InquirySpace Teacher Guides:
Parachute Experiment and Model

1) Summary

The goal of this pair of activities is to explore the terminal velocity of a falling object. The model shows a falling parachute, and the physical parallel is a falling coffee filter whose position is measured with a motion sensor below it. In both cases, terminal velocity is usually reached before the object hits the ground. The student has the task of changing parameters (mass and area) and interpreting the distance-time and velocity-time graphs in order to measure the effect of these parameters on terminal velocity.

It is recommended that the simulation-based be done first, since the data are clearer and easier to collect. Then when students tackle the hands-on experiment, they will have a picture of what a graph showing terminal velocity looks like.

2) Learning Goals

In the simulation-based experiment, students will:

- Set and run a model, collect data for various values of the parameters (mass and area), and export it to the CODAP table.
- Understand what terminal velocity looks like on a velocity-time graph and measure it for each run.
- Construct graphs to study the results.
- Use the scaling, hide/show, connecting-lines and movable-line features to study the graphs.
- Arrange the data and graphs to see the effect of one parameter at a time.
- Draw conclusions about relationships based on the graphs.
- Explain terminal velocity in terms of the forces on a falling object.

In the hands-on experiment, students will:

- Use the motion sensor to collect a distance-time graph of a falling coffee filter.
- Make multiple runs with different numbers of nested coffee filters (to change the mass).
- Recognize and select the portion of the collected data that is relevant—in this case, the time during which the coffee filter is in free fall.
- Be able to identify meaningful patterns when the data is noisy or confusing.

3) Teacher Preparation

The most important step in preparing to run InquirySpace activities with students is to run the "Teacher Version" of each activity. These are available on the InquirySpace portal.

http://inquiryspace.portal.concord.org

Teacher versions are essentially duplicates of the student versions with the addition of tips for successful classroom use. These tips are written in red within each activity. By running the activities yourself, you will become familiar with many important elements of the activity including the:

- flow of the activity between Lab and Experiment Tabs,
- physical set up of the hands-on experiments,
- use and limitations of sensors,
- functionality within the CODAP environment,
- questions that students will be asked to answer, and
- approximate amount of time needed to complete it.

4) Materials

Break students into groups of three. Each group will need the following:

An account on the InquirySpace Portal. For help on registration and class set up, please see the Portal and Quick Start Guide.

Simulation-based experiment (per group):

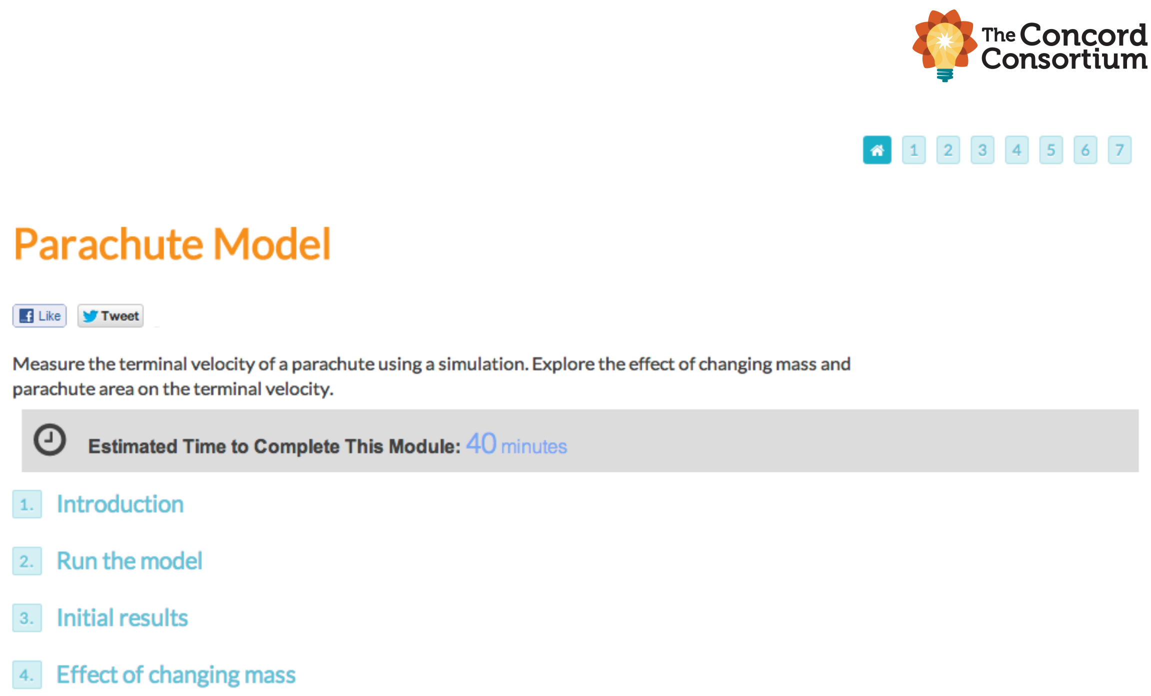
- Computer
- Internet connection

Hands-on experiment (per group):

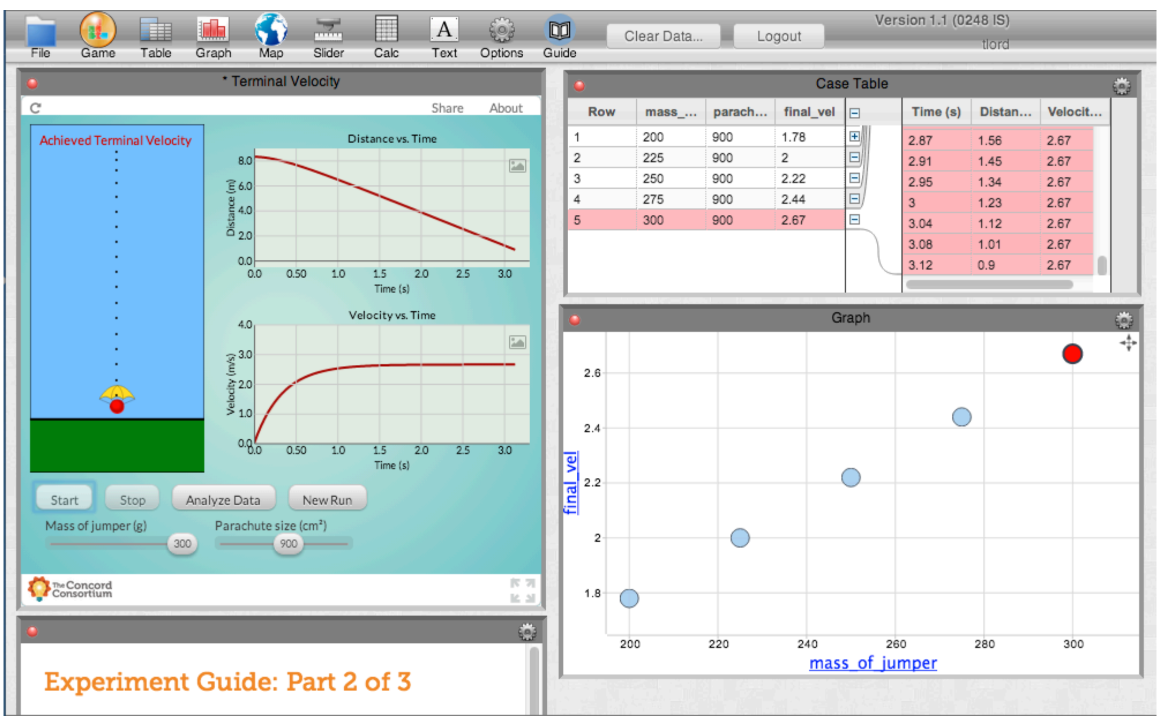
- Computer
- Internet connection
- Flat-bottomed commercial coffee filters (at least five)
- Vernier motion sensor and LabQuest Mini
- Floor space next to the computer

5) The Student Experience

When you run the Teacher Version of the activity, you will become more familiar with the flow of InquirySpace activities. The student version of each activity follows the same flow. When the student clicks the **Run** button under an activity in the InquirySpace Portal, the activity will open in a new tab. Students should follow the steps of the activity in sequence. Any answers to questions within the activity are automatically saved to their account.

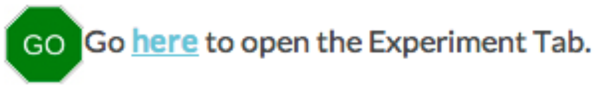


Each InquirySpace activity has two parts, the Lab Report (shown in the screenshot above) and the Experiment Tab (shown in the screenshot below).

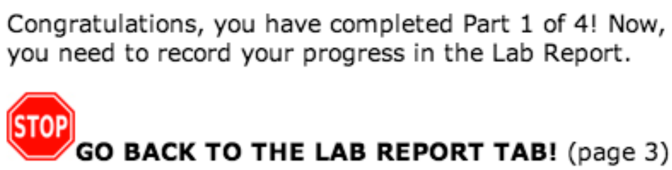


The Lab Report Tab is what is first launched via the Portal. The Lab Report for each activity gives background information and instructions for setting up experiments, asks questions, and saves answers. Eventually, the instructions within the Lab Report will ask students to collect and analyze data using the CODAP environment, which is referred to as the Experiment Tab. The Experiment Tab is where students will use sensors or run models to collect data, create graphs, and analyze data.

When it is time to use CODAP, students will see this sign in the Lab Report:



The CODAP environment will open in a new browser tab. CODAP is a separate piece of software with its own ability to save work. Work in the Experiment Tab is not yet shown in the Portal Reports (this feature is in development). As students work through the InquirySpace activity, they will move back and forth from the Experiment Tab to the Lab Report Tab. Remind students to read the instructions carefully and watch for Stop and Go signs! They will be directed to return to the Lab Report with messages like this:

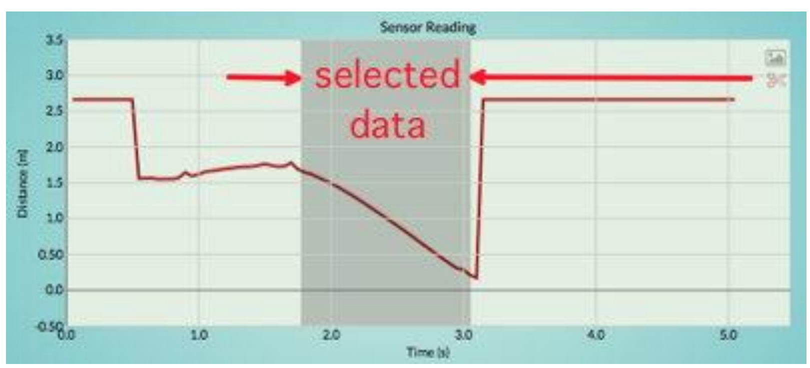


6) Potential Trouble Spots

Simulation-Based Experiment

- Collecting data is quick and easy, so the harder task will be to group the runs so that the effect of each variable can be viewed separately. CODAP places all the runs in the same table and all the runs appear on every graph. However, There are various ways in CODAP to hide/show and highlight the various runs so that that can be analyzed one at a time (see "Tips" below). This may take some practice and extra instruction.

Hands-on Experiment



- When students drop the coffee filter, there will be extraneous data before and after the short period when the filter is actually falling. Students must select and analyze only the relevant portion using the "scissors" icon.
- Students may have trouble recognizing the relevant data.
- The data will not be "clean" compared to the model data in, for example, the Springs Experiments. Students will need to choose the average or most likely terminal velocity from a messy collection of points.
- Since the mass (number of filters) is not automatically exported, students must enter that in the table after each run.
- If students use multiple filters and don't drop them from high enough (2 m), terminal velocity may not be reached. This will be evident in the velocity vs. time graph, if they

know what they're looking for!

- The distance measurement is in meters, so the distance data will be decimal, e.g. .56m (56cm), which may confuse some students.

CODAP Graphs

- There are two "levels" of graph in CODAP: the time-series graphs that are exported from the sensor collector (distance vs time and velocity vs time), and run-level graphs, which compare the outcomes of different runs (e.g. mass, terminal velocity).
- Graphs are created using the upper menu item, then labeled by dragging the column header of a variable (attribute) to the X or Y axis. An attribute can also be dragged into the field of the graph; this colors the points according to their value.
- If the X-axis is time and the Y-axis is distance or velocity, a time-series graph is created.
- If the run-level attributes (e.g. mass, area, final velocity) are dragged to the axes, run-level comparisons can be made and students can explore the relationships among variable, e.g. mass vs. terminal velocity, area vs. terminal velocity. This is the primary goal of these two activities.
- There are various ways in CODAP to hide/show and highlight the various runs so that that can be analyzed one at a time. This may take some practice and extra instruction.
    - Runs (one or many) are made bold in the graphs when students highlight them in the table.
    - At the top of the graph is a "Show All - 1 2 3 4 …" menu for showing individual runs.
    - The non-highlighted runs can be hidden altogether using the "hide/show" choices under the graph's gear menu.
    - If "run number" is dragged into the field of the graph (rather than the axes) and then treated as "categorical", each run is a different color.

7) Discussion Topics

Students will need your help to make their work with InquirySpace activities a meaningful experience. Help them make sense of their observations by facilitating full class and/or small group discussions at the beginning of each class, at the end of each activity, and before the start of the next one. Often stopping a class in the middle of an activity for discussion is difficult because groups work at their own pace. However, bringing the class together between activities is an important role for teachers to play.

- The relationship between distance-time and velocity-time graphs is a good discussion topic.
- Why does the distance-time graph become a straight downward-sloping line, while the velocity becomes a horizontal line?
- How would you recognize when, in the physical experiment, the terminal velocity has not been reached by the time the coffee filter hits the floor?

7) The Physics

Students could do both of these activities entirely as exercises in measurement and analysis of relationships using graphs, but they should at least try to develop an explanation based on what they have learned about forces and acceleration. Here are some questions that might elicit a good discussion of the physics behind terminal velocity.

- What are the forces on the falling object? [Gravity downward, air resistance upward.]
- What causes those forces? [Gravity is due to the mass being attracted to the mass of the earth. Air resistance is due to the air being accelerated or pushed aside by the object's solid surface.)
- Do those forces changes as the object falls? [Gravity stays the same. Air resistance increases with velocity.]
- Under these conditions, what would you expect the velocity to do over time? [The velocity would increase, but more slowly as air resistance increases.]
- Under what conditions are the upward and the downward forces equal? [Gravitational force equals air resistance force.]
- If the forces are equal and opposite, what would you predict about the velocity? [It should become constant.]
- Does every falling object have a terminal velocity? What about a feather? A penny? A bowling ball? A person with no parachute?
- Would terminal velocity be different at different heights above the earth? Why? [At higher altitudes, thinner air would mean less air resistance. Gravity would be somewhat less but that's a much smaller effect. So, terminal velocity would be much greater at higher altitudes.]
- What about terminal velocity in water? What's that like? [It's much less, since resistance is proportional to the fluid/gas density.]

8) NGSS Standards

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.