copy values for the independent variable and associated velocities into a CODAP data table they create.
  - They only need 2 columns - One for their independent variable [Distance up ramp] and one for velocity.
  - They will also produce a parameter space graph from which to interpolate a value of their independent variable for a given speed in the kickball challenge.

- While they are working, hand out the value for [Distance up Ramp] that they will use for the challenge. Ask students to work as a group to predict velocity of the ball on the floor given this value.

Teacher Tip: You may want to pull the class together to scaffold how to use the [Distance up Ramp] vs. Velocity value graph for predicting velocity, or work with individual groups as they struggle to calculate the distance they will need for the kickball challenge. However, you are encouraged to let them work at the problem together and to use what they know about velocity units to help them solve the problem.

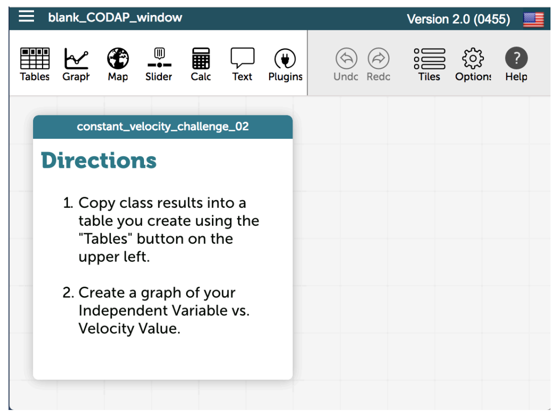
Student Activity Page 5: Collect and analyze class data

Use this page to gather class results for velocity versus values of your independent variable.

Instructions
Use this blank CODAP document to create a table and graph of class results. When finished, answer the questions below to get ready for the kickball challenge.

12. How can you use the graph of **Independent Variable** vs. **Velocity Value** to predict the velocity of the ball given any value for your independent variable?

13. Pick a point between any two graphed values for your independent variable. What would the velocity of the ball be if the experiment was set up to use that value for your independent variable?



Wait for your teacher to give you your kickball challenge value for your independent variable before continuing...

14. What value of the independent variable did your teacher give you will use for the challenge?

15. How far do you predict the ball will roll in 3 seconds if you use the value for your independent variable when releasing the ball?

16. How certain are you about your prediction? [1 - Not at all certain,2,3,4,5 - Very certain]

17. Explain your certainty rating.

Wait to continue
Once you have calculated your distance value, you are ready for the challenge!

Name: CODAP Kickball Challenge Class Results
[Link to Shared View]
https://codap.concord.org/releases/latest/static/dg/en/cert/index.html#shared=48329

[background image for click to play]
https://inquiryspace-resources.concord.org/codap-logo-for-click-to-launch.png

Directions
1. Copy class results into a table you create using the "Tables" button on the upper left.
2. Create a graph of your Independent Variable vs. Velocity Value.
https://inquiryspace-resources.concord.org/physics/Activity2-3-html-instructions/constant_velocity_challenge_02.html

5. Kickball challenge (45 minutes)

- Set expectations for the challenge:
  - Set safety boundaries as appropriate such as giving the blindfolding student something or someone to hold onto for stability, limiting kick strength, etc.
  - Remind student groups about the rules of the kickball challenge, specifically that (1) Groups may not test their ball roll after being given a value for their variable, and (2) Beyond counting down, all non-blindfolded students must remain silent.

- Take the challenge, group-by-group, with (ideally) with the class as spectators:
  - Collect balls and give each group a value for their independent variable.
  - Remind groups that they may not run a physical test at this point.
  - Ask each group to write down a calculated distance and method for having their blindfolded group member attempt to kick the ball after the ball is rolling on the floor for 3 seconds. Suggest one person gives a 3-2-1-kick countdown once ball hits the floor. Consider 2-3 practice countdowns before the first ball roll.
  - Run testing group-by-group with the class as spectators. Consider using a best of 3 ball rolls for judging.

- Ask students to return online to reflect on challenge results.

Student Activity Page 6: Reflection

Answer the questions below then hit "Next" to finish this activity.

19. How did your group figure out where to stand to kick the ball?
20. How accurate was your prediction?
21. What expected or unexpected challenges did you run into?
22. If you were not 100% certain about your prediction, what could you do differently next time to be more certain?

Review reflection question answers and link to next activity

- Ask students about their challenges and what they might do differently next time.
- Tell them that so far they have been focused just on the motion of the ball on the floor, and in the next set of activities they will begin to look at the motion on the ramp in preparation for designing their own experiments.

Curriculum Notes (Send to Inquiry Space for curation)**:**

- Andrew Njaa, Falmouth HS - Helping students understand slope outside a "y=mx+b" mathematical context is a classic obstacle, but students do need to learn to generalize. This course (physics) is probably the first time students are asked to be this formal about space and time, so we have to both be aware of the usual misconceptions and be prepared to move students through the stages. So y = mx + b becomes xf = vΔt + xi. As teachers, we tend to be pretty explicit about this notation and model it.

- Modeling classrooms (e.g. Mechanics v3) may choose to move directly to mathematical models of constant velocity before moving on to acceleration.