Motion Research Brainstorm

Research Tools: Now that you have studied various motion scenarios and used 2 powerful tools of analysis:

- Vernier GoDirect carts and graphical analysis – This is a great tool for studying any motion which involves carts.
- Vernier video analysis - This tool allows you to study any motion which you can capture on video.

Choosing a Motion Example: It is now time for you to brainstorm a motion you would like to study along with a research question that pertains to that motion. The motion you choose to study should be:

- Interesting to you – Try to find something that you are curious about
- Safe and repeatable – To do rigorous research you will need to be able to collect and analyze multiple data sets
- One dimensional – The motion you study should be approximately linear. (2D motion will be next trimester.)

Motion Idea: Describe the motion that you would like to study in as much detail as possible. Feel free to include a photo or a link to a video.

Research Question: What question do you have about the motion you are intending to study? The best research question will be a question you are genuinely curious about.

Research Ideas: What are your initial ideas about how you might investigate your research question. How will you construct the experiment? What data will you collect? How will you analyze that data? What questions or concerns do you have about your initial research idea.

You should plan to complete this research brainstorming assignment and be ready to discuss your ideas during you student-parent-teacher conference.

Independent Motion Analysis Research Project

For this project, you will investigate a research question about the motion of your choice. You will construct an electronic poster to share your results in a research symposium.

Selecting a motion scenario for analysis – You are free to select any motion which you find interesting. Your selected motion scenario should be:

- motion along a relatively straight line (1-dimensional motion)
- easy to create and analyze using readily available equipment
- repeatable and safe

Generating a research question – Your research question should be:

- Interesting to you. If it's not interesting to you, your research results are unlikely to be interesting to your peers.
- A question that might be answered using graphical motion analysis. An ideal question would involve more than just observing the outcome of an experiment.
    - For example, this research question is interesting: "Will a disk or a sphere win a race down an inline?" However, it can be answered with a simple experiment and would not necessarily involve any detailed motion analysis.
    - An example of research questions which involve detailed motion analysis would be: "When an object rolls down an incline, does the object accelerate at a constant rate? If so, how does properties of the object and incline influence the rate of acceleration?"
- It is OK if your research questions evolve during your research. Discuss any significant changes with your teacher.

Data Collection – You have several options for collecting data depending on what type of motion you decide to investigate.

- If you study motion involving a Vernier Cart you can use Vernier Graphical Analysis as we did when we explore motion on inclines with and without friction.
- If you are able to collect video then you can analyze it with Vernier Video Analysis as we did when we studied the motion of a billiard ball after a collision.
- If you want to capture acceleration data and use numerical integration to determine velocity and position as a function of time you could use your phone and a free app called PhyPhox.

Research Project Stages

I. Preliminary Research Plan – For this assignment, you should

a. decide/confirm a motion scenario to investigate and a research question
b. create a materials list
c. describe your plan (**methods**) for investigating the research question in enough detail so that someone else could conduct the investigation. Your plan should include a least one photograph and one diagram.

II. **Electronic Poster** – You will construct a digital poster that:

- Introduces your motion scenario and research question in a way that piques the interest of your audience.
- Presents your experiment and data analysis procedures in a way that would allow another research team to replicate your experiment and analysis.
- Discusses your results and any conclusions that may or may not be drawn from your research
- Includes at least two different graphs, one diagram, and one photograph.
    - Principles for Effective Presentation of Graphical Data
    - Principles for Effective Presentation of Technical Photographs
- Guidelines for Effective Scientific Posters

Research Symposium – During our research symposium you will have 3 minutes to present your digital poster to the class. After several groups have presented, there will be additional time for students to ask questions of the research teams.

Grading –This project is worth 40 points.

- **Effort and Challenge (5 pts)** - Did you make productive use of time both in and outside of class? Is your research appropriately challenging based on readily available resources and your knowledge and skills as a physicist? If your research does not seem sufficiently challenging, please ask your teacher for suggestions.
- **Research Question (5 pts)** – Is your research question clear and engaging and is your experimental design appropriate to address your research question?
- **Data Analysis (5 pts)** Is your data analysis correct and relevant to the research question you are investigating?
- **Experimental Design (5 pts)** - Does your research incorporate empirical data that has been collected in a thorough, careful, and controlled manner? Have you taken appropriate steps to minimize and quantify experimental uncertainty and control of variables?
- **Collegiality and Engagement (5 pts)** – Did you actively and enthusiastically participate in the symposium? Did you offer feedback and raise questions about the research of your classmates?
- **Data Presentation (5 pts)** Is your data along with experimental uncertainty presented clearly following these principles Principles for Effective Presentation of Graphical Data
- **Experimental Methods (5 pts)** Does your poster explain your experiment clearly including effective use of at least one annotated photograph and diagram? Principles for Effective Presentation of Technical Photographs
- **Poster Presentation (5 pts)** Is your poster attractive and visually accessible? Does it effectively introduce your question, motivate your research, and discuss your research results? Is there a logical flow to your poster that a reader can follow.

  Guidelines for Effective Scientific Posters

One-Dimensional Motion Research Scenarios

Fifteen low-cost investigations built around velocity-time and acceleration-time graphs

Measurement Tools

Most of these scenarios can be measured with one or more of the following tools: a smartphone running the free phyphox app, which reads the phone's built-in accelerometer; free video analysis software such as Tracker or Vernier Video Analysis, used with a phone video and a meter stick in the frame; the Vernier Go Direct Motion Detector; and the Vernier Go Direct Sensor Cart. Vernier data can be collected and graphed in the Graphical Analysis app.

Part 1: General Scenarios

1. Falling coffee filters

Setup: Drop nested paper coffee filters from about 2 m and track them with a motion detector or video.

Research questions

- How does terminal velocity change with the number of stacked filters? When you double the number of filters, does the terminal velocity double, or does it increase more slowly?
- How long do the filters take to reach terminal velocity, and how does that time change as you add filters? Look for the point where the v-t graph flattens and the a-t graph drops to zero.
- Does crumpling or reshaping a filter change its terminal velocity more than adding filters does?

2. A marble sinking through a thick liquid

Setup: Drop marbles or steel balls into a tall clear bottle of dish soap, corn syrup, shampoo, or vegetable oil and film them against a ruler.

Research questions

- How does terminal velocity depend on ball diameter? When the diameter doubles, does the terminal velocity double, quadruple, or something else?
- How does the temperature of the liquid change the terminal velocity? Compare syrup from the fridge, at room temperature, and warmed in a water bath.
- Does a ball reach its terminal velocity sooner in a thicker liquid? Compare the slope of the v-t graph at the start of each run.

3. A magnet falling through a copper or aluminum pipe

Setup: Drop a small neodymium magnet through a length of copper plumbing pipe and compare it with a non-magnetic object of the same size.

Research questions

- How does the magnet's terminal velocity change with the number of magnets stacked together, or with the pipe's wall thickness or metal?
- How quickly does the magnet reach terminal velocity compared with an object falling through open air? Is its v-t graph shaped like the coffee filter's?

- Does cutting a lengthwise slit in the pipe change how much the magnet slows, and by how much? This works with aluminum foil tubes or a cut pipe.

Safety note: *Neodymium magnets snap together hard enough to pinch skin, so handle them carefully and keep them away from phones and cards.*

4. A bouncing ball

Setup: Drop a ball onto a hard floor beneath a motion detector and record several bounces in a row.

Research questions

- How does the ratio of rebound speed to impact speed (read straight off the v-t graph) depend on drop height, floor surface, or type of ball?
- How does ball temperature affect the bounce? Compare a tennis ball or racquetball taken from the freezer, at room temperature, and warmed.
- What does the a-t graph show during the brief moment the ball touches the floor? Does a softer ball stay in contact longer and reach a lower peak acceleration?

5. A balloon-powered car

Setup: Tape an inflated balloon to a toy car or a light cart and release it along a straight track or hallway.

Research questions

- Does the car's acceleration stay constant as the balloon empties? Does the a-t graph stay flat, rise, or fall during the run?
- How does the car's top speed depend on how far the balloon is inflated, or on the width of the nozzle (made from straws of different widths)?
- Once the balloon is empty, does the car slow down at a constant rate? Is the v-t graph a straight line from that point on?

6. A cart pulled by a hanging cup of washers

Setup: Tie a string to a cart on a tabletop, run it over a pulley at the table's edge, and hang a paper cup from the other end. Put washers in the cup and on the cart.

Research questions

- How does the cart's acceleration change as you move washers one at a time from the cart into the cup, keeping the total number of washers the same? Is the graph of acceleration against the number of washers in the cup a straight line?
- Where does that graph cross the horizontal axis? How many washers must be in the cup before the cart moves at all?
- What happens to the cart's motion when the cup hits the floor? Describe how the v-t and a-t graphs change at that moment.

7. Dropping a hanging Slinky

Setup: Hold a Slinky by its top coil so it hangs stretched, then let go. Film it with a phone in slow motion.

Research questions

- Does the bottom of the Slinky really stay still for a moment after release? How long does it hang there, and how does that time depend on how far the Slinky was stretched?

- How do the v-t graphs for the top coil, the middle coil, and the bottom coil compare? Does any coil fall with the free-fall acceleration of about 9.8 m/s²?
- Does a plastic Slinky behave differently from a metal one?

8. A yo-yo falling and climbing on a stationary string

Setup: Tie the end of a yo-yo's string to a fixed support, such as a hook, a ring stand, or a broom handle across two chairs. Wind it up and release it from rest so it unwinds downward, reverses at the bottom, and climbs back up. Place a motion detector on the floor pointing up, or film the yo-yo against a meter stick. A homemade version works well too: two old CDs or plastic lids glued to a short dowel or thread spool.

Research questions

- Is the acceleration the same on the way down as on the way up? Is the v-t graph one continuous straight line through the turnaround, or does its slope change?
- How does taping coins near the rim of the yo-yo change its acceleration, compared with taping the same coins near the center?
- How does the thickness of the axle affect the acceleration? Wrap tape around the axle to make it thicker and compare. Does the v-t graph stay perfectly straight as the string unwinds, or does it curve slightly?
- What happens during the turnaround at the bottom? How large is the spike in the a-t graph compared with free-fall acceleration, and how does it change with release height?
- What fraction of its starting height does the yo-yo regain on each cycle? Graph the highest point reached against the cycle number to see whether it shrinks by the same fraction each time.

9. A soccer ball rolling along a turf field

Setup: Kick a soccer ball along a straight line on a turf field and film it from the side with a phone on a tripod, with cones placed at measured distances in the background. A motion detector placed behind the ball also works for shorter rolls.

Research questions

- Does the ball slow down at a constant rate? Is the v-t graph a straight line, or does the rate of slowing change partway through the roll?
- Does the rate of slowing depend on how fast the ball starts? Compare gentle, medium, and hard kicks.
- How does the surface change the motion? Compare dry turf, wet turf, natural grass, and pavement, or a fully inflated ball with a softer one.
- Can you predict how far the ball will roll from its starting speed alone? Test whether the total distance is proportional to the starting speed or to the square of the starting speed.

10. A falling paper whirligig

Setup: Cut and fold a paper whirligig (a paper helicopter with two blades) and drop it from a measured height, tracking it with a motion detector above or video beside it. A paper clip at the bottom keeps it falling straight.

Research questions

- How does the length of the blades change the whirligig's terminal velocity? Trim the blades in steps and graph terminal velocity against blade length.

- How does adding paper clips at the bottom change the terminal velocity and the time it takes to reach it?
- How does a spinning whirligig compare with the same piece of paper falling with its blades folded flat? Compare the shapes of the two v-t graphs.

Part 2: Vernier Go Direct Sensor Cart Scenarios

The Go Direct Sensor Cart records position, velocity, and acceleration directly and sends them by Bluetooth to the Graphical Analysis app. These scenarios work best on a Vernier track or any smooth, level surface.

11. Two carts colliding on a level track

Setup: Place two Go Direct Sensor Carts on a level track. Push one gently into the other, which starts at rest, and record the velocity of both carts at the same time. Change the type of collision by turning the carts so their magnetic bumpers face each other (the carts bounce apart), or by sticking hook-and-loop strips on the ends (the carts stick together).

Research questions

- How do the velocity-time graphs of the two carts compare before and after the collision? When the carts bounce apart, does the moving cart stop completely while the other takes off at the same speed?
- When the carts stick together, how does their shared velocity afterward compare with the first cart's velocity before? Is it always about half, regardless of how hard the first cart is pushed?
- How do the results change when one cart carries extra add-on bars? Graph the after-collision velocity of each cart against the number of bars added.
- How long does the collision itself last? Compare the width and height of the acceleration spike for magnetic bumpers, hook-and-loop strips, and the cart's spring plunger. Does a longer collision always produce a lower peak acceleration?

12. A cart oscillating between two springs

Setup: Attach a spring to each end of a Go Direct Sensor Cart and hook the other ends of the springs to the end stops of the track, so the cart sits stretched between them. Pull the cart a few centimeters to one side, release it, and record its back-and-forth motion.

Research questions

- Where in the motion is the cart moving fastest, and where is its acceleration largest? Compare the position, velocity, and acceleration graphs over the same stretch of time to see how their peaks line up.
- What does the graph of acceleration against position look like? Is it a straight line, and what does its slope tell you about how quickly the cart oscillates?
- Does the time for one complete back-and-forth trip depend on how far the cart is pulled before release? Test five or more starting distances and graph the period against each one.
- How does loading the cart with add-on bars change the period? Does doubling the load double the period, or change it by a different amount?
- How quickly do the swings die out? Graph the maximum velocity in each cycle against the cycle number to see whether it shrinks by a steady amount or a steady fraction each time.

Part 3: Vernier Go Direct Motion Detector Scenarios

The Go Direct Motion Detector measures most reliably between about 15 cm and 3 m. It works best with targets that have a flat or broad surface facing it, and it needs a clear path with no tables or walls inside its beam. Use the cart setting on its switch for objects on a track and the normal setting for everything else. Scenarios 1, 4, 5, 8, and 10 also work well with the motion detector.

13. Walking to match a motion graph

Setup: Set the detector on a table at waist height, pointing across an open floor. A student walks toward and away from it while trying to match a target position-time or velocity-time graph shown in Graphical Analysis, which has a built-in graph-matching feature.

Research questions

- Which features of a target graph are hardest to match: a constant velocity, a sudden change in velocity, a smooth speed-up, or standing still? Measure the gap between the target and the actual graph for each type.
- Does accuracy improve with practice? Graph a matching score against the number of attempts for several students and compare how quickly each one improves.
- How quickly can a person go from standing still to a steady walking speed? Compare the steepest slope on the v-t graph for walking, jogging, and walking backward.
- Is it easier to match a position-time graph or a velocity-time graph that describes the same motion? Have the same students try both versions.

14. A block sliding to a stop on a table

Setup: Place the detector at one end of a long table and give a wooden block, a book, or a small box a quick push away from it. Record the motion from the moment the block leaves your hand until it stops.

Research questions

- Does the block slow down at a constant rate? Is the v-t graph a straight line all the way to zero, or does it curve near the end?
- How does the surface change the rate of slowing? Compare bare tabletop, paper, felt, sandpaper, and a wet surface, or tape different materials to the bottom of the block.
- Does stacking a second block on top change how quickly the pair slows down?
- Does the rate of slowing depend on how hard the block is pushed? Compare five or more starting speeds and graph the slope of the v-t graph against each one.

15. A ball tossed straight up

Setup: Mount the detector high on a ring stand or shelf, pointing straight down, and toss a ball upward beneath it so it rises and falls without hitting the detector. A basketball or a playground ball gives a strong, steady signal.

Research questions

- Is the ball's acceleration the same on the way up, at the very top, and on the way down? Many people expect the acceleration to be zero at the top, and the a-t graph tests that idea directly.
- Does a light beach ball have the same acceleration as a basketball? Compare the slopes of their v-t graphs, and see whether the beach ball's acceleration on the way up matches its acceleration on the way down.

- How does the time spent rising compare with the time spent falling for each ball? Is the v-t graph symmetric around the top of the flight?
- How does the height of the toss change the total time in the air? Graph flight time against the maximum height reached and look for the pattern.

Safety note: *Keep tosses gentle and centered so the ball doesn't hit the detector. A protective wire cage over the sensor face is a good idea if you have one.*

Tips for Strong Projects

For any of these scenarios, the strongest projects measure one variable carefully across at least five values and plot it against a number taken from the motion graphs, such as a slope, a terminal velocity, or a peak acceleration. That plot becomes the central evidence for the research question. Repeating each trial at least three times and averaging the results makes the pattern much easier to trust.