TEACHER GUIDE
Physical Science

LEARNING UNDEFEATED
Educate | Elevate | Empower

It's All in Your Head

Topic(s): Forces and Motion

Grade level(s): 6th-8th grades

Time: One class period, 50-60 minutes

NGSS Alignment: MS-PS2-1

TEKS Alignment: 8.6C

LSSS Alignment: 6-MS-PS2-1

ACTIVITY OVERVIEW

This activity dives into Newton's Laws of motion by having students investigate concussions. Students will investigate the mechanism of concussions and then will explore material testing and product design.

This activity is divided into two parts. The first part challenges students to use a model to investigate how a concussion happens. Specifically, students will identify what happens to the brain with varying levels of impact force. The second part challenges students to use force plates to collect data about possible helmet materials. After the data collection, students are encouraged to apply their data toward a new helmet design.

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ALIGNMENT TO STANDARDS

NGSS:

MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.

TEKS:

8.6C. Investigate and describe applications of Newton's three laws of motion such as in vehicle restraints, sports activities, amusement park rides, Earth's tectonic activities, and rocket launches.

LSSS:

6-MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.

LEARNING OUTCOMES

Students will know:

- Newton's three laws of motion.
- What a concussion is.
- How concussions happen and the different ways we can get them.
- That different materials absorb impact differently.

Students will understand:

- The dangers of concussions and their lasting impact.
- The relationship between impact force and concussions.
- The relationship between impact force, acceleration, and time of impact.

Students will be able to:

- Capture slow motion videos of a modeled concussive event.
- Interpret video data to understand the mechanism of a concussion.
- Collect force data for a collision of a dropped object with the ground.
- Calculate averages from collected trial data.
- Analyze collision data to determine the most protective material.
- Design a helmet following the provided criteria and constraints.

CAREER CONNECTIONS

Materials Engineer

Materials engineers develop, process, and test materials used to create a wide range of products.

Work Environment: Materials engineers generally work in offices where they have access to computers and design equipment. Others work in factories or research and development laboratories.

Duties: Professionals in these jobs have the following duties and more: design and direct testing procedures, monitor how materials perform, evaluate how materials break down, develop ways to keep a product from failing, and evaluate the impact of materials on the environment.

Median Salary: $95,640 per year (US Bureau of Labor Statistics, 2020)

Source: https://www.bls.gov/ooh/architecture-and-engineering/materials-engineers.htm

Industrial Designers

Industrial designers combine art, business, and engineering to develop the concepts for manufactured products.

Work Environment: Industrial designers work in a variety of industries. Although industrial designers work primarily in offices, they may travel to testing facilities, design centers, clients' exhibit sites, users' homes or workplaces, and places where the product is manufactured.

Duties: Professionals in these jobs have the following duties and more: sketch ideas, use computer software to develop virtual models, create physical prototypes of their designs, determine if a product design is practical and safe.

Median Salary: $71,640 per year (US Bureau of Labor Statistics, 2020)

Source: https://www.bls.gov/ooh/arts-and-design/industrial-designers.htm

Drafters

Drafters use software to convert the designs of engineers and architects into technical drawings.

Work Environment: Although drafters spend much of their time working on computers in an office, some may visit jobsites in order to collaborate with architects and engineers.

Duties: Professionals in these jobs have the following duties and more: design plans using computer-aided design (CAD) software, work from rough sketches by architects, specify dimensions, materials and procedures for new products.

Median Salary: $57,960 per year (US Bureau of Labor Statistics, 2020)

Source: https://www.bls.gov/ooh/architecture-and-engineering/drafters.htm

Mechanical Engineering Technologist/Technician

Mechanical engineering technologists and technicians help mechanical engineers design, develop, test, and manufacture machines and other devices.

Work Environment: Mechanical engineering technologists and technicians work primarily in factories or in research and development labs.

Duties: Professionals in these jobs have the following duties and more: prepare drawings of the assembly process, set up and conduct tests, recommend cost-effective changes in equipment design.

Median Salary: $58,230 per year (US Bureau of Labor Statistics, 2020)

Source: https://www.bls.gov/ooh/architecture-and-engineering/mechanical-engineering-technicians.htm

It's All in Your Head (1 class period)

BACKGROUND INFORMATION

This activity dives into Newton's Laws of Motion by having students investigate concussions. Students will investigate the mechanism of concussions and will then explore material testing and product design.

Students should be introduced to Newton's three laws of motion prior to this experiment. Students should be familiar with forces and how they affect motion of different objects.

In our experiment, we utilize a force plate when testing the protective properties of the helmet materials. The plate will measure the force experienced during the collision. Our curriculum is designed only for students to measure the change in peak force for each material, but a more advanced class could look at how average impact force and time of the collision affect impulse. A simulation of an egg drop is linked below as it is a great resource for introducing impulse to students.

Newton's Laws of Motion
https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/newtons-laws-of-motion/

Demonstrating How Helmets Affect Impulse and Impact Force
https://www.youtube.com/watch?v=IpfSPAoUUcQ

Egg Drop Simulation
https://www.physicsclassroom.com/Physics-Interactives/Momentum-and-Collisions/Egg-Drop/Egg-Drop-Interactive

History of Helmets in Football (article)
https://www.smithsonianmag.com/arts-culture/leatherhead-to-radio-head-the-evolution-of-the-football-helmet-56585562/

Evolution of Football Helmets (video)
https://www.youtube.com/watch?v=WYYiqx6legw

REAGENT PREPARATIONS

Brain Model

- Fill quart container with 10 oz of water (about 300 mL)
- Slowly stir in about 17 g of salt
- Ensure the golf ball floats in the salt water
    - If not, add more salt until the golf ball floats
- Keep the golf ball in the water, then slowly stream 200 mL of fresh water down the side of the container
    - This should create a layer on top of the salt water since the fresh water is less dense. If done properly, the golf ball should remain floating in the middle of the container. If the fresh water is poured too quickly, the layers will mix and the model will not work.
- Keep for use with multiple classes. Over time and as the model experiences impacts the layers will mix and you will see the golf ball start to sink to the bottom. For this reason, we recommend disposing of the liquid at the end of each day and remaking the model if teaching this activity multiple days in a row.

String

- Cut string into lengths of 1 yard

TECHNOLOGY PREPARATIONS

LabQuest Data Collection Settings

*The settings changed on the LabQuest do not save and will reset to default when the device is powered off.

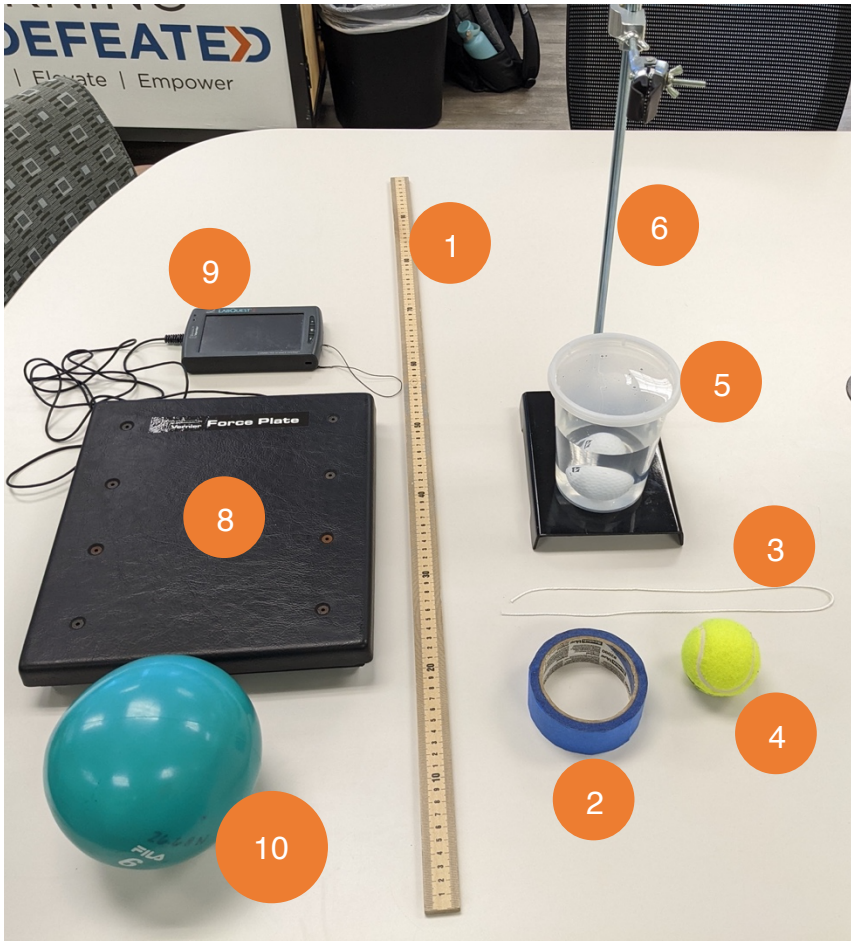
1. Plug in the force plate wire to CH 1 of your charged LabQuest device.
2. Turn on the LabQuest by pressing the red power button on the top left side of the display.
3. Hit the home button on the right-hand side of the LabQuest to access applications.
4. Select the LabQuest app located in the top left corner of the screen.
5. Choose "**Sensors**" in the top menu bar.
6. From the drop-down menu select "**Data Collection.**"
7. **Mode:** should read Time Based.
8. Make sure your settings read the following:
    Rate: 1 sample/ms
    Interval: 1 ms/sample
    Duration: 100 ms
    Enabling Triggering selected when CH 1: Force Plate 850N is INCREASING across 2.5 N
    Collect 10 points before trigger

LabQuest Calibration

1. To calibrate your force plate for use, click on the upper left corner picture of an odometer. A red box with the Force meter should appear. Click anywhere in the red box and a drop-down menu appears.
2. Click "**Zero**," making sure there is nothing on your force plate.
3. Click the red meter box.
4. Click "**Calibrate**."

5. Click "**Calibrate now**."
6. Place the 6 lb. medicine ball on the force plate, and enter **26.68 N**.
7. Remove the 6lb. medicine ball and place the provided 10 lb. dumbbell on the force plate, and enter **44.54 N**.
8. Click "**OK**."

STUDENT STATION SETUP



Each station accommodates 6 students who will work on the activity as a group.

1. Meter stick
2. Tape
3. 1 yard of string
4. Tennis ball
5. Brain model
6. Metal stand and clamp
7. Slow-motion camera (not provided)
8. Force plate
9. LabQuest
10. 6 lb medicine ball
11. Flexible foam (not pictured)
12. Styrofoam (not pictured)
13. Microbead pillow (not pictured)

LESSON PLAN

Teacher's Note: The lab activity itself is designed to take about 50-60 minutes to complete. To introduce the concepts and terms, we recommend reviewing the provided introductory slides (slides 4-10) to students prior to the scheduled lab time. In addition, the activity challenges students to use their collected data to design a new helmet. This is not accounted for in the time of the activity itself and would occupy another 20-30 minutes of class time or could be assigned as homework.

Slide 1: Think, Pair Share

- As students enter, pass out the *It's All in Your Head* worksheet and have students read the activity introduction while the class settles in.
- After reading, instruct students to look at the question at the bottom of the first page. Have students "Think, Pair, and Share." (Think about the question on their own, then discuss it with a partner, then finally discuss as a class.)
    - What are concussions and how are they caused?
        - *Concussions are a brain injury. They can be caused by a blow to the head or a violent shaking of the head and body.*

Slide 2: It's All in Your Head

- Introduce today's activity about Newton's Laws of Motion and ensure students are aware that it is a laboratory activity.

Slide 3: Learning Objectives

- Explain to students that at the end of today's activity, they will have done the following:
    - Captured slow motion videos of a modeled concussive event.
    - Interpreted video data to understand the mechanism of a concussion.
    - Collected force data for the collision of a dropped object with the ground.
    - Analyzed collision data to determine the most protective material.
    - Designed a helmet following the provided criteria and constraints.

Slide 4: Newton's Laws of Motion

- Have students view the GIF on the slide and ask them what kind of motion they see. Ask them if the ball is always moving or if it stops and starts.
    - Students should note that the ball is moving back and forth between the stationary stick figures. They should also note that the ball is always stopped before it is kicked.
- Ask students how the stick figure stops the ball from rolling past him, and then how he gets it moving again.
    - Students should note that the figure has to stop the ball by putting his foot out and gets it moving again by kicking it.
- Explain to students that both of these interactions are examples of forces. Forces are pushes or pulls on an object in a certain direction. These forces affect how an object moves.

Slide 5: Newton's First Law of Motion

- Introduce Newton's First Law of Motion then talk through the provided rolling ball GIF. Explain that the red arrow indicates a force on the ball causing it to roll to the right. Tell students that according to the First Law of Motion, this ball should keep rolling forever. Ask students if they think this is likely.
    - Students will most likely respond that it is almost impossible to keep a ball rolling forever.

- Remind students that these situations all rely on the context of the full system. If this ball was in outer space, where it's a vacuum, we would expect that once the force is applied, the ball would move in that direction forever unless another force acts on it. But here on Earth we have a force that can slow us down: friction. *Advance slide to show blue arrow for friction and stop the GIF.*
- As another force is applied, in this case friction, the ball slows to a stop. This is because the forces acting on the ball, though in different directions, are equal. We can only have motion when there are unbalanced forces acting on the object.

Slide 6: Newton's Second Law of Motion

- Introduce Newton's Second Law of Motion and its equation. Clarify to students that if we want two different weighted objects to move at the same acceleration, we'd have to apply different forces.
- *Advance slide to show example GIF*. Have students watch the GIF two or three times then ask them what they observed.
    - Students should observe that there is a foot rigged to kick a bowling ball, which doesn't move very much after the kick, and a balloon, which moves a lot after the kick.
- Advance slide and tell students to first focus on the situation with the bowling ball. Ask students whether they think the bowling ball has a small mass or a large mass.
    - Students should note that bowling balls are heavy and dense and therefore have a large mass. *Advance slide to make the "m" in the equation grow larger.*
- Then ask students if the bowling ball moved very quickly after the kick.
    - Students should note that the bowling ball does move but slowly. *Advance slide to make the "a" of the equation shrink.*
- Advance slide and tell students to now focus on the situation with the balloon. Ask students if the force applied (the kick) is more, less, or the same as the one for the bowling ball.
    - Students should note that the kick is the same. The leg is lifted to the same height and let go to allow the same kick each time. This means that the force of the kick is the same in both cases.
- Explain to students that because they both experience the same force, the "f" in both equations stays the same size. Next, ask students to compare the mass of the balloon to that of the bowling ball: is it more, less, or the same?
    - Students should note that the bowling ball is much heavier than the balloon. *Advance the slide to make the "m" in the equation shrink.*
- Then ask students if the balloon moved very quickly or slowly after the kick.
    - Students should note that the balloon moves very far and very quickly. *Advance the slide to make the "a" in the equation grow.*
- Challenge students to think of how they could make both items move at the same rate.
    - If they want the rate of motion (acceleration) to remain the same for both items. They will need to apply different forces to account for the difference in masses. They should expect to apply a larger force for the bowling ball than for the balloon.

Slide 7: Newton's Third Law of Motion

- Introduce Newton's Third Law of Motion. Focus on the runner GIF and walk through the forces in that scenario. The runner is pushing backward on the ground and the ground is pushing the runner forward.

- Advance the slide to show a similar scenario in another GIF. Explain that as the corgi pushes backward on the carousel, the dog is pushed forward. Ask student what direction the carousel and the corgi are moving in?
    - Students should note that, because the force of the carousel on the dog is propelling the dog forward, the dog moves in a clockwise motion. They should also note that, because the force of the dog on the carousel is propelling the carousel backward, the carousel moves counterclockwise.
- Advance slide to show an image of a book on a desk. Remind students that these reaction and action forces apply even when an object is at rest. Ask students to look at the two arrows being applied to the book. Both arrows are the same size, just in different directions. Newton's First Law of Motion says that if there are no unbalanced forces, then an object will remain at rest. So the force of the gravity pulling down because of the weight of the book is balanced by the reaction force of the table pushing up on it, keeping it at rest.

Slide 8: Collisions Part 1

- Explain to students that collisions occur when one object hits another and causes a change in motion. For the example in the GIF, the orange figure closest to us is mostly stationary until the blue figure runs into them. After the collision the orange figure accelerates forward and the blue figure slows down slightly. Each figure experiences a change in acceleration because of the force of the collision.
    - *Teacher's Note: Make sure students are aware that at least one object needs to be in motion prior to the collision but that there are many options for motion after the collision. Both items could move (but at different rates or directions than before), one item could stop moving completely, or both items could end up stopped.*
- Advance the slide to show an image of a car collision. Explain to students that collisions like car accidents can be serious and can result in a lot of serious injuries. For this reason, engineers and scientists work to make sure collision damage can be reduced. They do this by using both Newton's Second and Third Laws.
- When objects, like cars are moving towards each other, to decrease damage, they need to decrease the force applied. Ask students if they can recall the equation derived from Newton's Second Law of Motion.
    - F=ma
- Ask students how we can decrease the force.
    - Students should note that you can decrease the mass or the acceleration or both.
- Remind students that in most collisions, you can't lose mass to lessen your collision force. This is why we have to decelerate, or slow down, in anticipation of a collision - to decrease the force we apply on the object.
- So why do we need to lessen the force we apply on the other object in an oncoming collision? Because of Newton's Third Law. We will experience that same force in the opposite direction.

Slide 9: Collisions Part 2

- Remind students that when objects collide, the duration of the collision needs to be accounted for. If an object deforms during the collision, the duration of the collision is extended. Explain that as the ball deforms it is making the total collision time longer. How this helps reduce force can be explained with Newton's Second Law.

- *Advance slide to show the equation from Newton's Second Law.* Ask students to define acceleration.
    - A change in an object's velocity over time, ($\Delta v/\Delta t$), or (v_f-v_i/t_f-t_i). *Advance the slide to show this depicted under the original equation.*
- With this altered equation, talk through an example. Two balls of the same mass, 20 kg, are dropped from the same height. *Advance slide to have this information and images appear.* Both balls have a velocity of 10 m/s right before the collision and come to a stop after the collision. *Advance slide to have this information appear.* The duration of the collision with ball A is 0.001 seconds and the duration of the collision with ball B is 0.002 seconds. *Advance slide to have this information appear.* Ask students to calculate the force experiences by ball A and ball B.
    - Students should calculate the force for ball A being 200,000N and the force for ball B being 100,000N. *Advance slide to show this on the screen.*
- Reinforce to students that by only changing the time of the collision, we can change the object's acceleration and therefore help to change the applied force.

Slide 10: Today's Investigation

- Introduce students to the lab activity with the provided video. Ask students if they, or someone they know, has ever had a concussion. If they are comfortable, ask them what it was like and what symptoms they experienced.
    - Students will most likely know of concussions, either from personal experience or through someone they know. All cases are due to a high impact collision. This could be from sports, car accidents, falling, etc. Common symptoms they might have experienced include headaches, nausea/vomiting, sensitivity to light, trouble focusing, dizziness, and even memory issues.
- Explain that in the lab activity, students will be learning about how concussion events cause brain damage and will get to test different materials we could put in a new helmet design.
- Review lab safety protocols with students prior to beginning the activity. Break students into groups of four to six and assign each group a station in the laboratory/classroom.

Slide 11: Part I: Understanding Concussions Through the Use of a Model

- Review the procedure for Part 1 "Understanding Concussions Through the Use of a Model." Describe to students that they need to create a pendulum with their string and tennis ball like the one depicted on the slides.
- Once students have constructed their pendulum, remind students of the angle they will use to provide a force to their "brain." *Advance the slide to show an image for the 45-degree example.*
- Have students follow the procedure through step 6.
- Once groups have finished through step 6, if time allows, review the "Quick Check" questions with students. This can also be a student's exit ticket or homework.
    - What happens to the components of the skull and fluid (container and water) versus the brain (golf ball) during and after the collision? (Table 1)
        - *Skull and fluid - the container deforms slightly and this causes the water to move around inside the container.*
        - *Brain - the brain moves a little bit but remains mostly centered in the container.*
    - The action force was provided by the falling tennis ball. Was there a reaction force from the skull? How do we know? (Hint: If there was no reaction force, the tennis ball would continue moving in the same direction.)

        - *We know there was a reaction force provided from the container to the tennis ball because the tennis ball bounced backward from the direction it was originally falling.*
- Remind students of the angle they will use to provide a force to their "brain." *Advance the slide to show an image for the 90-degree example.*
- Have students continue on through step 9.
- Once groups have finished through step 9, if time allows, review the "Quick Check" questions with students. This can also be a student's exit ticket or homework.
    - What happens to the components of the skull and fluid (container and water) versus the brain (golf ball) during and after the collision? (Table 2)
        - *Skull and fluid - the container deforms a lot and is pushed to move completely from its starting position. The water inside moves a lot as well and splashes inside the container.*
        - *Brain - the brain moves a lot and sometimes bounces off the insides of the container.*
    - How does the increase in angle affect the motion of the brain?
        - *With the higher angle, there is a larger impact force on the brain model. This larger force causes more motion of the brain, especially motion that can potentially cause damage to the brain.*
        - *Teacher's Note: Emphasize that the brain hitting the skull is where the damage is caused. The brain is made of generally fragile and squishy material and can bruise easily when in contact with a hard surface like the skull.*

Slide 12: Part II: Materials Testing for a Helmet

- Review the procedure for Part 2: "Materials Testing for a Helmet." Have students secure their meter stick then describe to students that they will start by testing the impact of their head (the medicine ball) with the force plate with no protective materials.
- Advance the slide to play a video to walk students through the steps of collecting data as well as analyzing data.

Slide 13: Part II: Materials Testing for a Helmet

- Review and record collected data (one group's or an average of the class) in the table on the slide.
- Then have student groups choose a material or pair of materials to test. They'll place the material on the force plate and drop the medicine ball from the same height.
- Review and record collected data for each material (one group's or an average of the class) and compare to the control data on the slide.
- If time allows, review the "Quick Check" questions with students. This can also be a student's exit ticket or homework.
    - Which material(s) worked the best at reducing force in the impact?
        - *For materials on their own, the microbead pillow or the foam work significantly better than the Styrofoam. When combined, the materials do an even better job at reducing forces and increasing time of collision.*
    - Using Newton's Second Law, explain how increasing the time of the collision reduced the maximum force experienced.
        - *By increasing the time of the collision, it allowed for a longer time to change velocity which results in a lower acceleration. By decreasing acceleration while maintaining the same mass, the force experienced is decreased.*

- If the force of the medicine ball on the plate was decreased with these materials, how would that affect the force of the plate acting on the medicine ball?
    - *Due to Newton's Third Law, when the force of the medicine ball on the plate is decreased, so too is the force of the plate on the medicine ball.*

Slide 14: Lab Clean Up

- Before class ends, have students reset their stations for the next class. Make sure all consumable supplies are disposed of in the trash.