1. Mystery (Inertia) Stations

Objective: Students can articulate the effect of an object's inertia on its resistance to changes in its state of motion by writing a paragraph detailing observations made at the "Inertia Stations."

Engage

1. Students are introduced to the "Mystery Stations," and are told that they are designed to illustrate a central concept in physics. Their objective is to identify what they all "have in common."

Explore

2. Students visit the stations in Table 1 and write a brief prediction of what they think will happen prior to actually performing the activity.

Activity	**Description**
Shake it	Students shake a bowling ball, then shake a table-tennis ball
Tower of washers	Students quickly slide a playing card back and forth against a tower of stacked washers, knocking the bottommost washer out, leaving the tower standing.
Pennies on elbow	Students place a penny on their elbow in front of them, then quickly pull their elbow away and snatch the penny from the air (*Figure 1*). Students may stack multiple pennies and engage in a class-wide competition to see who can catch the most amount of money.
Tennis ball hat	The tennis ball hat has a tennis ball on each end of a cut and bent wire hanger (*Figure 2*). The wire balances on a student's head, enabling the student to spin around while keeping the tennis balls stationary.
Tablecloth trick	Students perform the classic tablecloth trick, where the tablecloth is quickly removed from beneath a place setting of dishes, leaving the dishes safely in place.
Egg (or ball) into beaker	An egg (or ball) is placed on top of a cardboard tube stand, sitting on top of a TupperWare cover (it's important that is has a lipped edge). The Tupper-Ware cover is flicked away, which knocks the tube out of the way, allowing the egg to fall safely into the beaker of water (*Figure 3*).
Crash test	A figurine is placed on top of a cart. The cart and figurine is set in motion towards a short wall. When the cart hits the wall, the figurine continues in motion.

Table 1

Figure 1. Student places penny on elbow, then quickly pulls elbow away to snatch the penny from the air.

Figure 2. The tennis balls are positioned below the wire hanger's contact point on the student's head, allowing the student to rotate while keeping the ball hat balanced.

Figure 3. When flicked horizontally, the TupperWare lid knocks the marker out of the way, allowing the egg to land safely in the beaker of water.

Explain

3. When all stations have been visited, students write a paragraph that explains what they all have in common.

Evaluate

4. Teacher leads discussion that pushes students towards the statement of Newton's 1st Law and the term *inertia*.

Elaborate

5. Students write a revised explanation of what the stations have in common, using the term *inertia* and phrases from the statement of Newton's 1st Law.
6. Students watch "Target Shopping Cart Accident" <http://www.youtube.com/watch?v=xl1PUVOeWp8>, and pretend that they work for an insurance company handling Target's claim for the accident. They must write a paragraph to their manager (their teacher), explaining what happened and why. Students must reference Newton's 1st Law and use the term *inertia*, but explain in such a way that a non-physics student would understand.

2. Carts & Masses

Objective: Students will design and conduct an experiment using carts and masses to discover the relationship between force, mass, and acceleration.

Engage

1. Students are informed that they will construct gliders to be launched from a catapult. But not yet–at this point in time, they are going to design an experiment to determine what happens to an object when there's a net force acting on it.
2. Show students video footage of airplanes being catapulted from aircraft carriers.

Explore

3. Students are shown the experimental setup (*Figure 4*).

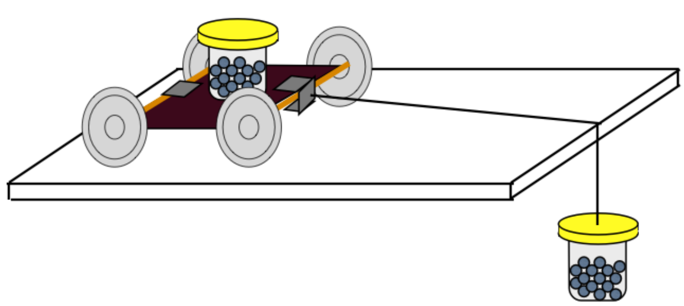


Figure 4. Experimental setup for cart & mass activity

4. Students respond to the following questions, and provide an explanation for their thoughts:

    a. What will happen to the cart when there is a force applied to it?
    b. What if the applied force is increased? What about the cart's motion will change?
    c. What if the cart's own mass is increased? How will its motion change?
5. Have students design and execute experiments to test their hypotheses (at least 5 trials for each hypothesis). At this point in the course, students may or may not have been taught experimental design.

Explain

6. Have students graph the data in a way that makes sense to them and have them explain what knowledge they can gain from the data.

Elaborate

7. Guide students to analyze their experiments by asking the following questions (class discussion):
    a. Why is it a good idea to do multiple trials?
    b. What "aspects" were the same from one trial to the next?
        i. …We call these factors "constants"
    c. What "aspects" changed from one trial to the next?
        i. … We call these factors "variables" (they vary)
    d. What variable did you change on purpose?
        i. …We call this the "independent variable" since you're *free* to set it to be whatever you want
    e. What variable changed as an effect of changing your independent variable?
        i. …We call this the "dependent variable" since its value *depends* on what your independent variable is
8. Guide students towards Newton's 2^{nd} Law:
    a. What happens if we apply a net force on an object?
        i. …it accelerates (Although students who make this claim are correct, they must be able to support it with evidence. Acceleration is not measured directly with meter sticks and stop watches, so they must decide what data to collect in order to show that the acceleration changes in direct relation to an applied net force.)
    b. What happens if that net force is increased?
        i. …its acceleration increases
    c. What happens if the mass of the object itself increases?
        i. …its acceleration decreases
9. We have a mathematical expression for this: $F_{net} = ma$.

Evaluate

10. Teacher should give a problem set on $F_{net} = ma$.

3. Force Meters

Objective: Students construct rubber band force-meters to aid in the investigation of forces and Newton's 3rd Law.

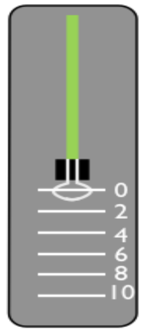


Figure 5. Rubber band force-meter

Engage

1. Show a brief clip of astronauts walking (bouncing) on surface of the moon: <http://www.youtube.com/watch?v=16D0hmLt-S0?>.
    a. Ask, "Why do objects weigh less on the moon?"
        i. Because there is "less gravity"
    b. "So gravity is one factor that affects how much an object weighs. What else determines the weight of an object?"
        i. The amount of "stuff," or matter, it's made up out of. We call this quantity *mass*.

Explore

2. Ask, "How can we use a rubber band to actually determine the weight (the force due to gravity) of an object?" Guide students towards building the rubber band force-meter.

Explain

3. "In order to actually put numbers on our force meters, we have to know the formula for figuring out the amount of gravitational force F_g from a certain amount of mass m."
4. The formula is $F_g = mg$ (or $W = mg$)

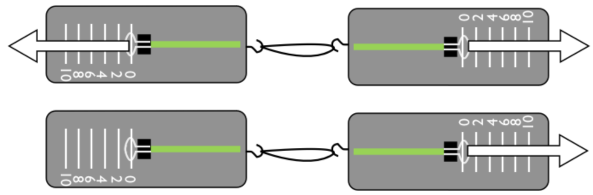
Elaborate

5. Ask, "How is this related to Newton's 2nd Law, $F_{net} = ma$?"
    a. For an object falling under the influence of gravity, the net force is its weight F_g, and its acceleration is simply its acceleration due to gravity g (neglecting air resistance).

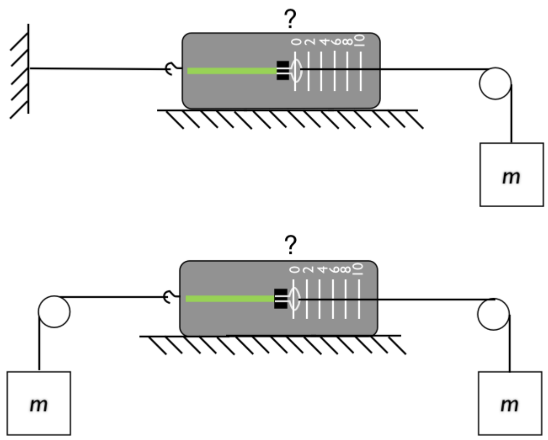
Evaluate

6. Students should now create an accurately labeled scale on their force-meters, displaying the applied force in units of Newtons.
7. Teacher should give a problem set on $F_g = mg$.

4. Tug-of-War



Figures 6 (a) and (b): A student and a partner each pull on the opposing force-meters and observe that they show the same reading. In the second scenario, one student holds his force-meter still, while the partner pulls his force meter to the right.



Figures 7 (a) and (b): Students predict the reading on the force meter in each of the two scenarios depicted prior to testing.

Engage

1. Demonstration: two students on skateboards (or in roller skates, or sitting in rolling chairs) push off of each other. Then, student A pushes off of student B, and vice-versa. Students predict what they think will happen prior to the demonstration. Encourage students to apply their knowledge of Newton's 2^{nd} Law to defend their ideas.
2. Ask students why they think that it doesn't matter who does the pushing.

Explore

3. Students attach their force-meters with rubber bands or string and record…
   a. the reading on each force-meter when both students pull (*Figure 6 a.*)
   b. the reading on each force-meter when one student keeps his force-meter stationary while the other student pulls (*Figure 6 b.*)

Explain

4. Teach mini-lecture on Newton's 3^{rd} Law.

Elaborate

5. Students write predictions for the force-meter readings for each of the two scenarios in *Figure 7*.
6. Students test their predictions, and teacher guides class discussion surrounding the results.

Evaluate

7. Teacher should give homework assignment to provide students with practice articulating Newton's 3rd Law.

5. Force Stations

Objective: Students are introduced to free-body diagrams (FBDs), and must create accurate FBDs of physical systems at stations around room.

Engage

1. Students watch discovery channel video clip on the physics of skydiving (~3 min.): <http://www.youtube.com/watch?v=ur40O6nQHsw> . In the video, overlaid arrows represent forces on the skydiver's body. Students are told that they, too, will depict forces using arrows.

Explore

2. Students rotate around force stations in the room and explore each system
    a. Students identify the labeled station
    b. From their analysis of the station, they attempt to draw all the forces on the body of interest
        i. Object at rest on table
        ii. Cart rolling across table
        iii. Object hanging by string
        iv. Object hanging by two strings at an angle to each other
        v. Ball rolling down ramp
        vi. Object stationary on ramp
        vii. Ball falling through air
        viii. Coffee filters falling through air

Explain

3. Teach mini-lecture on FBDs
4. Students revise any force station FBD that is incorrect

Elaborate

5. Students cut out picture from magazine (which they brought into class earlier in the week) that shows an interesting physical scenario.
6. Students create FBD for one or multiple objects in the cutout picture.

Evaluate

7. Give homework assignment on FBDs ("Free-Body Exercises: Linear Motion" from <u>The Physics Teacher</u> is included at the end of this activity guide).

6. Culminating Activity—Glider Engineering

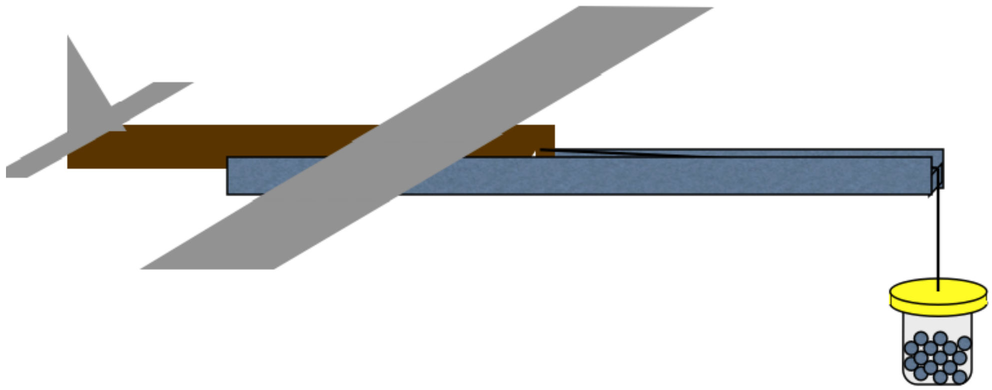


Figure 8: Glider & gravity-driven catapult launch system

Engage

1. Introduce the culminating activity (if not done at the beginning of the unit). Inform students that they are going to play the role of aeronautical engineers. The objective is to design and build a glider that will travel the greatest distance from a catapult. Red Bull Flugtag videos may be shown for inspiration: <https://www.youtube.com/watch?v=5Im8VtLQgh4>
2. Students read New York Times article, "Navy Has Catapult to Launch Planes," from 1921

Explore

3. Making the glider fly
    a. Have students build paper airplanes to get a feel for some of the basics of glider construction.
    b. Ask, "What affects how the airplane flies?"

Explain

4. Teach mini-lesson(s) on fundamentals of flight
    a. Lift, drag, weight, propulsion
    b. Yaw, pitch, roll
5. Ask students, "Given the objective of the project and the constraints, what are the most important aspects of the glider's design? How will you develop tests to scientifically work towards the best glider design possible?"

Elaborate

6. Glider engineering & testing
    a. Students design their gliders in their journals
    b. Students construct their glider
    c. With their teams, students devise an experiment to determine the optimal design of a single aspect of the glider (e.g.: vary the position of the wing, the angle of the ailerons,

the angle of the elevators, the height of the vertical stabilizer, the mass on the glider's nose, etc.)

d. Prior to running the experiment, students should write a prediction for the outcome of their tests in their journal, as well as an experimental procedure

Evaluate

7. Design Report I
   a. Students must successfully answer the following questions in order to be green-lighted for the glider launch competition

   Design Questions:
   1. What experiment did you conduct to improve upon your glider's design?
   2. Why was this experiment important or worthwhile?
   3. What was the outcome of your experiment, and how did your findings help to justify your design decisions? (Include all data tables, graphs, etc.)

   Analysis Questions:
   4. If a constant net force of 25 N is applied to your glider, what will be its acceleration?
   5. At the acceleration determined in #4, what will be the glider's speed after traveling 1.5 m along the catapult? Assume that the glider starts from rest.
   6. At the launch speed determined in #5, how far will the glider travel in 2.0 s of flight? Assume that the glider travels in a straight line, and that air resistance is negligible.
   7. The glider's pilot is known to lose consciousness during an acceleration greater than 4.0g. According to your expected acceleration during launch, will your pilot survive?

   Free-Body Diagrams
   Provide a FBD for your glider in each of the following scenarios:
   8. The glider in the catapult, being held back by a pull (prior to launch)
   9. The glider accelerating along the catapult, before taking flight
   10. The glider flying through the air (include drag)
   11. The glider at rest on the ground

8. Teacher facilitates the glider launch in a safe location

9. Design Report II
   a. Students add to their original design report by reflecting on the performance of their glider in the competition
   b. Teacher may incorporate additional analysis requirements for the report

Honors Physics Addendum: Students should determine the ratio of lift force to drag force through an analysis of the glide angle (*Figure 9*). The tangent of the glide angle is equal to the ratio of the vertical distance to the horizontal distance covered by the glider. The free-body diagram of the glider reveals that the tangent of the glide angle is also equal to the ratio of drag to lift forces. Video analysis can yield an accurate measurement of the glide angle.

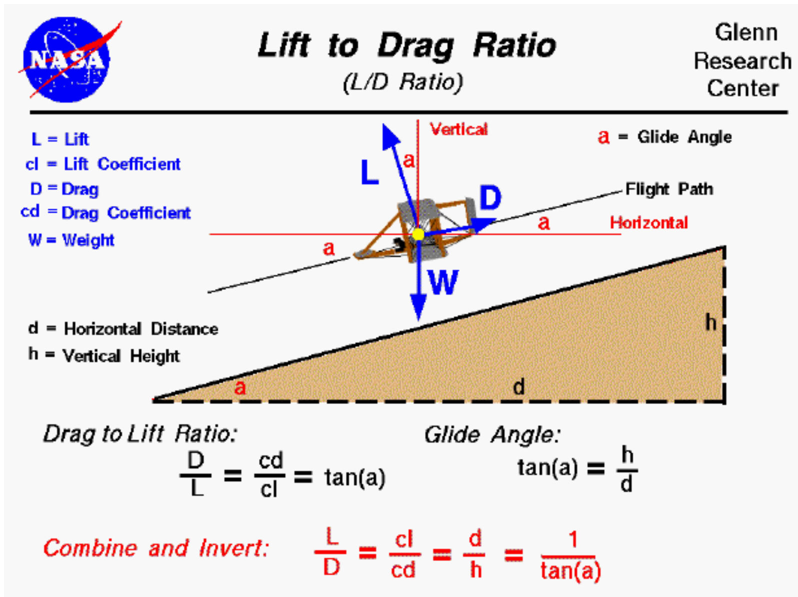


Figure 9: Lift to Drag Ratio as determined through analysis of glide angle.

*During all activities teacher serves as a facilitator of student learning (i.e. student centered instruction). Most tasks should be completed by students after simple directions, or facilitated questions to enhance student learning.

**Use of student handouts serves as guidelines for students.

Accommodations

All individual accommodations for students should be met with respect to your particular students and classroom dynamics and will vary from class to class and group to group. Facilitator should always differentiate instruction by providing the necessary blend of guidance and exploration for each student group and their specific needs.